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With best compliments

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FRUIT PRODUCTION IN ETHIOPIA

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ALL RIGHTS RESERVED.
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Higher education institutions are entrusted with the task of developing highly qualified, deeply motivated and innovative human resources that can play a critical role in the implementation of the various development programs of Ethiopia. Moreover, these institutions are expected to produce and transfer advanced and relevant knowledge and skill for socioeconomic development and poverty alleviation of the country. However, the production of scientific publications that are the precursors of achieving such goals has remained as a major constraint in many of the higher education, research and development institutions in Ethiopia.

Cognizant of this need, Dr. Derbew Belew and Dr. Prof. Jeong Cheon Soon were inspired to write this book entitled “Fruit Production in Ethiopia”. The authors with decades of teaching and research experience in fruits have made an exhaustive effort to provide the readers with comprehensive, current and relevant information on a wide variety of fruit crops grown in Ethiopia. Publication of this book is very relevant and timely as emphasis has been given by the Government of the Federal Democratic Republic of Ethiopia to develop research and development strategies in horticulture in general and fruit production in particular. It is my strong conviction that this book will have practical importance in promoting fruit production and thereby raising its role in the national development agenda.

I strongly believe that higher education and research institutions, development organizations, private investors, students, researchers and many other individuals in the field would immensely benefit from this book.

Kaba Urgessa (PhD)
State Minister,
Ministry of Education
The agriculture sector plays an important role in the Ethiopian economy. Fruit Production is an important part of horticulture that plays a pivotal role in the livelihoods and food and nutritional security of the community in the country. In recent years, there has been an increasing demand for fruit consumption, particularly in big cities in Ethiopia, with commercial and small scale production in the rural and periurban areas. The few enlightened fruit growers in the country are becoming increasingly aware of the complexity of the factors affecting the productivity and quality of their crops and are clamoring to learn more about the background to their success and failures. Hence, to achieve successful and sustained production of good quality fruits, application of appropriate knowledge and management practices are imperative. To this end, scientific fruit production and management guides and textbooks are critically important. This book, “Fruit Production in Ethiopia”, is a practical book which unequivocally tries to provide relevant information on the production and management of some major tropical, subtropical and temperate fruit crops. The authors exerted significant effort and made good use of their broad knowledge and rich practical experiences while writing this book. The book covers economically most important fruit crops in Ethiopia and also deals with those crops that are yet left behind any proper attention.

Dr. Derbew Belew and Dr. Prof. Jeong Cheon Soon have significant teaching and research experiences in horticulture in general and fruit production in particular. I believe that the book will benefit invariably various stakeholders, including students, teachers, researchers, development and extension workers, farmers and interested persons directly or indirectly involved in the fruit value-chain in Ethiopia.

The senior author, Dr. Derbew Belew, has been a member of the academic staff of the Jimma University for nearly two decades. He has been
involved in wide arrays of research, teaching and outreach endeavors of the University. I have known him for such a long time as one of the most competent academic staff of the university with a zealous attitude in discharging any responsibilities vested in him. I am honored and privileged to write this Preamble for this book which is enriched with practical and comprehensive information. I therefore would like to attest that the authors deserve special credit for publishing this timely and useful book in view of the current emphasis given to the Subsector by the government of Ethiopia. I once again congratulate the authors for their excellent achievement in producing this book.

Fikre Lemessa (PhD)
President, Jimma University
Shortage of appropriate text books, relevant to the local conditions is one of the major problems of the Ethiopian tertiary level agricultural education institutions. This book entitled "Fruit Production in Ethiopia" is developed with a prime aim of alleviating this acute shortage. The book is written in a relatively simple language and designed to be used as a text and reference material for a wide range of practitioners, including participants of customized short term trainings, undergraduate and postgraduate students who take courses on fruit production and management. Moreover, it is hoped that teachers, researchers, development and extension workers, private investors and farmers who are interested in fruit production and management would be able to benefit out of this book.

Efforts have been made to include relevant information obtained from some of the past national attempts and experiences gained in the production and management of various fruit crops in Ethiopia. The book is organized into 19 chapters. The first chapter deals with definition and divisions of horticulture; the importance of fruits; the potentials and problems of fruit production in Ethiopia; definition and classification of fruits. The second and third chapters, respectively cover the sexual (generative) and asexual (vegetative) propagation methods of fruit crops. The fourth and fifth chapters address the principles and practices to be followed in establishment and management of nursery and orchard, respectively. The sixth chapter deals with harvesting and post harvest handling of fruits, while chapters seven to eighteen cover individual fruit crops: citrus, banana, grapes, avocado, mango, papaya, pineapple, guava, passion fruit, strawberry, pome fruits (apple and pear) and drupe fruits (peach and plum). Chapter 19 focuses on a brief description of some of the economically viable and yet currently underutilized fruits in Ethiopia. Finally, glossary of technical terms, nutritional values of some selected fruits and index are included as appendices.
We have been so fortunate to have the privilege of receiving useful and constructive suggestions and comments from prominent professionals and colleagues. Many people have contributed towards the successful accomplishment of this academic undertaking both individually and collectively. We owe a special debt of gratitude to Dr. Adhanom Negasi, Zenebe Woldu, Asmare Dagnew, Dr. Seifu Gebremariam, Beshir Kedi, Dr. Girma Adugna, Dr. Ali Mohammed, Esayas Mindesel, Dr. Tilahun Zeweldu, Dr. Tesema Chekol, Dr. Asfaw Zelleke, Prof. Solomon Demeke, Prof. Tessema Astatkie, Prof. Tefera Belachew, Dr. Kassahun Bantte, Dr. Berhanu Belay, Sirawdink Fikreyesus, Sileshi Belew, Kahasay Hagos, Bekalu Amenu, Fasika Tegegn, Beira Hailu, Dr. Edosa Etissa, Jürgen Eckert, Ayalew Talema, Amare Gebeyehu, Melkamu Dumessa, Mola Atnaf, Juliyana Gebresillassie, Susan Sipos, Mannfred Boehm, Professor Dr. Kim Kyung Ryang, CEO of Institute of International Rural Development (IIRD), IIRD office members, Ms. Park So Young, Ms. Kim Hye Bin, Ms. Jeong So Yeong, Mr. Lee Yong Jin and Dr. Yang Jeong Hee. Without their relentless contributions, this book would not have come to a reality.

Last, but not least, we would like to thank Jimma University (Ethiopia) and Kangwon National University (South Korea) for their unreserved support in the preparation and publication of the book.

Derbew Belew
Jeong Cheon Soon
## 1. INTRODUCTION

- Horticulture .................................................. 1
- Nature of horticultural crops ............................... 4
- Major divisions of horticulture ............................ 6
- Importance of fruits ......................................... 9
- Present status of fruit production in Ethiopia ....... 10
- Problems associated with fruit production in Ethiopia 15
- Prospects of fruit production in Ethiopia .............. 23
- Definition and classifications of fruit ................. 26

## 2. SEXUAL PROPAGATION OF FRUITS

- Sources of seed ............................................... 38
- Harvesting and processing of seeds ...................... 41
- Environmental factors affecting seed germination .... 42
- Seed dormancy ............................................... 44
- Seed coat dormancy ......................................... 46
- Treatments to overcome seed coat dormancy .......... 46
- Embryo dormancy ............................................ 47
- Double dormancy ............................................ 49
- Seed viability tests ......................................... 50

## 3. VEGETATIVE PROPAGATION OF FRUITS

- Apomixis ....................................................... 55
- Propagation by cuttings .................................... 59
- Propagation by layering .................................... 61
- Propagation by grafting .................................... 66
- Propagation by budding ..................................... 72
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budding</td>
<td>84</td>
</tr>
<tr>
<td>Micro propagation</td>
<td>89</td>
</tr>
<tr>
<td>4. FRUIT NURSERY ESTABLISHMENT AND MANAGEMENT</td>
<td>99</td>
</tr>
<tr>
<td>Nursery site selection</td>
<td>100</td>
</tr>
<tr>
<td>Growing seedlings in a field nursery</td>
<td>102</td>
</tr>
<tr>
<td>Propagation structures</td>
<td>104</td>
</tr>
<tr>
<td>Potting soils</td>
<td>105</td>
</tr>
<tr>
<td>Raising seedlings in plastic tubes</td>
<td>106</td>
</tr>
<tr>
<td>5. ORCHARD ESTABLISHMENT AND MANAGEMENT</td>
<td>112</td>
</tr>
<tr>
<td>Site selection</td>
<td>112</td>
</tr>
<tr>
<td>Land preparation</td>
<td>120</td>
</tr>
<tr>
<td>Planting systems</td>
<td>126</td>
</tr>
<tr>
<td>Laying out the field and digging holes for planting</td>
<td>133</td>
</tr>
<tr>
<td>Fertilizer application program in fruit farms</td>
<td>137</td>
</tr>
<tr>
<td>Irrigation</td>
<td>143</td>
</tr>
<tr>
<td>Pest management in orchards</td>
<td>155</td>
</tr>
<tr>
<td>Mulching</td>
<td>168</td>
</tr>
<tr>
<td>Training and pruning of fruit plants</td>
<td>170</td>
</tr>
<tr>
<td>Pollination and pollination management</td>
<td>179</td>
</tr>
<tr>
<td>Fruit thinning</td>
<td>185</td>
</tr>
<tr>
<td>6. HARVEST AND POSTHARVEST HANDLING OF FRUITS</td>
<td>191</td>
</tr>
<tr>
<td>Fruit maturation, ripening and senescence</td>
<td>191</td>
</tr>
<tr>
<td>Harvesting</td>
<td>198</td>
</tr>
<tr>
<td>Postharvest factors influencing fruit quality</td>
<td>201</td>
</tr>
<tr>
<td>Postharvest handling of fruits</td>
<td>204</td>
</tr>
<tr>
<td>Postharvest treatments of fruits</td>
<td>206</td>
</tr>
<tr>
<td>Methods of fruit cooling</td>
<td>211</td>
</tr>
<tr>
<td>Effects of temperature on storage of fruits</td>
<td>211</td>
</tr>
<tr>
<td>Hygiene and sanitation</td>
<td>214</td>
</tr>
<tr>
<td>7. CITRUS</td>
<td>222</td>
</tr>
<tr>
<td>Botany</td>
<td>222</td>
</tr>
<tr>
<td>Ecological requirements</td>
<td>226</td>
</tr>
<tr>
<td>Crop husbandry</td>
<td>227</td>
</tr>
<tr>
<td>Importance of rootstocks for commercial citrus fruits production</td>
<td>254</td>
</tr>
<tr>
<td>Important rootstocks used for citrus and their principal characteristics</td>
<td>255</td>
</tr>
<tr>
<td>Growing rootstock seedlings</td>
<td>259</td>
</tr>
<tr>
<td>Citrus fruits of major economic importance in Ethiopia</td>
<td>263</td>
</tr>
<tr>
<td>8. BANANA</td>
<td>277</td>
</tr>
<tr>
<td>Botany</td>
<td>278</td>
</tr>
<tr>
<td>Ecological requirements</td>
<td>282</td>
</tr>
<tr>
<td>Crop husbandry</td>
<td>285</td>
</tr>
<tr>
<td>Harvest and postharvest handling</td>
<td>298</td>
</tr>
<tr>
<td>9. GRAPES</td>
<td>306</td>
</tr>
<tr>
<td>Botany</td>
<td>307</td>
</tr>
<tr>
<td>Ecological requirements</td>
<td>312</td>
</tr>
<tr>
<td>Crop husbandry</td>
<td>313</td>
</tr>
<tr>
<td>Harvest and postharvest handling</td>
<td>323</td>
</tr>
<tr>
<td>10. AVOCADO</td>
<td>327</td>
</tr>
<tr>
<td>Botany</td>
<td>327</td>
</tr>
<tr>
<td>Ecological requirements</td>
<td>335</td>
</tr>
</tbody>
</table>
Crop husbandry ................................................................. 336
Harvest and postharvest handling ...................................... 340

11. MANGO ............................................................................ 346

Botany ................................................................................... 346
Ecological requirements ..................................................... 349
Crop husbandry ................................................................. 351
Harvest and postharvest handling ...................................... 355

12. PAPAYA ........................................................................... 359

Botany ................................................................................... 359
Ecological requirements ..................................................... 364
Crop husbandry ................................................................. 365
Harvest and postharvest handling ...................................... 369
Production of papain ........................................................ 370

13. PINEAPPLE .................................................................... 376

Botany ................................................................................... 376
Ecological requirements ..................................................... 378
Crop husbandry ................................................................. 379
Harvest and postharvest handling ...................................... 385
Production of Bromelein ...................................................... 386

14. GUAVA ........................................................................... 389

Botany ................................................................................... 389
Ecological requirements ..................................................... 390
Crop husbandry ................................................................. 391
Harvest and postharvest handling ...................................... 394
<table>
<thead>
<tr>
<th>15. PASSION FRUIT</th>
<th>397</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botany</td>
<td>397</td>
</tr>
<tr>
<td>Ecological requirements</td>
<td>398</td>
</tr>
<tr>
<td>Crop husbandry</td>
<td>400</td>
</tr>
<tr>
<td>Harvest and postharvest handling</td>
<td>403</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>16. STRAWBERRY</th>
<th>405</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botany</td>
<td>405</td>
</tr>
<tr>
<td>Ecological requirements</td>
<td>406</td>
</tr>
<tr>
<td>Crop husbandry</td>
<td>407</td>
</tr>
<tr>
<td>Harvest and postharvest handling</td>
<td>412</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>17. POME FRUITS</th>
<th>414</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilling requirements</td>
<td>414</td>
</tr>
<tr>
<td>Apple</td>
<td>420</td>
</tr>
<tr>
<td>Apple rootstocks</td>
<td>429</td>
</tr>
<tr>
<td>Pear</td>
<td>430</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>18. DRUPE FRUITS</th>
<th>435</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peach and Nectarine</td>
<td>435</td>
</tr>
<tr>
<td>Plums</td>
<td>444</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>19. UNDERUTILIZED FRUITS IN ETHIOPIA</th>
<th>449</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loquat</td>
<td>449</td>
</tr>
<tr>
<td>Casimiroa (White Sapote)</td>
<td>450</td>
</tr>
<tr>
<td>Annonaceous fruits</td>
<td>452</td>
</tr>
<tr>
<td>Cactus pear</td>
<td>455</td>
</tr>
<tr>
<td>Date palm</td>
<td>457</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

CHAPTER 1

INTRODUCTION

Ethiopia is located in Eastern Africa between 3° and 18° North latitude, 33° and 48° East longitude, and lies within the tropics. It has diverse Physio-geographic features with high and rugged mountains, flat topped plateau, deep gorges, incised river valleys and rolling plains. The diversity of the terrain is fundamental to variations in climate, natural vegetation and soil composition. Although the whole Ethiopia lies within the tropical latitude, the climate is cool to cold in the highlands and warm to hot in the extreme lowlands. The altitude ranges from 126 m below sea level in the Dalol (Danakel) Depression along the great rift valley in the north-east border with Eritrea, to the highest mountain, Ras Dashen, in the Semien Mountains north of Lake Tana, rising to 4,620 m a.s.l. (Awulachew et al., 2007). This extreme ranges of altitude results in varied conditions of tropical to alpine ("Wurch"-extreme cold) climates.

Ethiopia is also endowed with elaborated 18 major and 49 sub-agro-ecological zones (EARO, 1998), which are classified on the basis of temperature, elevation and moisture regimes. They exhibit wide variations in rainfall (both in quantity and distribution), temperature, altitude, topography and soil conditions. The rainfall distribution is seasonal and is mainly governed by the inter-annual oscillation of the surface position of the Inter-Tropical Convergence Zone (ITCZ), which passes over Ethiopia twice a year (PGRC, 1996). This causes variations in the wind flow patterns and the onset and withdrawal of winds from north and south.

According to the PGRC (1996) report, the mean annual rainfall in Ethiopia ranges from 500 to 2,800 mm. The southwestern part of the country receives the highest annual rainfall up to 2,800 mm in some areas. The
central and north-central regions receive moderate rainfall, which declines towards northeast and eastern Ethiopia. The northern and southeastern regions receive annual rainfalls of about 500 and 700 mm, respectively. The relative humidity regimes closely follow the rainfall pattern. The rainfall pattern and the high variation in temperatures (< 10°C and > 30°C) influence the types and diversity of vegetation and their distribution over the country. Due to such large agro-climatic diversity, different tropical, subtropical and temperate fruit crops are grown in different parts of the country.

Furthermore, Ethiopia is endowed with different water resources. It has 12 river basins, 11 fresh and nine saline lakes, four crater lakes and over 12 major swamps or wetlands (Awulachew et al., 2007). The majority of the lakes are found along the Great Rift Valley Basin. Awulachew et al. (2007) emphasized that having such meteorological and hydrological variability needs due attention in order to enhance their utilization and management.

Despite the fact that different fruit crops have been grown in different parts of Ethiopia, their distribution and supply to the major cities and towns is still inadequate. Poor road conditions, among others, are the major factors that have limited their wider distribution from their area of production. This can be ascertained from the current high prices of fruits in the major local market outlets. In turn, it justifies the need to increase production (supply) and improve the above stated limitations so as to conform to the current demand and make the prices affordable to the public at large. This will as well simultaneously enable the growers fetch better profits from the sale of their produce.

At present, the nutritional value of fruits is gradually getting better recognition by the public and their inclusion as part of the regular diet is equally increasing. To this effect, the demand for fruits is increasing steadily among the public at large, but more particularly among the educated and well to do segments of the society. The trend will definitely continue to grow as the awareness and knowledge base of the population is improved. In doing so, the public needs to be continuously sensitized on the nutritional and dietary values of fruits so that they will include them in their daily diet. Much of the awareness creation work towards this end has to be spearheaded by the
responsible training, research, academic and extension institutions as well as the public media. As an adjunct to this, efforts should also be made to improve the existing market places and marketing facilities. Given the necessary attention by all responsible bodies, fruits, apart from their fresh use will contribute significantly as raw materials for industries in the process of manufacturing value added products such as marmalades, jams, concentrated juice, etc.

On the other hand, a number of wild and semi-wild edible fruit species are found in various parts of Ethiopia. Wild and semi-wild edible fruits refer to species that are neither formally cultivated nor domesticated, but are available from their wild and semi-wild natural habitats and used as sources of food (Beluhan and Ranogajec, 2010). They grow naturally on farmlands, forests and sloppy marginal areas as well as fallow or uncultivated lands (Ruffo et al., 2002; Zemede Asfaw and Mesfin Tadesse, 2001; Getachew Addis, 2009; Demel Teketay et al., 2010). They are adapted to the local culture and environment, and therefore, propagate and grow naturally easily with few requirements for external inputs such as fertilizers and pesticides; thus, they can easily be integrated into sustainable farming systems (Ruffo et al., 2002).

As stated above, wild and semi wild fruits are relevant to household food and nutrition security as well as income generation since several rural people derive a significant proportion of their food, energy requirements and income from such species (IBC, 2005). Such species like ‘Eshe’ (Mimosis kumel), ‘Kurkura’ (Ziziphus spina christi), ‘Inkoy’ (Ximenia americana), ‘Dokma’ (Syzygium guineense), ‘Tamarind’ (Tamarinda indica) etc. are widely appearing in some local markets.

Despite the wider role of such fruit species in the livelihood of the rural communities, the existing ethnobotanical information is very limited and fragmentary and; as such, their contribution, management and utilization are not exhaustively documented. There is also a paucity of information concerning their taxonomy, genetic diversity, and uses, among other issues. Traditional knowledge of such plants is thus in danger of being lost, as habits, value systems and the natural environment changes. There is especially
a widespread decline of knowledge of such plants among young people and urban dwellers.

Therefore, to preserve this knowledge, which potentially is highly valuable for future generations, information on these species needs to be recorded systematically (FAO, 1992; Zerqe, Asfaw and Mesfin Tadesse, 2001; Tigist Wondimu et al., 2003; Demel [Teketay et al., 2010]). Basic information pertaining to such species is available from the local people who are the custodians of the resources and knowledge (Demel and Abeje, 2004). As such, assessment and better understanding of such resources is crucial in making use of the local peoples’ knowledge to define their cultural domains (Fantahun et al., 2010). Promoting research on such species is also crucial in order to safeguard this information, develop nutritional diversity and combat food insecurity for future generations (Cardini et al., 2006).

**Horticulture**

**Definition:** The term horticulture is derived from two Latin words, *hortus*, meaning garden, and *colere* (or *cultura*), meaning to cultivate. Therefore, the term horticulture means “garden culture” or the culture of garden plants, and this implies cultivation within rather restricted areas.

In a broad sense, the term horticulture may be defined as the science and technology of pomology, olericulture, floriculture and landscape designing. It involves the production, processing, and merchandising of fruits and nuts, vegetables, roots and tubers, cut flowers and ornamentals, beverage crops (e.g., coffee, tea, etc.), herbs and spices, medicinal plants; and other groups of plants with similar botanical, cultural and utilization characteristics.

The cultivation of garden plants in contrast to the cultivation of field crops is practiced in an extensive manner. Horticulture relies on growing and manipulating plants in a relatively intensive manner. In other words, the horticulture crops require very intense care in planting, cultural operations, manipulating growth, harvesting, packing, marketing, storage and processing. In addition, returns obtained from a given area of horticultural crops are relatively higher compared with field crops (Christopher, 2001).
Presently, horticultural crops (e.g., fruits, vegetables, cut flowers, ornamentals, coffee, tea, spices, etc.) are not solely grown as home gardens, but also in large quantities at a commercial scale level, primarily for business enterprises.

Horticulture is both an art and a science. It is an art because propagating, pruning, spraying, etc., require special techniques and skills which must be mastered if the work is to be done properly. The skills attained through practice lead into art. The scientific reasons underlying these techniques explain why the various operations are performed in particular fashions to constitute a true science. The primary objective of horticulture is to develop ways by which horticultural plants could yield optimum benefits to the people.

Nowadays, horticulture is becoming a fast growing and an important sector in the Ethiopian Agriculture. The rapidly growing demand for horticulture commodities and products together with the booming floriculture market and as well as the growing market for fresh and processed fruits and vegetables are evidences of the phenomenon which are paving the way for the growth of horticulture in the country. Consequently, horticulture is set to play a greater role in the national economy. In addition, there are many opportunities to bring exports of horticulture commodities and products, especially coffee, cut flowers, fruits and vegetables by strengthening the existing markets as well as exploring new markets. Due to the enormous potential of horticulture (both on domestic and international front), the growing demand of horticulture commodities and products, could become a key driving factor in stimulating agricultural growth. The potential advantages of horticultural farming in terms of higher yielding farm output and remunerative returns, is likely to encourage horticulture farming on a larger scale. Numerous policy and development initiatives including the establishment of the Ethiopian Horticulture Development Agency, together with the massive financial and technical support available in the horticulture sector, are likely to provide a greater impetus to the process of horticultural development in the country.
The horticulture sector has a large employment potential by supporting a series of direct and indirect activities related to area development, nurseries, cultivation and farming, crop maintenance, production, postharvest management, trading, storage, processing, transportation, marketing and distribution of horticulture commodities and products. Growth in horticulture sector is expected to not only create employment but also to fetch foreign exchange earning and significantly contribute to food needs of the country.

Nature of horticultural crops

Horticultural crops are often considered crops which require intensive culture and smaller areas to grow in contrast to agronomic or field crops which require extensive culture and larger areas to grow. The foregoing distinction does not always hold true because there are some horticultural crops which grow in larger areas than the field crops that require intensive culture.

Horticultural cropping systems are intensive in terms of investment, labor requirements and other inputs and are often (but not always) confined to smaller parcels of high quality land. Protected cultivation (e.g., glasshouses or plastic tunnels) and irrigation are common. Accordingly, the products of horticultural enterprise usually have a much higher per unit value than crops grown in less intensive systems. Generally, the horticultural crops have the following peculiar characteristics:

1. Require high capital, labor and technology input per unit area, thus are intensively cultivated crops.
2. Water is the major constituent, hence easily perishable (or have short shelf-life).
3. High yield per unit area. Horticultural produce is perishable. Packing, storage and transport facilities should be available ahead of picking time so as to maintain freshness (good quality) of the products until they reach the final users. In addition, it is advisable if orchards are situated in close vicinity to the market places or to the processing
industries where the product could either be sold-out or processed prior to appreciable loss in its quality.

4. Most of the fruits are normally consumed by human beings in fresh form, i.e., without cooking. Such products should be therefore handled carefully, starting from field management and harvesting to its ultimate utilization. Mechanical injury and contamination with pathogens, harmful chemicals, dust or any other extraneous material should be avoided as this may affect quality (e.g., appearance) or cause health problem to the consumer.

The production of horticultural crops in Ethiopia is a large challenge since they must meet high quality standards both in terms of product safety and internal characteristics, as well as in terms of external characteristics. Horticultural crops can be hazardous to health when they are not used in adequate sanitary manners. Some of the possible hazards that may be encountered include the following (Bunt and Piccone, 1993):

**Toxins.** Fresh fruits and vegetables contain nutrients, vitamins and minerals essential for growth and health and are important components of healthy diet. However, some fruits and vegetables may contain natural toxins which could be potentially harmful to our health. Natural toxins are poisonous substances present naturally in some fruits and vegetables. They are produced by plants to defend themselves against fungi, insects and predators, and offer a protective mechanism for the plant. Seeds or stones of apples, pears, apricots, plums, peaches, etc. are known to have toxins naturally. The flesh of these fruits is not toxic, but the seeds (such as bitter apricot seeds) and stone contain cyanogenic glycoside. When the consumer chews the fresh seeds or stone, the cyanogenic glycoside in it can be transformed into hydrogen cyanide, which is poisonous to the consumer (CFS, 2005). According to this report, young children are more susceptible so swallowing only a few seeds may cause cyanide poisoning.

Some natural toxins such as alkaloids can be produced in potato tubers exposed to light. Mycotoxins such as aflatoxins can be produced in
some dried fruits and nuts infected with *Aspergillus flavus*. Aflatoxins are the most known potent carcinogens. The infection of apples by *Penicillium expansum* results in the production of another mycotoxin (patulin).

**Micro-organisms.** Though relatively rare, there have been cases when fresh melons, spinach, raspberries, herb mixes, and green onions have been contaminated with germs (bacteria, viruses, or parasites) usually found only in the intestinal tracks of animals (Kuzynsko *et al.*, 2006). It is important to remember that fruits and vegetables are grown in soil around farm animals, wild animals and birds. Animals may deposit feces in pond water that irrigates the crop, or in the field itself. Under such conditions water used to wash the products might not be safe to use. Improper sanitation procedures used in the field may also lead to contamination. Bacteria can be developed especially in some vegetables due to their high pH and therefore they can be a potential health hazards.

**Agricultural chemicals such as pesticides and heavy metals.** Horticultural crops can be major vehicles in contaminating themselves with different agricultural chemicals, especially pesticides. The presence of these chemicals in horticultural crops can be due to their intentional use either before or after harvest or due to other external contamination sources such as industries and contaminated water.

Some recommendations regarding avoidance of hazardous to health materials from horticultural products include the following:

1. Control of decay organisms by avoiding mishandling/rough handling of horticultural crops, and the use of adequate postharvest technologies such as refrigeration.
2. Avoid the excessive use of pesticides, especially those that are known hazardous to health.
3. Make sure that irrigation water (especially that is coming from, or pass close to industrial plants) is not contaminated with agricultural chemicals (pesticides, heavy metals, etc.).
4. Use adequate treatments that can decrease or eliminate sources of hazards.

**Major divisions of horticulture**

The classification suggested here is based upon the areas of specialization. This is done in order to bring about uniformity in a consideration of the crops studied in the various branches of horticulture. Broadly, horticulture can be subdivided into various sub-specializations including the following:

**Pomology** - The term pomology comes from Latin word *pomum* meaning 'fruits' and Greek term *logy* meaning 'science'. Thus, pomology is a branch of horticulture, which deals with the study of fruit and nut crops. In a broader sense, pomology is the science and practice of growing, harvesting, handling, storing, processing, and marketing fruits. *Citriculture*, specifically deals with the study of citrus fruits; and *Viticulture*, dealing with the study of grapes (*Vitis* spp.) also come under pomology. The description and classification of grape varieties is taken care by a separate branch referred to as *Ampelography*. This discipline basically deals with description and documentation of local and exotic varieties of grape found in a given country.

**Olericulture** - The term *Olericulture* is originated from Latin word 'oleris' meaning potherb and English word *culture* meaning braising of plants. Thus, Olericulture is a branch of horticulture, which deals with the study of vegetables. It is the science and practice of growing, harvesting, storing, processing, and marketing of vegetables.

**Floriculture** - A branch of horticulture which deals with the study of ornamental plants. It deals with all the operations and practices incident to the care of all such plants as are cultivated exclusively for their flowers and foliage. Floriculture plants are grown for aesthetic and functional value and play important roles in social events and leisure activities.
Landscape and Nursery Industry - This branch of horticulture is the science and practice of propagating, growing, installing, maintaining, and using grasses, annual plants, shrubs, and trees in the landscape. Landscape is the appearance of land as it appears to the eye. Landscape gardening deals with landscape architecture and such plant materials are essential to landscape development. It is an integral part of modern architectural design. In the practical sense, the identification of plants, planning, planting and maintenance of home grounds, parks, school grounds, and municipal estates are phases of landscape gardening.

Importance of fruits

Conditions for increasing horticultural crop production in Ethiopia are very favorable. This is partly because horticultural crops production is labor-intensive in general. Ethiopia endowed with abundant labor in relation to capital has a competitive advantage in the production and exports of horticultural crops. Fruits could play a major role in being better alternatives in diversifying the Ethiopian agriculture in view of giving higher returns. Fruit production could contribute in improving productivity of land, creating employment, generating income to the farmers and entrepreneurs, enhancing exports and foreign exchange earnings and above all providing nutritional security to the people. Importances of fruits and/or fruit production are described as follows:

Nutritional and medicinal values - Fruits are important for their carbohydrate and vitamin contribution to the human diet. For instance, banana being very rich in carbohydrate, serves as a staple food in some parts of the world. Most fruits contain large quantities of sugars with high vitamins such as vitamin A and C, which are not abundant in many Ethiopian staple foods. Fruits like avocado are rich in fat and other nutrients. Fruits are important sources of ingredients to balance human diet; hence they play an important role in alleviating malnutrition problems in many developing countries including Ethiopia. It is now universally accepted that fruits are protective foods,
helping to protect the human body against undesirable health problems by supplying valuable vitamins and certain mineral salts. The principal mineral elements in fruits include Ca, P, K, Mg, S and Fe, which are essential for growth and proper functioning of the body. Several fruits contain pectin which is essential for stimulating intestinal activity and promoting bowel action. The cellulose in fruits adds bulk to foods, and helps to stimulate the intestinal activity similar to that of pectin without producing any friction or irritation in the intestine. Regular consumption of fruits has accordingly been considered useful in preventing constipation. In developed world, current dietary guidelines recommend inclusion of fruits in the daily diet of several servings due to their relatively low caloric value and negligible sodium, cholesterol, and fat (Borchers and Hyson, 2003), with the exception of almonds, which provide approximately 80% of energy as fat (USDA, 2000). The nutritional value of some fruits is presented in Appendix.

The health-supporting characteristics of some fruits have been widely recognized, but many people still regard fruits as luxury rather than food, which should be part of the daily diet. Like many other plants, the medicinal value of fruits is well recognized traditionally and in modern-day. For instance, organic acids, such as malic, citric, tartaric, oxalic, etc. are among some of the common constituents of fruits known to act in certain cases as mild laxatives. In fact there is a common saying “an apple a day keeps the doctor away”. This saying points-out the nutritional as well as medicinal properties of fruits in providing balanced diet for people in all age groups. It is generally proven that changing food habits (i.e., regular consumption of vegetables and fruits) in developed countries are the major factors in the improvement of health and lengthening average life expectancy of their citizens.

Numerous epidemiological and some intervention studies indicate that increased consumption of fruit, nuts, and vegetables is associated with decreased risk of heart disease, cancer, and possibly other chronic diseases (Steinmetz and Potter, 1996; Ness and Powles, 1997; Kris-Etherton et al., 1999). There is evidence on the beneficial roles of fruits and vegetables in the human diet that provide protection against cellular damage caused by
exposure to high levels of free radicals. Free radical scavengers (e.g., antioxidants) have attracted special interest because they can protect the human body from free radicals that may cause many diseases, including cancer, and contribute to the aging process (Armstrong et al., 1993). The principal nutrients thought to provide the protection afforded by fruit and vegetables are the antioxidants (Cadenas and Parket, 1996) and dietary fiber (non-starch polysaccharides) (Kritchevsky and Borfield, 1995). The term antioxidant can be considered to describe any compound capable of quenching active oxygen species without itself undergoing conversion to a destructive radical (Nishikimi and Yagi, 1996). Antioxidant enzymes can either catalyze such reactions or are involved in the direct processing of active oxygen species. Hence, antioxidants and antioxidant enzymes function to interrupt the cascades of uncontrolled oxidation.

Fruits contain many different antioxidant compounds (i.e., vitamin C and E, carotenoids and phenolic compounds, etc.), that serve as radical scavengers. Some components of fruits and vegetables are strong antioxidants and function to modify the metabolic activation and detoxification/disposition of carcinogens, or even influence processes that alter the course of the tumor cell (Wargovich, 2000).

**Feed value** - The feed value of fruits as livestock fodder, is also important. By-products from processing industries, unused parts of fruits (e.g., skin/peel of fruit), serve as feeds for animals. Flowers of most fruit crops are visited by insects (notably honey bees) and are excellent sources of pollen and nectar which are good rewards (forage) for them.

**Income source** - Nowadays, there is an increasing demand in the consumption of fresh and processed fruits locally, and the country is also exporting fresh fruits and processed products from which considerable amount of foreign exchange is earned. In addition, increasing fruit production in the country saves foreign exchange currency which is used to import fruits elsewhere. Some local industries (e.g., winery) are still importing fruits paying a considerable amount of foreign currency to satisfy their raw material
requirements to run the industries.

The economic profitability of fruit production depends on its meaningful utilization. Fruit farming is an expensive and skillful job. The initial investment cost is high though it tends to decrease as the fruit plants develop and start bearing. In general, tree fruits take longer period to reach production after they are being transferred to permanent field. But, this is not true with the annual fruit crops as they bear fruit quickly. It is advisable to adopt intercropping or multistoried cropping system in perennial fruit orchards (with appropriate crops, provided other factors for raising these crops are favorable) so as to effectively utilize the space especially during early stage of orchard establishment. The intercropping system compensates the initial poor and slow returns from orchards. However, a much higher productivity of the orchard and minimum risk practices are followed, if multistoried cropping system is adopted in the orchard.

**Employment opportunity** - The management of orchards from land preparation to harvesting together with the subsequent operations in between require a large number of human-force of different age and sex group throughout the year, hence creating employment opportunity to a greater extent like in cultivation is also common in marketing, and distribution. Expansion in fruit production leads to the introduction and establishment of fruit processing industries, which in turn brings employment opportunities in new areas.

**Raw material source** - Fruits directly or indirectly serve as raw materials for processing into various products (e.g., marmalade, jams, jellies, squash, wines, essential oils, etc.) for many industries. Fruit production has its requirement in running large and medium scale industries, where fruits serve as the only or one of the raw materials. Therefore, fruit production has a great possibility in trade and industrial development of the country.

**Decorative and shade value** - Fruit production on spare lands in the urban areas, places of public interest, school compounds, gardens and along roads/highways, has an advantage not only to enjoy the fruit but also to
increase the beauty of the surroundings. Generally, for aesthetic value, fruit trees have found their place in urban and village landscapes, park plantations to attract the community and add value to the surrounding. Fruit trees also provide shade for animals (including humans) and some shade for living crops in multiple cropping systems.

**Soil and water conservation** - Fruit plants help to mitigate soil erosion by wind or water; because their roots act as webs to hold the soil in place. Their leaves and branches intercept the rainfall and reduce the impact of raindrops (i.e., dispersion of soil particles). The roots improve drainage (infiltration), which in turn increases the amount of water to be stored in the soil thereby decreasing run off.

Some fruits are especially appropriate for efficient utilization of marginal lands which usually are poor to grow agricultural crops, and this is another advantage in favor of fruit production. There are a number of fruit crops, including indigenous fruit species, which fairly thrive and produce in dry land, adverse soil conditions, or irregular terrain, where other crops generally fail to grow or yield satisfactorily.

**Social and cultural value** - Due to their long association with humans, fruits have a permanent seat in the social life of humans. As a consequence of their long association with human beings, various fruits have acquired their place in art, music, literature, customs and habits of various nations of the world. The description of fruit as symbolic insertions in the poems and literatures, conferring titles to individuals in the names of fruits are indications of their popularity and social position in various countries. In Ethiopia, for example, people are called in the names of fruits like ‘Birtukan’ for orange, ‘Tiringo’ for citron, ‘Lomi’ for lime, ‘Rahman’ for pomegranate, ‘Woenshet’ for grape, ‘Inkoy’ for wild plum (*Xylocenia americana* L.) etc., expressing their affection to the fruits.

**Fuel wood** - Fruit plants, like other shrubs and woody plants, serve as a source of fuel to provide heat and energy for cooking. Furthermore, they
serve for construction and fencing purposes; timber for manufacturing furniture, and leaves for thatching the roofs, etc.

In Ethiopia, indigenous fruit species such as 'Koshim' (*Dovyalis abyssinica*) are grown around houses and home gardens as live fences. Live fences generally have a number of advantages over wooden posts. The cost of live fencing is low, and apart from some attention at the beginning, the fence will continue to grow on its own. Properly selected species for fence can be a source of fuel-wood, medicine, fruit, food or other useful household products. Live fences also serve as wind break and can also improve soil conditions if appropriate species are selected.

**Present status of fruit production in Ethiopia**

Fruits of major economic importance (e.g., citrus, banana, grape, avocado, mango, papaya, pineapple, passion fruit, strawberry, etc.) in Ethiopia are all introduced from other regions of the world. Generally, it is believed that these fruit crops have been introduced to the different parts of the country through missionaries, diplomats, merchants, and native scholars. However, the exact period of introduction, routes and sources of introduction are not fully known for many of the fruits. At present these fruits are produced at different levels in the country: (i) under small farmer (peasant) holdings, small groves or backyard fruit trees; (ii) small-scale orchards; and (iii) large-scale orchards, under government and private ownership.

Usually, small farmers grow fruit seedlings raised from seeds collected from cultivars of unknown origin, which are often inferior. Types and varieties of fruits used are generally from unknown sources, that is, with no guarantee on their quality, parentage or performance and with no assurance of their suitability to grow in the recommended localities. With small farmers, growing of the wrong variety or in the wrong location is not uncommon feature in Ethiopia. Use of insufficient organic and inorganic fertilizers, poor methods of irrigation, cultivation, pruning and crop protection are also common problems associated with fruit growing at small farmers' smallholdings. Consequently, yield per unit area is low and fruit quality is
poor. Harvested fruits from this sector are mainly utilized for home consumption and at times for local markets.

Unlike the small farmer holdings, large-scale orchards are commonly established with well identified and characterized cultivars of desirable traits. Improved cultural practices are followed and relatively better yield and quality produce are obtained from this sector. Fruits produced from large scale farms usually meet local and export market quality standards. Hence, they satisfy the domestic demand (for fresh consumption and raw materials for processing industries) and are exported for foreign currency earnings through international markets.

According to the CSA (2011), reports the area and production estimates of fruits under commercial farms in Ethiopia as indicated in Table 1-1.

Table 1-1. Estimates of area and production of fruit crops under commercial farms (2010/11).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (ha)</th>
<th>Production (ton)</th>
<th>Yield (ton/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocados</td>
<td>304.47</td>
<td>2244.2</td>
<td>7.80</td>
</tr>
<tr>
<td>Bananas</td>
<td>1608.92</td>
<td>14060.2</td>
<td>8.98</td>
</tr>
<tr>
<td>Guavas</td>
<td>60.04</td>
<td>142.1</td>
<td>3.03</td>
</tr>
<tr>
<td>Lemons</td>
<td>31.42</td>
<td>124.7</td>
<td>4.51</td>
</tr>
<tr>
<td>Oranges</td>
<td>1411.36</td>
<td>2035.7</td>
<td>14.20</td>
</tr>
<tr>
<td>Papayas</td>
<td>563.54</td>
<td>22562.5</td>
<td>39.51</td>
</tr>
<tr>
<td>Pineapples</td>
<td>55.51</td>
<td>552.3</td>
<td>9.95</td>
</tr>
<tr>
<td>Total</td>
<td>5266.51</td>
<td>70041.9</td>
<td>87.98</td>
</tr>
</tbody>
</table>

Source: CSA (2011)

Problems associated with fruit production in Ethiopia

*Absence of broad genetic base* - Economically important fruit species grown in various parts of Ethiopia are exotic which have been introduced into the country through time. The number of cultivars under production is very limited which made further improvement difficult because of their narrow
genetic resource base. Apart from their narrow genetic resource base, most of the existing fruit planting materials in the farmers' hands are of unknown origin, most of them inferior in yield and quality and vulnerable to various diseases and insect pests.

Poor knowledge of the society on the nutritional value of fruits - Until recently, the nutritional value of fruits was not well known, and hardly included in daily diets. Even today, the majority of the population in Ethiopia consider fruit as a luxury food rather than necessary food stuff. Thus fruits are mainly consumed during fasting time, or when people get sick or on special occasions. It is now known that humans cannot live on agricultural produces solely but also need fruits as supplementary food stuff.

Lack of improved planting material and production technology - In the last few decades, there has been a trend of increase in fruit production because of the increase in local and export demands. However, lack of improved planting materials and production technologies are still becoming the bottlenecks for the ever-increasing demands of the growers. Looking at these problems, efforts are being made by the Ministry of Agriculture to produce planting materials of various fruits. Currently, nurseries in different parts of the country are distributing planting materials (of choice fruits of particular area) to the farmers. Some research centers, universities and colleges in this regard are also taking part.

In Ethiopia, nurseries of repute which can provide seedlings, cuttages, layerages or graftages of the choice varieties of different fruit species for sale are very limited. In many countries, fruit nurseries are skillful ventures where modern propagation techniques and production technologies are delivered. In such nurseries, fruit trees are made up of two parts vis-à-vis the scion (forming tree head) and the rootstock (which develops into the root system). Selection of proper cultivar is a vital decision for a breeder. Sufficient attention must also be paid to the choice of rootstock. By choosing a suitable type of rootstock, size and other characteristics of the tree can be influenced or changed, and also the age at which the tree comes to bearing is shortened.
To promote fruit production, be it at large scale or at homestead level, there need to be reliable source of fruits of desirable characteristics (true-to-type) to begin with. Establishment of nurseries at different parts of the country may be achieved by the involvement of various government institutions, non-governmental organizations, investors, professionals, etc.

Lack of appropriate postharvest technology - Most of the fruits are liable to deteriorate quickly after maturity. Apart from problems related to harvesting, postharvest losses of fruits are severe due to lack of proper handling and transportation facilities. However, if canning or fruit preservation factories are available, the excess harvest can be utilized for making storable processed products like jams, jellies or squashes, etc. Such provisions will diversify the ways of utilizing the products and help controlling the price in the market.

Disease and insect pest problem - A serious disease or pest of a fruit crop can be a major production problem in some areas. Various diseases and insect pests are known to cause serious damages to cultivated fruits. Disease and insect problems are threatening low input farmers even to the extent of discouraging them to maintain their crops or further to expand their fruit plantation. For instance, in recent years leaf and fruit spot of citrus (Phaeollamularia angolensis) has been found to be a disastrous disease to citrus production especially in south western part of Ethiopia.

Marketing - Marketing comprises all the operations and activities involved in the movement of commodities from the producers to the consumers. Agricultural marketing plays an important role in accelerating and sustaining the economic development of a given country. Price stability and equitable distribution of product cannot be achieved without an organized, well equipped and efficient marketing system (Banerjee, 2003). Dixie (2005) stated definitions of “marketing”, particularly relevant to horticultural marketing in the following two ways:
1. INTRODUCTION

(1) "Marketing involves finding out what your customers want and supplying it to them at a profit". This stresses two important points:

- the marketing process has to be customer oriented;
- marketing (as a commercial process), has to provide farmers, transporters, traders, processors, and other related subjects with a profit or they will be unable to stay in business. Marketing therefore involves:
  - identifying buyers;
  - understanding what they want in terms of products and how they want to be supplied;
  - operating a production-marketing chain that delivers the right products at the right time;
  - making enough profit to continue operation.

(2) "Marketing is the series of services involved in moving a product from the point of production to the point of consumption". This definition emphasizes that marketing is a series of interconnected activities. In the case of horticultural marketing, these include:

- planning production;
- growing and harvesting;
- grading of products and their packing, transport, storage, processing, distribution and sale;
- sending information from production area to market (e.g., products available, volumes) and from market back to producing areas (e.g., prices and supply levels, consumer preferences and changes in taste).

According to Banerjee (2003), some of the most important objectives of marketing include: (1) linking the producers and consumer by bringing the products from the producing centers and offering them to consumers; (2) fetching a profit but reasonable selling price for the producers; (3) keeping the price of the commodities within the reach of the consumers; (4) presenting the
commodities in a saleable, readily consumable and attractive form with minimum deterioration in appearance, quality and taste; (5) keeping the cost of marketing as minimum as possible to maintain the interests of both producers and consumers; and (6) keeping the demand and supply in balance.

The way horticultural markets operate is complex. Markets are not very rational (Dixie, 2005). Very often, they appear to panic or overreact. If traders believe that there is a shortage of a product, prices will rise. Often, the increase is out of all proportion to any shortfall in supply. The converse is also true. If the market expects even a small oversupply, then prices fall rapidly. Overcoming surpluses is difficult, but it is more likely to be achieved through better market information and through farmers carrying out the marketing activities.

In various fruit growing areas of Ethiopia, the harvesting periods of most fruits coincide, and as a result the bulk arrival of the commodity at a point of time often saturate local markets. This market glut often leads to a drop in price of fresh fruits and consequently lowers the motivation of fruit growers. Price uncertainty may even discourage the growers to a level not to give proper management for their orchard for next bearing season.

In Ethiopia, fruits from small farmer holdings are produced in small quantities by each producer, and are then brought from the grower's fields to the local markets commonly by the farmers (back loads), horses/donkeys or by lorries/trucks. To reach most of the markets, the fruits travel may be long in terms of both distance and time. Without adequate access to transport, farmers are at a disadvantage to take their produce to the market. They have to depend on visiting buyers. With available transport, growers have control over which market the product is transported to and are therefore potentially in a better marketing position. Improved and efficient transportation system like larger loads, quicker turn-around times and better utilization of capacities, are all proven methods of lowering costs and it is opening new market opportunities.

Most fruits, as farm produce, are bulky, voluminous and highly perishable; and thus they are subject to considerable damage during transport. Especially, the fully ripen fruits have to be harvested and sold (or consumed)
immediately as any delay would possibly cause heavy wastage. Loss in transportation will be more if the roads are poor. Good returns can be obtained, from good road transport and from introduction of cold storage trucks at reasonable rates.

Most of the horticultural commodity (including fruits) markets in Ethiopia generally operate on demand and supply. In horticulture, the prices received by the farmers and prices paid by urban consumers has a larger gap which reflects inefficient marketing arrangements. Most farmers consider themselves as “price takers”, thinking that they have no control over prices and have at any cost to accept what is offered (Dixie, 2005). They neither know how to find new buyers nor how market demand is working and which products are most profitable to grow. They lack the knowledge as how to improve the prices they receive and the profitability they expect from their production. In order to alleviate prices and profitability problems encountered by farmers, development workers and extension advisors should support farmers better informed about the market. The farmers then are decision makers on their marketing. Development workers and extension advisors must never tell farmers what they should do or what products to sell. Government institutions (both federal and regional) can help farmers in many ways, without actually working with them directly. Promotion on farmers’ products, provision of market information, identifying new markets, advising on technologies and improvement of market infrastructure are powerful means to ensure farmers get good returns from their produce.

In Ethiopia, the marketing system is more complex and traditional as the production system itself. In general, problems associated with marketing of fruits in the country can be summarized as follows:

- Absence of organized outlets as groceries and department stores (at least in big cities and towns) in the country, standard packing materials, cold trucks and stores;
- Lack of processing plants;
- Limited knowledge on the nature and requirements of each fruit type (maturity, ripening, storage, etc.).
• Limited knowledge on the nutritional values of different fruits by consumers;
• Uncertainty of the consumers about the quality and variety of the different fruit types;
• Lack of information on marketing opportunities and price situations by producers;
• Minimum attention given by the extension system to fruit production;
• Lack of organized producers to bargain for better price;
• The negative roles of middlemen on the market between consumers and producers;
• Lack of consistency on the supply of production;
• Minimum control over the quality (including safety) of the produces and
• Minimum promotion work to expand sustainable market for fruits.

Therefore the following issues are suggested to improve the existing fruit marketing system in Ethiopia in a sustainable manner:

• Develop comprehensive policy to the industry;
• Develop a marketing system that benefits all elements involved in the process (identify the clusters and map the value chain of fruit market);
• Develop research to overcome challenges in the production processes (production to consumption);
• Conduct training of elements involved in the sub-sector to enhance knowledge based development of the industry;
• Organize producers to build up their bargaining power;
• Promote through marketing and other essential information about horticultural crops in general (and fruits in particular) to all in need;
• Strengthen the extension system to the sub-sector as a means of food security and ensuring the health of consumers, creating strong link with processors and consumers, reducing the cost of production and marketing;
• Organize sustainable outlets and put in place proper packaging, storage and transportation facilities;
- Develop food safety (hygiene and sanitation) standards and exercise control mechanism to guarantee consumers and ensure better price for products and
- Organize collecting and distributing centers with proper storage facility.

Prospects of fruit production in Ethiopia

The fruit production has a great prospect in trade and industrial development of the country. In addition, the fruit crops may fit well in crop diversification programs in various scales ranging from organized large orchards to a few trees in the backyard, marginal land etc. The potential of fruit production in Ethiopia may broadly be explained considering the following conditions:

1. Favorable agro-ecological conditions for successful production of various fruit crops.

   a) **Climate** - Climate refers to the average condition of the atmosphere over long period, whereas the term weather is the current and temporary atmospheric conditions. It includes conditions of temperature, rainfall, wind, and air pressure. Ethiopia being mountainous and located in the tropics, its climate is modified by altitude. Climatic components like temperature, humidity, wind speed, rainfall, hail and frost are critical for the successful fruit production and have to be carefully studied before fruit production is implemented. Ethiopia has different climatic zones/conditions (notably “Kolla”, “Woina Dega” and “Dega”). With proper selection of sites, it is possible to successfully grow many species and varieties of tropical, subtropical and temperate fruit crops. The country possesses a great potential to expand fruit farming, especially in low rainfall areas, under irrigation schemes.
b) Soils - Porous, well-drained/aerated and deep soils are preferred for successful fruit cultivation. Most soils in Ethiopia satisfy these requirements and are reasonably satisfactory for the production of different fruit crops.

2. Availability of market

a) Local market - Demand for horticultural products in general and fruits in particular grows rapidly with urbanization and increased income. Due to the increasing awareness of the nutritive value of fruits, their consumption (e.g., fresh fruit, juice, etc.) has increased considerably over the last few years. Such demand is supposed to increase fruit production in the future, with a potential local market.

b) Export market - The diverse agro-climatic conditions in the country provide a strong potential for improving the export performance in fruits and their products (processed forms) (Seifu, 2003). Ethiopia has also competitive advantages in terms of suitable climate for growing larger variety of fruits (tropical, subtropical and temperate), cheap labor cost and increasing flow of investment in the sector.

Most of the fruits produced in Ethiopia are consumed within the country while there is little export (Yohannes, 1994; Seifu, 2003; Ferdu et al., 2009). The main fruits produced and exported are bananas, citrus, grapes, mangoes, papaya, avocados, guava and strawberries (CRA, 2007; Joosten, 2007).

Fruit export is directed mainly to Djibouti, Sudan and the Middle East countries like Saudi Arabia, United Arab Emirates and Yemen markets. Exports of fruits, mainly strawberry, to Europe are negligible (CRA, 2007; Joosten, 2007; Ferdu et al., 2009; Lemma, 2010). However, both in Europe and the Middle East a growing interest exists for fruits
from Ethiopia. Some farms that are currently exporting fruits are indicated in Table 1-2.

As far as the country maintains quality of products, export market will not be a problem. In order to meet the export market requirements, farming practices and marketing systems of the country need to change. Traditional fragmented small-sized producers and labor-intensive fruit production system need to be optimized and linked to companies that organize the distribution of products in the export market.

3. Transport facilities - A good transport system helps in bridging the distance between the site of production and the place of consumption. There are encouraging new road and railway construction activities underway to link even some remote areas. Extensive upgrading of the existing asphalted roads is also going on in various parts of the country. All these infrastructure works obviously will have significant contribution for the expansion of fruit production in various parts of the country.

4. Value addition - In Ethiopia, fruits are processed at very limited scale. For perishable commodity like fruits, adequate processing facilities are required. Recently, tendencies towards establishing processing industries, especially in the private sector are becoming possible. Value added fruits not only benefit the investor but also create new jobs and sustain the production all year round.
Table 1-2. Some public and private firms involved in export of fruits.

<table>
<thead>
<tr>
<th>Fruit Firms</th>
<th>Fruit crops</th>
<th>Destination markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET FRUIT</td>
<td>Different fruits</td>
<td>Djibouti, Sudan</td>
</tr>
<tr>
<td>Africa Juice Share Company</td>
<td>Mango, passion fruit, papaya</td>
<td>Netherlands, South Africa</td>
</tr>
<tr>
<td>ILAN TOT PLC</td>
<td>Strawberry</td>
<td>Netherlands, United Arab Emirates, Saudi Arabia, UK, China, Norway, South Africa</td>
</tr>
<tr>
<td>Almeta Impex PLC</td>
<td>Grapes, strawberry</td>
<td>United Kingdom, Middle East</td>
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<tr>
<td>Afruta Fruit and Vegetable Exporter PLC</td>
<td>Strawberry, other fruits</td>
<td>Djibouti</td>
</tr>
<tr>
<td>Segel Trading PLC</td>
<td>Orange, banana, mango</td>
<td>Djibouti</td>
</tr>
<tr>
<td>ELFORA Agro Industries PLC</td>
<td>Avocados</td>
<td>Saudi Arabia</td>
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<td>Small Private Firms</td>
<td>Different fruits</td>
<td>Djibouti, Sudan, Yemen, United Arab Emirates, Saudi Arabia</td>
</tr>
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</table>

Source: CRA (2007); Lemma (2010)

Definition and classifications of fruit

Fruits are morphologically very diverse and difficult to find a satisfactory comprehensive definition if one is only restricted to inspection of the mature organ. The common fruit definition as defined in the Oxford English Dictionary, “a fruit is the edible product of a plant or tree, consisting of the seed and its envelope, especially when juicy and pulpy”.

In horticultural terms, the word fruit is defined as a matured ovary with or without associated parts. In other words, a fruit is essentially a continuation of the ovary, which singly or in aggregate and with or without other parts, persists after flowering and usually develops as an auxiliary organ of seed dispersal. The ovary may be subdivided into two or more carpel (then termed compound ovary), each bearing one-to-many ovules. Individual carpels develop into sections of a whole fruit, as with citrus, where each familiar
segment of the fruit represents one matured carpel. If the ovary is not subdivided, then it is termed simple (Rieger, 2006). The ovules will mature into seeds if fertilized. Fruit is generally a seed-bearing organ of the plant. However, there are some fruits that are seedless, developed either through the process of parthenocarpy or by other means.

Parthenocarpy is the formation and development of a fruit without pollination and subsequent fertilization. Different types of parthenocarpy are known: (1) *Stimulative parthenocarpy* - In this type of parthenocarpy formation and development of fruit is stimulated by pollination but pollen tube does not reach ovule to effect seed formation (e.g., Black Corinth variety of grape, seedless guava, etc.), (2) *Stenospermocarpy* - Here fruit is formed as a result of both pollination and fertilization, but embryo aborts (after making early growth) leading to seedlessness (e.g., Thompson Seedless grape), and (3) *Vegetative parthenocarpy* - In this type, fruit formation and development occurs without stimulus of pollination (e.g., banana, pineapple, satsuma mandarin, Washington navel orange, common fig, etc.).

Various criteria are used to classify fruits (the plant and/or the useable part); of which the following are the most commonly used ones:

1. **Classification based on whether fruits are leaf shedding or not:** *deciduous* and *evergreen fruits.*

**Deciduous fruits** are fruit plants that shed their leaves at the end of each growing season. Such fruit plants lose their leaves under adverse conditions (e.g., cold, dry conditions). Most of these fruit plants are of temperate origin. Apple, pear, peach, plum, grape, etc. are examples of deciduous fruits. As a result of originating in temperate climates, with a distinct seasonal rhythm, deciduous fruit trees have good cold hardiness and require chilling for uniform bud-break and good cropping.

**Evergreen fruits** are fruit plants that are never entirely leafless. Such fruit plants have leaves that stay on the plant throughout all of the seasons. This does not mean that the leaves never die or fall off. It means that when they
do, they are replaced by new ones and the plant is never without greenery. Most fruit plants of the tropical and subtropical origin are known to be evergreen. Banana, pineapple, mango, passion, guava, citrus, passion fruit, avocado, etc. are examples of evergreen fruits.

2. Classification based on their climate adaptation:

Based on crop-plant production systems, there are four climatic zones: (1) tropical, (2) subtropical, (3) warm-temperate, and (4) cool-temperate. These zones can be delineated according to their distance from the equator (latitude). In general, the tropical zone lays 0-20°, the subtropical 20-30°, the warm-temperate 30-40° and the cool-temperate 40-60° north and south from the equator. These differences in latitude may account for the difference in temperature, length of the frost-free growing season, and intensity and duration of light between any two zones (Edmond et al., 1983).

The degree of heat varies more or less directly with the distance from the equator. As a result, the tropical zone has the highest temperature, the longest frost-free growing season, and the highest intensity of light. This is followed by the subtropical, the warm-temperate, and the cool-temperate zones, in descending order.

Tropical fruits - Fruit plants in the tropical group do not withstand freezing temperatures, and many do not grow well if temperatures drop below 10°C. These plants do not require cold temperature exposure for either vegetative growth or flower initiation.

In tropical regions average annual temperature is above 18°C. Minimum temperatures never fall below 0°C except at the highest elevations. Tropical regions, especially those within 10° north or south of the equator, experience small fluctuations in day length at all elevations and diurnal temperatures in low and mid elevations (Desalegn and Paul, 1998). Local climatic conditions vary considerably within the tropical regions based on elevation or proximity to water or mountain ranges which affect wind patterns and rainfall. Therefore, tropical regions may be further subdivided into
lowland, midland or highland tropics and into wet (humid) or dry (arid or semiarid) regions (Davies and Albrigo, 1994).

**Subtropical fruits** - Fruit crops that grow at low altitudes of the temperate zones nearest the equator. Most of them can also grow in the true tropics, but is not produced well.

Subtropical regions are characterized by mean annual temperatures between 15°C and 18°C but have greater diurnal temperature fluctuations than tropical regions. Moreover, many subtropical areas are exposed to temperatures below 0°C on a regular basis with temperatures as low as -7°C (Davies and Albrigo, 1994). Most of mature sub-tropical fruit trees tolerate some subfreezing temperatures but may be severely injured or killed by low temperatures. The extent of freeze-damage may vary depending on the type of fruit species and particular location within subtropical regions. For instance, locations in proximity to large water bodies will have moderate temperatures, as a result of which low temperatures rarely cause extensive crop or tree losses. Citrus and avocado are examples of subtropical fruits.

**Temperate fruits** - These fruit crops are grown in the temperate-zone regions of the northern and southern hemispheres. These plants withstand very cold winter temperatures and do in fact require winter chilling for good productivity. Grape, peach, strawberry, apple and plum are among temperate fruits that are grown in Ethiopia.

3. **Classification based on the mode of development of fruit:**

**True fruit** - True fruit is a fruit that is derived from an ovary (e.g., citrus, grape, guava, etc.).

**False fruit** - A fruit that is developed from an ovary plus associated parts of a flower, e.g., strawberry, apple, pear. In pome fruits (apple, pear), the ovary region of the flower consists of both the ovary itself and surrounding adherent portions of the flower. Pome fruits thus have an “inferior” ovary. As the fruit
grows, the fruit flesh is derived to a great extent from the non-ovarian tissues surrounding the embedded ovary. The ovary proper develops as the cartilaginous inner tissue (endocarp) at the fruit’s core (Lakso and Goffinet, 2003). The main flesh of the fruit is derived from the inner (pith) and outer (cortex) tissues that surround the ovary and micro-vules (seeds). The hypanthium just above the inferior ovary of the flower will enlarge to varying degrees, to contribute flesh to the fruit’s terminal lobes.

4. Classification based on the number of ovaries incorporated in the structure:

**Simple fruit** - Simple fruit is a fruit derived from a single pistil. Depending on the nature of the fruit covering (layer of rind), simple fruits can be monocarpellary (e.g., mango, grape) or multicarpellary (poly-carpillary) (e.g., citrus). Other parts of the flower do not contribute in the formation of a simple fruit. On the basis of the nature of pericarp, simple fruits may be either dry or fleshy/succulent (or juicy) when mature.

**Multiple (composite) fruit** - A fruit which is derived from many individual ovaries (entire inflorescence) fused into a single structure borne on a common stalk (e.g., pineapple, mulberry).

**Aggregate fruit** - An aggregate fruit develops from a flower with numerous simple pistils. In other words, aggregate fruit is a fruit which is derived from many ovaries on a common receptacle. Aggregate fruits are actually a bunch of simple fruits, e.g., strawberry. In strawberry, many achenes, single-seeded true fruits, form a fleshy fruit on a common receptacle.

5. Classification based on the nature and structure of the ovary wall (pericarp):

The ovary wall is composed of three distinct layers: exocarp, mesocarp and endocarp (Fig. 1-1). These layers may develop into distinct parts of the fruit. Generally, the exocarp becomes the fruit peel or skin, the mesocarp becomes
the fruit flesh, and the endocarp becomes the innermost part of the flesh or a specialized tissue surrounding the seed(s), as with a pit. In many cases, however, the three layers are indistinguishable, and the term pericarp is applied to denote all ovarian tissues surrounding the seed/s (Rieger, 2006).

Figure 1-1. Layers of the ovary wall: (a) Exocarp (b) Mesocarp (c) Endocarp

**Berry** - A fruit with one or more carpels that develops few to many seeds. Papaya, grape, avocado, guava, bullock's heart, etc. are examples of berry fruits. There are also seedless fruits like banana, and some cultivars of grape. A typical carpel consists of a lowermost swollen structure (ovary), which remains attached to the thalamus; the middle, stalk like (style), and an apical knob-like part (stigma). Botanically, thalamus (receptacle or torus) may be defined as the apical part of pedicel, which bears the floral leaves like sepals, petals, stamens and carpels.

**Hesperidium** - The fruit of citrus species is a special kind of berry called a hesperidium. It is a fruit with several carpels containing a leathery rind with inner pulp juice sacs or vesicles (Fig. 1-2). In a hesperidium, there are numerous hairs (trichomes) that become swollen with liquid and form the “fleshy” part that surrounds the seeds. The endocarp projects inside and forms many chambers. The exocarp and mesocarp together constitute the skin of the fruit, for example, orange, mandarin, lemon, lime, grapefruit and other citrus fruits.
Drupe - A simple fruit derived from a single carpel. The exocarp becomes the thin skin; the mesocarp becomes thick and fleshy; the endocarp becomes hard and stony (Fig. 1-1) and is often referred to as the pit. Generally, drupe fruits are fleshy which have a central cavity containing a large hard seed (stone). Peaches, plums, mangoes and apricots are examples of drupe fruits.

Pome - A simple fruit made up of several carpels. It develops from syncarpous (carpels united with one another) and inferior ovary, in which thalamus enlarges and surrounds the seeds. Some fruits are fleshy, which have a central cavity containing several small seeds (pips). Apple and pear are typical examples of pome fruits.

Nut - One seeded fruit with a thick, hard, stony pericarp. A nut is dry, indehiscent fruit with hard shell. Unlike fleshy and juicy fruits, the edible part of nuts is the seed (endocarp), which is often rich in oil. Macadamia nut, cashew nut, and walnut are examples.

6. Classification based on ripening behavior:

Climacteric - Climacteric fruits are defined as fruits that enter 'climacteric phase' after harvest (i.e., they continue to ripen after harvest). They experience a sudden rise in rate of respiration at the time of ripening. During the ripening
process the fruits emit ethylene along with increased rate of respiration. Ripe fruits are soft and delicate and generally cannot withstand rigors of transport and repeated handling. Therefore these fruits need to be harvested hard and green, but fully mature and are ripened near consumption areas. Avocado, banana, papaya, mango, guava, passion fruit, apple, pear, peach, plum, jackfruit, fig, etc. are examples of climacteric fruits.

**Non-climacteric** - Fruits experiencing simple gradual decline in rate of respiration at the time of ripening are known as non-climacteric. These fruits produce very small amount of ethylene and do not respond to ethylene treatment. There is no characteristic increased rate of respiration or production of carbon dioxide. Non-climacteric fruits once harvested do not ripen further. Therefore these fruits must be allowed to attain proper stage of maturity being attached to the fruit plant. Pineapple, oranges, mandarins, grapefruit, lemon, lime, grape, pomegranate, loquat, strawberry, etc. are some of the fruits included under this category.

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CHAPTER 2

SEXUAL PROPAGATION OF FRUITS

Sexual propagation is the raising of plants by means of seeds, which are formed as a result of the union of male and female gametes within the ovule of a flower (Hartmann and Kester, 1983; AHS, 1999). A seed is a miniature packed plant ready for sowing with nourishing tissues and a protective cover. In sexual reproduction the new plant results from the growth of the seed (zygote) and may or may not resemble both parents, depending on the genetic similarities between them.

Propagation by seeds is the major method by which plants reproduce in nature and one of the most efficient and widely used propagation methods for cultivated crops, including most fruit plants (Sharma, 2002; Yadav, 2007). It involves meiosis, reduction division of chromosomes. Seed is formed as a result of pollination and subsequent fertilization. During flowering, pollen is transferred from the anther to the stigma (pollination), where it germinates. A pollen tube grows down the style into the ovary until it reaches the embryo sac within the ovule. Two male gametes from the pollen tube are discharged into the embryo sac, one to unite with a female gamete (fertilization) to produce the zygote and the other to unite with the two polar nuclei to produce the endosperm. The zygote is diploid (2N) and divides to become the embryo. The endosperm is triploid (3N) and develops into a nutritive tissue for the developing embryo. In horticultural terms the fruit plants multiplied by seeds are known as seedlings and this term may be applied throughout the life of that plant.

The relationships between flower structure (Fig. 2-1) and parts of the fruit and seed are as follows (Hartmann and Kester, 1983):
Ovary .................................................. Fruit (sometimes composed of more than one ovary plus additional tissues)

Ovule .................................................. Seed

Integuments ....................................... Seed coats (seed coverings)

Nucellus ............................................. Perisperm (usually absent or reduced, sometimes storage tissue)

1 sperm nucleus + egg nucleus ——— Zygote (embryo) 2N
1 sperm nucleus + 2 polar nuclei ——— Endosperm (food storage material) 3N

The seed has therefore three essential parts: embryo, endosperm and seed coats (seed coverings or testa).

Figure 2-1. Details of the pollen, ovary, and ovule structure. Left: pollen grain germinating on stigma; notice the two haploid generative nuclei. Right: an ovary showing a single ovule containing a mature embryo sac and its eight haploid nuclei. It is surrounded by the diploid nucleus that is enclosed within the two integuments, all of which are genetically the same as the mother plant.

Source: Hartmann and Kester (1983)

Advantages of sexual propagation of fruits include (Hartmann and Kester, 1983; Sharma, 2002; Yadav, 2007):
• It is an easy, simple and economical method of propagating fruit plants as long as genetic variability can be controlled within acceptable limits.

• Some of the plants (e.g., papaya) do not respond well to asexual means and are generally propagated by seeds.

• New varieties can be developed (hybrids are developed). Naturally, occasionally sexual propagation may lead to the production of chance seedlings having characteristics superior to the parent plants.

• Helps to produce commercial crops. Relatively large number of plants can be produced within a very short period of time. Rootstocks are usually propagated by means of sexual propagation because they are hardy and develop better root system.

• Sexually raised plants are long lived, have extensive root system as compared to vegetatively propagated plants. Young plants can have high root-to-shoot ratio that enables them to withstand adverse environmental conditions (e.g., moisture stress, prevailing wind), as the plants will have deep root penetration and better anchoring capacity.

• Seedlings are mostly disease free (especially virus free) as most virus diseases are transmitted with vegetative propagules and tools (e.g., budding and grafting knives).

• Seeds, if stored properly, can be kept for longer duration for future use.

• Seeds of some fruits like citrus and mango varieties are capable of producing more than one seedling from one seed arise from the cells of the nucellus. These nucellar seedlings can be utilized for raising uniform plants, if they can be carefully detected at early stage.

However, sexual propagation has the following disadvantages (Hartmann and Kester, 1983; Sharma, 2002; Yadav, 2007):

• Most of the fruit plants are heterozygous in nature. Multiplication of these plants by sexual means results into segregation of characters and the resultant plants are not true-to-type.

• Susceptibility of some cultivars to disease and nematodes when they are grown on their own roots. The beneficial influences of rootstock
and scion variety cannot be explored in sexual propagation.

- Seeds of many fruits are to be sown immediately after extraction from the fruits as they lose their viability very soon.
- Seeds of some plants germinate with difficulties.
- Plants raised from seeds take longer time to come into bearing as compared to the vegetatively propagated ones.
- Seedling raised plants are generally tall and spreading type causing considerable difficulties for carrying out various management practices such as harvesting.

In most cases it is thus best to avoid using seedling plants for establishing a commercial orchard. Seedlings are normally grown as a rootstock onto which desired fruit cultivars are budded or grafted.

In botanical terms, a seed is a fertilized ovule, and for practical purposes, it is a dry unit of propagation that transmits genetic material from generation to generation (Doijode, 2002). To produce a viable seed, both pollination and fertilization must take place (AHS, 1999). In some cases, however, the fruit may mature and contain only shriveled and empty seed coats with no embryo or with one that is thin and shrunken. Such “seedlessness” may result from several causes (Hartmann and Kester, 1983): (a) parthenocarpy (the development of the fruit without pollination or fertilization); (b) embryo abortion (the death of the embryo during its development); or (c) the inability of the embryo to accumulate the required food reserves.

Sources of seed

Good-quality seed has the following characteristics (Hartmann and Kester, 1983; AHS, 1999): It is genetically true to species or cultivar; capable of high germination; free from disease and insects; and free from mixture with other crop seeds, weed seeds, and inert and extraneous material. Fruit seeds may be obtained from seed orchards and/or fruit-processing industries.
Seed orchards or plantations are used to maintain a certain seed source of a particularly valuable genotype. Seed orchards are used directly or indirectly for the production of virus free rootstocks, if can also be used for breeding purposes and indexing virus.

Seed orchards (seed bearing fruit trees) can be raised (established) from seedlings derived from three different sources: (a) seedling trees produced from selected parent material and developed through natural or controlled pollination; (b) clonal seed orchards in which selected clones are propagated vegetatively by grafting, budding or cuttings; and (c) seedling-clonal seed orchards in which certain clones are grafted or budded into branches of some of the trees. In other words, selected clones (desired for seed production) are grafted and/or budded into branches of the already established (seed propagated) fruit plants.

Various fruit tree rootstock clones are self-pollinated and are planted on separate blocks. An isolation zone at least 120 m wide should be established around the seed orchard to reduce pollen contamination (cross pollination) from other sources.

Fruit processing industries - In addition to the above three sources (i.e., seed orchards), sometimes, seeds for rootstocks production may be obtained from fruit processing industries (i.e., as byproducts). However, this kind of seed source can be undesirable, if one does not know the genetic identity or the virus status of the seed source.

Harvesting and processing of seeds

Maturity and ripening - A seed becomes mature when it has reached a stage at which it can be removed from the plant without impairing its germination capacity. As a rule, seed is said to be matured when no further increase in dry weight will occur. If the fruit is not physiologically mature or the seed is harvested when the embryo is insufficiently developed, the seed will be thin, light in weight, shriveled, poor in quality and short lived.
Extraction of fruit seeds - The important fruit species used for food are characterized by having fleshy fruits. Fleshy fruits include berries (grape, avocado, guava, papaya, etc.), drupes (mango, peach, plum, etc.), pomes (apple, pear), and aggregate fruits (strawberry, raspberry). The flesh must be removed promptly to prevent spoilage and injury to the seeds. Cleaning by hand treading in tubs, and rubbing through screens are suitable methods for small lots of seed. Relatively large fruits can be cleaned conveniently by placing the fruits in a wire basket and washing them with water from a high-pressure spray machine. For large lots of seed, a macerator is convenient.

A macerator is constructed with a watertight feeder where water is passed through it along with the fleshy fruits, and the pulverized mass is diverted into a tank where the pulp and seeds can be separated by floating. A floating process involves placing the seeds and pulp in water so that the heavy seeds will sink, while the lighter pulp, empty seeds, and other light extraneous materials float. This procedure can also be used for removing the poor quality (e.g., immature) seeds.

Fruit-tree seeds collected from the wastes of drying yards, canneries or juice presses should be separated from the pulp, washed as quickly as possible, and should not be allowed to ferment or heat in the piles. Such seeds can be extracted (or purified) by flotation or washing with high pressure spray machines, and dried under shade to the optimum moisture level of each species.

Seed storage - Seeds are usually stored for varying lengths of time after harvest. Viability at the end of any storage period is the result of the initial viability at harvest as determined by factors of production and methods of handling, and the rate at which deterioration takes place. This rate of physiological change or aging varies with the kind of seed and the environmental conditions of storage, primarily temperature and humidity (Hartmann and Kester, 1983; Sharma, 2002).

Seeds of certain species are short-lived if they are not allowed to germinate immediately in their natural habitat. For instance, seeds of many tropical fruit plants grown under high temperature and humidity are
short-lived. The group includes plants such as citrus, jackfruit, macadamia, avocado, mango, loquat and many other fruits of similar character.

The storage conditions that maintain seed viability are slow respiration and other metabolic processes without injuring the embryo. The most important conditions are low moisture content, low storage temperature, and modification of storage atmosphere (Hartmann et al., 1981). Of these, the moisture temperature relationships have the most practical significance (Hartmann and Kester, 1983). Many kinds of short-lived seeds are sensitive to desiccation and lose viability if the moisture content becomes low. For instance, citrus seeds can withstand only slight drying without loss of viability.

Environmental factors affecting seed germination

An understanding of the ways in which plants grow and reproduce, and of the relevance and application of practical techniques, will allow the gardener to propagate plants with ease and confidence. Success in propagation usually depends on providing a supportive environment for the plant material and, later, for the new plants (AHS, 1999). Environmental factors affecting seed germination include the following (Hartmann and Kester, 1983):

**Water content** - Water content is a very important factor in controlling seed germination. Hartmann and Kester (1983) have reported that below 40 to 60 per cent of water in the seed (on fresh weight basis) germination does not occur. Optimum moisture status of the growth media or germination media (seed bed, seed germination chamber) need to be met for maximizing germination rate. Shallow seeded and small sized seeds need due consideration.

**Temperature** - Three temperature points (minimum, optimum, and maximum), are usually designated for seed germination (Hartmann et al., 1981). These points (or temperature ranges) can vary from species to species. Minimum is the lowest temperature range for effective germination. Maximum is the highest temperature range at which germination occurs. Optimum temperatures
for seed germination fall within the range at which the largest percentage of seedlings is produced at the highest rate (Sharma, 2002).

Among other essential factors (moisture, oxygen) to initiate germination, temperature is perhaps, the most important environmental factor that regulates germination and controls subsequent seedling growth (Yadav, 2007). The temperature affects both germination percentages and germination rate (i.e., low at low temperature but increases continuously as temperature rises to the optimal level for each species). Above an optimum level, where the rate is most rapid, a decline occurs as the temperature approaches a lethal limit and the seed is injured. Unlike germination percentage, germination rate may remain relatively constant, at least for about the optimum temperature range, if sufficient time is allowed for germination to occur.

**Aeration** - Good exchanges of gases (particularly oxygen) between the germination medium and the embryo are essential for rapid and uniform germination. The supply of oxygen to the embryo can be limited by the condition of the soil medium or by the restrictions imposed by the seed coverings. Oxygen supply is limited where there is excessive water in the soil medium. In most kinds of seeds there is probably some physical restriction in the movement of oxygen to the imbibed embryo, due either to the inner membranous seed coat or to the enclosing nucleus or endosperm.

**Light** - In some cases light is essential to the germination of some kinds of seeds. The light requirement for seed germination is very complex, depending on the age of seed, degree of seed imbibition with water, temperature, day length, and certain germination-stimulating chemicals (Hartmann *et al.*, 1981). In certain crop seeds, light either promotes or inhibits the germination process. Photochemical reactions occur between 290 to 800 nm radiation. The molecule absorbs the light particles, which stimulates the germination process. In general, wavelengths of 660 to 700 nm (red light) promote germination, and wavelengths of 700 to 760 nm (far-red) are inhibitory (Doijode, 2002).

**Disease control during seed germination** - The control of disease during seed
germination is one of the most important tasks of the propagator. The most universally destructive pathogens are those resulting in "damping off" which may cause serious loss of seeds, seedlings, and young plants.

**Freedom from toxic amount of salts** - If the germination medium is watered lightly but frequently after the seeds have been planted, evaporation of water from the surface leaves salt deposits. If this situation continues, the salinity can increase to such a level that it will injure or kill the seedlings as they germinate. This is a particular problem with small, shallow-planted seeds that may dry out quickly, and in areas having high salt concentrations in the water. This problem can be prevented by using soil mixtures and water low in salts, by withholding fertilizers, and by irrigating more copiously but less frequently so that excess salts are leached out.

**Seed dormancy**

Seed dormancy normally refers to the failure of viable seeds to germinate under favorable germination conditions (Hartmann and Kester, 1983; AHS, 1999; Sharma, 2002). Seed dormancy can result from structural or physiological conditions in the seed covering, particularly the seed coats, or in the embryo itself or both.

Various types of seed dormancy result from different germination controlling mechanisms within the seed. Classifications have been developed to explain the biological mechanisms involved and suggest ways to overcome dormancy. The following categories of seed dormancy are known (Nikolaeva, 1977; Hartmann and Kester, 1983; AHS, 1999): seed coat dormancy, embryo dormancy and double dormancy.

**Seed coat dormancy** - Seed coats or other tissues covering the embryo may be impermeable to water and gases, particularly oxygen, which therefore cannot penetrate to the embryo and initiate the physiological processes of germination. This situation usually occurs in species that produce hard seed coats. Seed coat dormancy is further distinguished into three classes (Hartmann
and Kester, 1983; Hartmann et al., 1990; Sharma, 2002):

1. Physical dormancy is characteristic of a large number of plant families in which the seed coats and sometimes hardened sections of other seed coverings are impermeable to water.

   Hard seededness depends on the genetic nature of the species, environmental conditions during seed maturation, and environmental conditions during seed storage. For instance, drying at high temperatures during ripening will increase hard seededness.

   In nature, seed covering are softened by various agents of the environment. These include: mechanical abrasion, alternate freezing and thawing, attack by soil microorganisms, passage through the digestive tracts of birds or mammals or fire.

2. Mechanical dormancy refers to seed covering that are too hard to allow the embryo to expand during germination.

3. Chemical dormancy Chemicals that act as seed germination inhibitors (various phenols, coumarin, and abscicic acid) have been extracted from various plants parts and identified. Seeds of citrus, stone fruits, grape, apples and pears are known to have germination inhibiting chemicals.

Treatments to overcome seed coat dormancy

Seed dormancy is genetically controlled and modified by pre-and- postharvest environmental factors. Application of some treatments is beneficial in overcoming dormancy in particular crop plants. The following are common treatments to overcome seed coat dormancy (Hartmann and Kester, 1983; AHS, 1999; Doijode, 2002; Sharma, 2002):

Scarification - Scarification is any process of breaking, scratching, mechanically altering, or softening the covering to make them permeable to water and gases. Various scarification methods are known: mechanical
scarification, hot water scarification and acid scarification.

**Mechanical scarification** - Softening seed coats by rubbing with sandpaper, cutting with a file, or cracking with a hammer or a vise are simple methods useful for small amounts of relatively large seed. For large-scale mechanical operations, special scarifiers are used. Scarification should not proceed to the point at which the seeds are injured.

**Hot water scarification** - In this type of scarification the seeds are dropped into four to five times their volume of hot water at 77 to 100°C (Hartmann and Kester, 1983). The heat source is immediately removed, and the seed is soaked in the gradually cooling water for 12 to 24 hours. The ratio of water to seed should be 1:5 (Sharma, 2002). Following this the unswollen seeds can be separated from the swollen ones by suitable screens and either retreated or subjected to some other treatment. The imbibed (swollen) seeds should usually be planted immediately after the hot water treatment.

**Acid scarification** - In this type of scarification, dry seeds are placed in containers and covered with concentrated sulfuric acid in a ratio of about one part seed to two parts acid (Sharma, 2002). The seeds along with acid should be stirred continuously to avoid acid injury to the seeds. The treatment time depends upon the kind and amount of seeds, varying from 15 minutes in some species to 6 hours or even more in others.

The amount of seed treated at any one time should be restricted to no more than about 10 kg to avoid uncontrollable heating (Hartmann and Kester, 1983). Containers should be glass, earthenware, or wood; but metal or plastic should be avoided. At the end of the treatment period the acid is poured off, and the seeds are washed thoroughly under running tap water for 10-15 minutes to remove the acid from the seeds (Sharma, 2002). According to the author, the treated seeds may be placed in a large amount of water with small amount of baking soda to neutralize the adhering acid. Afterwards, the treated seeds may be sown immediately when wet or dried and stored for later sowing.
Embryo dormancy - Embryo dormancy results from physiological conditions or germination blockage in the embryo itself that prevent embryo from resuming active growth even if all environmental conditions are favorable. Embryo dormancy is characterized principally by the requirement of a period of moist chilling for germination and the inability of the excised embryo to germinate normally. The process called stratification normally overcomes it (Hartmann et al., 1990).

Stratification is a method of handling dormant seeds in which the imbibed seeds are subjected to a period of chilling to after-ripen the embryo. The usual stratification temperature is 0 to 10°C (Hartmann and Kester, 1983). The time required for stratification depends on the kind of seed and sometimes upon the individual lot of seed as well. For seeds of most species, one to four months is sufficient for low-temperature stratification. There are two common stratification methods (Hartmann et al., 1990; Sharma, 2002): refrigerated stratification and outdoor stratification.

Refrigerated stratification - In this method dry seeds should be fully imbibed with water prior to refrigerated stratification. 12 to 24 hours of soaking at warm temperatures may be sufficient for seeds without hard seed coats or coverings. Longer periods are required, with aeration, for seeds, enclosed in hard endocarp or pericarp; soaking for three days to a week or more may be necessary.

Outdoor stratification - Where refrigerated storage is not available, stratification may be done by storing outdoors, either in pits several centimeters deep or in raised beds enclosed in wooden frames. Essentially the same seed preparation procedures are used but outdoor winter chilling and natural rainfall provide the required chilling temperature and moisture. However, the seeds need to be protected against freezing, drying and rodents.

Hartmann and Kester (1983) and Sharma (2002) have reported that the following conditions are required to undergo stratification process (that is to break embryo dormancy):
1. **Imbibition of moisture by the seed** - If the seed is enclosed by a hard endocarp or other seed layer, water imbibition may be slow so that the required after-ripening period (i.e., a period during which physiological changes occur within the seed after harvest that enable germination to take place) becomes much longer. Scarification and stratification processes are generally known to improve imbibition of seeds of fruits.

2. **Temperature** - Temperature is the most important factor affecting the rate of after-ripening. Temperature ranges above freezing point, around 2 to 7 °C, are generally said to be most effective.

3. **Aeration** - Good aeration that provides oxygen during seed stratification is necessary for proper after-ripening.

4. **Time** - The time required to after-ripen dormant seeds of most perennial fruit plant species is from one to three months although, for certain species, five to six months are necessary.

**Double dormancy** - Double dormancy is characterized by having both seed coat dormancy (lack of water permeability) and a dormant embryo (Hartmann and Kester, 1983; AHS, 1999). This type of dormancy is characteristic of species of trees in families having seeds with hard seed coats. In double dormancy, to produce germination both blocking conditions must be eliminated in proper sequence (Hartmann et al., 1990). Warm followed by cold stratification generally overcomes these situations. In nature, various agents of the environment that affect physical dormancy soften the seed coat when the seed falls to the ground, then the seeds are killed as they over winter.

**Seed viability tests**

In seed testing, the sample on which the test is made must be representative. A bulk should be well mixed prior to sampling. This is safely accomplished with dormant seed, but if germination has begun considerable damage may be done. Seeds should be taken from not less than ten different positions in the bulk, whether this is in sacks or rigid containers or in a single heap. When
the individual samples are found to be more than sufficient they should be put together, well mixed and then halved by a single movement (Hartmann and Kester, 1983; Garner et al., 1985). If necessary, one of these halves may be remixed and halved again, to obtain a manageable sample for testing. Seed may be tested for a variety of characteristics such as purity, internal condition and, above all, germination percentage and vigor (Hartmann et al., 1990).

Purity is the percentage by weight of the “pure seeds” present in the sample. Pure seed refers to the principally named kind, cultivar, or type of seed present in the seed lot. After the working sample has been weighed, it is divided visually into (a) the pure seed of the kind under consideration; (b) other crop seed; (c) weed seed; and (d) inert material, including seed-like structures, empty or broken seeds, chaff, soil, stones, and other debris.

Viability can be determined by several tests, of which, the direct germination, excised embryo, and tetrazolium tests being the most important. In the direct germination test the germination percentage is determined by the per cent of normal seedlings produced by the pure seed. To produce a good test, it is desirable to use at least 400 seeds picked at random and divided into lots of one hundred each (Hartmann and Kester, 1983; Hartmann et al., 1990). If any two of these lots differ by more than 10 per cent, a retest should be carried out. Otherwise, the average of the four tests becomes the germination percentage.

Each sample to be tested should be soaked or otherwise moistened and placed in a suitable temperature. Small seeds may be lined-out on moist filter or blotting paper and covered with glass covers within a controlled cabinet. Large seeds, such as avocado, are better partially buried in a layer of sand or clean fibrous material. Generally, direct germination test is used to test viability of non-dormant seeds.

The excised-embryo test is used to test the seed viability of fruit trees whose dormant embryos require long periods of after-ripening before true germination will take place. In this test the embryo is excised from the seed and germinated alone. Procedures for germinating excised embryos are similar to those for germinating intact seeds. Petridishes with a moist substratum, such
as blotting or filter paper, are used. The embryos are placed on the filter paper so that they do not touch (overlap). The dishes are kept in the light at a temperature of 18 to 22°C. At higher temperatures, moulds may develop and interfere with the test. The time required for the test varies from three days to three weeks (Hartmann and Kesten, 1983).

Nonviable embryos become soft, turn brown, and decay within two to ten days; viable embryos remain firm and show some indication of viability, depending upon the species. Types of response that occur include spreading of the cotyledons, development of chlorophyll, and growth of the radicle and plumule. The rapidity and degree of development gives some indication of the vigor of the seed.

The *tetrazolium test* is a biochemical method in which viability is determined by the red color appearing when the seeds are soaked in a 2, 3, 5-triphenyltetrazolium chloride (TTC) solution (which is colorless by itself). This type of test is especially useful in evaluating dormant seeds, just harvested, and also when seeking the cause of non-germination of firm seeds that remain dormant at the end of growth tests (Hartmann, et al., 1990). The TTC test is used primarily to obtain rapid results for both non-dormant and dormant seeds. For the tetrazolium test the seeds should be soaked in water for a day or more to facilitate even absorption of the chemical and subsequent clean cutting, where this is necessary.

According to Hartmann and Kesten (1983) and Hartmann et al. (1990), a suitable solution is 0.25% per cent 2, 3, 5-triphenyl-tetrazolium chloride in water, i.e., one gram tetrazolium salt in 400 mL of water. Seed immersed in this solution for one to two days in complete darkness at temperatures of 23 to 32°C, should be adequately stained. The solution is discarded and the seed kept wet and cool by immersion in water in a refrigerator at 4.4 to 10°C till testing. In the test the seed coat is removed to reveal the degree of staining of the tissues. Strong, healthy, viable tissues are stained red. Weaker tissues, of old seed or seeds badly harvested or improperly stored, will be mottled or only palely colored, whilst dead tissues are white. Confirmation of the individual staining reaction may be obtained by inspection of sliced seed.
Various quick viability tests have been devised to provide data for a rapid, report on germination capacity. One easy means of determining the possible germinability of a seed lot is a “cut test”. Seeds of a representative sample are simply cut in half to see whether there is an embryo inside. If the embryo has aborted or has been eaten by insects, the seed would not germinate. Generally, in the “cutting” test the seeds are simply cut open and empty or damaged ones counted. The mere presence of an embryo, however, does not mean it is alive.

Another simple test is to float the seeds in water. Quite often the “floaters” are empty seeds and can be skimmed off (Hall, 2003). Full seeds usually sink and are the ones to be planted. Strictly speaking, the latter tests (cut test and floating) are not viability tests; but are useful to rule out seeds that have no possibility of germinating. They still do not give the viability status of seeds with full-sized, apparently sound embryos.

References


Vegetative or asexual propagation refers to the propagation of new plants directly from existing source (mother) plant and not from the seeds. It is accomplished entirely by mitosis, the cell division process by which the plant grows. Each daughter cell is an exact replica of its mother cell (Hartmann et al., 1990). Chromosome numbers and composition do not change during cell division. Mitotic cell division produces the adventitious roots and shoots as well as the callus necessary for successful vegetative propagation.

Vegetative propagation is possible because living cells contain genetic information in their nuclei necessary to reproduce the entire plant (Hartmann et al., 1990). This property is called totipotency. New plants can start from a single cell, either adventitiously on intact plants or in aseptic culture systems.

Advantages of vegetative propagation in fruit production include (Hartmann and Kester, 1983; Hartmann et al., 1990; Sharma, 2002; Yadav, 2007):

1. Asexually propagated fruit plants are true-to-type, replica of their plants. Most of the fruit plants like avocado, mango, citrus, guava, etc. are cross pollinated and heterozygous in nature and the genetic architecture of the offsprings can only be maintained true-to-type through vegetative propagation.

2. Asexual propagation is necessary to maintain fruit cultivars that produce no viable seeds. For example, this is true of all the superior varieties of banana, pineapple, and with some varieties of grapes and oranges. In other cases germination may be very poor or very slow, and it is frequently more convenient to use vegetative methods.
3. Fruit plants grown from seed go through a juvenile period during which flowering does not occur. Vegetative propagation retains the flowering capacity and shortens the time of reproductive maturity (reduces the long non-flowering juvenile characteristics of most seedling fruit plants). The long delay in flowering of juvenile seedlings is economically undesirable. Fruit producers can overcome this delay in flowering by grafting a scion from a mature tree onto any rootstock (seedling or mature), because a mature scion maintains its flowering state in a graft to a juvenile seedling (Mudge et al., 2009). Generally, asexually propagated fruit plants possess short juvenile phase and come into flowering/bearing earlier than the seedling trees.

4. Combination of more than one genotype into a single plant - Vegetative propagation by grafting and budding makes it possible to unite more than one genotype and combine desirable features of both into a composite plant. Most fruit orchards are combinations of a seedling (or clonal) rootstock chosen for root characteristics, combined with a cultivar chosen for its fruiting characteristics. A related practice is to use grafting to "build" a tree with multiple varieties. A multi-grafted tree (also called "cocktail tree") consists of several scion varieties worked onto a single rootstock, assuming all are compatible with it (Ingels, 2009). Various fruit plants that are closely related may be grown on a single rootstock, such as most citrus varieties, most stone fruits, or a selection of pome fruits (Lewis and Alexander, 2008). When self incompatibility is a problem, as in apple, a pollinizer (pollen donor) can be grafted to achieve cross pollination within a single tree (Mudge et al., 2009).

5. Generally the grafting and/or budding methods enable the grower to exploit the benefits of rootstocks and scions. Some of the advantages of combining of clones are: (i) to correct, by doing top-working, the initial mistakes of planting inferior varieties in the orchard; (ii) to facilitate cross pollination in self-unfruitful varieties. Such fruit varieties
can be made to bear fruit if compatible variety (pollen donor) is grafted on to their branches. Instead of planting occasional staminate trees, or trees of a variety suitable for pollination, single branches of these may be grafted into occasional pistillate trees or trees of the main variety.

6. Size control - Certain rootstocks will result in dwarfing or invigoration of the scion cultivar. In apple, a single scion cultivar grafted onto the full range of size-controlling rootstocks can result in trees ranging from 2 to 10 m in height (Mudge et al., 2009). Apple varieties remain dwarf when grafted/budded on dwarfing rootstocks such as M9, M26 and M27, as a result of which harvesting of fruits becomes easier. In other species also certain inter-specific scion/stock combinations will result in dwarfing, such as orange \((Citrus sinensis)\) on trifoliate orange \((Poncirus trifoliata)\).

7. Control of growth form - During the juvenile period the seedling plant not only fails to produce flowers and fruit, but also often exhibits distinct morphological features (e.g., thorniness). Such undesirable traits can be avoided by vegetatively propagating the adult form, using appropriate rootstock. Citrus trees and some others are naturally thorny. It has been observed that when these are propagated by vegetative means, the size of the thorns is greatly reduced in many cases. This is a great advantage, as large thorns often damage the fruit. Grafting to create unusual growth forms in a practice called \textit{arborsculpture} involves intertwining and grafting together the stems of two or more plants in order to create domes, chairs, ladders, and other fanciful sculptures (Mudge et al., 2009).

8. Economics - In general, mass propagation by vegetative means is not more economical than comparable propagation by seedlings but its use is justified by the superiority and uniformity of specific clones (Hartmann and Kester, 1983). The major economy in vegetative
propagation comes from the elimination (avoidance) of the juvenile phase and shortening the time to reach reproductive maturity. Seedlings begin as juvenile plants, which are, by definition, incapable of flowering. In fruit trees, period of juvenility typically lasts several years, before the plant undergoes a transition to the mature phase, when it becomes capable of flowering. The next generation of seedlings is juvenile. The long delay in flowering of these juvenile seedlings is economically undesirable. Fruit producers can overcome this delay in flowering by grafting a scion from a mature tree onto any rootstock (seedling or mature), because a mature scion maintains its flowering state in a graft to a juvenile seedling (Mudge et al., 2009).

Disadvantages of vegetative propagation (Hartmann and Kester, 1983; Hartmann et al., 1990; Sharma, 2002; Yadav, 2007):

1. Asexually propagated fruit plants are short-lived (in many cases) and are not vigorous compared to seedling trees. In grafted or budded plants this is probably due to imperfect compatibility between rootstock and scion. Some grafted/budded plants probably live as long as do seedlings of the same species.

2. New variety cannot be evolved by this method. Hence it restricts diversity of vegetation.

3. Sometimes it is expensive, as it requires special techniques. For instance, propagation by tissue culture technique is more expensive than the conventional vegetative methods.

4. Sometimes asexual propagation may disseminate diseases, e.g., in citrus tristeza virus (quick decline) is reported to be transmitted or spread through budwood.
Methods of asexual propagation

Apomixis

*Apomixis* is the occurrence of asexual reproductive process in place of the sexual reproductive processes of reduction division and fertilization to produce an embryo (Hartmann *et al*., 1990). It is a phenomenon in which the genetic identity of the mother plant is transmitted to daughter plants that develop by seed formation and germination. That means a cell in the embryo sac or nucellus fails to undergo meiosis but forms a zygote genetically similar to the mother plant. It is a form of vegetative reproduction by the seed in tree fruit crops such as citrus, apple and some tropical fruits (Westwood, 1993). Seedling plants produced in this manner are known as *apomicts*. Some plants may produce a mixture of both sexual and vegetative embryos, and others may be totally apomictic. Plants that produce only apomictic embryos are known as *obligate apomicts* (for instance in the case of recurrent apomixis); those that produce both apomictic and sexual embryos are *facultative apomicts* (e.g., in the case of adventitious embryony). Apomictic seedlings although are vegetative in origin, the resulting plants are initially juvenile.

Different types of apomixis are distinguished (Hartmann and Kester, 1983; Hartmann *et al*., 1990):

*Recurrent apomixis* - In this type of apomixis an embryo arises directly from the egg nucleus (diploid) without fertilization. An embryo sac (female gametophyte) develops from the egg mother cell (or from some adjoining cell with the egg mother cell disintegrating), but complete meiosis does not occur. Consequently, the egg has the normal diploid number of chromosomes, the same as the mother plant. It is commonly found in seeds of apple and raspberry.

*Adventitious embryony* - This type of apomixis is also known as nucellar embryony or nucellar budding. In this case the embryos rise from a cell or group of cells either in the nucellus (usually) or in the integuments. It differs from recurrent apomixis in that such embryos develop outside of the embryo.
sac and in addition to the regular embryo. Nucellar embryos are found in citrus seeds.

Such seeds can contain several nucellar embryos in addition to the sexual embryo. Thus several seedlings are obtained from one seed, a situation known as Polyembryony (Fig. 3-1). It may result from nucellar embryony, and/or from the occasional development of more than one nucleus within the embryo sac.

Even though plants arising by apomixis maintain the clone, they go through the juvenile phase to mature transition stages just as any woody plant seedling would, taking a number of years to flower and fruit. Apomictic seedlings would not normally be suitable for reproducing fruit and nut cultivars in which the juvenile phase involves a delay in onset of bearing and undesirable growth characteristics. The practical significance of apomixis is that it can fix heterosis, that is, progeny are genetically identical to their mother and the potential impact on agriculture has been widely discussed (Hanna, 1995). Apomictic seedlings are useful for producing uniform rootstock cultivars in some species (e.g., Citrus and Malus species).

Figure 3-1. Polyembryony in trifoliate orange seeds as shown by the several seedlings arising from each seed. One seedling, usually the weakest, is of sexual origin while the others are nucellar. Source: Harmtann and Kester (1983).
Propagation by cuttings

Raising of plants through cuttings is a simple, quick, and cheap method of plant propagation (Sharma, 2002). In propagating by cuttings, a portion of a stem, root, or leaf is cut from the parent plant, after which this plant part is placed under certain favorable environmental conditions and induced to form roots and shoots, thus producing a new independent plant which, in most cases, is identical to the parent plant.

Cuttings can be classified according to the parent of the plant from which they are obtained: Stem cuttings, leaf cuttings, leaf-bud cuttings, and root cuttings.

Stem cuttings

The stem cutting, which is one of the most important types in fruit propagation, can be divided into three groups, according to the nature of the wood used: hardwood, semihardwood, and softwood:

In propagation by stem cuttings, segments of shoots containing lateral or terminal buds are obtained with the expectation that under the proper conditions adventitious roots will develop and thus produce independent plants. There are two types of adventitious roots (Hartmann et al., 1990): (1) Preformed roots, and (2) Wound induced roots. Preformed root initials and primordia develop naturally on stem while they are still attached to the parent plant. When detached from the parent plant and placed in appropriate rooting media and environmental conditions, they root easily. Plants producing such type of roots are generally easy-to-root. Wound induced roots develop only after being detached from their parent plant and provided with favorable condition for rooting.

The type of wood, the stage of growth used in making the cuttings, the time of year when the cuttings are taken, chemical treatments and several other factors can be very important in securing satisfactory rooting of some fruit plants. The selected shoot should be healthy and should not be too vigorously growing. The shoot growing in shade and in inner side of the tree...
is also not good for preparing cuttings. The length of cutting is variable depending on the plant species and often ranges from 10 to 45 cm. The cuttings should possess at least two to three nodes (or buds). The lower is made round just below the node and the upper cut is given about 1 to 2 cm above the upper node in slanting manner. Preparing cuttings in this manner helps in identifying the lower and upper portions (proximal and distal ends, respectively).

Many investigations have shown that the application of certain chemicals promotes the development of roots and/or shoots of stem cuttings. Among the numerous chemicals which have been tested indoleacetic acid (IAA), indolebutyric acid (IBA), and naphthaleneacetic acid (NAA) have produced the most remarkable results (Hartmann and Kester, 1983; Hartmann et al., 1990; Christopher, 2001).

These chemicals not only speed up the healing of the wound and the formation of roots, but they also induce the development of a large number of roots and are now used throughout the world in the propagation of many kinds of fruit plants.

*Hardwood cuttings* are those made of matured, dormant hardwood after leaves have dehisced and before new shoots emerge. The use of hardwood cuttings is one of the least expensive and easiest methods of vegetative propagation. Hardwood cuttings are easy to prepare, are not readily perishable, may be shipped safely over long distances if necessary, and require little or no special equipment during rooting. Grapes, plums, fig, pomegranate, etc. are commonly propagated by mature stem parts (often one season old).

*Semihardwood cuttings* are those made from woody, broad-leaved species. Partially matured wood of deciduous fruit plants could also be considered as semihardwood. Examples of fruit species propagated in this manner are given in Table 3-1. The cuttings are made 7.5 to 15 cm long with leaves retained at the upper end. If the leaves are very large, they should be reduced in size to lower the water loss and to allow closer spacing in the cutting bed.

It is necessary that semihardwood cuttings be rooted under conditions
that will keep water loss from the leaves at a minimum. Commercially, they are ordinarily rooted under intermittent mist sprays or, in cool, moist climates, under polyethylene sheets laid over the cuttings. Keeping basal end (bottom) of the cuttings relatively warm and growth-regulator treatments are also beneficial.

*Softwood cuttings* are prepared from the soft, succulent, new growth of deciduous or evergreen species. Many valuable fruit plants can be propagated successfully by softwood cuttings. Examples of fruit plants propagated by softwood cuttings are presented in Table 3-1.

Softwood cuttings generally root easier and quicker than the other types but require more attention and equipment. This type of cutting is always made with leaves attached. They must, consequently, be handled carefully to prevent drying, and be rooted under conditions, which will avoid excessive water loss from the leaves. That is, softwood cuttings are propagated under mist chamber where humidity is high. Since the wood of such cuttings is immature, low quantities of carbohydrates have been stored in the tissues and, as would be expected, maintaining leaves in the turgid condition is necessary not only for making additional carbohydrates, but also for making auxinic hormones.

In making softwood cuttings, it is important to obtain the proper type of cutting material from the stock plant. Such material will vary greatly, however, with the species being propagated. Extremely fast-growing, soft, tender shoots are not desirable, as they are likely to deteriorate before rooting. The best cutting material has some degree of flexibility but is mature enough to break when bent sharply. Weak, thin, inferior shoots should be avoided as well as vigorous, abnormally thick, or heavy ones. Average growth from portions of the plant in full light is the most desirable to use. Some of the best cutting materials are the lateral or side branches of the stock plant.

Heading back the main shoots will usually force out numerous lateral shoots from which cuttings can be made. Softwood cuttings are 7.5 to 12.5 cm long with two or more nodes. The basal cut is usually made just below a node. The leaves on the lower portion of the cuttings are removed, with those
on the upper part retained. Large leaves should be reduced in size to lower the transpiration rate and to occupy less space in the propagating bed. All flowers or flower buds should be removed.

The cutting material is gathered in the early part of the day and should be kept moist, cool, and turgid at all times. Laying the cutting material or prepared cuttings in the sun for even a few minutes will cause serious damage. Soaking the cutting material or cuttings in water for prolonged periods to keep them fresh is undesirable.

Table 3-1. Kinds of cuttings used in propagating fruit crops.

<table>
<thead>
<tr>
<th>Kind of cutting</th>
<th>Fruit crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood</td>
<td>grape, plum, pear, fig, mulberry, pomegranate</td>
</tr>
<tr>
<td>Semihardwood</td>
<td>citrus, avocado, passion fruit, macadamia</td>
</tr>
<tr>
<td>Softwood</td>
<td>guava, peach, apple, plum, nectarine, pear</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>pineapple</td>
</tr>
<tr>
<td>Leaf-bud</td>
<td>citrus (e.g. lemon)</td>
</tr>
<tr>
<td>Root</td>
<td>apple, pear</td>
</tr>
</tbody>
</table>

*Herbaceous cuttings* - Pineapple is a herbaceous plant, cuttings of which exude a sticky sap and do better if the basal ends are allowed to dry for a few hours before they are inserted in the rooting medium.

**Leaf-bud cuttings**

In leaf cuttings adventitious roots form/develop much more easily than do adventitious buds. The limiting factor in leaf cutting propagation is generally the difficulty in the formation of adventitious buds, and not adventitious roots. That is why propagation of difficult-to-root plant species (including most fruit plants) is commonly performed using leaf-bud cuttings.

Leaf-bud cutting consists of a leaf blade, petiole, and a short piece of the stem with attached axillary bud. Such cuttings are of particular value in
plants where adventitious roots but not adventitious shoots are initiated from detached leaves; the axillary bud at the base of the petiole provides for the new shoot. A number of fruit plant species can be started by leaf-bud cuttings. However commercial importance of this method for multiplication of fruit crops is limited. Examples of fruit plants that are readily started by leaf-bud cutting are given in Table 3-1.

Leaf-bud cuttings are useful as substitutes for stem cuttings in obtaining as many plants as possible from scarce propagating material. A leaf-bud cutting gives one and perhaps two (if the plant has opposite leaves) and generally requires a minimum of two nodes. Leaf-bud cuttings are best made from material having well-developed buds and healthy, actively growing leaves.

Treatments of the cut surfaces with one of the root-promoting substances stimulate root production (Hartmann and Kester, 1983). The cuttings are inserted in the rooting medium (commonly, sand, or sand and peat moss, 1:1) with the bud 1.3 to 2.5 cm below the surface. Such cuttings are rooted under high humidity as described for semi hardwood or softwood cuttings.

**Root cuttings**

A fruit plant species which naturally send up shoots (suckers) from the root system are most satisfactory for propagation by root cuttings. Some fruit plants can be propagated by cutting the small, young roots into pieces about 2.5 cm long and planting them horizontally in soil about 1.3 cm deep or vertically with the upper end (nearest the crown of the plant) just below the soil level (Hartmann and Kester, 1983). Like in leaf cuttings, root cuttings, initiate both new shoot system and new adventitious roots from adventitious buds. One or more new adventitious shoots form along the root piece, and either this shoot forms roots or the root piece itself develops new branch roots, thus producing a new plant.

Best results with root cuttings are likely to be attained if the root pieces are taken from young stock plants in late winter or early spring when the roots are well supplied with stored foods but before new growth starts.
It is important with root cuttings to maintain the correct polarity when planting. To avoid planting them upside down, the proximal end (nearest the crown of the plant) may be made with a straight cut and the distal end (away from the crown) with a slanting cut. The proximal end of the root piece should always be up. Some of the fruit plant species, which can be propagated by root cuttings, are indicated in Table 3-1.

Propagation by layering

Layering is a propagation method in which a portion of plant is forced to produce adventitious roots while it is still attached to the parent plant (Hartmann and Kester, 1983; Mitov et al., 1990). In other words, layering is a method of plant propagation where the original (or mother) plant continues as a source of food and water during the development period. It is often used in species that are particularly difficult to root, as the intact stems allow a continuous supply of water, nutrients and plant hormones to the place of root development. The rooted, or layered, stem is detached to become a new plant growing on its own roots. Layering is similar to propagation by cuttings except that, instead of severing the part to be rooted from the mother plant, it is left attached and receives water and nutrients from the mother plant.

The advantages of layering (Hartmann and Kester, 1983; Mitov et al., 1990) include:

- Less maintenance than cuttings. Unlike regular stem cuttings, those produced by layering are still attached to the mother plant and therefore require less maintenance. Their supply of water is not significantly decreased since they are still attached to the root system of the mother plant. This eliminates the need for resource and labor intensive practices such as shading or regularly misting of young cuttings. Layering also reduces or eliminates the need to harden off cuttings before planting since they are already in their native environment.
- Allows propagation to be performed on-site. Layer can be done on site.
where there may be well established plants of a species that we want to propagate. Since layering usually consists of bending a branch down below the soil line, often the only required materials are a shovel and stakes to hold the branch below ground and to keep shoot tips upright. This can reduce the amount of time and resources needed in hauling plants and supplies from place to place.

- Natural accumulation of photosynthates and hormones due to girdling, incision, or bending
- Often a large plant is the product
- Easy to do with little investment

Disadvantages:

- Takes a long time to produce new plants,
- Produces only a few plants per mother. Not ideal for plants when one wants a lot of from only a few mothers, or for sites where resources and time are particularly in short supply. This form of propagation is usually limited to plants which form growing points readily and that this method does not facilitate the production of large numbers of individuals in a relatively short time. In other words, the number of individuals which can be produced from any given parent plant by layering is relatively few compared with the number which can be produced by cutting.

As layering beds are often used for many years (e.g., mound layering in apple), utmost hygiene has to be practiced to prevent the spreading of pests and diseases, especially nematodes and viruses. Regeneration of fruit plants by layering depends on (Hartmann et al., 1981; Hartmann and Kester, 1983; Crocker, 1994): nutrition, stem treatment, light exclusion, physiological conditioning and rejuvenation.

*Nutrition* - The stem remains attached to the plant during rooting and is continually supplied with water and minerals through the intact xylem.
**Stem treatments** - Adventitious roots are induced to form on the attached stems by various manipulations (e.g., notching, girdling, bending shoot to a sharp “V”, etc.) of the stems that cause an interruption in the downward translocation of organic materials (carbohydrates, auxin, and other growth factors) from the leaves and growing shoot tips. These materials accumulate near the point of treatment, and rooting occurs as it would on a stem cutting.

**Light exclusion (etiolation)** - Elimination of light from the part of the stem where roots are to develop is a feature common to all methods of layering.

**Physiological conditioning** - Root induction during layering may be associated with particular physiological conditions in the stem associated with the time of year. For many types of layering, the timing is associated with the movement of carbohydrates and other substances toward the roots at the end of a seasonal cycle of growth.

**Rejuvenation** - Cutting back shoots in mound and trench layering and regenerating new shoots from the base annually has a parallel in the hedging methods used to rejuvenate stock plants for improved rooting of the cuttings that are taken from them.

The horticulturally most common layering techniques by which various fruit crops are propagated include (Hartmann *et al.*, 1981; Hartmann and Kester, 1983; Crocker, 1994): tip, simple, compound, mound, air and trench layering (Fig. 3-2).

**Tip layering** - It involves covering the tips of stems/branches with moist soil. Rooting takes place near the tip of the current season’s shoot. The shoot tip recurves upward to produce a sharp bend in the stem from which roots develop.

Tips are layered by hand, a spade or trowel to make a hole with one side vertical and one sloping slightly toward the parent plant. The tip is placed in the hole (2-5 cm deep) with the shoot lying along the sloping side
and the returned soil is pressed firmly against it. Thus, the tip cannot continue to grow in length and becomes “telescoped”, soon forming an abundant root system and developing a vigorous young vertical shoot. The rooted tip is separated from plant along with old shoot. Black berries and raspberries are naturally multiplied by this method.

**Simple layering** involves covering a flexible stem, usually a one-year-old shoot, just back of the tip with moist soil or other appropriate media. The layered portion of the stem usually is slit or notched, and the top of the stem with its leaves is allowed to remain above the surface of the soil.

**Compound or serpentine layering** - It is essentially the same with simple layering, except that the branch (stem) is alternately covered and exposed along its length. Several new plants are thus possible to grow from a single branch. This method is used for propagating fruit plants that have long, flexible shoots, such as the Muscadine grape (*Vitis rotundifolia*).

**Air layering or marcottage** involves placing the rooting medium around a branch of a tree. It is a method of propagation performed directly on branches of growing parent trees *in situ* and branches 1-2 cm in diameter usually work best (Crocker, 1994). The leaves of the branch to be air-layered are removed just below a good clump of foliage. The branch is girdled by removing a ring of bark 1-5 cm in width and about 30-45 cm from the terminal end of the branch. Remaining conductive tissue should be scraped away in the girdled area. In case of hard-to-root type plants, application of a rooting hormone, such as Indolebutyric acid (IBA) at 3,000-5,000 ppm is applied on the upper end of the cut for better rooting (Singh, 1994). The area is then covered with a handful of moist sphagnum moss and enclosed with a small sheet of clear polyethylene which is tied at both ends. Heat buildup in the moss due to exposure to direct sun can be prevented by wrapping the layer with aluminum foil. No further watering is needed because the moss absorbs moisture from the plant itself and the covering retards water loss. The layer can be removed after sufficient roots have formed by cutting the branch.
below the plastic wrap and planting in a container. In some plants, rooting occurs in two to three months or less. In general, it is desirable to remove the layer for transplanting when it is not actively growing.

Pruning of the rooted layer is usually advisable to reduce the top in proportion to the roots. Removal of a few leaves may also be satisfactory to reduce water loss. The rooted layer should be put into a suitable container (pot) in a cool, humid, and shady place until it becomes well established on its own new root system.

Air layering is used for propagating stiff-stemmed tropical fruit plants, such as mango, guava, jackfruit, etc.

*Mound (stool) layering* - This method consists in cutting back the stems of the plant during the non-growing season and covering the young stems with a mound of soil. After rooting, the shoot is separated from mother plant and planted in the nursery. Stooling is commonly practiced in plants that have easily rejuvenating (suckering) nature and in which the branches are firm and bending is difficult.

A stool bed can be used for 15 to 20 years with proper handling, if maintained in a vigorous condition and with disease, insect and weed control. Mound layering is primarily used commercially to produce apple and pear rootstocks. Guava and gooseberry can also be propagated by this method.

*Trench layering (etiolation method)* - In this method a plant or a branch of a plant is bent downward in a horizontal position in a shallow trench. When the shoots develop, the base is covered with 5 to 10 cm layer of soil, so that the shoot bases are etiolated. The process of etiolation facilitates rooting, which develops from the base of these new shoots. The rooted layers are separated from mother plants and planted in nursery so that they can be hardened for planting in field. Trench layering is used for woody species difficult to propagate by mound layering.
Figure 3-2. Steps in preparing four types of layers.
Source: Hartmann et al. (1981)
Propagation by grafting

Grafting is the art of connecting two pieces of living plant tissue together in such a manner that they will unite and subsequently grow and develop as one plant (Hartmann and Kester, 1983; Lewis and Alexander, 2008; Ingels, 2009). Grafting can be a natural or deliberate fusion of plant parts so that vascular continuity is established between them (Pina and Errea, 2005 cited in Mudge et al., 2009) and the resulting genetically composite organism functions as a single plant. Two adjacent intact plants or different branches of the same plant can become naturally or intentionally grafted together; deliberate grafting involves inserting a previously cut shoot into an opening in another plant growing on its own root system (detached scion grafting).

From a genetic perspective, grafting involves the creation of a compound genetic system by uniting two (or more) distinct genotypes, each of which maintains its own genetic identity throughout the life of the grafted plant (Mudge et al., 2009). Grafting is one of the more complex and labor intensive vegetative propagation techniques. It entails the union of the stem part of one plant (scion) with the root part of another one (rootstock) to form a new plant (stion). Grafting is preferred to budding if budding is unreliable for a certain variety, when the season is unsuitable for budding, or if the bark of the rootstock is too thick or too thin for successful T-budding (Lewis and Alexander, 2008). However, grafting has several disadvantages when compared to budding. It takes longer to cut the stock and scion, match the cambial layers, and wrap and cover the graft. Much more scion wood is needed for grafting.

The scion is the short piece of detached shoot containing several dormant buds, which, when united with the stock, comprises the upper portion of the graft and from which will grow the stem or branches, or both, of the grafted plant.

Stock (rootstock, under stock) is the lower portion of the graft combination. Stock is synonymous with either rootstock or under stock, but the latter two differ with respect to their configuration within the grafted plant (Mudge et al., 2009). Rootstock implies that only the root system of the
composite plant is derived from the original stock, whereas the term under stock is used when the lower portion of the grafted plant includes not only the root system but also some portion of the shoot system on which the scion is grafted. According to Mudge et al. (2009), in the simplest case, a grafted plant usually consists of a single graft union between a stock and a single scion. However, in a process called double working, a three-part grafted plant is constructed consisting of three genetically distinct parts (rootstock, interstock, and scion) separated in linear sequence by two graft unions. Rootstocks are of two types: (i) Seedling rootstocks, which are grown from seeds; (2) Clonal rootstocks- These are rootstocks produced asexually (a rooted cutting, or a layered plant).

“Stion” (stock-scion combination) is a plant developed by combining a rootstock and a scion cultivar, each controlled by different genes, to form a compound genetic system (the tree or vine). This term is coined by combining the first two letters of “stock” and the last three letters of “scion” to denote a plant composed of a stock and scion growing in combination (Rieger, 2006) regardless of the method of propagation followed (grafting, budding).

Interstock (intermediate stock, interstem) is a piece of stem inserted by means of two graft unions between the scion and the rootstock to subsequently form what is called multiple-component plant. Interstock is not a part of every grafted plant. It is used to join two species that will each unite with the interstock species but not with each other (Ingels, 2009). Some fruit varieties (e.g., pear, plum), do not join well on all kinds of stock. So a variety compatible for both rootstock and scion varieties has to be used as an intermediary. This process is known as double working. Generally an interstock is used for several reasons, such as to avoid an incompatibility between the stock and scion, to improve anchorage, or to take advantage of its growth-controlling properties (e.g., dwarfing, semi-dwarfing or invigorating character) in the scion cultivar.

Graft union (also called bud union in case of budding) is junction of the scion and rootstock portions of the trunk.

Cambium is a thin tissue of the plant located between the bark (phloem) and the wood (xylem). Its cells are meristematic; i.e., they are
capable of dividing and forming new cells. For a successful graft union, it is essential that the cambium of the scion be placed in close contact with the cambium of the stock.

*Callus* is a term applied to the mass of parenchyma cells that develops from and around wounded plant tissues. It occurs at the junction of a graft union, arising from the living cells of both scion and stock. The production and interlocking of these parenchyma (or callus) cells constitute one of the important steps in the healing process of a successful graft.

**Polarity in grafting**

Proper polarity is essential if the graft union is to be permanently successful. In all commercial grafting operations correct polarity is strictly observed. In top grafting, the proximal end of the scion is attached to the distal end of the stock (Hartmann and Kester, 1983; Sharma, 2002). In root grafting, however, the proximal end of the scion is joined to the proximal end of the stock (Fig. 3-3).

*Figure* 3-3. Polarity in grafting.
*Source:* Hartmann and Kester (1983)
The success of grafting is governed by the following important requirements (Hartmann and Kester, 1983; Sharma, 2002; Yadav, 2007; Ingels, 2009; Mudge et al., 2009):

1. The stock and scion must be compatible. When the graft union is successful and the two different plants become one, it is termed a compatible graft. If the two plants do not unite, even though there was no error in the technique used, it is termed an incompatible graft. In some instances, the graft may appear successful until months or years later when the plant suddenly dies or snaps off unexpectedly at the graft union (Ingels, 2009). Delayed incompatibility is the term used to describe such a situation. Mudge et al. (2009) broadly stated that interclonal (intraspecific) grafts are nearly always compatible, interspecific (intrageneric) grafts are usually compatible, intra-generic (intra-familial) grafts are rarely compatible, and interfamilial grafts are essentially always incompatible, though these generalizations are complicated by the observation that the degree of taxonomic affinity necessary for compatibility varies widely across different taxa.

2. The cambial region of the scion must be placed in intimate contact with that of the stock. While methods are varied, the goal of the propagator is always to place the separate cambiums of the stock and scion into close contact in order that the two may fuse (Ingels, 2009). The joining of the separate parts is made possible by the production of callus, or wood tissue, from the parenchyma cells of the cambiums of both stock and scion. The cells of the callus tissue intermingle until binding results. Cell differentiation follows and parenchyma cells become cambium cells. The new cambium, a product of the two previously separated plant parts, produces new vascular tissue.

3. The grafting operation must be done at a time when the stock and scion are in the proper physiological stage;
4. Immediately after the grafting operation is completed, all cut surfaces must be protected from desiccation (i.e., all cut surfaces must be waxed); and

5. Proper care must be given to the grafts for a period of time after grafting.

Scion - stock (shoot - root) relationships

Combining two (or more, in the case of use of interstocks) different plants (genotypes) into one plant by grafting, one part producing the top and the other part the root-can produce growth patterns that are different from those that would have occurred if each component part had been grown separately. Some of these effects have major horticultural value, while others are detrimental and should be avoided (Hartmann and Kester, 1983).

Effects of the rootstock on the scion cultivar

The following include some of the major effects of the rootstock on the scion cultivar:

**Size and growth habit** - Size control, and sometimes an accompanying change in tree shape, is one of the most significant rootstock effects. Apparently the rootstock alters the vigor of a given scion cultivar. It would be very useful in developing new clonal rootstocks from seedlings to be able to predict whether such stocks would be dwarfing or invigorating. Rieger (2006) stated that control of tree is most widely exploited in apple, where there is a range of tree size obtainable by using different dwarfing rootstocks. The availability of dwarfing rootstocks has allowed many innovations in tree fruit culture, such as more efficient planting designs and training systems, reduced pesticide use, and an earlier return on investment for orchardists.

**Fruiting** - Fruiting precocity (earliness), fruit bud formation, fruit set, and yield of a tree can be influenced by the rootstock used. Pomologists say that
grafted trees are more precocious than seedling trees. Dwarfing rootstocks sometimes induce more precocity than nondwarfing or seedling rootstocks (Rieger, 2006).

Vigorous, strongly growing rootstocks in some cases result in a larger and more vigorous plant that produces greater crops over a long period of years. On the other hand, trees on dwarfing stocks may be more fruitful, and if closely planted, produce higher yields per unit area, especially in the early years of bearing.

Size, quality, and maturity of fruit - There is a considerable variation among plant species in regard to the effect of the rootstock on fruit characteristics on the scion cultivar.

Hartmann and Kester (1983) reported that, in citrus, striking effects of the rootstock appear in fruit characteristics of the scion cultivar. If sour orange is used as the rootstock, fruits of sweet orange, tangerine and grapefruit are smooth, thin-skinned, and juicy, with excellent quality, and they store well without deterioration. Sweet orange rootstocks also result in thin-skinned, juicy, high-quality fruits. Citrus fruits on grapefruit stocks are usually excellent in size, grade, and quality if heavy fertilization is provided. But when rough lemon is used as the rootstock, the fruits are often thick-skinned, somewhat large and coarse, inferior in quality, and low in both sugar and acid.

Fruit size of both ‘Washington Navel’ and ‘Valencia’ orange is strongly influenced by the rootstock. The largest navel orange fruits are produced on sour orange stocks and the smallest on the Palestine sweet lime. The largest ‘Valencia’ oranges are associated with the dwarfing trifoliate orange stock, whereas sweet orange rootstocks produce the smallest fruits.

Effects of the scion cultivar on the rootstock

Effect on the vigor of the rootstock - Vigor is the major effect of the scion on the stock, just as it was in the case of rootstock effect on scion cultivar.
If a strongly growing scion cultivar is grafted onto a weak rootstock, the growth of the rootstock will be stimulated so as to become larger than it would have been if left ungrafted (Mitov et al., 1990). Conversely, if a weakly growing scion cultivar is grafted onto a vigorous rootstock, the growth of the latter will be lessened from what it might have been if left ungrafted. It has been reported, in citrus, for example, when the scion cultivar is less vigorous than the rootstock cultivar, it is the scion cultivar rather than the rootstock that determines the rate of growth and ultimate size of the tree.

Methods of grafting

Whip grafting is useful for small material, 8-12 mm in diameter. The stock and scion should be of the same diameter, although this is not always possible. The scion is cut 5-15 cm in length to include 2-3 well developed buds (Crocker, 1994). Smooth, straight diagonal cuts 3.5-5.0 cm in length are made at the base of the scion and top of the stock. A reverse cut is then made in each, starting about a third of the distance back from the tip. It is about half the length of the first cut and should almost parallel it, not splitting the grain of the wood, to obtain a smoother fitting graft. The stock and scion are then inserted into each other with the tongues interlocking (Fig. 3-4). After matching the cambium of the two along at least one side, the union is wrapped securely with budding tape. The wrap should be removed later before it constricts growth. It is highly successful if properly done because there is considerable cambial contact (Hartmann and Kester, 1983; Mitov et al., 1990). It heals quickly and makes a strong union.

Splice grafting - In this type of grafting, a simple slanting cut of the same length and angle is made in both the stock and the scion (Fig. 3-4). These are placed together and wrapped or tied. The splice graft is simple and easy to make. It is particularly useful in grafting plants that have a very pithy stem or that have wood that is not flexible enough to permit a tight fit when a tongue is made as the whip graft (Hartmann and Kester, 1983; Mitov et al., 1990).
**Side grafting** - As the name implies, in this type of grafting the scion is inserted into the side of the stock, which is generally larger in diameter than the scion (Fig. 3-4). There are numerous variations of the side graft, among which the *side-veneer*, variation of side grafting, is widely used, especially for grafting small potted plants such as seedling evergreens to named cultivars.

**Approach grafting** - The distinguishing feature of approach grafting is that two independent, self-sustaining plants are grafted together. After a union has occurred, the top of the stock plant is removed above the graft and the base of the scion plant is removed below the graft.

Although approach grafts may be successful at any time it may be advantageous to graft either at the beginning of the rainy season in regions of light rain or at the end of a heavy rainy period, the object being to avoid both drought and rain-storms, and yet to coincide with a favorable period for growth (Garner *et al.*, 1976). According to these authors the following two useful methods of making approach grafts are known:

**Spliced approach graft** - The stock and scion, preferably of equal size, are sliced deeply with flat cuts to match; the cuts may be 2.5 to 5 cm in length. The cuts must be perfectly smooth and as nearly flat as possible so that when they are pressed together there will be close contact of the cambium layers. The two cut surfaces are then bound tightly together with string, raffia, or nursery person's tape. The whole union should then be covered with grafting wax. After the parts are well united the stock above the union and the scion below the union are cut, and the graft is then completed.

**Tongue approach graft** - The tongued approach graft is the same as the spliced approach graft except that after the first cut is made in each stem to be joined, a second cut (downward on the stock and upward on the scion) is made, thus providing a thin tongue on each piece. By interlocking these tongues a very tight, closely fitting graft union can be obtained.

**Wedge grafting** - In performing wedge grafting, two cuts are made coming together at the bottom and as far apart at the top as the width of the scion
(Fig. 3-4). These cuts extend about 2 cm deep into the side of the stub. After these cuts are made, a screwdriver is pounded downward behind the wedge chip from the top of the stub to knock out the chip, leaving a “V” opening for insertion of the scion. The base of the scion is trimmed to a wedge shape exactly the same size and shape as the opening. With the two cambium layers
matching, the scion is tapped downward firmly into place and slanting outward slightly at the top so that the cambium layers cross (Mitov et al., 1990).

In a 5 cm wide stub, two scions are inserted 180° apart, while in a 10 cm stub, three scions are inserted 120° apart (Hartmann and Kester, 1983). After all scions are firmly tapped into place, all cut surfaces, including the tips of the scion, should be thoroughly waxed.

Cleft grafting is one of the most widely used methods of grafting, being especially adapted to top working fruit trees, either in the trunk of a small tree or in the scaffold branches of a larger tree. In this case the branches to be worked should be cut hard back and split across the surface of the cut with a clefting tool (chisel or chopper). Two grafts (scion stick) are then cut with wedge-shaped ends, and are fitted into the split thus made, so that the cambium layer of the scion is in close contact with the cambium layer of the stock. Cleft grafting is useful also for smaller plants. In top working trees, this method should be limited to stock branches about 2.5 to 10 cm in diameter and to species with fairly straight-grained wood that will split evenly (Hartmann and Kester, 1983; Hartmann et al., 1990). Although cleft grafting can be done any time during the dormant season, the chances for successful healing of the graft union are best if the work is done just when the buds of the stock are beginning to swell but before active growth has started.

Inarching is similar to approach grafting in that both stock and scion plants are on their own roots at the time of grafting; it differs in that the top of the new rootstock plant usually does not extend above the point of the graft union as it does in approach grafting. It is commonly used to replace part or all of the root system of an established tree. Seedlings are planted around and close to the base of a tree after which they are grafted into the trunk of the latter. A slight modification of bark grafting can be used to attach the seedling to the trunk. Commonly an inverted T incision through the trunk bark at a height which will facilitate insertion of the tip of the seedling is used. The new rootstock is prepared by making a long sloping cut on the side of the seedling next to the tree and a short cut on the opposite side.
The prepared scion is then inserted into the T, nailed in place and the entire area waxed (Crocker, 1994). Scraping or shaving the bark of the established tree in the working area to make it more pliable is sometimes necessary.

Inarching is generally considered to be a form of “repair grafting” used to repair roots damaged by cultivation implements, rodents, or disease. This technique is employed for joining rootstocks to selected scion varieties which are otherwise difficult to root or to graft as detached scions (Hartmann et al., 1990). Inarching is also commonly used to invigorate weakly trees by augmenting their root systems, for bridging trunk and branch wounds and for furnishing bare limbs with lateral growths.

**Bridge grafting** is a form of repair grafting, and is used when the root system of the tree has not been damaged but there is injury to the trunk. Sometimes cultivation implements, rodents, or disease damage a considerable trunk area, often girdling the tree completely. If the damage to the bark is extensive, the tree is almost certain to die, because the roots will be deprived of their food supply from the top of the tree. The trees of some species, such as apple, can heal over extensively injured areas by the development of callus tissue. But trees of most species with severely damaged bark should be bridge grafted if they are to be saved.

Bridge grafting is done when the sap is flowing in the tree but the scion is still dormant. The parts that are to be bridged should be thoroughly cleansed, and all the dead and diseased bark and wood should be cut away to healthy tissue on both edges of the bark before grafting. Defoliated (dormant) scions of sufficient length (they should always be longer than the part to be bridged) for ease of manipulation are required. Small trees an inch or so in diameter can be saved by one side-cleft grafted bridge. Larger trees should have one bridge for every inch (2.5 cm) of their diameter (Garner et al., 1976). The scion portion of suitable length, inserted into incision, is fixed using nail (usually) and then sealed with wax. There should be a close follow up to remove sprouts/flushes coming out from inserted stick/scion so that it will slowly grow in diameter and partly or fully cover the damaged portion.
Bark grafting involves insertion of scion/s, usually one to three per stock, down in between the bark and wood of the stock. It is rapid, simple, readily performed by amateurs, and if properly done, gives a high percentage of “takes”.

Bark grafting is used to top-work trees during the growing season when the bark is slipping. Relatively large branches can be grafted but those 5-20 cm in diameter are normally used (Crocker, 1994). The scion is prepared by making a long, diagonal cut 3-5 cm in length on one side and a short reverse cut is made at the tip on the opposite side. Stock branches are removed in the same manner as for the cleft graft. A vertical slit about 5 cm in length is made through the bark at the top of the stub. The prepared scion is pushed down between the bark and the wood so that it rests either to one side of or is centered under the slit. Thick bark which makes it difficult to push the scion between it and the wood can be pared down. The scion is positioned against the bark and a slit is cut on either side and just the width of the scion. The upper of the bark flap is removed and the scion inserted in the opening, with the wedge at the base slipped under the flap of remaining bark. The scions can be held in place with string, tape or short wire nails. Usually 2 nails per scion are used, taken care not to split the scion.

Epicotyl (Stone grafting) - The method is commonly practiced in mango. Seeds (stones) are sown in moist sand bed and covered with 5-7 cm thick layer of farmyard manure for germination (Bal, 2002). In about 15 to 20 days seeds start germination. The germinated seedlings of 7 to 10 days age, whose leaves are coppery in color, are used for grafting. The tops of the seedlings are removed by giving a slanting cut at height of 5 cm from the stone. Leaves from scion shoot are defoliated 10 days ahead of grafting time so as to hasten sprouting. The scion shoot of 8-10 cm long from current season’s growth is prepared by giving a slanting cut at the base in one side so as to match with the cut end of stock. It is then placed on the stock and tied with polythene tape. The grafted seedling is then planted in a polythene bag filled with soil, sand and farmyard manure at a proportion of 1:1:1 and watered immediately. The polythene bags are kept in a partial shade condition and watered daily. When the scion produces four true leaves, they are transplanted
in the nursery bed. Stone grafting is practiced by the time when the environment is sufficiently moist (commonly June-July).

**Budding**

Budding may be defined as grafting of a bud on a stock plant. It is a special type of grafting, in which a small piece of shoot carrying a single vegetative bud is sliced from the scion wood and transferred to the rootstock (Lewis and Alexander, 2008). Usually, buds used for budding are found in the axils of leaves, between the leaf stalk (petiole) and the shoot, on the side of the petiole away from the base of the shoot. In contrast to grafting, in which the scion consists of a short detached piece of stem tissue with several buds, budding utilizes only one bud and a small section of bark, with or without wood. In other words, when the stem part of one plant (stion) consists of a bud only, the technique is referred to as budding. Budding is often termed “bud grafting” since the physiological processes involved are the same as in grafting.

Budding may result in a stronger union, particularly during the first few years, than is obtained by some of the grafting methods, and thus the shoots are not as likely to blow out in strong winds (Mitov *et al.*, 1990; Lewis and Alexander, 2008). Budding makes more economical use of propagating wood than grafting, each bud potentially being capable of producing a new plant. This may be quite important if propagating wood is scarce, i.e., it is a more economical form of grafting as more scions can be produced from a single tree. In addition, the techniques involved in budding are simple and can be performed easily by an amateur.

In budding it is important to use vegetative rather than flower buds. Vegetative buds are usually small and pointed, while flower buds are larger and more plump (Fig. 3-5).
Rootstocks for budding

In propagating nursery stock of the various fruit species by budding, a rootstock plant is used. It should have the desired characteristics of vigor, growth habit, and resistance to soil-borne pests, as well as being easily propagated. This rootstock plant may be a rooted cutting, a rooted layer, or more commonly, a seedling (i.e., a rootstock developed from seed).

Usually, seedlings nursed for one year are sufficient to produce a rootstock that is large enough to be budded. Nevertheless, seedlings of slow-growing species, and those grown under unfavorable conditions, may require two seasons. To produce nursery trees free of harmful pathogens (such as viruses, fungi, or bacteria) it is essential that the rootstock plant, as well as the bud wood, be free of such organisms.
Methods of budding

_T-budding (shield budding)_ - Shield budding is a technique involving a T-shaped cut in the rootstock with the scion consisting of a single bud (Fig. 3-6). Its use is generally limited to stocks that are about 6 to 25 mm in diameter, and are actively growing so that the bark will separate readily from the wood (Hartmann _et al._, 1990). The cut is started about 1 cm below the bud and completed a slightly shorter distance above the bud. The knife should be almost parallel to the axis of the budwood cutting toward the thumb. The shield is cut only deep enough to take a thin silver of wood under the bud (Crocker, 1994). The bud shield is inserted under the bark flaps of the stock and pushed between the wood and bark so that it is completely enclosed in the T. The bud should be wrapped with budding tape or strips. Commonly the bud is inserted into the stock 5 to 25 cm above the soil level in a smooth bark surface.

Inverted _T-budding_ - The techniques of the inverted T-bud method are the same as those already described (T-budding), except that the incision in the stock has the transverse cut at the bottom rather than at the top of the vertical cut.

In rainy localities, water running down the stem of the rootstock may enter the T-cut, soak under the bark, and prevent the shield piece from healing into place. Under such conditions an inverted T-bud may give better results, since it is more likely to shed excess water. In species that bleed badly during budding, the inverted T-bud allows better drainage and better healing (Hartmann _et al._, 1990; Mitov _et al._, 1990).

It is important in using the inverted T-bud method that a normally oriented shield bud piece should not be inserted into an inverted incision in the stock. The bud would then have a reversed polarity. Proper polarity should therefore, be maintained so as to achieve success in budding.

_Patch budding_ - In this type of budding, a rectangular patch of bark is removed completely from the bark and replaced with a patch of bark of the
same size containing a bud of the cultivar to be propagated. The bark of both
the stock and bud-stick must slip easily. Patch budding is commonly used on
plants in which the bark is either too thick or too brittle to allow easy
insertion of a bud shield. A two-bladed patch-budding knife can be used to
make two parallel, horizontal cuts 2-3 cm long on the stock (Crocker, 1994).
These cuts are connected at the ends by two vertical cuts and the bark patch
is peeled off and discarded. The patch of bark containing the scion bud is cut
from the budstick in the same manner. The cut scion should not be lifted but
slid off sideways to avoid damage. The scion patch is then inserted on the
prepared stock and securely wrapped, being careful that all cut edges are
covered.

Patch budding is somewhat slower and more difficult to perform than
T-budding, but it is widely and successfully used on thick-barked species, in
which T-budding sometimes gives poor results, presumably owing to the poor
fit around the margins of the bud (Hartmann and Kester, 1983; Hartmann et
al., 1990).

I-budding - In I-budding the bud patch is cut just as for patch budding that
is in the form of a rectangle or square. Then, with parallel bladed knife (the
same as for patch budding), two transverse cuts are made through the bark of
the stock. These are joined at their centers by a single vertical cut to produce
the figure I. The two flaps of bark can then be raised for insertion of the
bud patch beneath them (Fig. 3-6). I-budding should be considered for use
when the bark of the stock is much thicker than that of the bud-stick
(Hartmann and Kester, 1983).

Chip budding can be used at times when the bark is not slipping, i.e., before
growth starts or when active growth has stopped owing to lack of water or
some other cause. Chip budding is generally used with small material, 13 to
25 mm in diameter and, is not as fast or as simple as T-budding (Hartmann
and Kester, 1983). A thin slice of wood with a scion bud is removed by
making a smooth downward cut for a distance of 2-3 cm and just into the
wood (Crocker, 1994). A second cut is made at the base of the first one,
forming a notch. A chip is removed from the stock in the same manner. Only two thin lines of cambial tissue on both the stock and scion are present for healing, so it is important that matching occurs on both sides. However, matching along one side of a small scion is often adequate. The scion is then wrapped so that all cut edges are completely covered.

The chip bud is really a form of grafting, a variation of the side-veneer graft, with the scion reduced to a small piece of wood containing only a single bud (Fig. 3-6). It is widely used in propagating vinifera grapes on nematode resistant rootstocks (Hartmann et al., 1990).

Figure 3-6. Budding techniques: (a) T-budding (b) patch budding (c) chip budding
Source: Mitov et al. (1990)
Collecting scions and bud wood

The scion material must be taken from sources that are true to variety, that have superior performance, and if possible, from plants of known good health (Lewis and Alexander, 2008). Solid shoots that are well exposed to sunshine are selected, while weak and shaded shoots are avoided. It is best to collect and use scion wood on the same day, but wood from plants native to cool and temperate areas can be stored in a sealed plastic bag in an ordinary refrigerator. Propagating material of plants from tropical zones can be stored by keeping it in a cool room at about 10°C (Lewis and Alexander, 2008).

From a suitable mature tree in the surrounding, collect young, vigorous shoot tips of desirable size. Remove all leaves and the tip, collect in a small plastic bag in which some water has sprinkled, label carefully with species name and cultivar or clone number and immediately store in the cool box.

Propagation by runners

A runner, or stolon, is a horizontal stem extending along the surface of the ground. It is a slender whip-like shoot sent out from the parent plant to root at some distance away, and at certain intervals to produce fresh plants. When these runners contact the ground at a node, roots may develop below and a whorl of leaves above. After this has occurred, the individual plant may be cut from the mother plant and moved to a new location. The Strawberry is the best-known example of a runner-bearing plant, and gardeners readily seize upon this character to raise thousands every year.

Micro propagation

Micro propagation (also called tissue culture) involves the production of plants from very small plant parts, tissues, or cells grown aseptically in a test tube or other container where the environment and nutrition can be rigidly controlled (Hartmann and Kester, 1983; George, 2008). It has significant uses in vegetative propagation of horticulturally important species and cultivars.
Tissue cultures are started from pieces of whole plants. The small organs or pieces of tissue that are used are called explants. The part of the plant (the stock plant or mother plant) from which explants are obtained, depends on (George, 2008):

- the kind of culture to be initiated;
- the purpose of the proposed culture;
- the plant species to be used.

The kind of explant chosen, its size, age, and the manner in which it is cultured, can all affect whether tissue cultures can be successfully initiated, and whether regeneration can be induced (Arnold, 2005). Explants can therefore be of many different kinds, and the correct choice of explant material can have an important effect on the success of tissue culture.

Advantages (uses) of micro propagation include (Hartmann and Kester, 1983):

- Rapid mass propagation of clones;
- Development, maintenance, and distribution of specific pathogen tested (SPT) clones;
- In vitro culture systems have the potential for long distance shipment of propagation material; and
- Long-term storage of clonal material.

Micro propagation however, has its own problems, of which some are shown below:

- The facilities required are costly and economic considerations may not justify their use in commercially propagating many kinds of plants;
- Particular skills are required to carry out the procedure; and
- Errors in maintenance of identity, introduction of an unknown pathogen, or appearance of an unobserved mutant may be multiplied to very high levels in a short time.
The procedure of plant tissue culture (micro-propagation) has developed to such a level that any plant species can be regenerated in vitro through several methodologies. The rate of plant regeneration in tissue culture varies greatly from one species to another (Evans et al., 1981). Various cells, tissues and organs from numerous plant species (including fruit plants) can be cultured successfully to regenerate whole plants.

Plant regeneration is the cornerstone of tissue culture. The methodology involves knowledge of generation of genetic variable plants, anther culture, commercial cloning for the purpose of rapid multiplication of desirable or species difficult to propagate, and disease-elimination (through meristem culture). It has now become a powerful tool (discipline) for agricultural and horticultural research.

According to Hartmann and Kester (1983), there are five fundamental types of vegetative regeneration in tissue culture systems:

**Meristem-Tip elongation** occurs when the apical meristem on an excised shoot-tip continues to elongate in culture and are rooted to produce a small plantlet (Fig. 3-7). This procedure is used primarily to produce “virus-free” plants in which only the apical meristem (less than 0.5 mm) is removed with a few subtending leaves. Regeneration occurs by elongation of the apical meristem. Only a single plant for culture is produced by this method.
Auxiliary shoot proliferation - In this type of vegetative regeneration, lateral growing points on the explant at the nodes below the apical meristem are stimulated to grow and the apical meristem is inhibited. Growth from these axillary shoots provides a rapid multiplication system in which the number of potential plants is increased exponentially by repeated reculturing.

Adventitious shoot initiation - In this procedure excised plant parts can be induced to form adventitious shoots at high rates in many species. The procedure is useful not only for the micro propagation of plants traditionally propagated by adventitious shoots, but also for a wide range of other species. Adventitious shoots may develop either directly on the explant itself or indirectly in unorganized masses of callus tissue.

Organogenesis in callus cultures refers to the initiation of both adventitious shoots and roots from within masses of callus cells. These highly vacuolated
and largely parenchymatous callus cell masses can develop meristemoids, which initiate organs under particular cultural conditions. The process is similar to the initiation of adventitious shoots on explants except that an intervening period of independent callus growth has occurred.

*Embryogenesis* - Somatic or asexual embryogenesis is the production of embryo-like structures from somatic cells. Somatic cells within the plant contain all the genetic information necessary to create a complete and functional plant. Somatic embryos resemble zygotic embryos morphologically. They are bipolar and bear typical embryonic organs and are not physically attached to the tissue of origin (Arnold, 2005). However, they develop via a different pathway. Such embryos can further develop and germinate into plantlets through the events that correspond with the zygotic occurrences (Tisserat et al., 1979). Somatic embryos accumulate storage products that exhibit the same characteristics as those of the zygotic embryos. The storage products are also targeted to the correct subcellular compartments (Merkele et al., 1995). However, the amount of a particular storage product, as well as the timing of its accumulation can differ between somatic and zygotic embryos (Merkele et al., 1995; Yeung, 1995).

Somatic embryos can either differentiate directly from the explant without any intervening callus phase or indirectly after a callus phase (Williams and Maheswaran, 1986). Explants from which direct embryogenesis is most likely to occur include microspores (microsporogenesis), ovules, embryos and seedlings.

Successful in vitro propagation has several specific requirements as described below (Hartmann and Kester, 1983; Hartmann et al., 1990):

**Facilities** - Special laboratory type facilities and equipment must be provided in order to prepare the cultures, produce and maintain sterile conditions, and provide proper growing conditions.

**Selection** - Selection must be made of the plant parts to be used as explants and also the required culture conditions, such as sterilization, media, and
environmental conditions, which vary with different plant cultivars and species.

Contaminant elimination - Contaminants inevitably present on the surface of plant parts must be eliminated by disinfection. All culture media must be sterilized, and the rooms where the cultures are to be prepared and maintained must be kept free of contaminants as much as possible.

Staging - Once established in sterile culture, most species are carried through a series characterized as (a) explant establishment, (b) multiplication, (c) pretransplant (including root initiation and acclimation) and finally (d) transplanting.

Transplanting - Proper procedures must be utilized to enable the plant to be transferred successfully from the sterile, artificial environment of the culture vessel to the more rigorous conditions of the open greenhouse or nursery.

Nutrient media

Growth and development of explants in vitro is a product of the genetics, surrounding environment, and components of the tissue culture medium (Beyl, 2005). There are about 20 different components in tissue culture medium. These include inorganic mineral elements (macro- and micronutrients), various organic compounds (vitamins, sugars), plant growth regulators, and support substances (e.g., agar or filter paper) ( Harmann and Kester, 1983; Beyl, 2005).

Ingredients of the culture medium vary with the kind of plant and the propagation stage at which one is working. The composition of the nutrient medium must be optimized in order to obtain successful plant regeneration. Commonly used tissue culture media include Murashige and Skoog, Gamborg B-5, WPM, Nitsch and Nitsch, Schenk and Hildebrandt, and White (Beyl, 2005). The formulation developed by Murashige and Skoog in 1962 is the most common medium employed in the plant tissue culture (Harmann and Kester, 1983; Beyl, 2005). The Murashige-Skoog medium has been used widely for a range of culture types and species, particularly herbaceous plants.
and for tissue cultures in general. Generally the nutrient medium is composed of the following substances:

**Inorganic salts** - A plant tissue, growing *in vitro*, requires a combination of macro nutrients (nitrogen, phosphorus, potassium, calcium, magnesium and sulfur) and micronutrients (boron, cobalt, copper, manganese, molybdenum, iron, and zinc). The choice of these nutrients and their concentrations is species-dependent (Beyl, 2005).

**Organic compounds** include carbohydrates (including sucrose, glucose, fructose and starch), vitamins (thiamin, nicotinic acid, pyridoxine, inositol and others), hormones and growth regulators. The two most important hormone classes are the auxins and cytokinins that control root, shoot and callus formation. Gibberellins have sometimes been used to induce shoot elongation. A miscellaneous substance, citric acid or ascorbic acid, is often used as an antibrowning factor. Malic acid is added in some embryo culture media.

**Complex natural ingredients** - Various materials of unknown composition have been used to establish cultures when known substances fail to do so; sometimes these materials promote extra growth. Protein hydrolysates from casein or other proteins are often helpful, primarily to provide organic nitrogen and amino acids. Coconut milk is useful but must be filter sterilized. Malt, yeast extract and such substances as tomato juice and orange juice also have been used successfully. These substances are dissolved in water and added during preparation of the media.

**Inert supports** - Agar and liquid are commonly used as support substances while preparing the culture media. Agar is a high molecular weight polysaccharide that can bind water, and is used to solidify tissue culture media into a gel (Beyl, 2005). It enables the explant to be placed in precise contact with the medium (on the surface or embedded), but to remain aerated. Liquid media are preferred for some plant species whose explants exude toxic substances from a cut surface.
References


FRUIT NURSERY ESTABLISHMENT AND MANAGEMENT

A nursery could be considered as a location where plants are cared for during the early stages of growth, providing optimum conditions for germination or rooting and subsequent growth, until they are strong enough to be planted out in their permanent place. Setting up of a fruit nursery is a long term venture and needs lot of planning and expertise. Mistakes committed initially on any aspect like selection of soil, raising of right kind of cultivars/varieties, plant protection measure, etc., reduce the financial returns greatly from the investment, besides wastage of time and energy (Mitov et al., 1990). So careful planning is needed before setting up a nursery. The plan should show allocation of plots/area to different components of the nursery such as mother plants of different fruits/cultivars, rootstocks, roads/palms, water channels, drainage system, a building including adequate store and tool sheds. Provision of certain basic pre-requisites is a must for raising a fruit nursery on modern lines.

Tree fruit crops such as citrus, avocado, mango, guava, etc. require a field nursery where rootstocks are raised until they reach the stage of optimum growth for budding or grafting. Plants remain in the field nursery for a further period of a year or more, until they are ready for transplanting to the permanent site, or are sold. The main reasons for establishing a nursery or propagation center for fruit crops are the following (Mitov et al., 1990; Hall, 2003; De Bac, 2010):

1. Application of optimum conditions for germination of seed, growing of seedlings, rooted cuttings and graftages during their early development is easier and economical. Since the majority of fruit crops are propagated by vegetative means; the propagules require special skill and aftercare
before transferring them to the field. In a controlled condition in nursery, all these can be provided successfully by skilled labour.

2. Direct sowing method is not so successful when compared with transplanting of seedlings raised in nursery. Raising seedlings under nursery saves seeds, especially expensive seeds, e.g. seeds of improved varieties of most fruit crops.

3. Raising of seedlings or saplings in nursery provides more time for preplanting preparations. In order to obtain an even stand in the field, weak and diseased plants can be eliminated in nursery condition.

4. Adjustment of the raising of seedlings, against natural adverse conditions, is only possible in nursery. For instance, seedlings, rooted cuttings and graftages are made ready for transplanting to field at the start of the rains.

5. Nursery hardened plants are preferred for casualty replacement in orchard.

**Nursery site selection**

The following conditions should be considered while selecting a fruit nursery site (Mitov *et al.*, 1990; Hall, 2003; Mbora *et al.*, 2008):

1. The nursery site should have a flat or gently sloping surface. This helps in quick draining out the excess water during the heavy down pour. The area should be somewhat elevated than the adjoining area to avoid water logging and congestion.

2. Type of soil, drainage and soil fertility are the three basic components to be considered while selecting the soil for establishing a nursery. The area should have light to medium soil (preferably, a clay-loam soil) and should be well drained, to a depth of at least 1 m. Generally most of the fruit
crops do well in friable, loamy soil, rich in organic matter with the soil reaction varying from slightly acidic to near neutral (pH 5.5 to 6.5).

3. The location of a nursery site or propagation plot should be:

- separated from the production field;
- located as close as possible to fruit-producing areas;
- on land which was not previously planted under the same fruit crop, to avoid build-up of diseases and other pest population;
- outside the range of roots and shade of trees, hedges and buildings;
- in an area not prone to frost;
- near a source of water for irrigation;
- protected from strong winds; and
- readily accessible by all-weather roads (accessible all year round) for the transport of plants (seedlings), so that customers are able to get seedlings easily, in addition nursery staff can also be able to manage plants and transport mature seedlings to planting sites and/or markets.

4. The nursery area should be fenced and kept clean from weeds within and around the nursery which otherwise may host pests (diseases, insects and others).

5. Rotation of nursery site - Once the soil in the nursery has been used, there is always a risk of it harboring diseases and other pests which will infect a second crop of seedlings. If diseases and other pests are observed on the seedlings raised in the nursery, then the site should not be used again until it has been rested and fumigated.

If pests have not been observed on the seedlings, then the nursery site can be used for the second time provided that the fertility is built up with well-decomposed organic matter and mineral fertilizers such as super phosphate.

6. It is also necessary to consider the reliability of locality where a nursery is to be established for the business. This means that the nurseries should
be established in the known locality. Since such a place is known to the customers and consequently the nursery gets the advantage of publicity. Apart from this, skilled labour and various inputs are also readily available.

Growing seedlings in a field nursery

*Nursery row culture* is a basic nursery operation used for outdoor seed propagation of fruit trees. Rootstocks of most fruit and nut species are propagated by planting directly in nursery rows. Cultivars are budded or grafted to the seedlings in place.

*Nursery soil preparation* - Nursery production requires a fertile, well-drained soil of medium texture. Preparation of soil for planting may include rotation with other crops and incorporation of a green manure or animal manure. Pre-plant fumigation of soil and weed control are essential aspects of most nursery operations.

A common size of seedbed is 1.1 to 1.2 m wide. The length varies according to the size of the operation (commonly, the minimum is 5 m). Beds may be raised to ensure good drainage. Generally there are three types of nursery beds (Hall, 2003; Singh, 2004; Mbora *et al.*, 2008): Flat, Raised and Sunken nursery beds. Flat nursery beds are recommended when there is no fear of heavy rain and in areas where the soil is light sandy to sandy loam (where there is no problem of water stagnation).

Raised nursery beds are used for raising seedlings during rainy season when stagnation of water is expected to be problematic and cause some soil born diseases like damping-off.

Sunken nursery beds are prepared in areas where cold weather (winter) is prevailing during raising of nursery plants. This type of nursery is prepared 10 to 15 cm downward from the soil surface (Singh, 2004). The air blows across the surface of soil and the seedlings in this type of nursery bed are not hit by cool breeze of the air. Such beds are also convenient to cover them with polythene sheets so that seedlings or rooted cuttings can be
protected from cool air.

**Time of planting** is based mainly on the dormancy conditions of the seed, the temperature requirements for germination and the management practices at the nursery.

**Depth of planting** is critical factors that determines the rate of emergence and perhaps stand density. If too shallow, the seed may be in the upper surface that dries out rapidly; if too deep, emergence of the seedling is delayed. Depth varies with the kind and size of seed and, to some extent, the condition of the seedbed and the environment at the time of planting. Type of germination also influences depth of planting, for instance cherry seeds (one of the deciduous fruits) have *epigeous* germination (the cotyledons are above ground) while peach seeds have *hypogeous* germination (the cotyledons remain below the ground). Shallow planting is often used for plant species that have epigeous germination.

As a guide, seeds should be planted at a depth two to three times their diameter and should be covered firmly with soil. The soil should then be kept moist but not wet until the seedlings have emerged. The soil should not dry out completely at any time during the germination period. Equally important is that it should not be too wet so as to avoid an outbreak of *damping off*.

The *optimum seed density* depends primarily on the species but also depends on the nursery objectives. Where fruit plants are to be budded or grafted in place, the width between rows is about 1.2 m and the seeds are planted 7.6 to 10 cm apart in the row (Singh, 2004). Seeds known to have low germinability must be planted closer together to get the desired stand of seedlings. Large seed (e.g., avocado) can be planted 10 to 15 cm deep, medium-sized seed (e.g., citrus, bullock’s heart) about 7.6 cm, and small seed (e.g., guava, passion fruit) about 3.8 cm (Mbora et al., 2008). Spacing may vary with soil type. If germination percentage is low and a poor stand results, the surviving trees (seedlings) may grow too large to be suitable for budding. Fruit plants to be grown to a salable size as seedlings without budding could
be spaced at shorter intervals and in rows closer together.

Nursery design and layout

In the design of a commercial nursery, all the necessary structures and other facilities are arranged to ensure a constant flow of activities. The figure below is a ground plan of a simple commercial nursery showing some of the major structures and facilities.

![Ground plan of a simple commercial nursery](image)

**Figure 4-1.** Ground plan of a simple commercial nursery.
Source: Dhliwayo et al. (2003)

Propagation structures

Structures range from simple shade houses to complex and automated greenhouses, which vary in the extent to which they control the environment. Propagation structures are desirable in a nursery because they permit the
nursery worker to control the environment. The size of the propagation structure also influences the comfort of the workers attending to the seedlings (or nursery).

A simple shade structure can be constructed by using poles to support a roof of wire mesh or other locally available appropriate materials on which a thin layer of thatching grass is tied to give filtered sunlight beneath. Poles should be treated with a wood preservative to prevent rotting and termite damage. The structure can be used to propagate many species and for growing newly transferred (pricked) stock.

Potting soils

A good potting soil must meet a number of conditions if high quality nursery stock is to be produced. Firstly, a mix must adequately support the plant. This means that it must be heavy enough to prevent the plant from falling over, without being so heavy that handling and shipping costs are unduly increased. Secondly the mix must provide a reservoir for air, moisture and nutrients. Air and moisture compete with each other to occupy the spaces between the particles of the mix. Water tends to occupy small spaces while air occupies large spaces. For this reason, the size of the spaces between soil mix particles is very important. In the ground most clay-containing soils will aggregate or clump together in such a way that there is space for both water and air. However, when soils are transferred to a pot (plastic tube), the aggregated particles, are usually destroyed (dispersed) and only very small spaces remain. Hence the soils do not contain sufficient air for good growth of plants. For this reason field soils are almost never good potting soils unless they are amended to increase their aeration. If the roots of potted plants reach near the soil surface, or occur near the sides of the planting pockets, or near drainage holes seedlings grow much more slowly than is desirable. Besides, owing to low oxygen diffusion and wet conditions, the likelihood of root rot diseases may increase.

The soil mix must, however, hold sufficient quantities of water since the root system is confined to a small container. Otherwise seedlings need to
be watered frequently. For this reason, soil mix must contain water absorptive materials. Many types of organic matter (preferably compost) are very efficient in this regard.

Thirdly, the mix must supply all the nutrients the plant needs—both macro- and micro-nutrients. These nutrients have to be added to the mix and pH adjusted to an optimum level. In addition to aforementioned requirements for a soil mix, condition of pests and heavy metal contamination deserve due attention.

Furthermore, soil mix should be stable enough to ensure that its properties do not change drastically during the period of time that the plant is in the nursery. Materials which tend to compact or organic matter which tends to decompose rapidly are usually not satisfactory ingredients in soil mixes; because, although they may perform satisfactorily initially their influence (or effect) can change with time.

The last but not least desirable attribute of the soil mix is its standardization. A precise recipe should be used in making the mix (e.g., soil, sand, compost, nutrients) and these same ingredients should be used each time the mix is made.

Raising seedlings in plastic tubes (containers)

This technique has been developed for raising seedlings which will not be transplanted under optimum field conditions, for kinds which are difficult to transplant bare root (i.e., for seedlings whose roots are sensitive to environmental conditions); and seeds of high value such as “Solo” papaya.

The filled plastic tubes (polythene tubes) are arranged close together in a standard sunk seed bed (in Ethiopia, 1 x 5 m, seedbed is common) so that the bed can be easily irrigated and it is to let the water percolate into the tubes from beneath. Two general sequences of operation are followed in the initial establishment of the seedling plants to be grown in containers: direct seeding and transplant method.

*Direct seeding* - Seed may be placed at the desired spacing in a seed flat or
directly into an individual container. Direct seeding is used mostly with medium- or large-sized seeds or those for which transferring (or pricking) them to wider spacing within the nursery, so as to improve their growth before being transplanted to the field, is particularly harmful. One or two seeds are sown in each tube (container). The surface is then covered with dry grass and hand watered. The grass (mulch) is removed as soon as the seedlings emerge above the soil level. Seedlings are transplanted to the field as soon as small roots can be seen emerging from the bottom of the tube or else the roots need to be pruned. At planting the tube should be slit down on one side to avoid any constriction of the root system.

**Transplant (pricking) method** - In some cases, it is desirable to transfer young plants into containers of various sizes as an intermediate stage between the seed or cuttings and transplanting to permanent sites. This practice is often followed in the case of mango, avocado and guava rootstocks (which are to be grafted later). In general the practice is necessary for plants, which have to be transported long distances to permanent sites.

The advantage of using plants grown in containers is that 100 per cent of the roots are in the container. Thus, the plant goes through limited transplant shock if given adequate follow-up care. Container-grown plants can be planted into the field year-round. The main disadvantage of container-grown plants is the possibility of deformed roots. “Rootbound” plants have roots circling inside the container. The entangled roots are a physical barrier to future root growth and development. If this condition is not corrected by loosening the root mass at planting time, the plant may experience slow growth and establishment because of the girdled roots.

**Watering** - The seed beds should be watered immediately after sowing. Examine the seedbeds daily and apply water if the surface of the soil becomes all dry. At the stage when the seedlings reach a height of 5 cm, thinning should be carried out if necessary and watering should be changed to surface irrigation if overhead irrigation will not be continued. The water must be admitted slowly through siphons or tubes to the bed and should not
exceed a depth of 2 cm. Frequency of watering will depend on local conditions. The beds should be examined daily and re-watered if necessary.

**Fertilizer application** - The type and rate of fertilizer to be applied should be decided based on soil analysis of the nursery site and the requirement of the species.

**Wind breaks** - In windy places, it is advisable to establish temporary windbreaks at 50 m intervals in the nursery. A suitable temporary windbreak can be made by sowing a single line of pigeon pea, with the seeds spaced at 50 cm in the row. Protection from wind will increase the rate of growth and reduce wind or related damage to plants.

**Plant protection** - Plant protection in the nursery includes the disinfecting of soil to prevent soil-borne diseases as well as spraying of fungicides and insecticides to control fungal and bacterial diseases and insect pests on seedlings. The control measures differ according to the crop. Selective removal of diseased seedlings ("rossing") is also common practice in nursery pest management.

**Grafting and budding of fruit plants** - Fruit seedlings or cuttings are normally grafted or budded onto a desirable rootstock under nursery condition, where they will be well protected from adverse conditions. Because grafting and budding of fruit trees are specialized operations, experienced workers are needed to get the best results. All new growings (suckers) from the rootstock portion of the grafted or budded nursery material should be removed (desuckered) routinely so that the sprouting of the scion will be facilitated.

To ensure the young trees establish and grow well, the following guidelines need to be considered (Mitov *et al.*, 1990; Dhliwayo *et al.*, 2003; Hall, 2003; Mbora *et al.*, 2008):

- When planting trees, be sure not to cover the bud union with soil. Plant to the same depth as the trees have been grown in the nursery.
• Keep young trees well watered and protect them from strong winds using windbreaks.
• Ensure adequate permanent windbreaks are in place to provide wind protection of your crop.
• Use trunk guards if sunburn and vertebrate pests such as rabbits are a problem.
• Trunk guards are only required for the first one to two years.
• They should not restrict or cut into the trunk and should be checked regularly for the presence of ants or any soil buildup which can cause collar rot.
• Always provide adequate fertilizer and monitor trees for any pest and disease problems.
• Keep weeds under control, since they compete with the fruit trees for water and nutrients.

Nursery plants can be delivered for field planting in several ways: with sleeved soil (a soil-ball) or bare-root, pruned and stripped of leaves or with leafy branches. The method preferred depends on climate and other conditions. Transport of course, is far cheaper with bare-root plants, but they run the risk of drying out, distortion, breakage, or infestation. Therefore, this can only be done in a wet season, over short distances and when the plants can be set out immediately. With bare-root and leafless plants the risk of transporting diseases, nematodes and scales from nursery to field is decreased. In most cases pruning (capping) is needed in the nursery, in order to start a framework of branches.

Transplanting to permanent location - The final step in nursery production is transplanting seedlings to their permanent site (field). Correct planting technique begins with loading (transporting) the plant at the nursery or garden center. Gardeners should be very careful with plant material. A few important considerations with regard to handling of nursery plants, while loading and transporting, include the following:
1. Protect the roots, stems, and foliage from reach of direct sunlight (and high temperature) during transport.

2. Shield plant tops from wind.

3. Lift plants from underneath the root ball with the appropriate equipment.

4. Handle container-grown plants by the container and never by the tops of the plants.

5. If plants must be held or stored on the planting site, it is best to place them in a location protected from the wind and sun.

The seedlings may be transplanted bare-root or with the soil-ball (soil-block). Bare-root transplanting invariably undergo root damage and transplant shock, which may affect establishment and/or plant growth. The use of the soil-ball minimizes transplant shock. In both cases success in transplanting depends to a large extent on the previous handling of the plants. The operation requires that the plant be “hardened” prior to its shift to the open field. Hardening involves a checking of growth resulting in the accumulation of carbohydrates, which makes the plant better able to withstand adverse environmental conditions. This can be achieved by temporarily withholding moisture and minimizing the level of the nursery shade (this practice is commonly called hardening) for a sufficient period of time.

Before being moved into the field, the plants should be watered thoroughly. Planting is done in the field by hand or, in some cases, by transplanting machines. Transplanting is usually carried out at a stage when the seedlings are still easy to handle and can easily be carried by hand. In transplanting both bare-root and soil-ball seedlings, it is often a good idea to prune off some of the leaf surface to reduce transpiration losses during the period before the new roots are established (Williams, 1975). At transplanting time it is usual to carry out some screening of seedlings, selecting what are considered to be strong plants which will grow well, and rejecting others which are weak or diseased.
Temporary storage of bare-root seedlings - If the seedlings cannot be planted soon after delivery, a trench can be dug in a shady location and the roots covered with moist soil.

In general quality planting material requires quality nursery management. Planting material produced under poor conditions will never perform well when established in the field. Therefore quality seedling production is necessary for quality tree production.

References


The primary consideration before setting up an orchard and vineyard is to analyze the available resources in the context of those, which are essential for a successful fruit production. Knowledge of soil and climatic conditions occurring in the native range (center of origin or diversity) provides clues about site selection and cultural methods that should be employed when growing these crops in new areas. Careful planning for orchard establishment is of great importance to ensure steady high returns year after year. Since the production of most fruit crops is a long-term undertaking, poor initial decisions can be costly and difficult to correct later. All available pertinent information should therefore be sought out before final commitments are made.

Site selection

Site selection is one of the most important decisions a grower will make over the life of an orchard. Virtually every aspect of production and marketing is, to a degree, affected by site. It affects cropping consistency, fruit quality, pest pressures, and marketing success.

Fruit growing is a long-term undertaking, and the trees, once planted, remain in their positions for many years. It requires a great deal of initial investment, and in most cases returns start coming in after a number of years. Great variation often occurs, even within a farm, as to the adaptability of certain fields for successful fruit growing. Future success depends largely on the selection of a suitable site; hence, the site for fruit growing should be selected carefully.
Each species of fruit has specific environmental requirements, which must be met for optimum growth and production. Land survey is a very important prerequisite for the foundation of a new farm or re-organizing an existing one.

Major aspects of land use planning, which should be investigated, are climate, soil, vegetation (natural) and previous cropping history, topography, irrigation potential, infrastructure, logistics and communications in relation to markets. Site selection and site development go hand-in-hand. Some factors in site development, such as water availability, and ensuring adequate water drainage, are best addressed through selection of good sites. Site preparation should establish a favorable soil environment for the trees and address factors that may have a negative impact on fruiting and orchard management. Orchard site preparation should begin at least six to 12 months in advance of planting.

**Climate** - It is extremely important to learn as much as possible about the weather patterns of the proposed planting site. Meteorological information can often be obtained from neighbors who have lived in the area for many years, national meteorology (government weather services) or any other sources. Several weather conditions (climatic factors) are of particular importance in fruit growing.

**Temperature** is one of the most important environmental factors influencing the growth and development of fruit plants and fruit quality. The favorable temperature range for the growth and development of any particular fruit plant is known as the *optimum temperature range*. Within this range the two fundamental processes, photosynthesis and respiration, are proceeding in such a way throughout the life cycle of the plant that the highest marketable yields are produced. Therefore, the intended orchard site should have the optimum temperature range for successful growth and development of the fruit(s) to be grown.

Low-lying sites, such as, river bottoms or low spots in rolling hills, should be avoided because cold air, which is heavier than warm air, is likely to flow downhill and settle to the bottom of the valleys. Under these
conditions there occurs, temperature inversion, where slopes may be several
degrees warmer than depressions below them. Cold air collects in low areas
(Fig. 5-1), from which it cannot go out. In these areas fruit trees are most
likely to be subjected to frost damage, therefore orchard site should be
selected in a gentle slope with good air drainage.

![Frost Pocket and Slope with good air drainage](http://www.wvu.edu/~agexten/horticult/fruits/om100.pdf)

**Figure 5-1.** Frost damage is best prevented by proper site selection.
Choose a gentle slope with good air drainage.
Source: [http://www.wvu.edu/~agexten/horticult/fruits/om100.pdf](http://www.wvu.edu/~agexten/horticult/fruits/om100.pdf)

Rain - Fruit plants require adequate soil moisture throughout the growing
season. Amount and distribution of the annual rainfall can vary widely from
place to place. Some areas receive relatively small quantities each year (arid
and semiarid) whereas others receive large supplies (humid). In the arid and
seamirid areas (where rainfall is erratic and scanty) the application of
irrigation water is required for the production of high yields. Conversely,
humid areas receive sufficient amounts of rainfall per annum. Since
effectiveness of rainfall is more important than amount, the application of
irrigation water may serve as insurance for the production of high yields. A
better situation exists where water supplies for irrigation are available during
times of drought. A pattern of continual rains during the pollination period
could result in poor crops by interfering with bee activity; and washing out
stigmatic fluid, and shedding pollen grain. Continual rains, during the fruit
harvesting period, cause problems not only in harvesting operations but also in
promoting various fruit diseases (fungi, bacteria).

The proposed site should not be subjected to periodic flooding (from nearby rivers or streams, faulty irrigation, poor hydraulic conductivity). Selecting a site for an orchard involves below ground considerations as well, primarily soil depth and soil texture. A desirable orchard soil should be deep and well-drained. Soil drainage is probably the most important factor in the longevity of an orchard. This is because of the inherent inability of certain types of fruit trees to survive when planted in imperfectly drained soils. Most fruit plants will not tolerate water around their roots for any length of time, as the water stops air penetration to the roots.

Wind can be detrimental from several aspects. It can damage plants by desiccation, by physical breaking young, tender shoots, leaves; and can scar bruise young fruits. The branches are broken, the fruit is blown off or scarred, particularly if the tree is thorny, and even the leaves may be whipped off. Strong winds also affect bee activity in orchards. Reduced bee activity during windy days in the pollination season can seriously reduce fruit set and yields. Sites that have a history of strong winds should therefore be avoided or appropriate windbreak trees should be established.

Hail can destroy bloom, leaves, and young fruit on trees. Flowers and leaves are sometimes knocked from trees, but the worst damage occurs when young fruits have formed and are exposed. Hailstones, even small, soft ones, can severely pit and scar young fruits. Therefore the frequency of hailstorms at the proposed site should be determined in advance, as they are very damaging especially to soft fruits such as strawberry, peach, nectarine, papaya, etc., as such fruits are particularly liable to damage and are easily injured mainly due to thin skins. In papaya, the large leaves are also likely to be torn. There is no way of protecting the trees from hail.

Elevation - The elevation of the land refers to the altitude of the surface of the land above or below sea level. Differences in elevation make for marked differences in temperature between the two places. Altitude and temperature
are inversely related, that is, the higher the altitude the lower the temperature of the site and vice versa. In the tropics, for every increase in elevation of 100 m, there will be fall in temperature of 0.6°C. Such a difference will cause considerable variation in flowering and fruit maturity period of a particular fruit species. This may, however, provide scope for extending the harvesting period of a particular fruit and should be taken into account while selecting a site.

Tropical fruit crops thrive at the low elevations; subtropical fruit crops thrive at the intermediate elevations; and warm-temperate and even cool-temperate crops thrive at the high elevations.

**Soil characteristics** - The soil should be investigated very thoroughly to assess its suitability for fruit production. Soil type, texture, structure, permeability, drainage and reaction (pH), content of essential elements, organic matter and soluble salts are important factors to be considered when selecting a site for fruit crop production. Soil type provides information on both the physical and chemical characteristics of the soil. Ideally soils should be a sandy loam with good structure. Avoid heavy clay soils and soils with impermeable layers. The ideal orchard soil should be deep at least 1.8 m, well-drained, non-saline, fertile silty loam to a fine sandy loam. The surface should slope gently, allowing for the removal of runoff (from heavy rains) and permitting good infiltration of irrigation water.

Most fruit trees grow best on deep, well-drained, medium-textured soils having moderate fertility. Planting orchard trees on unsuitable soil handicaps the orchard’s productivity for the life of the planting and can make the enterprise marginal or unprofitable. It is also important to note that highly fertile soils do not necessarily make good fruit sites. Excessive tree growth can cause shading in the lower and interior portions of trees. Undue vigor will contribute to increased disease pressure, poor fruit quality, and a failure to develop flower buds for the following year in the lower and interior portions of the tree. Fertilizer can be added to soils of low to moderate fertility in sufficient amounts and at the correct time to obtain the desired results.
Topography - The principal factors are the slope of the land, its aspect, exposure to wind, liability to frost hazard and effectiveness of the natural drainage system. The suitability of land for different purposes can be determined by a study of topography. The degree of land slope will generally decide its suitability for different types of fruit crops. Provided a suitable layout is used to protect the soil against erosion, fruit crops can be grown on land, which has up to 15% slope (Mitov et al., 1990). Commonly commercial orchards are located on flat to gently rolling land, and the best site is south facing with a slope of between 4% and 8%, because operating equipment on steeper slopes may be difficult. Level or gently sloping land is most suitable for annual fruit crops (e.g., strawberry) or short-term perennials such as pineapple, provided drainage is satisfactory. More sloping sites can be used for long-term perennial fruit trees. As sloppy lands constitute a difficult terrain, most horticultural operations are carried out manually, making the entire crop management practice a highly laborious occupation. In some parts of Ethiopia, where the land is hilly or mountainous, the smallholder fruit production is found on steeper gradients. This is being followed traditionally, without significant use of conservation practices. In such areas, practical conservation farming options need to be introduced so as to effectively utilize the land while minimizing possible soil erosion by water. Very steep slopes and broken land however should be reserved for permanent pole and fuel plantations, which will also have the effect of decreasing runoff.

Vegetation - The natural vegetation is determined by climate, soil, topography and pests. In many cases the primary vegetation will have been destroyed by cultivation or drastically changed by over-grazing. It is important to investigate previous land use for cropping or grazing and to observe whether serious soil erosion has occurred. Much can be learned about soil conditions on previously cropped land by observing the kind of weeds, which are growing on it.

Availability and quality of irrigation water - Water availability and water quality should be assessed in searching for orchard sites. An assured and reliable source of water is critical for production. In low rainfall areas,
assurance should be obtained that there is a potential source of ample high-quality irrigation water. Water samples can be analyzed by standard laboratories for the level of soluble salt and water-borne diseases.

In Ethiopia, most fruit crops are produced with supplementary irrigation. If a stream (or river) is to be used as the water source, flow rate and reliability must be assessed to be sure that adequate amounts of water are available during peak demand periods. If a pond is to be used, its size and recharge rate must be adequate to satisfy the demands. It is therefore essential to assess the irrigation potential of any farm, which is being evaluated for fruit orchard/vineyard development.

**Drainage** - Most orchard crops require well-drained soils. A good orchard site should have ample surface drainage to take care of excess water, especially during main rainy season, when drainage through the soil is difficult. Avoid soils having poor internal and surface water drainage characteristics. Heavy, shallow soils should also be avoided, as root growth will be restricted and trees will be more seriously impacted by drought, excess water, and low temperatures.

**Availability of markets for the fruit** - Market considerations should play a large part in site selection. It is essential to know that a market (local or export) will be available for the produce by the time production begins. If fruit is to be transported to a central packing facility, distance and the quality of the roads need to be considered. Retail, consumer markets need to be readily accessible to customers.

**Availability of labor** - In establishing a large, commercial fruit-growing enterprise the availability of reliable workers to do the extra labor required should be assessed. Extra labor is often needed to harvest the crop, to prune the trees and for fruit thinning. Other operations such as weed control, fertilization and irrigation, can usually be handled with a minimum crew and are often done by the technicians and/or by the owner.
Social factor - The selected orchard site should not displace the community. If this situation is unavoidable, proper compensation should be paid, or otherwise the local community may have a negative attitude towards the farm; and there could be unforeseen problems in running planned activities on the farm.

Selecting fruit cultivars and rootstocks - Success of any orchard mainly depends upon the availability of right type of planting material. Initial planting material is the basic requirement on which the final crop depends both in quality and quantity. In case, any mistake made during initial years, cannot be rectified in subsequent years and will cause everlasting damage to productivity and income of fruit growers. Non-availability of genuine seeds and elite planting material is one of the major constraints in obtaining expected productivity in fruits.

Once the kind of fruit crop to be grown has been decided, the cultivar will have to be selected, a decision that can determine the success or failure of the enterprise. This decision should not be taken lightly. Varietal selection is frequently made on the basis of yield potential, disease resistance, or suitability for local conditions, and often without sufficient consideration of market preferences and postharvest behavior. Availability of planting material (both rootstock and scion) of the desirable cultivars is still a very limiting factor in our country where fruit growing is not well developed.

In fruit plants with two parts, that is, budded or grafted plants, it is very important that the prospective fruit grower decide not only what the top fruiting cultivar (scion) is to be but also what the rootstock trees should be. The choice of a suitable rootstock is important for the long-term health and productivity of a given orchard. Rootstock choice will be a compromise based on a number of factors including soil type, scion varieties, climate and locality. Rootstocks also determine to some extent the period of crop maturity, fruit quality and tree growth habit. Rootstocks vary significantly in their resistance to fungal and viral diseases, nematodes, soil conditions such as pH and salinity, in their compatibility with different scions and in their effects on fruit quality.
Scion cultivars/varieties selection should be based on what end product or market we want to supply, domestic or export. We can often obtain market requirements for fruits by talking with local agents, exporters, fruit suppliers and processors. It is better to make these decisions before we buy and plant varieties, than to try and find a market after we have spent time and money growing trees and producing fruit.

**Infrastructure** - The existing infrastructure must be assessed in order to decide what further development is needed to bring the land into suitable and economic production. The principal aspects that should be studied include:

**Communications**: Telephone, radio links, farm access roads, distance from main roads, railway ports, markets and processing plants.

**Services**: Availability of human-power, housing, farm buildings, electric power, water supply, and social amenities.

**Land improvement**: Soil conservation and irrigation system, land levelling and grading, windbreaks, fuel and pole plantations, and established perennial crops.

**Logistics and communications in relation to markets** - The distance to markets, ports and processing plants (industries) should be within an economically feasible range. New processing plants, grading and packing stations, cool stores, etc. should be erected in the center of a fruit production area. The road system within a farm should be planned in conjunction with the windbreak system, and should be in accordance with the quantity of produce to be transported.

**Land preparation**

The purposes of land preparation are to:

- level the land where needed;
- incorporate crop residues, green manure and cover crops;
• prepare and maintain a seedbed in good tilt;
• help control weeds, diseases, and insects;
• improve the physical condition of the soil, and
• help control erosion where needed.

Fruit crops may be established on new or on cultivated land. If the new land selected for the orchard is covered with timber or any primary vegetation, one of two plans may be adopted: partial or complete clearing. In all cases the latter is preferable, but the former can be made to give good results.

If it has been decided to plant the trees in a partial clearing, the rows in which they are to stand should be cleared out, or the ground should be staked off and a space in the form of a circle cleared for each tree. This row or space should be carefully cleared. No roots of the adjoining standing plant should be left in it. It is important that all roots be taken out, for these frequently harbor insects and diseases that may attack the fruit trees later on and cause much problem. In other words, the selected planting position should be free of all roots of primary vegetation, stones and perennial weeds. If a complete clearing is to be made, it is best to begin operations at least one year prior to planned planting time. The second operation must be leveling or grading. This is a very important operation for the permanent cultivation of fruit crops, especially for surface irrigation layout. Rough leveling is carried out by bulldozers followed by fine leveling with land-graders or land-levelers.

The development of new land should be carried out by a contractor since the necessary machinery is too expensive for a single farm. Where the subsoil is strongly alkaline, grading must be reduced to a minimum. Plowing can be done by disc ploughs, mouldboard ploughs, or rotary cultivators. For plowing fields for fruit production, the mouldboard plough or the rotary cultivator are preferred because of their better working quality compared with the disc plough. A recommended soil preparation for deep-rooted fruit crops are sub-soiling (about 90 cm deep), deep plowing, leveling and plowing again. After using mouldboard ploughs, land should be disked and harrowed diagonal to the direction of plowing. The aim is to break down clods and to reach an even and finely tilled soil surface.
Though fruit trees are deep-rooted, it is not necessary to prepare the soil to the full depth of their ultimate root penetration. In most cases, it is sufficient to prepare the planting holes. In some cases, zero or minimum tillage can also be used, especially for shallow rooted, short-term perennials such as pineapple, provided that other growing conditions are optimum. Cultivating the whole field (orchard) is not done except in cases where cover crops are to be grown and incorporated into the soil. Since young fruit trees do not have sufficient roots or large enough canopies to prevent erosion, a ploughed orchard can expose soil to erosion. For this reason the ground between rows of trees should be grassed and mowed or slashed periodically. Only the area within 1-2 m of the tree itself is kept completely free of vegetation, but this should be mulched.

On slopes of 10-15%, well-maintained terraces are necessary to prevent soil erosion (Mitov et al., 1990). Generally, combinations of ridging, terracing, and cover crops are necessary in the tropical orchard if severe erosion is to be prevented.

**Fencing** is an important feature of an orchard since young trees are likely to be eaten by animals if they are not protected. In addition, when trees begin to fruit, theft may become a problem. Fencing will help to alleviate both of these problems. However, in Ethiopia fencing is normally accompanied with alert day and night guards, and the result is often satisfactory.

**Windbreaks** (sometimes known as shelterbelts) are rows of vegetation, usually trees, strategically placed to protect an area from wind damage. Windbreaks are usually rows of tall trees planted close together. A windbreak works by filtering and slowing the wind that enters the protected area. Effective windbreaks provide protection from prevailing winds. Wind can have a definite harmful effect on fruit production in many ways including:

- stressing plants, reducing their growth, vitality and yield;
- physically damaging plants by breaking stems or branches, stripping leaves, or tearing fruit or flowers from fruit plants;
• drying the air around plants, causing them to lose moisture;
• pulling moisture from soil pores on the surface, drying soil;
• removing topsoil and organic matter from exposed soil.

Windbreaks prevent crop damage, conserve moisture in plants and the soil, and reduce soil wind erosion. It is well known that windbreaks can result in a 45-60% reduction in wind velocity as well as reducing transpiration by as much as 65% (Mazumdar, 2004). The primary benefits of planting windbreaks are to:

• improve crop quality and yield by protecting crops from wind damage;
• conserve moisture by reducing evaporation and transpiration;
• protect from hot, dry winds and dust.

Some specific examples of how production can be improved by windbreaks are listed below:

• Fresh fruit get premium prices based on appearance; fruits that are bruised, blemished, or damaged by wind usually have to be sold at a lower price.
• Orchards for fruit production benefit from wind protection. In a fruit orchard protected by a windbreak, more fruit can be produced because flowers and young fruits sustain less wind damage; stress on the trees can be reduced, improving their growth and productivity; and in some cases fruit set can improve because insect pollinators tend to be more active in the protection of a windbreak.

Johnsson and Skaar (1979), and Grace (1988) suggested that wind could play an important role in water use efficiency (WUE) at the physical, physiological and molecular level via perturbation responses, abrasion of leaf surfaces, and mechanical breakage. Damage to leaf surfaces can decrease a plant’s ability to control water loss by stomatal control. If mechanical stimuli elicit wound responses and production of non-productive tissue at the expense of productive
tissues, a plant's ability to increase carbon fixation capacity as it grows may not increase as fast as its capacity to lose water increases.

Windbreaks are rows of trees or shrubs that reduce the force of the wind. A windbreak of trees and shrubs works by filtering and breaking the force of the wind. Permeable windbreaks that let some wind pass through are most suitable. The slight movement of air through the windbreak forms a cushion of slow-moving air on both sides of the windbreak (Fig. 5-2). The effects of reduced wind speed are:

- Moderated soil and air temperatures;
- Increased relative humidity;
- Reduced evaporation and increased soil moisture. These effects are determined by a windbreak's height, length, density, location and species of trees or shrubs.

Ideally, they should be planted two to three years before the orchard is established so that they are sufficiently large to provide immediate protection to the newly planted orchard trees. The choice of the windbreak species depends on the location of the orchard. Windbreaks should not serve as an alternate host for pests that can attack fruit plants intended to be grown; it should be a tall and multipurpose tree, which is strong enough to resist the impact of wind. It should be densely planted to block the wind.

Height of windbreak trees is more important than thickness, but a tree with a dense head is more effective than one of the same height with few branches. Generally, the height that would be attained by the trees or shrubs in the rows, when fully grown up, should be greater than the orchard trees, for in such case, they are capable to protect the orchard trees against speedy wind, which blows mostly at the upper layer of atmosphere. A windbreak normally has its maximum effectiveness for a distance about four times as great as its height, but has some effect over about twice that distance. Whereas complete protection as possible is desired, windbreaks should be planted at intervals in the orchard, as well as along the windward side. In many cases, however, the orchard trees themselves offer considerable
resistance to the wind, and only one windbreak is necessary. It has been known that a straight wind of the velocity of 48 km per hour when strikes against an effective windbreak row of 10.5 m height reduces the wind velocity to 16 km per hour for 45 m and to 24 km per hour for 60 m on the leeward side (i.e., the side turned away from the wind) (Mazumdar, 2004).

Sometimes roots of the windbreak trees make way to enter the soil in the orchard where the roots of the fruit trees abound, wherein the water and the nutrients that are supplied to the fruit trees are actually taken up by them through their feeder roots. As a result, the feeder roots of fruits are deprived of getting the inputs and eventually, their growth is hindered. The extended root growth in the direction of orchard tree side may be managed by digging a long trench of about 1 m depth between the windbreak row and the first row of the fruit trees (windward side). The trench should be dug about 3 m away from the last row of windbreak (leeward side) and subsequently inspected regularly and whenever the roots of the windbreak trees would come to notice, these should be cut off with appropriate implement. Later on, the trench may be filled up, if necessary and the same practice should be repeated after every two or three years.

Digging of trench should be done in the secondary wind break row also, if such a row has been set inside the orchard. In this case however, trench should be dug on both sides of the windbreak row since fruit trees exist on both sides of it.

Application of appropriate management to windbreak trees or shrubs should not be overlooked. They usually do not need much care once established in the soil. Nevertheless, to make them more effective, some operations like training and pruning may be necessary to give desired size, shape or form.
Planting systems

Planting system refers to different methods of planting trees keeping in view the crops and varieties chosen in one side and the fertility gradient of blocks on the other. The main objective of the planting system is to accommodate the maximum number of fruit trees per unit area without affecting the efficiency of production (Singh, 2005). Prior to ordering the planting trees, an orchard and/or vineyard plan should be drawn on paper to show the location and cultivar name of each tree, irrigation system, trellises or tree supports (for support requiring fruit plants like grapes and passion fruit), orchard roads and paths, packing shed and any other permanent features of the plantation site. If the plan is drawn properly, the number of plants, stakes, and so on can be determined and obtained before the start of planting. A stake is set where each tree is to be planted.

Different planting systems are used in fruits depending mainly on topography of the land, the growth habit of the tree, method of training/pruning and the type of machine intended to be used for the various farm operations.

*Square planting* - In this planting system, fruit plants are arranged equidistant, the distance from tree to tree in the row is the same as from row to row.
Planting is done at each corner of a square, that is, the plants are at the right angle to each other, every unit of four plants forming square. It is usually recommended for orchard sites with a slope up to five per cent (Mitov et al., 1990). The square planting system is easy to layout and allows cultivation and irrigation in two directions.

**Rectangular planting** - Unlike the square planting, in this system the spacing between rows and between plants is not the same. Trees are set out in straight rows that line up at right angles to one another with spacing between them in a row somewhat less than that between rows (forming a rectangle). Like a square, it is the easiest to layout and manage with respect to cultivation and harvesting operations. Rectangular planting allows more space for the trees as they mature and also provides adequate space for power driven equipment (e.g., tractor/harvester). Commonly, this planting method is practiced on sites with slopes of five to eight per cent range (Mitov et al., 1990). Trees with lateral inflorescence, such as citrus and avocado, can just as well be set out in a rectangular planting system.

The total number of plants in both square and rectangular planting systems is given as:

$$\text{Number of plants} = \frac{\text{Area in square meter}}{\text{Planting distance (m²)}}$$

To determine number of trees per hectare (TPH), in single-row orchards (e.g., rectangular planting system), locate the desired or planned in-row spacing of trees on either the vertical or horizontal axis. Next locate the between-row spacing on the other axis. The number of trees per hectare can be found at the intersection of the two spacings. For example, if we want trees to be spaced 10 m in the row with 8 m between-row spacing, we would go down the left-hand column to 8 m and follow across to where the 10 m column intersects, and we would find the number of trees per hectare to be 125.
Hexagonal or Equilateral Triangles. The hexagonal system is also called as the equilateral triangle, as the trees are planted in the corners of equilateral triangles. Six trees thus form a hexagon, with another tree at its center. Trees with circular crowns (e.g., date palms) are said to give better results when planted in an equilateral triangular planting system. This allows cultivation in three directions and accommodates about 15 per cent more trees per hectare at any given distance, than by the square system (Samson, 1986; Singh, 2005). If the distance between trees is ‘d’, then a tree takes up $\frac{1}{2}d^2\sqrt{3}$ m$^2$ (Samson, 1986). Let us put ‘d’ at 10 m; using square planting, 100 trees/ha can be planted. In an equilateral triangle a tree occupies $\frac{d}{2} \times 100 \times 1.73 = 86.5$ m$^2$, so the density is 10,000/86.5 = 116.

The hexagonal system should not be confused with the triangular system (Fig. 5-3c). In the latter, the trees are planted as in the square system, except that those in the even-numbered rows are midway between, instead of opposite to, those in the odd. This system bears the same relation to the hexagonal as the rectangular does to the square. Somewhat fewer trees per unit area may be planted than in the square system with the rows the same distance apart.

Triangular planting - It is a system in which plants in alternate rows are offset half the space between plants in a row. The distance between the rows is the same or more than that in row (Fig. 5-3c). Thus, a series of isosceles triangles (two sides equal instead of three, as in an equilateral triangle) is formed. This is easier to layout than the hexagonal system but results in nine per cent fewer plants than the square or rectangular systems (Ray, 1999).

Quincunx or diagonal planting - This method of planting is a variation of the square system (Fig. 5-3c). An extra tree, often a temporary one, is set in the center of each square. In other words, the central tree is usually the filler, which is kept for a short period or till the main trees, develop to full canopy size. Filler plants are usually short-statured and early bearing. These plants are grown with the objective of generating income during the pre-bearing period of the main crop in the orchard. Generally, the quincunx planting system
increases returns per hectare considerably over the square system in the early years of the planting while the trees are still small. With this system of planting the center tree must be pulled out to give the full space to the permanent trees, when competition for space is becoming evident at the latter growth stage.

The total number of plants planted in quincunx planting system, as modified square system, is calculated as shown below (Singh, 2004):

Step 1: Calculate for square planting system using

\[
\text{Number of plants} = \frac{\text{Area in square meter}}{\text{Planting distance (m}^2\text{)}}
\]

For example, if the area given is one hectare (100 x 100 m = 10,000 m\(^2\)); and spacing is 10 x 10 m, the total number of plants required to cover one hectare of land, using the formula given above, will be:

\[
\text{Number of plants} = \frac{10,000 \text{ m}^2}{10 \times 10 \text{ m}} = 100 \text{ plants}
\]

Step 2: Calculate additional plants as follows:
Additional plants = (Number of rows lengthwise -1) x (Number of rows widthwise -1)

Considering the same information given above; total number of additional plants is given as: (10-1) x (10-1) = 81

Step 3: Calculate total number of plants by adding plants planted in square system of planting + additional plants planted in the center of square. Thus, the total number of plants required to cover one hectare of land, where they are planted at a spacing of 10 x 10 m is: 100 + 81 = 181

*Contour planting* - This system is used on rolling slopes or hillsides where some terracing may be needed (Fig. 5-3d). Terraces are embankments constructed on contour across the slope and are used to reduce the steepness
and length of slope and to intercept surface runoff and convey it to a stable outlet at a non-erosive velocity (Morgan, 1986). In contour type of planting system, considerable care must be taken to stop erosion by heavy rains or by irrigation through diverting the water to run along the tree rows rather than directly down slope. The contour line should therefore be designed and graded in such a way that water flows through the irrigation furrows at slower rate so that it is able to penetrate the soil but does not cause erosion. As contour lines travel across a hillside, they will be close together on the steeper parts of the hill and further apart on the gentle parts of the slope. Contour planting is followed just as is done in square system. The marking should be done from the lowest level to the top. The planting distance in the contour system may not be uniform (Singh, 2005).

Hedgerow planting - This system is basically the same as the rectangular system of layout. Here the fruit plants are spaced closely in rows. The variation in the pattern consists of two to three or five closely-spaced rows with a wide middle between rows. The spacing between the fruit trees or shrubs in the rows is usually kept much less (one-half to one-third the distance between rows) so as to look like a row of compact hedge (Ray, 1999). It is known to be best for dwarf deciduous trees and requires special pruning and training techniques (Fig. 5-3f). The primary advantages are high yield and low labour requirements per hectare.

There is now a growing interest in dwarf trees because this allows for high plant density per unit area and yield. The advantages of this are much higher early yields, and less expense in picking the fruit, and spraying and pruning the trees.

Plant distance within and between rows depends on several factors. The major ones may be described as follows:

The ultimate tree size of the species and cultivar at maturity - Dwarfed trees (e.g., spur type apple) will not get nearly as large as those of the strong-growing, vigorous type tree species and, therefore, can be planted much closer together.
The type of rootstock used - Fruit trees on the most invigorating rootstocks would need to be planted farther apart than those on the most dwarfing rootstocks.

Soil fertility - Here one must consider whether a planting site has a sandy, shallow, infertile soil, where the fruit trees would be slow-growing and never get very large or has it a deep, highly fertile clay loam, where the trees are likely to reach their maximum size. Wider spacing should therefore be given to fruit trees that are to be grown on fertile lands.

The planned tree density - This factor is under the grower’s control. In recent years, the so-called high-density orchard plantings, particularly with apples and to a lesser extent with citrus and pears, have become popular.

Generally greater spacing would be used with conditions of high soil fertility, long growing seasons, vigorous, large-size cultivars, invigorating rootstocks, ample rainfall or irrigation, and heavy use of fertilizers; spacing would be closer in the opposite situations.
Figure 5-3. Systems of planting. (a) Square planting (b) Rectangular planting (c) Triangular planting (d) Contour planting (e) Quincunx planting (f) Hedgerow planting
Source: Mitov et al. (1990); Rice et al. (1994).
Laying out the field and digging holes for planting

An important operation in the preparation of the planting site is the laying out of the field. Laying out an orchard on level land is a simple matter of establishing a straight baseline, usually next to a fence or roadway. Then, lines at right angles to the baseline are established at both ends of the plot and one or two places in the middle. The laying out operation consists of locating planting sites (or positions) on the field. Materials required for this purpose are ranging poles, measuring chains or tapes and pegs or stakes to mark the planting sites.

A baseline is adopted at one side of the block in which the planting sites are to be marked. Along this baseline, the various sites are marked at the appropriate distances required for the crop to be planted. To set out right angles in the field, a measuring tape, two ranging poles, pegs and three persons are required. The first person holds together, between thumb and finger, the zero mark and the 12 m mark of the tape. The second person holds between thumb and finger the 3 m mark of the tape and the third person holds the 8 m mark. When all sides of the tape are stretched, a
triangle with lengths of 3 m, 4 m, and 5 m is formed (Fig. 5-5), and the angle near person one is a right angle. Instead of 3 m, 4 m, and 5 m a multiple can be chosen: e.g., 6 m, 8 m, and 10 m or e.g., 9 m, 12 m, and 15 m.

Next, place stakes along the baseline and the right angle line for sighting to extend these lines. From this point on, any desired row and tree spacing can be established using a tape measure or knotted rope to measure off the proper intervals. If an auger is to be used, place a handful of lime to mark the spot where each tree is to be planted.

In laying out triangular planting system, a base line is set on one side of the field as in the square system. A large triangle with a ring in each corner is used. The sides of this triangle are equal to the distance to be kept of the plants in the orchard. Two of these rings are placed on the stakes of the base line. The position of the third ring indicates the position of the plant in the second row. This row is then used as a base line. The whole area is laid out in a similar manner (Bal, 2002).

Experienced workers can do quite well at placing a fruit plant in the appropriate location and planting it at the proper depth. However, when less
experienced workers are involved, the use of a planting board to ensure right position of the tree in the planting pit is advisable, at least until the workers become familiar with it. Since digging a hole for the tree means removing the stake used for layout, you may want to make a planting board for a guide. Planting board is a piece of plank about 1.52 m long, 20 cm wide and 2-3 cm thick having three V-shaped notches, one at the center and two notches at the two ends (Fig. 5-6). It is used for marking of pits (hole positions) and subsequent planting of seedlings, rooted cuttings, budded or grafted fruit plants.

The planting board is placed over the planting hole at the position of the tree with its central notch at the stake. Two pegs are driven in the ground at the notches at the two ends of the planting board. The board is then removed, leaving the two pegs in the ground. The hole, in which the tree is to be planted, should be large enough to allow the roots to extend naturally, or at least not to be twisted around each other. Depending mainly on the species/variety, and soil conditions, hole size of 0.6-1.0 m in both width and depth is fairly sufficient for most fruit plants. When holes are dug; topsoil should be placed in one pile and subsoil in another. The hole should then be refilled with a mixture of 50% topsoil and 50% well-decomposed manure, compost, or other decomposed organic matter. In soils where phosphorous is lacking, super phosphate should also be added as the hole is refilled. The hole should be allowed to settle for several weeks and then planting can begin. In some cases, however, when holes are left open for some time, a hard surface is formed, and that before planting, the walls of the hole should be scraped. It is therefore generally said that, the best time to dig the holes is when it is most convenient and economical.
Planting

In Ethiopia the most common season for planting of fruit plants is the start of the main rainy season as this allows for rapid establishment and vigorous growth. Thus, by the end of the rainy season the roots have spread to a considerable extent and frequent irrigation may not be necessary.

In preparation for field planting, bare-root plants must be kept cool and the roots must be kept moist and protected from the sun. When the bare-root trees arrive, they will be wrapped in banana leaves (where available), plastic, or some other moisture-conserving material (e.g., jute bags). After they are unwrapped, the roots should be immersed in water for a few hours before being planted.

In planting, some of the soil is removed from the previously prepared hole and a cone-shaped pile of soil is placed in the center. The root system is trimmed to remove damaged or diseased roots and is then spread in the hole. Roots should not be kinked or bent, but should be arranged as they would if grown naturally. In the case of budded or grafted plants, the bud or graft joint of the plant should not be allowed to come in contact with soil as there will be a tendency for the plant to develop roots from the scion portion (above the point of graft union) defeating the real purpose of grafting. The hole can then be refilled, taking care that air spaces do not remain around the roots by firming the soil at regular intervals during the operation. The plant should never be set lower in the field than it was in the nursery. As the soil has to settle, it is sensible to plant about 10 cm higher than the ground level (Samson, 1986). The last step is to prune off half to a third of the top shoots to compensate for the loss of roots, which occurred in the digging-up process. Failure to prune will result in weak growth during the first year and an increased incidence of plant death.

Container-grown plants should be removed from their pots (or polythene tubes) and any circling roots should be cut off. Soil is removed from the prepared holes and the plants are then set and covered to the same depth that they were growing in the container. Planting is carried out at the beginning of the rainy season.
The most critical period in the life of the orchard or vineyard is the first year after planting. During this time it is important that plants are not allowed to dry out and need to be protected and are kept free from insect and disease infestations.

Mulching is a beneficial practice both to prevent weed growth and to conserve soil moisture. Mulches can be of any organic material including dried grass, banana leaves, chopped plant refuse, and the like. To be most effective, mulches should be at least 10 cm thick and should be placed in area 1-3 m in diameter around the tree but not touching the trunk itself.

In budded or grafted fruit plants, it is always essential to remove the shoots which arise from the stock portion of the trunk below the bud or graft-joint. There is a necessity to fill gaps as some plants in large establishments may die during the first two years after transplanting. The gaps are filled up by planting fresh saplings of the same cultivar. This planting can be done preferably during the planting season. Staking (Provision of support), to protect young fruit plants from strong winds and allow them grow straight in upright position, is another important practice in early days of orchard establishment.

Fertilizer application program in fruit farms

A sustainable optimum yield of fruits depends, besides other factors, such as water and solar radiation, on the availability of essential elements and the content of organic matter in the soil. Soil fertility has a direct effect on all aspects of crop growth and development. Usually, fruits grown under low fertility conditions are slow to mature, have a greater tendency to develop abnormal shape, do not store well, and ripen irregularly after harvest. In some cases, postharvest disorders can be linked directly to the deficiency of a particular mineral, but often other environmental factors, such as water stress are involved. Generally, when the crop requirements are higher than the soil supplying capacity, nutrients are applied as manures or fertilizers or both.

Manures are plant and animal wastes that are used as sources of plant nutrients. They release nutrients after they get decomposed. Different
types of manures are known: Farmyard manure (FYM), compost, and green manure. Farmyard manure is the decomposed mixture of dung and urine of farm animals along with litter and left over material from roughages or fodder fed to the cattle.

Compost refers to a mass of rotted organic matter made from waste. The compost made from farm waste like straw, weeds, other orchard trash and other waste.

Green manure may be defined as green, undecomposed plant material used as manure. Green manures are obtained (i) by growing green manure crops or (ii) by collecting green leaf (along with twigs) from plants grown in wastelands, field bunds and forest (Reddy and Reddi, 2002).

If fertility status of the orchard soil is low, fruits should be supplied with proper nutrition. In this case, four important points deserve due considerations:

1. Determination of the type of fertilizer to be used: The specific need of a particular crop can be met out by a specific fertilizer. The selection of a suitable fertilizer depends largely on the essential element level of the soil with respect to the contents of the fertilizer, the essential element requirements of the crop, and the season of the year. These factors should be closely observed as wrongly selected fertilizers might greatly affect the uptake and utilization of nutrients by the plants.

The essential-element level of the soil - Very often, world soils vary in their capacity to supply essential elements. Thus, if the same crop is grown on different soils, though other factors are kept constant (temperature, moisture, light intensity, etc.), each soil may require different ratios of nutrients.

The essential-element requirements of the crop - Different fruit crops grown on the same soil also differ in fertilizer requirements. In other words, the nutrient requirements of crops vary with species, and even within the same species the requirement may differ from cultivar to cultivar.

The season of the year - Principal factors concerned are temperature and light. When other factors are favorable the temperature of the soil markedly influences the amount of available nitrogen. In general, if the soil
has been cold for a considerable period, the natural nitrate-nitrogen supply is likely to be low and artificial applications are necessary. On the other hand, if the soil has been warm for a considerable period, with other factors favorable, the natural nitrate-nitrogen supply is likely to be high.

2. Determination of time of fertilizer application: The absorption pattern of different nutrients by plants at their growth stages decides the time of fertilizer application. The time of fertilizer application is determined mainly based on the following two factors:

   The type of fertilizer to be used - Mobility of nutrients in the soil has considerable influence on availability of nutrients to plants. Less mobile types of fertilizers, such as phosphorus fertilizers (e.g., DAP) and organic fertilizers, are applied before planting or before active growth of plants has started; while fertilizers that contain readily soluble and available nutrients (e.g., nitrogenous fertilizers), should be applied when plants are actively growing. Because nitrogenous fertilizers are highly mobile and may be lost through volatilization and leaching if not utilized by plants application has to be in a split form so that plants can readily utilize them.

   Growth and development stage of the fruit plant - Nutrient requirement of crop differ significantly during different growth stages. Fruit trees, in general, require more nutrients at the emergence of new flushes and differentiation of floral buds. They also utilize the nutrients fast during the course of fruit development.

3. Determination of rate of fertilizer to be used: Different fruit crops need different quantities of nutrients. At the same time, soils differ in their capacity to provide plant nutrients to growing crops. Thus, for each fruit crop the quantities of nutrients which should be used to produce the best yields will depend on its specific requirements and on the resources of the soil. To achieve optimum fertilizer application of fruit plants, the following factors should be considered:

   The content of plant nutrients in the soil - This is determined by soil and/or leaf analysis. However, nitrogen content is not analyzed because of
high losses due to leaching or volatilization. Deficiency of some nutrients can also be visually judged based on symptoms observed on live plants in the field.

*Kind of the fruit species or cultivar* - The essential element requirements of different fruit species or cultivars grown on the same type of soil are known to be different. Some are light feeders (e.g., guava, pomegranate), while others are heavy feeders or demanding (e.g., banana).

*Age of the fruit plant* - The removal of different nutrients from the soil varies with the age of the fruit plant. Young plants at their juvenile stage require relatively less quantity fertilizer as compared to mature, fully developed, bearing fruit plants.

4. **Determination of method of fertilizer application:** Suitable method for a particular situation depends on the nature of the soil, crop and nature of fertilizer. For example, in soils low in phosphorus status, band placement of phosphatic fertilizer is reported to reduce fixation, while in soils of medium phosphorus status, incorporation of phosphorus fertilizer after broadcasting is better for higher availability. Understanding of the type of root system and spacing adopted for the crop; properties of fertilizers such as physical form, solubility and mobility, is also important for choosing convenient method for applying fertilizers (Gupta, 1999).

Various fertilizer application methods are followed in fruits' nutrition, depending mainly on the type and form (solid or liquid) of fertilizer, local conditions, and availability of resources. Generally, in fruit plantations, fertilizers may be applied by using any one or more of the following methods: *broadcasting, side dressing, ring application, foliar application* and *fertigation*.

In *broadcasting* the fertilizer (in solid state, either granular or dust) is spread over the entire soil area to be treated, with the main objective of distributing the whole quantity of fertilizer uniformly. Uniform distribution by this method makes nutrients more easily available especially to the fruit plants that are spaced closely. In broadcasting cost of operation is cheaper and less labor intensive. However, the method has limited importance for established
orchards as leaching loss of nutrients may be more.

*Side-dressing* is the application of fertilizers into the soil close to the plants (i.e., localized placement). In this method, fertilizers are spread around the base of the fruit trees, and the application is done once, twice or thrice a year, depending on the age of the fruit trees.

*Ring application* - In this method the fertilizers are applied in a ring encircling the trunk of the fruit trees extending the entire canopy. In any fruit tree, the growth of shoot and root is presumed to be proportionate, so is their spread (Chattopadhyay, 2003). On the basis of this assumption, it is thought that the roots have spread up to the area covered by the canopy of the trees, although it is not true in all the cases of fruit plants. Hence, the land area extending up to the canopy of a plant is thought to be the feeding zone of roots, and the nutrients are placed accordingly. The distance of ring to be prepared (i.e., for nutrient placement) from the tree trunk, varies with the species or variety, and age of the fruit tree.

*Foliar application* is a practice of spraying of leaves of growing plants with suitable fertilizer solutions. The solutions should be prepared in a low concentration (tolerable to the leaves) to supply any one plant nutrient or a combination of nutrients. This method also allows applying growth regulators, fungicides, and insecticides combined with fertilizer. Foliar spray of nutrients is recommended where the nutrients are required in small quantity, the cost of nutrient is high, the soil cannot retain the applied nutrient for reasonable period, the loss of nutrients by soil application is higher, the application is aimed at quick absorption and utilization of the same by the plants and the response is desired at a faster rate (Chattopadhyay, 2003). The nutrients are sprayed on the leaves in aqueous solution during the peak period of absorption in a diurnal rhythm. The foliar sprays may be done more than once, depending on the vigor and nature of the plant, growth rate, agro-ecological conditions, etc.

In citrus (Obreza *et al.*, 2008), for instance, a well-planned foliar nutrition program can supplement soil fertilizer applications especially when the citrus root system is unable to keep up with crop demand or when soil nutrients are unavailable. In some cases, a significant portion of nutritional
needs can be met with a foliar program. Foliar application is not intended to replace a soil-applied N-P-K fertilization program. However, some macronutrients can be foliarly applied at rates sufficient to influence young tree growth, yield, and fruit quality.

Foliar application can be used to help trees through short but critical periods of nutrient demand, such as bud differentiation, flowering, fruit set, and fruit development (Obreza et al., 2008). It is also useful when soil or environmental conditions are unfavorable for nutrient uptake by roots, such as cold weather, prolonged wet or dry soils, calcareous soil, or any other condition that decreases the ability of the tree to take up nutrients when there is a demand. Foliar spraying is particularly useful when a nutritional deficiency is diagnosed because it is the most rapid way to result in nutrient uptake by citrus trees.

Fertigation is the practice of direct application of liquid fertilizers through irrigation water. Fertilizers that are easily soluble in water are allowed to dissolve in the irrigation stream and carried into the soil in solution. In recent days, this method is followed in most developed countries on selected crops.

Advantages of fertigation (Obreza et al., 2008):

- Fertilizer is placed in the wetted area where the most active roots are located.
- Fertilizer may be applied more frequently in small amounts so that it is available when the tree needs it.
- Increased fertilizer application frequency can increase fertilizer efficiency and reduce leaching.
- Compared with conventional ground application, fertigation can produce similar or better tree growth, yield, and fruit quality with less fertilizer.

Disadvantages of fertigation:
• Fertilizer application uniformity and coverage depend on proper design, installation, and maintenance of the irrigation system.
• Extra equipment (injection device, tank, backflow prevention system) must be added to the irrigation system.
• Soluble fertilizers are more expensive than granular fertilizers on an equal nutrient basis.
• Fertilizers injected into an irrigation system may contribute to emitter plugging.
• Fertigation does not allow for variable rate fertilization based on tree size.

In some parts of Ethiopia, traditionally, organic fertilizers, such as farmyard manure, compost and other organic household refuses, are incorporated with irrigation water and are applied to the established fruit plants (e.g., bananas).

Irrigation

Irrigation can be defined as an artificial application of water for growing crops where or when rainfall is non-uniform or absent (spatially or temporally). In addition to absence or non-uniformity of rainfall, irrigation is required to grow crops under controlled environment (green house) or perennial crops (e.g., fruits).

Successful fruit growing requires, among other factors, adequate supply of water using rainfall and or irrigation. If the amount of rainfall is not adequate either in amount or distribution, a proper irrigation method should be adopted to obtain the maximum possible output at a reasonable cost.

One of the important factors for maximizing irrigation efficiency is determining the water requirements of fruit plants that vary widely with species/varieties, climatic factors (i.e., temperature, wind speed, radiation and humidity) that vary with seasons, soil conditions, and methods of application. Best results are obtained when water requirements of fruit crops grown in a given area and climate are determined first, and adequate amount of water is applied based on the soil moisture condition throughout the growing period. Irrigation should be so planned as to wet the root zone frequently (depending on the soil water holding capacity and daily water consumption) enough to
keep it from drying out and avoid moisture stress. If fruits are not supplied with sufficient water, the trees will not make normal growth, young fruits drop, and quality of mature fruits is inferior. Therefore, in choosing a site one must be sure that sufficient water will always be available.

Methods of application

The method of application is important; especially if the cost of water is high. Each method has its own advantages and disadvantages and it is difficult to propose one best irrigation method that fits for all areas and crops.

A large number of considerations must be taken into account in the selection of an irrigation system. These will vary from location to location, crop to crop, year to year, and farmer to farmer. In general, criteria like crop type, soil (texture), water supply (quantity, quality), topography, climatologic conditions, availability and reliability of energy (manual labor), available technology, compatibility of the system with other operations, economical and social considerations can be considered in choosing the appropriate method of irrigation (Brouwer et al., 1985; Key, 1986; Walker and Skogerboe, 1987; Walker, 1989; Chandrasekaran et al., 2010). Some of these considerations are discussed below.

Compatibility - The irrigation system for a field or a farm must function alongside other farm operations such as land preparation, cultivation, and harvesting. The use of large mechanized equipment requires longer and wider fields. The irrigation systems must not interfere with these operations and may need to be portable or function primarily outside the crop boundaries (i.e., surface irrigation systems). Smaller equipment or animal-powered cultivating equipment is more suitable for small fields and more permanent irrigation facilities.

Economics - Pressurized systems have high capital and operating costs but may utilize minimal labor and conserve water. Their use tends toward high value cropping patterns. Systems like surface irrigation are relatively less
expensive to construct and operate but have high labor requirements. Some systems are limited by the type of soil or the topography. The costs of maintenance and expected life of rehabilitation along with costs like energy, water, depreciation, land preparation, maintenance, labor and taxes should be included in the selection of an irrigation system. Additionally, availability (cost) of energy or skilled personnel to manage/operate a given irrigation system need to be considered in selecting irrigation method.

Topography - Topography is a major factor affecting irrigation, particularly surface irrigation. The main concerns are the location and elevation of the water supply relative to the field to be irrigated, the area and configuration of the fields, and access by roads, utility lines, etc. Field slope and its uniformity are two of the most important topographical factors. Surface systems, for instance, require uniform grades in the 0-5% range.

Soils - The soil's moisture-holding capacity, intake rate and depth are the principal criteria affecting the type of system selected. Sandy soils typically have high intake rates and low soil moisture storage capacities and may require an entirely different irrigation strategy than the deep clay soil with low infiltration rates but high moisture-holding capacities. Sandy soil requires more frequent, smaller applications of water whereas clay soils can be irrigated less frequently and to a larger depth. The distribution of soils may vary widely over a field and may be an important limitation on some methods of applying irrigation water.

Water supply - The quantity and quality of the source of water can have a significant impact on the irrigation practices. A water supply with a relatively small discharge is best utilized in an irrigation system which incorporates frequent applications. The depths applied per irrigation would tend to be smaller under these systems than under systems having a large discharge which is available less frequently. The quality of water affects decisions similarly. Salinity is generally the most significant problem but other elements like boron or selenium can be important. A poor quality water supply must
be utilized more frequently and in larger amounts than one of good quality.

**Crops** - Irrigation systems create different environmental conditions such as humidity, temperature, and soil aeration. Some crops have high economic value and allow the application of more capital-intensive practices. Deep-rooted crops are more amenable to low-frequency, high-application rate systems than shallow-rooted crops.

**Social influences** - Irrigation often means a technological intervention in the agricultural system even if irrigation has been practiced locally for generations. New technologies mean new operation and maintenance practices. If the community is not sufficiently adaptable to change, some irrigation systems will not succeed.

Generally the methods of irrigation can be classified into two: surface and pressurized systems. The surface irrigation systems can further be classified into flooding (wild and controlled), basin, border and furrow irrigation systems. The pressurized system can be further classified into sprinkler and drip systems. Another classification of irrigation system is the one that is known as: subsurface which can be gravity system or pressurized (sub-surface drip). The following include common methods of irrigation in orchards:

**Flood irrigation** - As the name implies irrigation is done by flooding the whole area and allowing the water to stand for two or three days to wet the entire field. Since standing water is present at least to a small depth, spreading of water is easy. There is no much land preparation and labor requirement for irrigation is minimal in this method. It is used where the landscape is graded and level. The method is said to be useful where intercrops or green manuring crops are grown in an orchard. However, the method has various disadvantages; wastage of water is more and it provides favorable condition for weed growth. In addition, the method may cause suffocation to the root system of fruit plants, which consequently exposes fruits to some diseases (e.g., foot rot). In spite of all these drawbacks, in
Ethiopia, the method is still followed in some orchards.

Generally, flood irrigation is well suited to mature orchards where the root zones are widely dispersed and the orchard is almost completely canopied. It assures better distribution than sprinklers whose patterns might be disrupted by trees, and gives a more uniform wetted area than can be realistically accomplished by drip emitters.

**Basin irrigation** - In this type of irrigation, water is applied to each fruit plant using a circular/ring basin (or occasionally square in shape), made around the trunk (Fig. 5-7). The basins are small when the trees are young and their size is increased with age of the trees. These basins are connected directly with one another through straight channel. There is less wastage of water and it checks weed growth. It is commonly practiced to irrigate young trees and is changed into furrow or check irrigation methods when the trees get bigger. Basin method is almost similar to check basin method except that in the latter method entire space is irrigated while in basin method only the basins around the trees are irrigated. The level of the soil near the trunk of the tree should be kept slightly higher than the level of the basin to prevent water from touching the trunk of the tree, as this may cause some bark diseases.

![Basin irrigation](image)

**Figure 5-7.** Basin irrigation (later changed into furrow irrigation when trees are well established). X represents the plant (A). Basin irrigation (ring basin) in an orchard (B).

Source: Jackson *et al.* (1985); Chandrasekaran *et al.* (2010)
The fields are usually level. Irrigation is done by filling the basin with water to some depth which is greater than the required depth to fill the root zone and left until it infiltrates. The bunds that surround the basins prevent water from flowing to the adjacent fields. Size of the basin depends on soil texture, stream size, irrigation depth and field slope.

Table 5-1. Basin size (ha) for different stream size and soil types.

<table>
<thead>
<tr>
<th>Stream size (l/s)</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
</tr>
<tr>
<td>15</td>
<td>0.01</td>
</tr>
<tr>
<td>30</td>
<td>0.02</td>
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<tr>
<td>120</td>
<td>0.08</td>
</tr>
<tr>
<td>150</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Check method (modified basin)** - The check method of irrigation is an improvement over the basin type. In this method, in between two rows of trees an irrigation channel is prepared. The channel is then connected through square or rectangular shaped beds. The checks, modified basins, contain one or more trees, and each time the land is irrigated, a basin must be formed by inclosing the space about them with a ridge sufficiently high and well made up to retain the water applied. The size of the basin is increased with the extension of a leaf drip (canopy) of each tree every year. The advantages of this method are that water can be applied uniformly. Generally, this method gives better results on porous soils than furrow system, and is commonly followed in the arid areas where irrigation water is in short supply. The only drawback of this method is that it needs more labour in preparing the surface to receive the water, in distributing it, and in getting the soil leveled and in tillage condition after the work of irrigation is completed.

**Furrow irrigation** - Furrow irrigation is a modification of flood irrigation and is confined to furrows rather than wide checks (Fig. 5-8). When fruits are
irrigated by this method, several furrows (commonly 2-4) for carrying water are made down the middle spaces between tree furrows. The number of rows, in between row space, varies with the size of the trees (usually influenced by species and variety), as well as with their age.

Water is used more efficiently with furrows than with flooding because the entire surface is not wetted, thus reducing evaporation losses. Water infiltrates into the soil and spreads laterally as it flows through the furrows in small streams. Furrow length depends on soil texture and stream size. The length ranges from 30 to 300 m (Reddy and Reddi, 2003). Long furrows cause greater loss of water because of deep percolation and excessive soil erosion at the head of the field. Lack of careful land preparation and maintenance of channels in furrow irrigation of crops may cause one end of the crop furrow to be over-irrigated and the other end under-irrigated.

The depth of the furrow should be such that the water can be controlled. Water should flow in the furrow for sufficient time to let it percolate across the bed, wetting the surface but not leaving the plant standing in water (Muya et al., 2009). The flow of water should be regulated so as to control its very gradual seepage into the sides and bottom of the furrows. For most fruit trees, furrows of 20 to 30 cm deep and 60 cm wide provide better use of irrigation water (Singh, 2004).

Figure 5-8. Furrow.
Source: Brouwer et al. (1985)
Furrows can be used on most soil types. However, as with all surface irrigation methods, very coarse sands are not recommended as percolation losses can be high (Brouwer et al., 1985). Soils that crust easily are especially suited to furrow irrigation because the water does not flow over the ridge, and so the soil in which the plants grow remains friable.

Design parameters of furrow irrigation

a) Shape and spacing of furrows: heights of ridges can vary between 15 cm and 40 cm and depends on stream size. The distance between the ridges should be based on crop spacing, adequate lateral wetting, and track of mechanical equipment. The shape of furrows is influenced by the soil type and the stream size.

In sandy soils, water moves faster vertically than sideways (lateral), narrow, deep V-shaped furrows (Fig. 5-9) are desirable to reduce the soil area through which water percolates. However, sandy soils are less stable, and tend to collapse, which may reduce the irrigation efficiency. In clay soils, there is much more lateral movement of water and the infiltration rate is much less than for sandy soils. Thus a wide, shallow furrow (Fig. 5-10) is desirable to obtain a large wetted area to encourage infiltration (Brouwer et al., 1985). The larger the stream size the larger the furrow must be to contain the flow.

Figure 5-9. A deep, narrow furrow on a sandy soil.
b) Selection of the advance/initial furrow stream: In permeable soils, the maximum non-erosive flow should be selected which can wet the end of the furrow as soon as possible. The maximum non-erosive flow ($Q_m$) is given by:

$$Q_m = \frac{c}{S}$$

where $c$ is a constant = 0.6 ; $Q_m$ is in L/s and $S$ is slope in %. The actual stream size should be determined by field tests. It is recommended if the initial stream size reaches the end of the furrow in $T/4$ time where $T$ is the total time required to apply the required irrigation depth. Normally stream sizes up to 0.5 L/sec can provide an adequate irrigation provided the furrows are not too long. When larger stream sizes are available, water will move rapidly down the furrows and so generally furrows can be longer. The maximum stream size that will not cause erosion will obviously depend on the furrow slope. In any case, it is advised not to use stream sizes larger than 3.0 L/sec.

c) Cut-back stream: It is recommended to cut the initial stream (discharge) to a safe discharge after it has reached the lower end of the field to reduce soil erosion. Cut back stream is the stream size to which the initial stream is reduced. One or two cutbacks can be carried out, removing some siphons or reducing the size at the head of the furrow.

d) Field slope: Longitudinal and cross slopes should be adapted to the natural topography to reduce costs of land grading. Usually small cross slopes can be tolerated and furrows should have a limited slope to reduce erosion.
minimum of 0.05% required to ensure surface drainage. Uniform flat or gentle slopes are preferred for furrow irrigation. These should not exceed 0.5%. Usually a gentle furrow slope is provided up to 0.05% to assist drainage following irrigation or excessive rainfall with high intensity. On undulating land furrows should follow the land contours. However, this can be a difficult operation requiring very careful setting out of the contours before cutting the furrows.

e) **Furrow length:** Furrows must be on consonance with the slope, the soil type, the stream size, the irrigation depth, the cultivation practice and the field length. Very long furrow will result in deep percolation (over-irrigation) at the upper end and under-irrigation at the lower end. The length of furrow should be selected based on field tests (texture, application depth, and slope). In sandy soils water infiltrates rapidly. Furrows should be short, so that water will reach the downstream end without excessive percolation losses. In clay soils, the infiltration rate is much lower than in sandy soils. Furrows can be much longer on clayey than on sandy soils. If the application depth (water to be stored) is small, short furrows are recommended. Applying larger irrigation depths usually means that furrows can be longer as there is more time available for water to flow down the furrows and infiltrate. Typical furrow lengths for various soil types and slopes are given in Table 5-2.

f) **Field width and length:** It may be more practical to make the furrow length equal to the length of the field, instead of the ideal length, when this would result in a small piece of land left over. Equally the length of field may be much less than the maximum furrow length. This is not usually a problem and furrow lengths are made to fit the field boundaries.

When the farming is mechanized, furrows should be made as long as possible to facilitate the work. Short furrows require a lot of attention as the flow must be changed frequently from one furrow to the next. However, short furrows can usually be irrigated more efficiently than long ones as it is much easier to keep the percolation losses low.
Table 5-2. Typical furrow lengths for various soil types and slopes

<table>
<thead>
<tr>
<th>Soil type</th>
<th>D (mm)</th>
<th>0.25</th>
<th>0.50</th>
<th>1.00</th>
<th>1.50</th>
<th>2.00</th>
<th>3.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>50</td>
<td>150</td>
<td>120</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>100</td>
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<td>60</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>260</td>
<td>180</td>
<td>120</td>
<td>120</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Medium</td>
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Sprinkler irrigation - In this method, water is applied as a spray or as rain drops. The water is pumped with pressure through the sprinklers attached to pipes and these sprinklers are adjusted in such a manner to overlap up to one-fourth area covered by the other sprinklers. These are then moved to the next point after sufficient percolation has taken place. To achieve uniform sprinkling of water, it is necessary to overlap the area of influence/water spread of each of the sprinklers.

Sprinkler irrigation is especially suitable for steep slopes and rolling topography where application of water using other surface irrigation methods is difficult. Sprinkler method of irrigation offers several advantages (Reddy and Reddi, 2003):

- Saving of water ranges from 25 to 50% for different crops.
- When water is applied like rain, there is little or no puddling effect on the soil (The real effect depends on the discharge from each sprinkler and the infiltration capacity of the soil).
- As the application rate is less than intake rate of soil, surface runoff does not occur.
- The use of sprinkler method of irrigation is suitable in sandy soils; and also in shallow soils where land leveling is not possible.
• Fertilizers, pesticides, herbicides, etc., can be applied along with irrigation water.

Generally, less labour is needed with sprinklers than either flood or furrow irrigation but the equipment and energy costs are higher. Some disadvantages of this irrigation method include: (i) difficulty to efficiently/evenly apply water under high wind velocity, (ii) unsuitability for areas which are hot, dry and windy as considerable amount of water is lost in the form of evaporation, (iii) high initial equipment cost, and also high power requirement for pumping water.

**Drip or trickle irrigation** is the latest development in irrigation systems. Small amounts of water are allowed to trickle/drip slowly into the soil through mechanical devices called *emitters*, wetting the soil around the tree without creating runoff (Brouwer *et al.*, 1985). Emitters are connected to a small plastic lateral tube, laid either on the soil surface or buried just beneath it for protection. The lateral lines are connected to a buried main line that receives water from a head source. The head source is the control station for the system. Here the water is filtered, can be treated with fertilizers, and regulated for pressure and timing of application.

Drip or trickle irrigation refers to the frequent application of small quantities of water at low flow rates and pressures. Rather than irrigating the entire field surface, as with sprinklers, drip irrigation is capable of delivering water precisely at the plant where nearly all of the water can be used for plant growth. Because very little water spreads to the soil between the crop rows, little water is wasted in supporting surface evaporation or weed growth. The uniformity of application is not affected by wind because the water is applied at or below the ground surface.

Drip irrigation can be an extremely versatile production tool in horticultural enterprises. It can stretch a limited water supply to cover up to 25 per cent more acreage than a typical sprinkler system. It can reduce the incidence of many fungal diseases by reducing humidity in the crop canopy and keeping foliage dry. It allows automation of the irrigation system, reducing labor requirements. It delays the onset of salinity problems when
irrigation water of marginal quality must be used.

Drip irrigation requires careful water treatment to prevent emitter blockage problems. Frequent inspection of the system is necessary to insure it is functioning properly. Improper design and component sizing can result in a system with poor uniformity of application and a much lower than expected application efficiency. A properly designed and installed drip irrigation system will normally be substantially more expensive than a sprinkler irrigation system initially. However, the lower operating cost and higher efficiency of the drip system can justify the added expense very quickly in many horticultural production systems. Some advantages of drip irrigation are:

- smaller lines than for sprinkler or furrow irrigation;
- little interference with orchard cultural operations because much of the soil surface is not wetted;
- less fluctuation of soil moisture because of the constant and slow drip application of water; and
- less water needed to grow a crop.

Some disadvantages of the drip irrigation are:

- the expensive filtration equipment needed because emitters clog frequently;
- uneven water distribution on hilly land - more water from lower emitters; less from higher ones;
- salts tend to concentrate on the soil surface because little water is moving downward to keep them washed from the root zone; and
- the foraging ability of roots is restricted to the small volume of wetted soil.

Pest management in orchards

Various pests such as weeds, diseases, insects, and vertebrates (e.g., birds, rodents and wild animals) attack and cause serious damage to both the plant and the useable parts like the fruits. Fenemore and Prakash (1992) have reported that effective pest control may be described as reduction or
maintenance of a pest population below the economic threshold level. A complete eradication or control of a given pest is seldom possible except for the swarming pests (e.g., locusts, armyworm, etc.) and exotic pests, which require to be eradicated as soon as they are observed. The strategy is, therefore, to manage them to a level below they cause economic yield loss. Hence, the term pest management is preferred to pest control.

**Weed management**

Weeds compete for nutrients, water, light, carbon dioxide and space leading to lower yields and quality of fruit crops. Weeds may also harbor pests and diseases, which attack the crop, detract from their appearance and increase postharvest spoilage incidence. In addition, weeds can cause inconvenience to various orchard/vineyard operations. In dry seasons, weeds die and ignite a serious fire hazard. At times, they can also harbor rodents like rats and mice that damage tree trunks especially when food is scarce. In well-managed orchards where irrigation water is scarce or expensive, weeds should be carefully controlled.

At the early stages of newly established fruit crops, weeds often cause more losses than insects or plant diseases. Subsequent weed control measures should be taken at the initial stages of orchards to improve growth, development and thereby increase yield at maturity/harvest stages. Fruit crops take longer period of time to cover the ground before sufficiently reduce weed infestation. Hence frequent and periodic weed management over an extended period is required for the growth and development of the fruit crops.

Weed control measures are categorized into cultural, physical, chemical and biological methods. Every weed control method has its own advantages and disadvantages. A single weed control method alone cannot achieve a complete control of weeds under all weed situations. Therefore, the weed control program should be designed in an integrated way to keep weed population below economic threshold level where there will not be significant weed competition between weeds and the fruit crops. Principal weed control methods include the following:
Cultural weed control method - Various cultural weed control methods such as tillage, irrigation, fertilizer application, intercropping, etc., when appropriately followed in orchards help to suppress and control weeds. Growing annual crops preferably legumes between rows in fruit crops provide good cover to suppress weeds and simultaneously improve soil fertility with their root nodules is advisable. This approach has the advantage on fruit crops/plants to compete weeds and reduce their growth. Cultural weed control method alone cannot achieve complete control of weeds, but reduces weed population to below economic threshold level.

Physical weed control method - Weeds are pulled out or killed by physical forces like hand weeding, hoeing, digging, mowing and slashing. Similarly, animal and mechanical power tractions in inter-cultivation operations are also important components of physical weed control method. Hand weeding is effective against annuals and biennials while controls only the upper portions of the perennial weeds. Where labor is not expensive, weeds can be controlled by slashing periodically with machetes or cutlasses. Tidy and clean weeding practices may not be recommended in orchards because erosion and consequently depletion of organic matter in the soil will be enhanced.

Some orchards are managed by a sod culture system allowing grasses grow low to cover the orchard floor. Sod culture system is mainly practiced on sloppy hillsides where soil erosion is a problem and water supply is in excess to support both grasses and fruit trees. Sod culture system should only be considered for mature orchards, once the allotted space is fully covered by the fruit trees shade. Rootstock and soil type should also be taken into consideration while selecting this option as dwarf rootstocks are more influenced by weed competition and light soils with low nutrients and poor soil moisture retention. Extra nitrogen and perhaps potassium must be added to the soil to compensate for whatever nutrient the grasses have utilized. Sod culture system of course incurs additional fertilizer costs, costs of mowing grasses, and possibly costs of irrigation.

Chemical weed control method - Different organic and inorganic compounds,
toxic by nature are used in weed control. These chemical products are called herbicides/weedicides, classified into four general categories based on their mode of translocation and selectivity: contact, systemic, contact non-selective, and systemic non-selective.

**Contact herbicides** kill plant tissues by contact at or near to the point of application rather than their translocation. Hence they need thorough distribution over the surface of the plant to kill the tissues in the buds and leaves. Contact herbicides applied on the foliage of a plant do not kill roots, but roots of simple annual weeds may die due to deprived shoots.

Contact herbicides are either selective or non-selective depending mainly on their differential wetting ability and cuticle structural differences, leaf arrangement, and bud location of weeds.

**Non-selective contact herbicides** indiscriminately kill all vegetations on contact.

**Systemic** or translocated herbicides enter the plant system and move into the vascular tissues. A translocated herbicide treatment, after entry, is capable of moving within the plant system to exert herbicidal effects away from the site of application above ground or underground parts of the plant. Selectivity of herbicides depends on some specific features of the enzymatic differences in the plant systems.

Trans-located (systemic) herbicides moves within the plant system from the site of application to its other parts, in variable amounts. It often kills the entire plant when even only a portion of the plant part was treated with the herbicide. Consequently, the trans-located herbicides are of particular significance in controlling perennial weeds. 2,4-D is a selective systemic herbicide commonly used to kill broad-leaved weeds, while Glyphosate is a non-selective systemic herbicide which indiscriminately kills vegetation at its disposal.

A particular herbicide application within each herbicide group on a particular crop at a given time depends on the type of weed flora, nature and level of weed infestation, soil type, rainfall and temperature. Closely related crops to some weed flora makes weed control difficult using selective herbicides where their effect will be equally harmful to the crops similar to that of the weeds which are supposedly to be controlled.
In developing countries, like Ethiopia, where machinery and chemicals in the control of weeds are limited, but where labor is available, weeds can easily be controlled pulling by hand and destroying with simple tools.

**Quarantine** - This is a weed control system adopted to avoid the introduction of weeds and weed seeds into new and clean areas. Plant quarantine measures offer the best and most economical protection against weeds and other pests like fungi, bacteria, viruses, nematodes, insects etc. before they get established to new and clean areas. Not a single weed control method per se can be successful without adequate preventive measures taken ahead of time to reduce weed infestation. Quarantine is a long term planning where weeds could be controlled or managed more effectively and economically ahead of their dispersal to infest new areas.

**Biological weed control method** - Reduction of weed infestation by direct or indirect use of biological entities such as plants, parasites, predators and pathogens. However, efficiency of this method for large scale weed control is not feasible.

Success on weed management could be achieved when various weed control methods are utilized on an integrated approach. Integrated weed control management by virtue of its nature integrates or allows different weed control methods complementing each other to achieve a complete control.

**Plant diseases management**

A plant disease causes abnormal physiological and biochemical processes on plant to become weak and finally lead to death.

Fruit crops are subject to a wide array of plant diseases. Plant diseases are caused by infectious and virulent pathogens such as bacteria, fungi, viruses, and mycoplasma-like organisms. The majority of fruit crops are susceptible to one or more of these pathogens, whereas some of them are susceptible to many of the pathogens.

Fruit disease causing bacteria are spread by rain splashes windblown
dust, birds, and insects. Unintentionally, people spread bacterial diseases from pruned infected orchard trees during the rainy season. Water easily facilitates the entrance of bacteria from pruning cuts into the next pruning cuts. Propagation of bacteria-infected planting material is a major way for pathogenic bacteria dispersal to over greater distances.

Control of bacterial diseases in fruit crops are difficult once contracted. However, use of resistant species or cultivars, bacteria-free seeds, eliminating/removing bacterial contaminated sources, preventing /avoiding surface wounds that permit the entrance of bacteria into the inner tissues, and propagating only bacteria-free nursery stock could be remedies to alleviate bacterial attack on fruit crops. Exposure to prolonged dry air, heat, and sunlight can sometimes kill bacteria in infected plant materials. Antibiotic treatments can also serve to kill bacteria in infected fruit crops.

Fungal diseases are generally easier to control than bacterial or viral diseases in fruit crops. The most satisfactory method to control fungal diseases is to follow strict sanitary measures by eliminating the pathogenic organisms from the propagating planting materials.

Fungal disease management measures include:

- Planting of only fungal disease-free, planting materials and certified seeds;
- Planting of only fungal resistant species and cultivars;
- Fungicidal seed treatments;
- Preventive and curative Fungicidal foliage sprays like in downy and powdery mildews of grape;
- Maintaining good soil drainage (e.g., in controlling damping off);
- Growing crops under unsuitable climatic conditions for pathogenic fungi (geographic isolation);
- Careful harvesting and proper handling of fruits to be free from cuts and bruises during harvest and transit;
- Storing fruits at an ideal temperature;
- Treating fruits with fungicides at postharvest time;
- Using biological control agents antagonistic to the fungal pathogen.
Viruses are pathogenic living things that infect most fruit crops. Several economically important viral and viral-like diseases in the tropical, sub-tropical and temperate regions are transmitted by insect pests. Among the important viral transmitting insect vectors are whiteflies, aphids, leaf hoppers, thrips and from the acarides, mites are also important. The activity of humans in propagating fruit plants by budding and grafting or by cuttings is not uncommon in the transmission of viral diseases to healthy fruit crops.

No chemical sprays are so far reported that control viral diseases. However, quite a number of insecticides and miticides are available that control viral transmitting vectors. Use of viral-free planting material is alternate option to curtail viral transmission in orchards to begin with. Another successful way to eliminate/avoid viral diseases is to excise the minute shoot tip of vigorously growing plants under aseptic conditions (tissue culture) and then allow the tip to develop into a new plant on a nutrient medium. The new plant developed by tissue culture will be free of viral disease. This is called a clone free of viral disease ultimately ready for propagation on new orchard field.

Mycoplasma-like organisms - The mycoplasma-like organisms in plants are small parasitic organisms intermediate in size between viruses and bacteria. Similar to viral diseases, diseases causing mycoplasma-like organisms are transmitted by insect vectors such as leafhoppers and aphids.

The method of controlling the spread of these diseases is an effective insecticide spray program against insect vectors. Though expensive, mycoplasma-like organisms can be controlled by using antibiotics, particularly tetracycline, which has been used to treat pear trees with the pear decline disease (Rice et al., 1994).

Nematode management

Plant-parasitic nematodes feed on root tips and feeder roots to cause severe damage. Nematode-infected roots are weak to supply water and nutrients to their respective mother plants. Consequently, infected plants cannot stand
stresses such as heat, drought, and nutritional deficiencies (Halbrendt, 2003). Parasitic nematodes are readily spread by movement of soil particles during plowing, movement of agricultural equipment from place to place, tools, shoes, birds, insects, dust, wind, and water. Movement of nematode-infected plants or plant parts also play a great role in the spread of parasitic nematodes to new orchard areas. Parasitic nematode problems in established orchards are difficult to control once retained. Hence, focus should be given on good management practices including preventive measures such as sanitation and good cultural practices (Halbrendt, 2003) prior to establishment of new orchards.

Methods that reduce crop losses from nematodes:

- Use and grow only nematode resistant species and cultivars;
- Use and grow only nematode-free nursery stock for planting;
- Avoid importing planting materials with roots having soil from nematode infected areas;
- Treat nursery with fumigant to control parasitic nematodes prior to planting. This method is commonly used at nursery level, because it is to use fumigants under permanent field condition;
- Use nematicides carefully to prevent injury or kill to the plants by avoiding close contact to the root zone of the fruit crops;
- Use crop rotation practice with short term perennial fruit crops to reduce and control certain nematodes.

Insect pest management

Insect pests may be classified according to the way they feed on plants in two groups (Edmond, 1983): (1) those with biting mouth parts and (2) those with sucking and/or rasping mouth parts.

*Insects with biting mouth parts* are classified according to the part of the plant they feed on and type of damage they cause. They form four more or less distinct groups:

*Stem and leaf eaters* - reduce the amount of leaf assimilative tissues
(chlorophyll) and hinder plant growth. Some of the examples include the caterpillars of certain butterflies and moths, cutworm, apple-tree tent caterpillar, grasshoppers, leaf miners, etc.

**Root feeders** - attack roots and cause loss of water and nutrient absorbing tissues. The strawberry rootworm and chafer larvae are typical examples of such group of insects.

**Stem borers** - Tunnel in the stem and interrupt sap flow, often destroying the apical part of the plant; these are stem borers like peach and apple tree borers.

**Feeders on fleshy fruits, seed, and storage organs** - cause pre-mature fruit falls; attack flowers and reduce fruit production; remove stored food from fruits and nuts with more of unmarketable and damaged fruits yield at harvest. Typical examples are mango fruit fly, Mediterranean fruit fly on citrus and larvae of fruit flies on guava.

**Insects with sucking or rasping mouth parts** pierce the epidermis, suck the tiny chloroplasts, soluble foods, and vitamins from the leaves or the succulent parts of the plant. Consequently, plants remain incapable of synthesizing their own food to support themselves. In due course, plants get weak and become susceptible to any external factors like diseases and drought. Examples of insects with sucking and rasping mouthparts are aphids, thrips, scales and mealy bugs.

**Management measures**

There is a large number of different methods of pest or disease control available to the crop protectionist or horticulturist, but careful deliberations is required in making a choice of methods. Generally, it is more useful from a pest point of view to regard control measures according to their basic nature as follows:

**Biological control systems** - sometimes referred to natural control system. It includes the following:
Predators: mammalian (man), aves, reptilia, arachnida, acarina, and insecta are the major predators. However, few predators are quite host specific. By and large, the majority of the predators are not particularly confined to any specific host. They are more of generalist on their nature of predation. The common example is the lady bird beetle hovering on aphids.

Parasitoides: these are almost entirely other insects and belong to two large groups (Diptera and Hymenoptera), and are small groups of Strepsiptera, together with a few species of entomophilic nematodes.

Pathogens: control by pathogens is sometimes referred to as microbial control. There are three main groups concerned: bacteria, fungi and viruses.

Rearing and sterilization: this usually refers to the sterilization of male by X-rays or gamma-rays and is called the sterile-male technique and control by this technique is termed autocide. Sterilization could be effected by exposure to various chemicals and this practice is called chemo-sterilization. Massive numbers of sterile male insects are released to give minimum or no hatch at all of offspring. Consequently, insect population declines with repeated male sterile release to reach finally below an economic threshold level.

Tolerant/resistant fruit crop varieties: use of tolerant/resistant plant species or cultivars to insects' attack is getting popular, especially on permanent fruit crops against pest attack.

Chemical pesticides - are the chief weapons for protecting plants and conserving plant products against pests. Only rarely does chemical application kill all the pests and the few which they survive usually soon give serious problems by the development of resistance. Chemical control is essentially repetitive in nature and has to be applied a new one with each pest out-break. However, this method is quick in action for the majority of pest outbreaks. Chemical control remains the method by which the surest and most predictable results are obtained. Mode of action of pesticides used to control
insects and mites are repellant and antifeedant fumigants, stomach poison, residual poison, ephemeral contact poison and systemic poison. Pesticides have their own merits in the control of pests when judiciously utilized. However, they may have negative impacts on the environment and non-target pests and at times even enhance resistance development that no more control by chemical pesticides is possible when utilized injudiciously.

**Vertebrates**

Birds and higher animals like apes, and monkeys are often serious pests in orchards. Rodents such as, mole rat, house mice etc. also cause great damage/losses to fruits, both on live plants and their produces. Tunnels made in the field by mole rats can cause trouble in fruit orchards by seriously damaging the roots of fruit crops.

Young fruit trees and planted seeds in nurseries are usually damaged by mice, rabbits and other wild animals. Rabbits commonly feed on bark and completely girdle fruit trees (e.g., apple trees). Unless bridge grafting is done promptly, even large trees may be killed.

Rodent control can be achieved by removing all food and water sources from the areas where they stay and, place bait traps in their way to kill them.

Birds as pests constitute a significant limitation to the productivity (Bruggers *et al.*, 1998) and quality of fruits. Certain birds are major threats to some fruit crops, such as grapes, strawberries, guavas, papayas, peaches and plums. Some birds cause tremendous damage by eating the ripe and half-ripe fruits. Bird damage is not only limited to yield loss, but in the case of wine grapes, the damage is also reflected on loss of wine quality (Loinger *et al.*, 1977).

In Ethiopia, traditionally, birds and other vertebrate pests are kept away from eating fruits by using *scarecrows*. Scarecrows hung on locally available wooden poles at several locations in the orchard. Visual scare devices (scarecrows) be changed regularly so birds will not be used to and realize that they are harmless. Change of locations, colors, and types of
scarecrows used enhance the effectiveness of control.

Noise devices are also available. Hanging bells on poles in a scattered manner all over the orchard and ringing those occasionally by pulling rope from ground, where the other ends are tied to the bells is also an effective control method. Affordable bells may be prepared from old and damaged kerosene tins. The tins may be hung with their open ends facing downwards. For ringing purposes, suitable objects like iron rods should be attached to the inside of a tin with rope (or wire) passing through the hole made at the other side of the tin. The most commonly used protective method in our country is the use of guards who make sound from time to time, and throw a ball of soil whenever they see birds coming to orchard.

Another non-destructive method of keeping birds from eating the fruits in vineyards and orchards is amplified recordings of birds distress calls played at intervals during the day at fruit maturity and/or harvest time. However, all of the above mentioned devices for bird damage protection are of limited value. Still bird damage could continue with all the protection measures are on place.

Other vertebrate wildlife, such as monkeys and apes, also cause serious damage to some fruit crops. Alert guards are required to protect fruits from the attack of such wild animals because the damage they cause at one moment is immense.

Protection from adverse weather conditions

Frost - Extremes of temperature are the most common sources of damage. Orchards in hollow or low area, surrounded by higher land may be damaged by frost in winter or late spring. In the case of some fruits, like the citrus fruits, the fruits may be injured. Damage to the foliage, and even the wood, also occurs.

The most common type of frost is that which occurs on clear calm nights, when much heat is lost by radiation. “Temperature inversion” occurs, there being a layer of warmer air above the layer of cold air near the ground. The period of lowest temperature is ordinarily very short, just before dawn.
The severity of the damage caused by frost depends not only on actual temperature, and the duration of the frost, but also on the condition of the plants. Young plants are more susceptible to damage than old ones, and new growth is more likely to be injured than that which has had time to mature.

A gentle slope with low-lying land at its base, to which the colder air may drain, is desirable. Therefore, it is very important to select orchard site at an elevation a little higher than surrounding land so as to ensure good air drainage through and away from the orchard.

Protection of orchards from frosts on still (silent or motionless) nights is often practicable, although the most effective methods may seldom be economical. In some parts of the country, orchard heating by means of many small fires is sometimes used. Straws, dried weeds, cow dung, etc. are used as fuel (for heating purpose).

**Heat** - Bunches, leaves, and fruits exposed to the sun become much hotter than the atmosphere. Heat is generally more harmful when accompanied by low humidity and by strong wind. This condition leads to very rapid transpiration and may desiccate the leaves and twigs. The ability of plants to withstand such conditions varies greatly with the species. Again, young trees are less hardy than old ones. This is a limiting factor in the case of certain fruits.

Erecting light thatches over young trees can reasonably easily protect them. The provision of adequate irrigation is essential, but desiccation may take place in spite of plentiful soil moisture, as the plant may be unable to carry the water to the leaves as rapidly as it is transpired. Intercropping fruit trees of dwarf and medium stature along with tall trees can provide partial shade, but this is probably more important in reducing the intensity of the light than in reducing the temperature.

Sunburn of the leaves, fruits, and bark is sometimes a serious factor. The stems of young trees are often exposed. The bark may be shaded by wrapping paper around the limb. Or whitewash may be applied, which causes much of the light to be reflected and thus prevents the bark from becoming as hot as it otherwise would.
Mulching

Mulching is covering the soil surface by spreading layers of straw, leaves and other plant trash or plastic sheets. Ideal mulch is one that is readily penetrated by rain, retains its form through the season and can eventually be cultivated into the surface soil; later to be replaced with further mulch. Some of the advantages of mulching in fruit growing include the following:

- protect the soil from rain erosion and especially from rain-splash;
- improve water infiltration;
- conserve soil moisture by preventing desiccation through surface evaporation;
- enrich the soil with nutrients when mulches are decomposed;
- encourage microorganisms living in the soil;
- improve soil structure; and
- reduce weed growth near cultivated plants.

The use of plastic mulch

Plastic sheets are useful in many ways:

- unlike plant mulches, they do not rot and, with due care, can be used again and again;
- they are labor-saving because unlike plant trash, they do not have to be chopped up and transported;
- they let plants derive even benefit from soil water for the whole cultural season, in contrast to the effects of plant mulch which vary as the season progresses; and
- finally, plastic sheets smother weeds more effectively because they cut out the light.

As plastic sheeting tends to be expensive and is not easily obtainable, it is worthwhile using cover material such as old fertilizer sacks, cement bags, and flour bags; all are particularly handy for tree seedlings. Even heavy-duty paper can be used. There are many kinds of plastic sheeting, of varying thickness,
different colors and different textures (smooth or porous). Thickness affects the resistance of the plastic. Color affects soil temperature: dark colored materials get hotter in the sun and cool off quickly at night; light colors keep the covered soil at a more even temperature. Smooth, un-perforated sheets do not let rainwater or evaporation through. Perforated and porous sheets let a certain amount of water through, but limit evaporation. This is true of sacks made of braided plastic fibers that are often used commercially for selling cereal grains, flours and other produce.

Two special precautions must always be taken when plastic sheets are laid on a cultivated patch or round the base of young trees:

- the ground must be thoroughly moistened before fixing the sheet in place and, if necessary, abundantly watered;
- water infiltration around the plastic cover must be encouraged by the right technique—tilling, straw cover, stone, mulch, etc.

Some tips about mulching (Dupriez and Leener, 1995) include:

- The plant waste used for mulching must not contain any seeds or vegetative propagules. The gardener must avoid spreading unwanted plants that will have to be controlled later on;
- There are two reasons why the layer of mulch must not be too thick: first it must not be allowed to absorb all the water during light rains, nor prevent air from reaching the soil. A layer between 5-10 cm thick is usually just right;
- The layer must not be too thin because it would not give effective cover and might rot quickly;
- Mulches are only spread on soil loosened by tilling or weeding. When soil is compacted under cover, mulch does not stop runoff completely and has only a limited effect on water infiltration;
- Mulch must let rainwater filter through. Large, spreading leaves should be avoided because rainwater falling on them flows away from the cultivated plants;
- Chopping up mulches is really worthwhile because it makes the layers of waste more permeable and speeds up rotting. A straw chopper or
compost crusher will do the job and

• Direct contact between plant leaves and mulches must be avoided because fungal diseases can be transmitted in this way.

Training and pruning of fruit plants

Training and pruning are well known but are by no means universal practices.

**Training** involves physical techniques that control the shape, size and direction of plant growth. Training is in effect the orientation of the plant in space. It may include bending, twisting, or fastening of the plant to the supporting structure.

**Pruning** involves the removal of parts of the top or root system of plants. Pruning of fruit plants is an integral part of the procedures used for high production of quality fruits. Three types of pruning are known (Samson, 1986): frame, maintenance and rejuvenation pruning.

A *framework* is best formed in the nursery; it usually consists of a single stem split up in four main branches, each occupying a sector. *Maintenance pruning* aims at the preservation of the status quo. *Rejuvenation pruning* is meant to bring declining trees back into production.

In successful fruit production it is essential that the fruit grower knows the correct pruning procedures as well as understanding the importance of pruning. Some specific reasons for pruning fruit plants (Hartmann *et al.*, 1981) are to:

*develop a strong trunk and scaffold system of branches*, well distributed around the tree, which are able to support heavy loads of fruit without limb breakage.

*control fruit production* Proper pruning encourages development of the type of shoot system required to produce the fruit. In older trees with little vegetative growth rejuvenation pruning can force the development of productive fruiting shoots. Pruning can also be used to limit excess
numbers of fruits (over bearing) by removing some fruit-bearing branches, giving a thinning effect that can improve fruit and quality. In general, shoot pruning reduces the number of growing points of any given fruit plant; this increases the supply of available nitrogen and other essential elements to the remaining growing points. Pruning the top, therefore, promotes the development of cells and the utilization of carbohydrates. Accordingly, it promotes the vegetative phase and retards the reproductive phase. If, for example, orchard trees are young and vigorous, pruning, if necessary, should be very light, since heavy pruning of the top delays flower-bud formation. On the other hand, if orchard trees are old and weak, severe pruning of the top helps to promote vigor and rejuvenation.

- **limit tree size** to the space allocated to it and to limit tree height to manageable size (i.e., fruit can be conveniently harvested). Pruning the top reduces the total vegetative growth. Numerous investigations have shown that pruning the top dwarfs the fruit tree. The total number of growing points is reduced, resulting in fewer developing shoots, fewer leaves, reduced photosynthesis, reduced amounts of carbohydrates translocated to the roots, reduced root growth, followed by a reduction in mineral and water absorption, which, in turn, decreases shoot growth. Generally, the more severe the pruning, the greater the dwarfing.

- **improve light penetration** to the inner and lower parts of the tree.

- **remove dead, broken, or interfering branches**. Failure to prune out jagged/rough, dead wood in tree fruits (example in citrus) makes harvesting difficult, harbors decay organisms and causes physical injury to the fruit, both before and during harvesting. Such damage and latent disease infection are major causes of quality downgrading and storage losses in citrus and many other tree fruits.

- **facilitate insect and disease control** by opening the tree, thus increasing penetration of spray materials to the interior branches and removing diseased branches.
There are two kinds of top pruning (Mathew and Karikari, 1990): (1) *heading back* and (2) *thinning out*.

**Heading back** consists of cutting back the terminal portion of a branch to a bud (Fig. 5-11), that is, the terminal portion of twigs, canes, or shoots are removed, but the basal portion is not. This procedure forces out new shoots from buds below the cut and retards terminal growth of the branch and favors lateral growth.

![Figure 5-11. Pruning by the heading back method.](Mathew and Karikari (1990)](source)

**Thinning out** is the complete removal of a branch to a lateral or main trunk (Fig. 5-12), that is, the entire twig, cane, or shoot is removed. Thinning out corrects an overly dense area or removes unneeded branches, or undesirable growth such as upright branches that compete or interfere with the leader and branches that will be structurally weak because of narrow crotch angles. Since the entire shoot or branch is removed, no lateral growth from that shoot or branch is possible. In general, heading back stimulates the development of more growing points than a corresponding thinning out.
When branches are headed back, it should be done with a slanting cut at an angle of approximately 45°, just above a healthy bud as shown in Fig. 5-13, with the bud opposite the slant. The lower part of the slant should be above the base of the bud. The cut should be clean and sharp to encourage rapid healing. No stub should be left above the bud and the cut surface should be as small as possible. Also when thinning out, branches should be cut close to the bulge on the main stem leaving no stub (Fig. 5-14). Any stub left will give rise to fungal infection due to delay in healing and this may eventually affect the main stem. Generally, evergreen fruit trees are pruned considerably lighter than the deciduous ones.
Figure 5-13. Ways of making pruning cuts (heading back method): (a) correct (b) incorrect, too far from bud (c) incorrect, too close to bud
Source: Mitov et al. (1990).

Figure 5-14. Ways of making pruning cuts (thinning out method): (1) incorrect, too close to the main stem (2) correct (3) incorrect, too far from the main stem.
Source: Mitov et al. (1990)
Bearing habit of fruit crops

The fruit bearing habit of a plant refers to the position and type of wood on which flower buds, and subsequently fruits occur. This is important in pruning and training because we want to encourage the type of wood that bears the fruit and minimize unnecessary vegetative growth. Understanding the bearing habits of fruits is important for proper pruning. Without this knowledge, a grower may destroy a major portion of the fruit buds and potential crop when pruning. Depending on fruit type, fruit is borne on specialized structures (such as buds, fruiting spurs, or fruit clusters) or on certain areas of the plant (such as first-year wood, "old" wood, "off" wood, or the current year's growth).

The position of flower or inflorescence on the shoot, relative to the growth of current season, is characteristics of the species or the variety and is subject to little change. The position of the flower bud is different in different species. The classification being based upon the location of the fruit buds and the type of flower bearing structure to which they give rise (Bal, 2002):

**Group I** - Fruit buds borne terminally, containing flower parts only and giving rise to inflorescence with leaves e.g., mango, loquat.

**Group II** - Fruit buds borne terminally, unfolding to produce leafy shoots that terminate to flower clusters as in apple and pear. The fruit buds are mixed and invariably give rise to very short growth and a few short internodes, leaves of ordinary size and a lateral branch arising in the axil of one of the leaves. This branch may bear fruit in the following season e.g., citrus.

**Group III** - Fruit buds borne terminally, unfolding to produce leafy shoots with flowers or flower clusters in the leaf axils.

This might be called as an incomplete ‘terminal bearing habit’ for the fruit bud itself is not borne terminally, but it is lateral to the growth upon which it appears. However, the flower buds are terminal. The terminal buds of the flowering shoots may differentiate flower parts for the following year’s production or new buds may develop from lateral leaf buds. It is found in
pomegranate, guava, etc.

**Group IV** - Fruit buds borne laterally, containing flower parts only and giving rise to inflorescences without leaves. If leaves are present, they are much reduced in size e.g., peach, plum, citrus.

**Group V** - Fruit buds borne laterally, unfolding to produce leafy shoots that terminate in flower clusters e.g., grape.

**Group VI** - Fruit buds adventitious since these are necessarily lateral, the plants included here might readily be classed with those of Group IV and V. However, this bearing habit is more or less distinct and these fruits may well be placed in a separate class e.g., the cacao bears in the same way. The flower buds appear first on the trunk as the trees grow and then on the branches.

**Group VII** - This is another group of plants which have fruit buds in the axils of the leaves and in which these buds unfold and develop their flowers and fruits very soon after the flower parts are differentiated. However, it is not possible to draw clear line between their fruiting habit and that described for group IV e.g., in papaya.

In the unopened flower bud of the grape, the inflorescence is terminal to a leafy shoot also within the bud. As the bud opens, however, the bud in the axil of the top most leaf of this developing shoot unfolds and continues the growth of the shoot. This results in pushing the flower cluster to one side so that inflorescence is lateral and opposite a leaf.

**Unfruitfulness in fruit plants**

Unfruitfulness is a major problem in many fruit crops and their varieties result in huge loss to growers and make fruit cultivation less profitable (Wani et al., 2010). Unfruitfulness in fruit crops refers to the state where the plant is not capable of flowering and bearing fruit. There are various factors responsible
for self unfruitfulness in fruit plants. Among others, the following worth mentioning here:

(1) *Unisexuality* (*dichogamy*) - This is the natural phenomenon in which a given plant bear unisexual flowers. Unisexual plants are broadly classified into two:

(i) *Monoecious* - These are plants that produce their male and female floral organs on different positions but on the same plant. In some fruit species, for instance, in walnut the male and female flowers are found on different positions of the plant. In monoecious plants there could be transfer of some pollen to the stigma of the same plant resulting in self-fruitfulness.

(ii) *Dioecious* - In dioecious fruit plants, such as papaya (most varieties), date palm, etc. the female and male flowers are borne on different plants. These plants are favored by nature to undergo cross pollination. It is therefore necessary to maintain certain proportion of female and male plants in the orchard so that successful pollination could be achieved.

(2) *Self-sterility* - Some fruit species are self sterile, that they cannot self pollinate and set fruit. This is due to sterility of male, pollen grains of which are nonfunctional or inactive. The female gametes, however, are normally functional. For instance, in Satsuma mandarin the pollen grains are sterile. In banana pollens are sterile due to triploidy. Unfruitfulness due to self-sterility is common in certain cultivars of apples and plums (Mitov *et al.*, 1990). Such cultivars require pollen donor cultivar to set fruit. In practice, this is achieved by inter-planting appropriate cultivar (pollinizer). The grower has to make sure that the two cultivars flower at the same time to achieve pollination.

(3) *Incompatibility* - In some fruit species, even though the flower structures are normal and pollination takes place, fruit will not set due to lack of fertilization. This happens due to self- or cross- incompatibility. *Self-incompatibility* is failure of pollen to effect fertilization on self-pollination. As a result, there will be no fruit set following self-pollination. But the same
flowers produce fruit on cross pollination. Self-incompatibility is observed in some varieties of mango, pear, pineapple, almond, apple, apricot, etc. (Shukla et al., 2004). Cross-incompatibility is inability of pollen of one variety to produce fruit when cross pollinated. This type of incompatibility exists among some varieties of sapota and sweet cherries.

In self-incompatibility, pollen grains may fail to germinate or entering the stigma, pollen tube may grow very slowly in the style to effect fertilization before the flowers drop, or the embryos (if fertilization does take place) degenerate (Singh, 1999). According to the author, the mechanism of self-incompatibility may involve the following interactions:

(i) **Pollen - Stigma Interaction** - This occurs just after pollen reaches stigma and generally prevent pollen germination. It happens only when the pollen and the stigma cells have the same self-incompatibility reaction (incomplete mating).

(ii) **Pollen tube - Style Interaction** - It occurs when pollen grains germinate and pollen tubes enter the stigma, but in incompatible combinations, pollen tube growth is retarded within the stigma or in the style.

(iii) **Pollen tube - Ovule interaction** - In this case, pollen tubes reach ovules and fertilization takes place. But in incompatible combinations embryos degenerate at an early stage.

(iv) **Dichogamy** - This is the situation in which the pistillate and staminate flowers mature at different times. Generally in dichogamy there may be more or less separation of the sexes and a prevention of self pollination in perfect flowered plants through the maturing of the two sex elements at different times. Dichogamy is incomplete when there is an overlapping in the seasons maturity of the two sex elements; otherwise it is complete. Complete dichogamy insures pollination with some other flower and perhaps with another plant bearing complementary flower. Two types of dichogamy are distinguished:
(i) **Protogyny** - This is the condition when pistillate flowers mature earlier than staminate flowers (e.g., avocado, many members of Anonaceae fruits). In protogyny, when the stigma is receptive, pollen of the same flower is not ripe (not shedding) as a result of which self pollination will not take place. However, some times (in some cultivars), it is found that self-pollination may occur.

(ii) **Protandry** - If the stamens ripen before the pistil is ready to receive pollen the flower is protandrous. Unlike protogyny, in protandry, anthers ripen first and by the time when anther burst, stigma of the same flower will not be ready to receive the pollen.

(5) **Heterostyly** - It is a type of dimorphism in which some of the flowers have short styles and long filaments and other flowers of the same species or variety have long styles and short filaments. The structure and arrangement are such that when these flowers are visited by pollen-carrying insects no self pollination takes place. This phenomenon is observed in some fruit species in which case self-pollination (self-fruitfulness) is prevented. For instance, self pollination is inhibited in some cherry cultivars, due to long style and short filament (Mitov et al., 1990).

**Pollination and pollination management**

*Jeong Cheon Soon*

Pollination is transfer (landing) of active or live pollen onto a receptive stigma. It is a fundamental process for sexual reproduction in most plants, and is essential for the production of fruit and seeds. Only flowers that are pollinated develop into fruit. Although some plants are able to pollinate their own flowers, most will produce better quality fruit and greater yield when they have another plant of the same type but of a different variety for pollination. Humans depend on animal pollination directly or indirectly for about one third of the food they eat (O'Toole, 1993; Richards, 1993).
Pollination is required for seed production, to increase seed quality and number, for fruit production and quality, to create hybrid seed and to increase uniformity in crop ripening (Corbet et al., 1991).

Self pollination occurs when pollen lands on the stigma of its own flower or another flower on the same plant. Cross pollination occurs when pollen is transferred to the stigma of a flower on another plant.

The process of pollination requires pollinators: agents that carry or move the pollen grains from the anther to the receptive part of the carpel. Most flowering plant species rely on pollinators (e.g., insects, birds, bats, and other animals) to carry pollen from the male to the female parts of flowers for reproduction.

Pollination also requires consideration of pollenizers. The terms “pollinator” and “pollenizer” are often confused: a pollinator is the agent that moves the pollen; a pollenizer is the plant that provides the pollen. Some plants are self-fertile or self-compatible and can pollinate themselves. Other plants have chemical or physical barriers to self-pollination and need to be cross-pollinated: with these self-infertile plants, not only pollinators must be considered but pollenizers as well. In pollination management, a good pollenizer is a plant that provides compatible, viable and plentiful pollen and blooms at the same time as the plant that is to be pollinated.

The term pollen source is often used in the context of beekeeping and refers to flowering plants as a source of pollen for bees or other insects. Bees collect pollen as a protein source to raise their brood. For the plant, the pollenizer, this can be an important mechanism for sexual reproduction, as the pollinator distributes its pollen. Few flowering plants self pollinate; some can provide their own pollen (self fertile), but require a pollinator to move the pollen; others are dependent on cross pollination from a genetically different source of viable pollen, through the activity of pollinators. One of the possible pollinators to assist in cross-pollination are honeybees.

While some plants are capable of self pollenization, the term is more often used in pollination management as a plant that provides abundant, compatible, and viable pollen at the same flowering time as the pollenized plant. For example some apple cultivars produce very little pollen; some
produce pollen that is sterile, or incompatible with other apple varieties. These are poor pollenizers. A pollenizer can also be the male plant in dioecious species (the male and female parts are on different plants), such as with papaya.

Pollination management is the label for horticultural practices that accomplish or enhance pollination of a crop, to improve yield or quality, by understanding of the particular crop’s pollination needs, and by knowledgeable management of pollenizers, pollinators, and pollination conditions. With the decline of both wild and domestic pollinator populations, pollination management is becoming an increasingly important part of horticulture.

The increasing size of fields and orchards (monoculture) increase the importance of pollination management. Monoculture can cause a brief period when pollinators have more food resources than they can use, while other periods of the year can bring starvation or pesticide contamination of food sources. Most pollinator species rely on a steady nectar source and pollen source throughout the growing season to build up their numbers.

Some crops, especially when planted in a monoculture situation, require a very high level of pollinators to produce economically viable crops. This may be because of lack of attractiveness of the blossoms, or from trying to pollinate with an alternative when the native pollinator is extinct or rare. In many such cases, various native bees are vastly more efficient at pollination, but the inefficiency of the honey bees is compensated for by using large numbers of hives, the total number of foragers thereby far exceeding the local abundance of native pollinators.

The following are a few terms important in understanding pollination and in selecting a pollenizer:

Self-fruitful or self-pollinator: The plant is able to pollinate its own flowers (e.g., peaches, most citrus, a few grapes, plums, and pears). The self-fruitful varieties can be safely planted in solid blocks.

Self-unfruitful or self-sterile: The plant requires pollen from another plant of the same type but different variety, but both varieties must have the same
bloom time (e.g., apples). In this case, provision for cross pollination is usually made either by planting trees of the compatible varieties in the orchard or by top-working such varieties on a few limbs (branches) of the trees here and there. Bosch and Kemp (2001) reported that even the normally self-fruitful varieties give increased yields as a stimulus of cross pollination. Therefore, planting of two or more varieties of the same kind of fruit and which have the same bloom period, is a safe procedure in the establishment of commercial orchards. The cross-pollination is aided effectively by insects in most fruits; and in this connection bees are the most useful agents.

*Sterile pollen:* The plant cannot pollinate itself or any other variety (e.g., some apples).

Fertilization (syngamy) is fusion of the one of the two sperm cells with the egg cell, producing a diploid zygote which subsequently develops to the embryo. The fusion of remaining sperm cell with the secondary nucleus leading to the formation of a triploid primary endosperm nucleus is termed as triplet fusion. When triplet fusion and syngamy take place simultaneously it is termed as the double fertilization (Shukla et al., 2004). Effective pollination and subsequent fertilization are required to achieve high yield and quality fruit.

Many varieties of fruit trees are self-fruitful, that is, they do not need to have a plant of another variety nearby with which to cross-pollinate. Other varieties need to have a partner (pollen donor) in the orchard so that they will be pollinated and produce a good crop of fruit. Even self-fruitful varieties often benefit from having a different variety of the same plant located nearby as a pollen donor.

Most flowers have both male and female functional parts. Some plants, however, may have only male flowers, in which the ovaries are nonfunctional, or female flowers, in which the anthers are nonfunctional. In others, the stigma may not be receptive when the pollen is available within the flower. In such flowers, the pollen must be transferred from the male flower to the female. If the flower has both functional parts and is receptive to its own pollen, it is said to be self-fertile. If the flower is not fertilized by
its own pollen, but is fertilized only when pollen comes from another plant or variety it is referred to as self-sterile. This phenomenon, for instance, is observed in some cultivars of apple and plum; and is overcome by inter-planting complimentary (cross-compatible) cultivar that would cross pollinate and produce good fruit yield. For achieving effective pollination, the following points should be considered (for a pollen donor cultivar):

- Compatibility/complimentarity to the main variety;
- Flowering and bearing at the same time or at the same age as the main variety;
- Adaptable to the agro-climate of the region;
- Regular and profusely flowering (giving good amount of viable pollen).
- Yield fruit of commercial value;
- Planting plans, spacing, and management of pollenizers (e.g., proper pruning).

Insects of many species visit flowers and pollinate fruit crops. These include bees, wasps, moths, butterflies, beetles, and thrips. Bees are the most efficient and the only dependable pollinators, because they visit flowers methodically to collect nectar and pollen and do not destroy the flower or the plant in the process. Various species of bees are highly efficient. Bees do an estimated 80 per cent of our insect pollination. It is very important not to spray insecticides during the blossom time of either the fruit trees or the other groundcover plants that may be growing near them. These toxic chemicals can kill bees and other beneficial insects resulting in poor pollination and consequent low yield.

Birds of several different species feed upon nectar, pollen, or insects in some flowers and serve as pollinators. None is of significance in pollinating cultivated crops as their visits are confined largely to deep-throated, usually showy wild flowers.

Due to their reproductive biology, fruit trees require particularly large and/or effective pollinator populations and, therefore, fruit tree yields are often pollination-limited. The flowering period of most orchards lasts for a few
weeks, and individual flowers are typically receptive for only a few days (Bosch and Kemp, 2001). If flowers are pollinated at the end of their receptive period, ovules are less likely to be fertilized before ovule degeneration. For these reasons, it is desirable to pollinate fruit tree flowers for as many days as possible, particularly early in the flowering period.

In general, the sooner pollination can occur after a flower opens, the greater the likelihood that fertilization of the ovules and seed development will occur. As time elapses, the pollen may be lost or damaged by heat, moisture, wind, etc.

In addition to the volume of the crop produced through adequate pollination, another value lies in the effect of pollination on quality and efficiency of crop production. Inadequate pollination can result in reduced yields, delayed yield, and a high percentage of culls or inferior fruits.

The fertilization process and the following segmentation and growth of the embryo and endosperm within the ovule are accompanied by changes in the surrounding ovary wall and often in the torus and other adjoining tissues. Most noticeable among these changes are a thickening and an increase in size, perhaps with some change in color, shape and position, so that it is evident very soon after flowering that the fruit has or has “set”.

The “fruit setting” in this context refers to the initial and appreciable swelling of the ovary occurring shortly after the period of petal fall. It is generally accompanied by some thickening of the pedicel or of the peduncle. Meanwhile, flowers that have not “set” are turning yellow or withering and falling off.

It is common that all the flowers will not set fruit, even though conditions are ideal. The usual failure of many flowers to set and mature fruit is due to various factors. The grower has to understand, however, that many cultivated fruit species or varieties characteristically produce more flowers than it can possibly mature into fruits and that consequently a certain amount of dropping is to be expected.

Destruction or alteration of nesting habitats, pesticide use, and the scarcity of alternative flowering plants are the main factors contributing to local wild bee population declines. Herbicide use affects pollinators by
reducing the availability of nectar plants (Kevan, 1975; Day, 1997).

**Fruit thinning**

Fruit thinning (defruiting) is a practice of removing excessive numbers of fruits from the tree in order to improve the general size and quality of the remaining crop. Very often most fruit trees (especially, temperate fruit trees such as apples, peaches, nectarines, plums, apricots and pears) set such heavy crops that the fruits do not grow to a satisfactory size. Limbs (fruiting branches) may break because of an overload of fruit, or drain food reserve, so that no or few flower buds develop for the following year. This leads to an alternate-bearing pattern (a cycle in which the tree bears excessively in one year and little the next year) or limb breakage. Thinning the fruit helps prevent these problems from developing (Ingels et al., 2001).

Fruit thinning is one of the most important cultural procedures for an orchardist or a home gardener. When the excess fruits are removed, the tree may then utilize all available nutrients to develop the remaining fruits to a larger size, as well as to increase root and shoot growth. These, in turn, can absorb more nutrients from the soil to manufacture more carbohydrates through photosynthesis.

Fruit thinning is the best way to increase the size of the unthinned fruits remaining on the tree. Final fruit size more or less depends upon the leaf-fruit ratio on a branch. The more leaves per fruit, the larger the final fruit size. The total yield at harvest is less for a thinned tree than for an unthinned one. In other words, fruit size is increased at the expense of total yield.

Fruit thinning can also reduce the spread of some diseases (Ingels et al., 2001). For example, if the fruits are touching each other, brown rot can quickly spread from one fruit to another just before harvest. Air movement around tightly clustered fruit is minimal, so the surface of unthinned fruit doesn’t dry quickly, allowing disease organisms to multiply and spread.

The amount of fruit to thin depends on the species and the overall fruit load on the tree. For example (Ingels et al., 2001), stone fruits such as
plums are fairly small, so they should be thinned 5 to 10 cm apart on the branch. Peaches and nectarines should be thinned to 7.5 to 12.5 cm. If the fruit load is light, but one or two branches have a large amount of fruit, less thinning is required because the total number of fruit is low. Unlike stone fruits, which produce one fruit per bud, pome fruits (apples and pears) produce a cluster of flowers and fruit from each bud.

Fruits may be thinned by hand (hand thinning) or using chemicals (chemical thinning) (using chemicals such as Ethephon, Naphthalene acetic acid) or mechanical tree shakers (mechanical thinning).

Hand thinning is the manual removal of fruit and is one management tool to reduce crop load to increase fruit size before harvest. It is the most precise and least risky method of thinning, but very labor intensive ( Falivene and Hardy, 2008). For hand thinning to be economically viable, significant increases in market returns would have to be achieved to offset the costs.

The key to effective hand thinning is the removal of small fruit that will not be of any market value. Remove all small, scarred, blemished or deformed fruit. A good visual guide is to remove about 20-30% of fruitlets (Falivene and Hardy, 2008). The main point to be kept in mind, while thinning by hand, is to remove all the small, undersized, misshapen, disease and insect attacked fruits. Close attention needs to be paid to the bottom of trees as a higher percentage of small fruit is located in this area.

Fruits are weaker sinks than shoots, and some fruits are weaker sinks than other fruits. Chemical thinners generally remove the smallest, weakest (slowest growing) fruit on the tree. Chemical thinning increases the source to sink ratio, increasing the carbohydrate supply to each of the remaining fruit and increasing the rate and duration of cell division.

Mechanical thinning (machine thinning) is removing or harvesting of fruits using inertia shaker. Deciduous fruit trees (usually plums, apples, peaches, etc.) mainly for processing purposes are harvested mechanically. However, this method has relatively limited application because of its nonselective nature.
References


The harvest and postharvest phase accounts for up to 60% of all costs in the production and marketing system for horticultural produce, and significant quality loss can develop if correct procedures are not followed (Hofman et al., 2002). In general, the risk of quality loss is higher when the time takes longer from harvest to consumption. Thus, the trend towards greater distances between production sites and the consumer in both domestic and international trade, and the storage of fruit to overcome localized market over-supply has increased the emphasis on postharvest technology and practice. Also, the increasing demand for quality, reduction in chemical use (especially postharvest), and the increasing interest in convenience foods is placing additional demands on postharvest technology in the horticulture sector.

Fruit maturation, ripening and senescence

*Maturation of fruit* refers to the final stage of fruit development while still attached to the plant. It includes cell enlargement, the accumulation of carbohydrates and other flavor constituents, and a decrease in acids. Maturity at harvest is the most important factor that determines storage-life, final fruit quality, and in particular aroma formation after storage (Fellman et al., 2003). Immature fruits are more subject to shrivelling and mechanical damage, and are of inferior quality when ripe. Overripe fruits are likely to become soft and mealy with insipid flavor soon after harvest. Any fruit picked either too early or too late in its season is more susceptible to physiological disorders and has
a shorter storage-life than fruit picked at the proper maturity (Kader, 1999). Two types of fruit maturation are recognized: commercial maturity and physiological maturity.

Commercial maturity is concerned with the timing of the harvest to meet particular market requirements. At optimum commercial maturity, products should be either at optimum consumer quality (in case of non-climacteric fruit) or able to achieve optimum consumer quality (in case of climacteric fruit). Physiological maturity refers to a particular stage in the development of fruit. Fruits designed for seed extraction (e.g., for rootstock establishment) are normally picked at physiologically mature stage, as this maturity stage allows the seed (embryo) to develop well, the fruit being attached to the mother plant.

Ripening of fruit refers to qualitative transformation of mature fruit into desired edible status characterized by degreening, softening, loss of astringency, decline in sourness, increase in sugars, development of characteristic flavor, aroma, etc. Ripening is the composite of the processes that occur from the latter stages of growth and development through the early stages of senescence and that result in characteristic aesthetic and/or food quality, as evidenced by changes in composition, color, texture, or other sensory attributes (Kader, 1999). In some species such as grapes and citrus fruits, phases of fruit maturation and ripening may overlap, while in others as in mango, banana, avocado, etc., these two phases are distinct.

The regulation of ripening is an extremely important factor in supplying the consumers with fruit of acceptable eating quality. As fruits also remain alive after harvesting, it is necessary to restrain their respiratory and metabolic activity in order to maintain cell life and optimize postharvest quality by delayed ripening and senescence. Postharvest quality deterioration is generally proportional to product respiration rate (Prange et al., 2005). Thus product life in storage is extended when biochemical processes are minimized by maintaining fruit at the lowest acceptable temperature.

The various kinds of fruits have different ripening patterns and
require different storage procedures. It is essential to understand these in order to know how to harvest and handle the fruits properly. Most fruits reach maturation and ripen on the tree, vine, or bush, at which time they should be picked. If not picked, they enter a stage of senescence and deterioration. Such type of fruits are said to be non-climacteric. However, other fruits are best harvested when they reach maturity on the tree and are ripened to eating condition off the tree. Such type of fruits are said to be climacteric.

Climacteric fruits are generally defined as fruits that undergo gradual ripening process, but never attain consumable ripening while attached onto the plant. In the climacteric fruits (Table 6-1), the respiration rate of cells slowly decreases as maturation proceeds. Following maturation, there is a rather abrupt reversal of the respiration rate. During ripening, respiration rises until it reaches fruit specific peak, the climacteric point (Fig. 6-1). After that, respiration rates decline and a deterioration process commences, leading to senescence and eventual death of fruit cells. The best ripe quality, for a given fruit, is observed around the stage which coincides with pick rate of respiration, which is termed as climacteric.

The initiation and duration processes of ripening may vary in different fruits of climacteric nature. In this regard two categories of fruit species may be recognized:

(i) Fruit species which initiate ripening process while still attached to the tree but the process gets accelerated after detachment, e.g., banana, mango, papaya, guava, passion fruit, peach, apple, plum, etc.
(ii) Fruit species which initiate ripening only after the fruit is detached from the parent plant, e.g., avocado.
Table 6-1. Climacteric and non-climacteric fruits.

<table>
<thead>
<tr>
<th>Non-climacteric</th>
<th>Climacteric</th>
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<tr>
<td>Grape</td>
<td>Apple</td>
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<td>Grapefruit</td>
<td>Apricot</td>
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<td>Lemon</td>
<td>Avocado</td>
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<td>Lime</td>
<td>Banana</td>
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<td>Loquat</td>
<td>Bullock's heart</td>
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<td>Mandarin</td>
<td>Cherimoya</td>
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<td>Orange</td>
<td>Fig</td>
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<td>Pineapple</td>
<td>Guava</td>
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<td>Pomegranate</td>
<td>Jackfruit</td>
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<td>Raspberries</td>
<td>Mango</td>
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<td>Strawberries</td>
<td>Nectarine</td>
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<td>Papaya</td>
<td>Passion fruit</td>
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<td>Peach</td>
<td>Pear</td>
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<td>Plantain</td>
<td>Plum</td>
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Source: Wills et al. (1981); Kader (1985)

**Senescence** is the period following fruit development, during which growth ceases and aging processes replace ripening processes. It is usually caused due to inherent physiological changes in the fruit, by pathogenic attack or poor handling/storage (e.g., desiccation). Senescence is considered to be a terminal, irreversible deteriorative change in fruits, leading to cellular and tissue breakdown and death. It is a conspicuous period of physical decline, particularly evident toward the end of the ripening of fruits. Senescence may occur before or after harvest.

**Non-climacteric fruits** are fruits that undergo gradual ripening process, and attain consumable ripening while attached onto the plant. Conversely, in non-climacteric fruits the respiration rate declines steadily and gradually during ripening, with no particular peak. Orange, mandarin, lime, lemon, grapefruit, grape, strawberry and pineapple are examples of non-climacteric fruits.
Figure 6-1. Respiration rate during ripening of four climacteric fruits, highest peak in avocado.

Fruit maturity determination

The principles that underlie the stage of maturity at which a fruit should be harvested are crucial to both its quality and its subsequent storage and marketable life (Thompson, 2003). Maturity indices (also called “harvest indices”) are important for deciding when a given fruit should be harvested to provide some marketing flexibility and to ensure the attainment of acceptable eating quality to the consumer.

Various factors are considered in determining the maturity of fruits; among which the following are commonly used: calendar date, color, shape, size, flesh firmness, texture, taste or mouth feel; and chemical measurements.

Calendar date (full-bloom dates and days after full bloom) is one of the most commonly used indices of maturity and is reasonably accurate if factors of
time of bloom and weather condition during the growing and harvesting season are considered (Moulin and Galzin, 1984). But its standardization requires a study for many seasons within a given area, location, cultivar and rootstock. Watkins (2003), stated that calendar dates alone have limited value in regions where temperature variations result in wide differences in bloom dates, but in more consistent growing regions, days from full bloom can be the most reliable harvest index for some cultivars.

**Color** is used for fruit where skin color changes occur as the fruit matures or ripens. Skin color is the most obvious change that occurs in many fruits and is often the major criterion used by consumers to determine whether the fruit is ripe or not. The most common color change is from green to yellow reflecting the loss of green pigment (chlorophyll). However in some fruits there are no perceptible color changes during maturation (e.g., avocado) as color changes may occur only on particular cultivars and not on others.

**Shape** is a criterion that often distinguishes particular cultivars of fruit. Fruit shape can change during maturation and thus can be used as a characteristic to determine harvest maturity, taking into account roundness, fullness, angularness, etc., depending on the fruit species or variety considered. In bananas the individual fruit becomes more rounded in cross-section and less angular as they develop on the plant. Roundness or fullness could, therefore be taken as simple and fast maturity index for bananas. Mangoes also change shape during maturation on the tree; on very immature fruits the shoulders slope away from the fruit stalk, on more mature fruit the shoulders become level with the point on attachment and on even more mature fruit the shoulders may be raised above the point of attachment (Thompson, 2003).

**Size** is an important criterion of fruit maturity determination that can be easily measured by circumference, diameter, length, width, weight, volume, etc. Normally immature fruits are small in size compared to mature fruits of the same type.
**Flesh firmness** - As fruits mature and ripen they soften, largely because the pectins comprising the middle lamella of cell walls dissolve (Wills *et al.*, 1998). This softening can be estimated subjectively by finger or thumb pressure. However, more objective measurement, yielding a numerical expression of flesh firmness, is possible with fruit pressure testers such as penetrometer (Fig. 6-2). These testers measure the pressure at which flesh yields to the penetration of a standard diameter plunger inserted to a standard depth, for instance mangoes are said to be mature when fruits have ability to withstand a pressure of 1.75 to 2 kg/cm² (Samson, 1986). Flesh firmness as a maturity index, is affected by many preharvest factors, including season, orchard location, nutrition, and exposure to sunlight, that are independent of fruit maturity (Watkins, 2003)

![Figure 6-2. Penetrometer.](image)

*Source: Mitov *et al.* (1990)*

**Texture** is also considered for judging readiness for harvest. Depending on the nature of the fruit considered, texture parameters, such as roughness, smoothness and graininess are taken for determining stage of maturity.

**Taste or mouth feel** - Taste or mouth feel method is a means of determining fruit maturity by sampling characteristic specimens (representative sample). In this method chewiness, fibrousness, grittiness, mealiness, stickiness, oiliness, sweetness, sourness, etc. may be taken as parameters to decide harvesting. Taste and mouth-feel method very much depends on the experience and
personal opinion of the grower.

**Chemical measurements** - Measuring the chemical characteristics of fruits is an obvious approach to determine maturity, particularly as they can often be directly related to taste (e.g., sweetness, tartness) of fruits (Wills *et al.*, 1998). The sugar-acid ratio of a given sample of fruit juice is often used as an indicator to determine stage of maturity and harvest of juicy fruits such as, citrus, pineapple and passion fruit. Fat (plant oil) content also is one of the maturity indices used to determine harvest maturity of oil rich fruits like avocado. The starch test, in which the hydrolysis of starch to sugars as fruit ripen is estimated by staining starch with iodine solution, has become popular for assessment of maturity of some fruits (e.g., apple, banana). The resulting patterns, which reflect the extent of starch hydrolysis, are rated numerically using starch charts, either specific to cultivar or generic (Watkins, 2003).

Reliable technical tests (maturity indices) need to be developed for important commercial fruits such as citrus, grapes, avocado, pineapple, mango, apple, etc. grown on large scale conditions, by identifying easy and less expensive maturity indices.

In Ethiopia, where multiple cropping on small acreages accounts for a large proportion of fresh fruit production, decisions on when to harvest are not made on technical test but on the individual's evaluation of when the fruit is in good enough condition to be harvested and is sold to realize the best price. A major factor influencing this decision, in peasant holdings, is the price which can be obtained at any given time, which frequently leads to fruits being harvested before or after they are at their best in order to get a good price.

**Harvesting**

Fruits vary considerably in the manner and the rate at which they mature; each species has its own characteristic pattern. The objective of harvesting fruit is to pick the fruit without damage and to get it to the market in the best possible condition. Although the scale of production, availability of labor
and type of fruit may vary, certain basic factors must be taken into account in the planning of any harvest operation. Equipment must be obtained, labor organized and marketable produce identified for harvesting, collection and removal from the field. Each of these tasks must be planned, managed and implemented efficiently if the value of the fruit is to be fully realized.

Training and supervision of labor are critical to a successful harvesting operation. Constant supervision is necessary to maintain quality and reduce subsequent spoilage of fruit. Training is required in both general principles and fruit specific techniques relating to maturity selection, detachment method, maintenance of equipment, field hygiene and division of labor. Teams of workers should work systematically through a plot or field, experienced workers picking the fruit and others carrying it to collection points. If fruits are relatively inaccessible, as with older mango and avocado trees, great care must be taken by pickers climbing in the trees if fruit is to be harvested free of damage.

The workers must be given strict specifications before entering the field and each worker's performance carefully supervised. Giving careful instructions on the correct method of cutting, twisting or pulling to remove/pick a fruit is necessary. Sharp edges on rings and bracelets, and long fingernails, are significant cause of postharvest abrasions and should be removed before harvesting starts.

Good management of the harvest operations is usually reflected in the speed at which produce moves from field to market place, packing station or storage center, provided that is not at the expense of careful handling and subsequent quality downgrading.

Harvesting techniques/methods for fruits are variable and depend to some extent upon whether they are immature, mature green or ripe when harvested:

(i) Mature or ripe fruit with natural stem ‘break points’ - Some fruits, such as passion fruit have a natural ‘break-point’, at which they can easily be removed from the parent plant, leaving the fruit stalk attached to the fruit. These are usually harvested by hand using the ‘lift, twist or pull method’.
Harvesting can be done by hand or machine.

(ii) *Mature green or ripe fruit not readily detached with the fruit stalk intact* - Many tree fruits fall into this category, including mango, citrus and avocado. These fruits are best harvested using clippers, and placed in harvesting bags carried by the harvester. With large trees, such as mature mangoes and avocados, fruits are harvested by the use of picking poles, with or without attached clippers, equipped with bags into which the fruit fall. This method is rather slow and requires considerable experience and skill, but is essential if high quality fruit is required. Alternatively the fruit is picked by the harvester either on a ladder, or who climbs the trees, and throws the fruit to a skilled ‘catcher’ on the ground, or into a large net. Pulling out of stems from fruit when harvesting has to be avoided at all costs, because broken skin at the point of attachment of the stem is particularly susceptible to a decay condition known as stem end rot.

(iii) *Immature fruit with soft stems but no natural breakpoint* - Some fruits are eaten in the immature state, some as vegetables or salads (e.g., papaya). Fruits of this type are usually harvested by hand (by snapping the stem), or cutting it with a sharp knife. Where knives are used they should be kept sharp and free from contamination with soil. Breaking off the stem instead of cutting is not recommended because the rough break is more susceptible to the establishment of infection by decay organism than a clean cut.

Fruit for fresh market is almost always hand-harvested. Often some mechanical aids are used; for example, hydraulic platforms that lift the pickers and move them around and about the tree can replace ladders, and conveyer belts can be used to transport fruits to bulk bins.

Fruits grown for processing are often harvested mechanically. The fruits are removed from the tree by vigorously shaking the main branches or trunk with a self-propelled, hydraulic shaker. Canvas catching frames held above the ground or roll out canvases catch the fruit and move it onto a conveyer belt. According to Samson (1986), foam rubber padding on metal frame supports reduces bruising. No matter what harvesting method is used,
close care must be taken to avoid injury to products.

**Postharvest factors influencing fruit quality**

Major quantities of horticultural crops (including fruits) are lost after harvest, especially due to improper handling. These quantitative and qualitative losses, estimated to be as high as 50% in most of the developing countries, are very important from the standpoint of human nutrition and health and national economy and ecology (Yahia *et al.*, 2004). These are losses in nutrition, in land used for cultivation, energy (fuel), machinery used, fertilizers, chemicals, irrigation water, labor force, etc., and above all they are significant economic losses. Like in many developing countries, in Ethiopia, the increase in yield and productivity is lagging significantly behind the increase in its population, and the nutritional need in the country. Therefore, reduction in postharvest losses should be considered as a strategic requirement, to satisfy growing demands of the population. The increase in yield and productivity, without reducing postharvest losses, will not be sufficient in securing the availability of food in the country.

Deterioration in fruit quality can be caused by a variety of stresses that may be grouped into four general, but often inter-related, categories (Wills *et al.*, 1998): metabolic stress, transpiration, mechanical injury stress and microbial damage.

**Metabolic stress** involves either ‘normal’ or ‘abnormal’ metabolism that leads to senescence or the development of physiological disorders, (e.g., extensive skin browning in bananas as a result of severe chilling injury).

**Transpiration** and subsequent water loss can also lead to rapid loss of fruit quality, with subsequent loss in salable weight and absolute monetary value. Water loss mainly affects appearance, through wilting and shriveling.

**Mechanical injury** like abrasions, bruises, cuts and tears cause loss of visual quality. Such injuries not only lead to an increase in the general metabolic
rate (wound response) as the produce tries to seal off the damaged tissues but also increase transpiration because natural barriers against the loss of water have been damaged.

*Microorganisms* can often be considered as a ‘secondary stress’, since their proliferation is generally facilitated by mechanical injury, transpiration and/or metabolic changes such as senescence and physiological disorders. Many microbial problems can be minimized or eliminated by careful and proper postharvest handling practices. Some of the major handling factors that contribute to loss of quality of harvested fruits are discussed below:

**Harvesting** - Mechanical damage during harvesting and postharvest handling operations not only affect visual quality, but also predispose fruits to disease-causing microorganisms. Inclusion of dirt (earth) from the field can aggravate this situation. Harvested fruits can overheat and rapidly deteriorate during temporary field storage. Failure to sort and discard immature, overripe, blemished or otherwise damaged fruits creates problems in the subsequent handling and marketing of the produce.

**Transport and handling** - The use of proper containers and their correct loading prior to transport are important factors in the distribution of fruits (Lin and Ma, 1983). Heavy losses of commodities destined for local markets occur nevertheless through careless packing, loading, unloading, and rough handling.

In large scale production, to get the fruit from harvest point to a collection point by the roadside may involve passing some distance of farm roads. Sufficient attention has to be given to the logistics of the transport, handling, etc. so as to minimize fruit damage. Poor handling and transportation over bumpy roads may increase fruits damage by mechanical means. In Ethiopia transport of fruits to the market is frequently carried out in overloaded vehicles on poor roads. Vehicles should therefore be driven slowly and also ridding on top of the produce avoided. The vehicles need to be shaded from both sun and rain. This may be achieved by covering protective
tarpaulin or similar material. At high temperature, fruits will become overheated, especially if there is inadequate shading, no ventilation and/or cooling system. Long distance transportation by open trucks on sunny days can have a sun-scorch effect on exposed parts. Inappropriate packing (e.g., overfilling, under-filling) may physically damage fruits by means of bruising or abrasion as a result of the commodity compression or sway/bend on transport.

**Storage** - Proper storage has the advantage of keeping the supply of perishable fruit even in off season fetching high price to the orchardists. Containers filled with fruit should not be left exposed to sunlight. Delay in placing fruits in cool storage after harvest often results in rapid deterioration in quality. Poor control of the storage conditions, too long a storage, and inappropriate storage could lead to deterioration in fruit quality. Storage at temperatures that are too low may induce physiological disorders or chilling injury. High temperature and high humidity can encourage both superficial and internal mould growth and stimulate activity of infesting insects. Mixed storage of different fruits (e.g., climacteric and non-climacteric fruits) should be avoided. Generally, storage should be done off the ground and with no bulk piling.

**Marketing** - Losses are common during marketing, especially when fresh commodities are exposed to heat. A serious reduction in quality can occur in fruits stored for lengthy periods in retail outlets. Major causes of fruit quality reduction during marketing include wilting, undesirable ripening and senescence, mechanical damage and disease development.

Yahia *et al.* (2004) recommended some means for reducing postharvest losses including:

- Harvest products at optimum maturity, and adequate (cool) time;
- Protect the product from exposure to the sun after harvest;
- Avoid mechanical injury during harvesting;
- Use of pre-cooling and refrigeration;
• Use of appropriate high relative humidity during storage and transport;
• Avoid infestation with diseases and insects, and use adequate control measures;
• Use appropriate packing and packaging systems;
• Transport products adequately;
• Store the product properly at the appropriate conditions;
• Adequate handling (avoid rough handling) of the produce during all the postharvest chain.

Postharvest handling of fruits

Harvested fruits are still living organs. They continue to respire and lose water as if they were still attached to the parent plant, the only difference being that losses are not replaced in the postharvest environment. Significant quantities of fruits are lost between harvest and consumption. The magnitude of these losses varies in accordance with the type of fruit. Fresh fruits to reach the consumer in the right condition must be marketed properly bearing in mind the most suitable temperature and humidity for each type as well as appropriate packaging and handling methods. Proper postharvest management practices are to be followed along with an integrated approach to postharvest crop management if the end user, i.e., the consumer, is to receive the fruit in a good condition. Failure to address these issues leads to stress to the produce rapidly followed by spoilage and losses.

The rate of deterioration process varies with the physical and physiological characteristics of the fruit and it is evidenced in three general ways (O'Brien et al., 1983):

Aging - Commodities with the highest rates of respiration normally have the shortest shelf-life span after harvest.

Desiccation - Desiccation is a very important quality factor that may seriously lower fruit quality. A water loss of 5% or more can significantly detract commodity appearance and may render the commodity unusable. Even when appearance factors are not seriously affected, loss in weight results in loss in
revenue if sale is based on fruit weight. The two basic factors that determine rate of water loss are:

a) the evaporative capacity of the air - This is a function of the difference between the vapor pressure potential (water-holding capacity) of the air and its actual vapor pressure (water content). The evaporative capacity of air increases at an accelerating rate as temperature rises above the dew point. The higher the evaporative capacity of the air is, the faster will be the transpiration rate and loss of water from the fruit. As temperature is essentially the overriding factor in relation to rate of desiccation, quality and market life of fruits obviously can be enhanced by rapid reduction of temperature as soon after harvest as practicable. Quick cooling may be even more important with machine-harvested fruits than with those harvested by hand, inasmuch as machine harvesting normally increase the number of skin breaks. Wherever such breaks occur, water loss tends to be excessive.

b) the physical characteristics of the commodity - This is related primarily to size and surface characteristics. The fruit surface is a barrier to the passage of gases and varies greatly with species and varieties. The skin of grapes is more impervious to water vapor and other gases than the skin of many other fruits. In contrast, the peach, and particularly the nectarine is highly permeable to gases. Apples are relatively impervious, though there are notable differences among varieties.

Considerable water loss may occur during transit over long distances, unless commodities are kept in sealed containers. Water loss can be minimized by protecting the loads with tarpaulins (which reduce air movement). However, a better control can be achieved if the commodity is hydrocooled (cooled with water) before transit.

Decay - due to pathogenic microorganism is a third important major factor in the deterioration of harvested fruits. Decay may be a primary concern in mechanized farming, as the chances of skin damage in machine harvested fruit are greater than those harvested (picked) by hand. The activity of most
microorganisms increases with temperature. Therefore, a rapid reduction in temperature after harvest is one of the best means of preventing or reducing the invasion of fruits by microorganisms. Fruits of advanced maturity are more susceptible to invasion, partly because they are softer and more sensitive to mechanical damage.

In conclusion, the rate of postharvest deterioration of fruit qualities can be effectively controlled by regulating the postharvest environment (such as temperature, relative humidity and proper handling). Fleshy fruits are best stored at relative humidity of about 95% or higher, whereas most nuts can be stored between 50-60% for several days, without appreciable loss in their qualities.

Postharvest treatments of fruits

Fruits, once detached from the plant, undergo a physiological response consisting of processes such as transpiration, respiration, and ripening. Transpiration leads to loss of water and the consumption of substrates during respiration that converts the stored energy into usable energy to sustain life. Thus, the higher the transpiration and respiration, the shorter the shelf life. Such processes are mainly responsible for wilting, shrinking, and loss of firmness among other phenomena, which adversely affect the sensorial quality of produce (Kader, 2002). The time a produce is exposed to any adverse condition is generally directly proportional to the decrease of quality of any horticultural produce (Leblanc and Vigneault, 2008).

The objectives of application of proper postharvest handling (technologies) are to maintain the fresh quality of the produce in terms of appearance, texture, flavor, nutritive value, etc; protect produce, maintain food safety, and reduce the average losses between harvest and consumption (Saraswathy et al., 2010). However, reducing postharvest losses should not be viewed strictly from the viewpoint of technology (Lin and Ma, 1983). According to them, education also plays a key role in reducing losses at virtually every stage of the food chain. Education programs must therefore be aimed at the farmer, the wholesaler, retailer, and even the consumer. Each of
these groups has a role to play and each must be considered in any effort to reduce postharvest losses.

A number of postharvest treatments are applied to fruits to maintain quality (including improving visual appeal). Some of the procedures involved are described below:

**Washing** - Washing may be important to remove sap (e.g., mangoes) and debris (e.g., bananas). Clean water is essential as fungal and bacterial levels may otherwise build up. A series of two or three washes may be required, possibly with mixing certified disinfectant with water to be used for the last wash. A chemical such as chlorine is often used with the wash water as disinfectant; the surface moisture must be removed after the fruit has been washed.

**Waxing (polishing)** - Fruits that have a waxy skin tend to lose water slowly. This observation has led to the application of wax to certain fruits that shrivel rapidly and lose consumer appeal on storage and marketing. In addition to reducing water loss, waxes are also applied to improve the appearance of fruits. The rate of water loss can be reduced by 30-50 per cent under commercial conditions, particularly if the stem scar and other injuries are coated with wax. Citrus fruits are commonly waxed because washing removes much of the natural wax from the peel, and thereby exacerbates fruit shriveling and loss of appearance (lustre). Many other fruits such as passion fruit, bananas, apples, etc. are also waxed to reduce weight loss and to increase consumers appeal. Several waxing formulas are available and used, but it is recommended that natural (rather than synthetic) waxes be used. Drying after waxing is essential. Waxes are sometimes mixed with fungicides such as TB2 (Yahia et al., 2004). Most waxes in commercial use may contain a mixture of waxes derived from plant and/or petroleum sources.

Waxes can be brushed, sprayed, fogged or foamed onto produce, or produce is conveyed through a tank of wax emulsion. The wax film must be thin. Following the application of wax, produce is generally dried and polished.
Disinfestation - Usually, fruits are fumigated to protect them against decaying organisms. For example, grapes are fumigated with sulfur dioxide gas to retard microbial infection such as gray-mold, and citrus fruits are fumigated with ethylene dibromide (EDB) to destroy the eggs and larvae of the Caribbean fruit fly. Papayas are fumigated to control fruit flies before the fruits are exported.

Degreening - The color of many fruits is governed by the presence in the skin of carotenoids and xanthophylls, which give the fruit orange or yellow colors, and chlorophylls, which give them a green color. The change from green to yellow or orange, associated with maturation and ripening of many fruit, may involve pigment synthesis but in many cases it is simply the breakdown of chlorophyll that has been masking the orange or yellow pigments (Thompson, 2003). The pulp of many early-season citrus cultivars becomes edible before the green skin color has completely disappeared. Exposure to low temperature during maturation is necessary for the development of an orange colored peel. This requirement explains why the peel of citrus grown in the low altitude tropics (high temperature condition) fails to degreen completely. Post harvest treatment with ethylene under controlled conditions hastens the loss of chlorophyll. This process is known as degreening. In other words, degreening is a process utilizing ethylene gas to hasten the color change in citrus fruits. It is synonymous term with gassing. Application of ethylene may be by an initial injection of the correct level or by continuously trickling it into the room (Thompson, 2003).

Light processing - There is increasing demand for ready-to-use fruits. This demand has promoted the development of the “lightly processed” fruit industry, which is also known as the “minimally processed” or “fresh cut” industry. Fruit slices such as mango “chips” are light processed product. Consumer demands for convenient but fresh and healthy foods are driving the food industries to apply new and mild preservation techniques, which satisfy the increasing market demands for fewer preservatives, higher nutritive value, and fresh sensory attributes. Traditional preservation technologies and techniques
highly affect the appearance, sensorial characters, and the nutritional value. “Minimal processing techniques have emerged to meet this challenge of replacing traditional methods of preservation whilst retaining nutritional and sensory quality” (Ohlsson and Bengtsson, 2002).

An extension of light processing is fruit drying. Drying has long been practiced to prepare raisins (commonly seedless cultivars) from grapes. Furthermore, the method has been applied to many other temperate, subtropical, and tropical fruits.

**Grading** - Sorting of fruits can be done during the harvest operation itself. Scarred, pitted, over-ripe or otherwise deficient fruits can be placed in separate harvest containers or discarded completely and removed from the field later. Grading is a critically important process because produce presentation, an aspect of quality, is often judged on the basis of uniformity. Uniformity is important as it represents a standard product for handling and marketing. Fruits are generally graded on the basis of size, weight, color, ripening stages, freedom from defects, composition, or a combination of some of these features (Kader, 2002; Yahia et al., 2004).

**Packaging** - After more rigorous preparation such as washing, sorting critically based on size, ripeness, color, etc., packing is performed in pack-house. The function of packaging is to ensure the safety and quality of the product from production through transportation to the customer including storage, transporting, and selling the product and informing the customer (Fellows, 1988; Yahia et al., 2004). Packaging also facilitates assembling of the produce into convenient units for handling. Selection of the packaging material must be made using the knowledge of product characteristics and requirements for food safety and quality control.

Nowadays, fruit is transported and sold in an enormous range of packages constructed of wood, fiberboard, jute or plastics. Modern packages and packaging of fresh produce are expected to meet a range of basic requirements. They must:
- have sufficient mechanical strength to protect the contents during handling and transport, and while stacked;
- be largely unaffected, in terms of mechanical strength, by moisture content when wet or at high relative humidity;
- stabilize and secure the product against movement within the package during handling (i.e., avoid both under-filling and over-filling);
- meet handling and marketing requirements in terms of weight, size and shape;
- offer security for the contents and/or ease of opening and closing in some marketing situations;
- not contain chemicals that could contaminate and taint the fruit or could be toxic to the produce or to humans;
- identify the contents (including type of fruit, origin, quality grade and weights or counts), proper handling instructions and aid retail presentation through comprehensive and accurate labelling;
- facilitate easy disposal, reuse or recycling; and
- be cost-effective in relation to the value and the required extent of protection of the contents.

Cooling - The aim of cooling is to slow fruits deterioration due to abnormal ripening or other undesirable changes so as to maintain their quality for as long as possible. It is generally accepted that the quicker the temperature of the produce is reduced to the optimum storage temperature, the longer will be its storage life. Rapid or fast cooling after harvest is generally referred to as "pre-cooling" and is particularly useful for highly perishable fruits (e.g., strawberry). Rapidly respiring fruits, which have a short postharvest life, should be quickly cooled immediately after harvest. Fruits that have a longer postharvest life generally do not need to be cooled quite so rapidly as the former. Nonetheless, they should still be cooled as soon as possible. Fruits that are susceptible to chilling injury should not be exposed to chilling temperatures, but need to be cooled according to their individual requirements. General temperature recommendations for non-chilling-sensitive, moderately chilling-sensitive and highly chilling-sensitive fruit groupings are 0°C, 5-7.5°C and 13-15°C, respectively (Wills et al., 1998).
Methods of fruit cooling

Fruits are normally cooled with cold air (room cooling, forced or pressure cooling) (Wills et al., 1998).

Room cooling - Probably the most common pre-cooling technique is room cooling, whereby fruits in boxes (wooden, fiberboard, plastic), bulk containers or various other packages are exposed to cold air in a normal cool store. For adequate cooling, air velocities around the packages should be at least 60 m/min (Wills et al., 1998).

Pressure (forced air) cooling - Pressure cooling involves passing cold air, along an induced pressure difference (gradient) past initially warm produce in specially vented containers. The pressure differential is induced by fans that circulate cold air through the produce and packaging, which constitute the resistance to air flow. Pressure cooling can cool produce (fruit) in about 10-25 per cent of the time required for room cooling.

Effects of temperature on storage of fruits

Temperature is the single most important factor governing the maintenance of post-harvest quality in fruits. Temperature responses of harvested fruits can be generally classed as:

- adverse low and high temperature effects; and
- normal intermediate temperature range effects.

Adverse low temperature effects - Freezing injury occurs at 0°C or at a low temperature, and involves intercellular and/or intercellular ice formation. The precise temperature at which freezing occurs depends upon the concentration of solutes in the tissue, with the freezing point being lowered further with increasing osmotic concentration (i.e., freezing point depression). For example, grapes, which have a very high sugar content (approximately 14 per cent of
fresh weight), do not freeze until the temperature falls below -2.0°C (Wills et al., 1998).

Freezing of tissue water initiates dehydration and osmotic stress of cellular structures, such as membranes and other constituents like proteins. In addition, expansion of the water upon freezing, especially intracellular ice formation (crystallization) can cause considerable physical disruption to the cell structure.

Chilling injury of susceptible fruits occurs at low temperatures that are above the freezing point of the produce. Injury is the result of imbalance metabolism and the loss of cellular compartmentalization at sub-optimal temperatures. Subtropical and tropical fruits are especially sensitive to chilling, with chilling thresholds for tropical fruits being around 13°C.

**Adverse high temperature effects** - The activity of enzymes in fruit (like in vegetables and ornamentals) declines at temperatures above 30°C. Continuous exposure of some climacteric fruits to temperatures around 30°C allows the flesh to ripen but inhibits fruit coloration. When fruit is held above 35°C, metabolism becomes abnormal and this results in a breakdown of membrane integrity and structure, with disruption of cellular organization and rapid deterioration of the produce. The changes are often characterized by a general loss of pigments, and the tissues may develop a watery or translucent appearance.

**Normal intermediate temperature (physiological temperature range) effects** - Harvested fruit is ideally transported and stored under reduced temperatures to maximize longevity. However, the effect of reducing temperature on the maintenance of fruit quality is not the same for different fruits. For instance, 0-30°C is normal for non-chilling-sensitive fruits, 7.5-30°C for moderately chilling-sensitive fruits and 13-30°C for chilling-sensitive fruits; (Table 6-2). The quality can be best maintained if fruit is held just above its freezing point or above its chilling threshold temperature in the case of chilling-sensitive fruits.
Table 6-2. Recommended temperature ranges to maximize storage life of selected fruits.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Fruits</th>
<th>Shelf life (weeks)</th>
<th>Optimum storage temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very perishable (Within 0-4 weeks)</td>
<td>Strawberry</td>
<td>1-5 days</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Banana, green</td>
<td>1-2</td>
<td>≥ 10</td>
</tr>
<tr>
<td></td>
<td>Mango</td>
<td>2-3</td>
<td>≥ 10</td>
</tr>
<tr>
<td></td>
<td>Avocado</td>
<td>3-5</td>
<td>5-9</td>
</tr>
<tr>
<td></td>
<td>Grape</td>
<td>4-6</td>
<td>1-4</td>
</tr>
<tr>
<td>Perishable (Within 4-8 weeks)</td>
<td>Mandarin</td>
<td>4-6</td>
<td>5-9</td>
</tr>
<tr>
<td></td>
<td>Passion fruit</td>
<td>4-5</td>
<td>5-9</td>
</tr>
<tr>
<td></td>
<td>Peach</td>
<td>2-6</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Pineapple, green</td>
<td>4-5</td>
<td>≥ 10</td>
</tr>
<tr>
<td>Semi-perishable</td>
<td>Orange</td>
<td>6-12</td>
<td>509</td>
</tr>
<tr>
<td>Non-perishable</td>
<td>Apple and Pear</td>
<td>8-30</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Grapefruit</td>
<td>12-16</td>
<td>≥ 10</td>
</tr>
</tbody>
</table>

Adapted from: Wills et al. (1998).

Lowering the temperature of both climacteric and non-climacteric fruits decreases their rate of deterioration (i.e., high quality is retained for a longer time). Besides, low temperature can be used to delay the onset of ripening of climacteric fruits. Normal ripening occurs only within a particular range of temperature (commonly 10-30°C). The best quality in fruit, however, generally develops at a ripening temperature of 20-23°C. Provided that a fruit is not sensitive to chilling, maximum storage life can be achieved at temperatures below the ripening range.

Processing of fruits

Most fruits are ripe at certain seasons of the year only. For a short time they are likely to be comparatively cheap and plentiful in the market, but at other times they are expensive if available at all. Processing is therefore the best way to utilize surplus production of fruits, particularly during the period of
seasonal glut. The major purpose of processing of fruits is to protect them from deterioration, as most of the fruits are likely to spoil very rapidly. Generally, the following are advantages of processing fruits:

- Processing helps in converting perishable fruits into a durable form,
- There are some fruits which are difficult to eat out of hand due to various hindrances, these fruits can be processed into a range of highly acceptable fruit products,
- Processing helps in reducing wastage, and
- A considerable amount of value addition takes place due to processing.

Hygiene and sanitation

Hygiene and sanitation play an important role in maintaining the quality of horticultural produce. The primary non-commercial element of product assurance is food safety, with consumers expecting a guarantee that fresh produce does not contain pesticides or microorganism residues that could harm health (Wills et al., 2007). Managing quality of perishables along the whole distribution chain from the farm or orchard to the final point of sale is very important. To achieve this, it is necessary to monitor and prevent quality problems as early as possible in the production process, rather than relying on endpoint and reactive inspection at a later stage during distribution when the product has become more valuable. Food products must fit the dual requirements of food safety and food quality. Besides, there is a third requirement: a continuous supply of the required products in the quantity needed by the customers. Food safety means that the food is free from microbes and/or toxins causing foodborne illness and free from foreign matter dangerous to human health (Barta, 2006). In other words, the product must meet public health requirements for microbiological quality (Schlotke et al., 2000).

Product quality is a prime criterion in gaining access to competitive markets. Market-oriented, successful food production must focus on the final consumer. The food product must be wholesome and safe and so food safety is an important requirement (Nenguwo, 2004). The aim of fruit and vegetable
production is to deliver a safe and wholesome final product to the consumer. Nevertheless, fresh fruits and vegetables have recently been identified and confirmed as a significant source of pathogens and chemical contaminants that pose a potential threat to human health worldwide (Anonymous, 2007).

Raw and minimally processed fruits and vegetables are an essential part of people’s diet all around the world. If hygiene and sanitation are not kept to the standard, several pathogenic bacteria, viruses, and parasites capable of causing human disease can be found on raw fruits and vegetables. Some of these microorganisms are capable of growing on whole, minimally processed or cut fruits and vegetables under routine handling and storage conditions (Camelo, 2004).

Food safety is related to the physical, chemical, and microbial conditions or influences under which food products are grown, harvested, stored, and transported to food markets. A food safety risk is a site condition or operational factor, which creates the potential to affect the safeness of your produce in a negative way. All risks ultimately have the potential to affect the health of the consumer by causing food-borne illness. Food-borne illness occurs when a person gets sick by eating food that has been contaminated with pathogenic microorganisms (Beuchat, 1996).

Fruits and vegetables can become contaminated with microorganisms capable of causing human diseases while still on the plant, in fields or orchards, or during harvesting, transport, processing, distribution, and marketing, or in the home. The most common ways of contaminating fresh fruits with pathogens (potentially causing food-borne illness) are: by direct contact with water containing microbial hazards; direct contact with animal manure or faeces; passing of pathogens by workers to produce during handling; and contact of produce with microbial hazards in the field, food facilities, or on vehicles, machinery, and equipment (Beuchat, 1996; Camelo, 2004). Contamination may also occur during postharvest handling, including at points of preparation by street vendors, in food-service establishments, and in home.

Prevention of contamination of fruits and vegetables with pathogenic microorganisms should be the goal of everyone involved in both the pre-harvest and postharvest phases of delivering produce to the consumer.
Reduction in the chances of contamination can be achieved through appropriate (hygienic) agronomic practices, harvesting, processing, shipping, marketing and preparation.

The use of properly composted manure and properly treated irrigation and spray waters, as well as pathogen-free water for washing will minimize the risk of contamination of fruits and vegetables with microbial pathogens. Good hygienic practice during production and transport, including sanitizing of harvesting equipment and transport vehicles, as well as the application of good hygienic practice during processing and preparation are critical (Beuchat, 1996). The highest level of hygiene must be practiced by all handlers (including consumers) of fruits and vegetables, from the field to the table, if any degree of success is to be achieved in minimizing the risk of contamination.

The microorganisms normally present on the surface of raw fruits and vegetables may consist of chance contaminants (e.g., bacteria or fungi) from the soil or dust, that have grown and colonized by utilizing nutrients exuded from plant tissues. Microorganisms capable of causing human disease can, however, be found on raw produce, and should be viewed as a threat to public health (Beuchat, 1996). What is not well known is where contamination occurs along the farm-to-fork pathway. Means to address this issue must address the entire system from production to consumption.

The presence of a pathogen on produce is of less consequence if the rind, skin or peel is to be removed before consumption (Burnett and Beuchat, 2001). Bananas, mangoes, pineapples and papayas, for example, fall in this category. However, the process of removing the rind, skin or peel from these fruits, perhaps with the exception of bananas, may result in contamination of the edible portion, thereby creating a risk to the consumer.

Camelo (2004) stated important ways which fresh product may acquire food borne illness from as under:

1. Use of water - Wherever water comes into contact with fresh produce, water quality determines the potential for microbial hazards to be present. The food safety objective in using water is to use good
quality water at the outset and to minimize the risk of cross-contamination. Food safety risk is minimized by adopting practices to maintain water quality, minimize the potential for contaminated water to contact the produce, and using procedures which monitor and detect potential water-borne threats to food safety on the farm.

2. Use of manure - While composted manure and produce waste are desirable sources of organic fertilizer and soil conditioner in tree fruits production, respectively, they are also significant sources of microbial hazards when stored, handled and used. Reducing food safety risks can be attained by: using manure or produce waste in a manner that prevents cross-contamination of water; adopting practices which minimize the potential for raw manure and produce waste to contact fresh fruits; and using procedures which monitor and detect potential manure-borne and produce waste threats to food safety on the farm.

3. Worker hygiene and sanitation - Farm workers can be a source of microbial hazards for fresh fruits. The micro-organisms are spread to produce through the use of unsanitary materials and equipment, improper hygiene, and ineffective sanitary measures. The most effective way to combat worker-borne contamination risk is through education, training and supervision of workers who handle produce.

4. Orchard, facility, vehicle, machinery and equipment sanitation - Poor management of materials, machinery and equipment on the farm can significantly increase the risk of exposing fresh fruits to microbial hazards. The food safety objective is to start with clean materials, machinery and equipment; use practices which minimize the potential for cross-contamination; and monitor and detect potential hazards before they affect the food safety of products.

Good agricultural practices (GAPs) can reduce the potential for microbes to contaminate fresh fruits. GAPs over which producers have control include:
• maintaining proper temperatures at all times to ensure quality and safety of produce ensuring that only clean food facilities are of sound construction and kept in good repair,
• maintaining overall farm cleanliness and good sanitary practices supervising the hygiene and sanitation practices of workers having a supply of potable water readily available to farm workers for washing and drinking, minimizing the potential for water contamination in irrigation, especially close to harvest, by using good quality water and preventing contaminated water from coming into contact with the edible product.

References


CITRUS (Citrus spp.)

Citrus fruits belong to the Rutaceae family. They are universally popular and are the most important fruits of all the subtropical fruits in world trade. Citrus fruits are known to have originated in the region stretching from India and China in the northwest, to Australia and New Caledonia in the southeast, where they are still found in the wild state (Ellison, 1986).

The term citrus is applied both to the trees and their fruit. Citrus is the most widely produced fruit, as a group of several species and it is grown in more than 80 countries (Chang, 1992). Nowadays the citrus fruits are grown in subtropics and tropical regions throughout the world, approximately between 40° north and south latitude.

Botany

The genus *Citrus* consists of two distinct subgenera (Goswami and Saxena, 1999; Morley-Bunker, 1999), *Eucitrus* and *Papeda*, easily distinguished by leaf, flower and fruit characters. The subgenus *Eucitrus* contains the important cultivated (or edible) species, all of which have pulp vesicles filled with pleasantly acid, subacid or sweet juice, free or almost free from droplets of oil. On the other hand, *Papeda*, comprises species which contain droplets of acrid oil in the pulp-vesicles which usually give the juice a very disagreeable, acrid, bitterish flavor; the petioles are long and broadly winged. Generally, none of the species of citrus belonging to this subgenus have edible fruits, but are known to have numerous local uses in various parts of the world.

There are ten spp. in *Eucitrus*, eight of which are cultivated (Morley-Bunker, 1999): *Citrus sinensis* (sweet orange), *C. aurantium* (sour
orange), *C. reticulata* (mandarin), *C. paradisi* (grapefruit), *C. grandis* (pumelo), *C. limon* (lemon), *C. medica* (citron) and *C. aurantifolia* (lime).

When the overall citrus production in the world is considered, sweet oranges are by far the most important species, but in most cases figures are given for these and mandarins combined. Next in order come grapefruit, lemons, and limes. Depending on area and production, and consumer preference, in Ethiopia, citrus fruits may be put in the following descending order: sweet oranges, mandarins, limes, lemons, grapefruits, citron and pumelo.

In general the genus *Citrus* can be described as follows (Ziegler and Wolfe, 1961; Goswami and Saxena, 1999): trees evergreen, small to medium in size, more or less thorny (single spines in leaf axils, older branches often spineless). Leaves unifoliate, the petioles with or without wings, the blade jointed to the petiole (except in citron). Flower buds without protecting scales, formed just prior to the advent of a flush of growth. Flowers usually large, fragrant, white mostly but in a few species white tinged with pink or purple; both stamens and pistil present in the same flowers normally. Fruits small to very large, with the typical leathery rind, the color at maturity varying from yellow through orange to a deep orange-red (in tropical areas the fruit may be fully but still green); the pulp varying from insipidly sweet (too sweet) to very acid, with droplets of oil in juice vesicles, which are acrid (bitter) in some species but not in any of commercial interest: segments 8 to 18, usually 10 to 14. Seeds none, few, or many (there may be from 4 to 12 in each segment), the cotyledons usually white, but pale green in the mandarin group.

Citrus fruit is a special kind of berry known as *hesperidium* (Fig. 7-1) that ranges widely in size, color, shape, and juice quality (Manner et al., 2006). The fruit is globose to ovoid in shape, filled with stalked spindle-shaped pulp-vesicles (*juice sacs*) commonly covered by a white spongy tissue (*albedo*, internal layer) and a peel (*flavedo*, external layer) with numerous oil glands, turning yellow or orange at full maturity; seeds contain one or many embryos (Hume 1957; Rice et al., 1994). The flavedo layer contains essential oils in the range of 0.5 to 3.0 kg per ton of fruit (Sattar et al., 1986). Citrus peel essential oils are extensively used as flavoring agent in candy, carbonated and non-carbonated beverages, bakery products, and ice
cream (Crouse, 1960). Studies of Wells (1970) on the utilization of various citrus oils indicated that lemon oil was used as 60% in soft drinks, 15% in cakes and biscuits, 14% in confectionery, 5% in flavorings, 3% in perfumery, 2% in pharmaceuticals and 1% in others. Similarly, orange, mandarin, tangerine and grapefruit oils were also being used as flavoring agents in different products such as bakeries, soft drinks and liquors and confectioneries.

![Illustration of citrus fruit](image)

**Figure 7-1.** Citrus fruit (*Hesperidia*).

Depending on species and cultivar, trees reach heights of 3-15 m (Manner *et al*., 2006). For example, trees vary in height from 3.0-4.5 m (lime), 3-6 m (lemon), 7.5-12.0 m (orange), and 9-15 m (grapefruit). Tree growth and form varies depending on the genetic background and whether the tree was established by seed or grafting. Generally, limes have a low-growing habit and long branches that arch outward. The typical form of sweet orange tends to be a conical shape, narrowing toward the top of the tree, with upright medium to large, compact horizontal branches. Grapefruit produces large trunks (0.5-0.75 m in diameter) and a large conical head. Trees produced from seed tend to have more thorns and upright branch growth than trees produced from grafting (Manner *et al*., 2006).

The leaves are generally evergreen (except for *P. trifoliata* Raf. with deciduous leaves). Those of the genus *Citrus* are simple and generally thin, with a more or less winged petiole. The genus *Poncirius* has trifoliate, palmate leaves. The color and shape of leaf blade and petiole wings of the genus *Citrus* are important for diagnosis (identification purpose). Lemon, for example, has pale green leaves that are more or less transparent. In grapefruit
and pumelo the petiole wings touch or partly overlap the leaf blade, which is not the case in sour orange. Generally, the leaf is ovate (egg-shaped), but it is rather elliptic in citron and oblong in mandarin. Usually the leaf margin is entire, but it is serrated in lemon or citron and crenulated in lime. Petiole wings are missing in citron, narrow in most species, broad in sour orange, grapefruit and pumelo (Fig. 7-2).

The flowers are white in all species except lemon and citron where they are purplish on the outside. The most noticeable differences are in the fruits; pumelo has the largest and limes the smallest. The surface may be rough as in sour orange, or smooth as in sweet orange. The peel is loose and easily detached from the segments in mandarin, but adheres in other species.

Figure 7-2. Leaves of different citrus plants and their relative (*Poncirus trifoliata*): (1) pumelo (2) grapefruit (3) sour orange (4) sweet orange (5) mandarin (6) lemon (7) lime (8) citron (9) trifoliate orange
Adapted from: Hume (1957)
Ecological requirements

Climate, soil and water are the chief environmental factors influencing the growth and development of citrus. Suitable climates for citrus are the tropical and subtropical humid regions of the world (Manner et al., 2006). The fruit is said to achieve its highest flesh quality in subtropical humid climates or the drier regions (i.e., Mediterranean climates) with irrigation (Rieger, 2002).

Climate is one of the most important factors affecting the profitability of a citrus industry. Temperature, rainfall and wind are the most important components of the climate that affect citrus production. Extremely hot or extremely cold temperatures are damaging to citrus. Frost could damage trees by injuring flowers, young leaves, and fruit (Samson, 1986; Bal, 2002).

The optimal temperature for growth of citrus is between 25°C and 30°C. A higher or lower temperature than optimum range diminishes growth of the plants and growth ceases at a temperature of 13°C. High temperature injury occurs at temperature above 42°C and is most severe during flowering or if cool temperatures are followed by hot. An apparent damage is deflowering and defoliation. Yet, citrus trees can withstand more extreme temperatures (up to about 50°C) fairly well and down to the freezing point or slightly below it (Samson, 1986; Goswami and Saxena, 1999). High temperatures are harmful for two reasons:

1. Respiration and transpiration continue at a high rate, while photosynthesis decreases sharply; and
2. Pigmentation of fruit does not take place; on the contrary, colored fruit may re-green. The re-greening is associated with activity of chlorophylase, an enzyme which is responsible to degrade chlorophyll (green pigment) and expose (unmask) other pigments (e.g., xanthophyll, in case of citrus). The activity of this enzyme is less under higher temperature conditions that is why in high temperature seasons mature fruits show re-greening. Most citrus species require full sunlight to grow well and produce fruit. Shading greatly decreases plant vigor and productivity (Manner et al., 2006).
For good citrus production, trees will require a well-distributed sufficient amount of rainfall or irrigation water. Where dry seasons occur, planning for irrigation is required. Water requirements vary according to climate and soils from as little as 450 mm to as much as 2,700 mm per year (Rice et al., 1994).

Wind can cause serious damage to citrus trees and fruit. Hot dry winds will often scorch trees by drying young leaves. Winds of high velocities will scar fruits and cause fruit drop, break branches and in the worst case can uproot the trees. Where wind is a problem, windbreaks can be effective in reducing the velocity below damaging levels.

Citrus trees will grow in a wide variety of soils but they grow best on medium textured and moderately deep, well-drained and fertile soils which are not high in soluble salts. Citrus does not stand waterlogged soil (Marte, 1987; Manner et al., 2006). The best pH for citrus soils ranges from 5 to 6. In soil, which is too acidic, citrus roots do not grow well and nutrients are leached out, and some elements may even become toxic (e.g., Cu, Fe, Al, Mn). At a pH above 6, fixation of nutrients (especially zinc and iron) will take place and trees develop deficiency symptoms. A low pH associated problems can be corrected by liming the soil.

Crop husbandry

Citrus can be propagated by many methods including seeds, cuttings, air-layering, grafting by many methods, and tissue culture (Manner et al., 2006). Although some cultivars can be reproduced by seed, this method is considered inferior. Varieties that are reproduced by seed require more time to produce fruit, are more susceptible to diseases, are more difficult to keep true to type, and tend to produce more thorns than grafted varieties. Their fruit is also harder to pick as a result of the upright and thorny growth.

Citrus cultivars can be propagated by seed or vegetative means. Although some cultivars can be reproduced by seed, this method is considered inferior. Varieties that are reproduced by seed require more time to produce fruit, more difficult to keep true to type, and tend to produce more thorns than grafted varieties. Common vegetative propagation methods of citrus
include cuttings, air-layering, budding, grafting, and tissue culture. T-budding (also called shield budding) is the most common and popular method of budding and used to propagate citrus fruits. Inverted T-budding is also used during rainy seasons (or in areas with frequent rainfall). In this method horizontal cut is prepared at the base of vertical cut. The shield shape of bud is inserted into vertical cut from the lower part of the cut.

There are literally thousands of citrus cultivars. Thanks to polyembryony and vegetative propagation, the great majority of them are well identified and established clones. With the exception of Mexican lime, commercial production employs scion cultivars budded onto a desirable rootstock (Samson, 1986). Many Citrus species reproduce apomictically by seed, through nucellar embryony (Tusa et al., 2002); these embryos are genetically identical to the mother plant, and develop within the same embryo-sac together with the zygotic embryo.

The kind of rootstock used can have a profound effect on the results obtained throughout the life of the plantation. The choice of rootstock is, therefore highly critical; and a number of factors, particularly the disease situation and soil conditions, have to be considered. Spacing within the orchard depends largely on the scion and rootstock combination. As a general guideline, oranges, mandarins and grapefruit are spaced 7-9 m apart and lemons 6-8 m apart. Limes can be planted 5 m apart. Spacing presently used in Ethiopia is indicated in Table 7-1.

Table 7-1. Recommended spacing for some citrus trees in Ethiopia.

<table>
<thead>
<tr>
<th>Type of fruit/cultivar</th>
<th>Spacing between rows and plants (m)</th>
<th>Plant population /ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange</td>
<td>8 x 4</td>
<td>313</td>
</tr>
<tr>
<td>Mandarin</td>
<td>7 x 3.5</td>
<td>408</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>9 x 4.5</td>
<td>247</td>
</tr>
<tr>
<td>Lemon</td>
<td>8 x 8</td>
<td>156</td>
</tr>
<tr>
<td>Mexican lime</td>
<td>8 x 8</td>
<td>156</td>
</tr>
<tr>
<td>Bearss lime</td>
<td>5.5 x 5.5</td>
<td>331</td>
</tr>
</tbody>
</table>

Source: Jackson et al. (1985)
Citrus trees respond vigorously to high levels of soil fertility although they are also highly sensitive to excess soluble salts in the soil; therefore fertilizer must be used with good judgment.

Normally citrus trees require regular application of nitrogenous fertilizers following planting. Phosphorous, potassium, and minor elements should be applied only when deficiency symptoms are observed or when soils are known to be deficient. Nutrient deficiencies are best determined by leaf analysis. Nitrogen should be applied according to the following rate (Jackson et al., 1985): 100 g of N/tree/tree age (year/annum), up to a maximum of 2,000 g/tree/annum.

Thus, a tree in the first year after planting should receive 100 g of N. This is equivalent to about 200 g of urea (46% N), or to about 500 g of ammonium sulphate (20.5% N). In the second year the application would be 200 g of N per tree, and so on until the maximum quantity of 2 kg of N per tree is reached.

Ammonium sulphate \((\text{NH}_4\text{H}_2\text{SO}_4)\) is preferred to be used in slightly acid or alkaline soils. Fertilizer should be applied by spreading over the area of the root zone followed by the mixing of the surface soil. However, at the early stage ring application can have a better effect.

When soils are known to be deficient in phosphorous or potassium, or when trees show deficiency symptoms of these elements, P and K may be applied according to the following rate: 25 g of P/tree/tree age/annum, up to a maximum of 250 g/ tree/ tree age/annum.

The annual application rate of nitrogen should be divided into two equal parts, the first half being applied at the time when the main growth flush is starting and the second about three months after flowering, when the fruits are swelling. If phosphorus and potassium fertilizers are used, the whole amount should be mixed and added together with the first half of nitrogen. Additional amounts of fertilizer must be applied to inter-planted crops (if any). During the first year after planting, the annual nitrogen application may be divided into monthly or bimonthly applications.

Citrus are susceptible to many diseases (Samson, 1986; Goswami and Saxena, 1999; Ladaniya, 2008). Perhaps, the most serious are those caused by
virus and virus-like organisms. These are transmitted by aphids, phyllids and other sucking insects as well as by vegetative propagation from infected trees. Control is therefore by correct propagation practices (using virus free propagules) and by controlling the insect vectors.

**Tristeza Virus Disease (quick decline)** - Tristeza virus is one of the most serious pathogens of citrus and is widespread throughout citrus-growing areas. Symptoms are highly variable among citrus species and cultivars and are affected by the strain of the virus and the environmental conditions (Manner et al., 2006). The aphid (Toxoptera citricida) transmits Tristeza virus disease (Goswami and Saxena, 1999). The symptoms begin with the dieback of small branches and twigs, yellowing of leaves and heavy bearing of small fruits. As the disease advances the symptoms, intensify, resulting in severe chlorosis and mottling. The feeder roots of the affected plants die, the bark of the larger roots is distorted and brittle, and dry rot symptoms are observed in case of lateral roots. After 7-8 years the branches of the affected plant dry up completely and the plants wilt completely. Few trees show wilting symptoms overnight and completely dry up in 2 or 3 days. Hence, Tristeza is also called a quick decline disease.

Where the virus is present, sour orange should not be used as a rootstock. In this case, rough lemon, sweet orange, or Cleopatra mandarin can be used as a rootstock. Symptoms of tristeza (viral disease) are rapid yellowing and death of foliage accompanied by branch dieback and eventually death. Good cultural practices, increasing the fertility levels of the soil and good drainage are useful in reducing the decline disease. The best method to check this disease is to control the aphid population by application of insecticides in the nursery and also in plantations.

*Psorosis or scaly bark disease* can be identified by bark lesions, which only develop six to ten years after infection. Since psorosis is transmitted almost entirely by propagation from infected trees the disease can be largely avoided by careful propagation practices.
**Citrus Exocortis** - Exocortis is characterized by drying narrow strips of outer bark, which tend to separate from the inner live-bark. The outer bark slowly peels off as it withers. The affected trees show lack of vigor resulting in dwarfing. The disease can be prevented by the use of virus-free budwood. Grafting tools should be disinfected after pruning branches from diseased trees.

*Citrus greening* is one of the most devastating citrus diseases, caused by a bacterium which grows in the bark, leaves, and veins of infected trees (Manner *et al.*, 2006). It is a serious problem in middle altitude areas. Huanglongbing (HLB) is the recognized common name adopted by the International Organization of Citrus Virologists (Da Graca and Korsten, 2004) and the American Phytopathological Society (Timmer *et al.*, 2000) for citrus greening disease. It is transmitted by the Citrus Psyllid (*Trioza erytreae*) and by propagation from infected trees. The initial symptoms are frequently the appearance of yellow shoots or mottled leaves on a tree. As the bacteria move within the tree, the entire canopy progressively develops a yellow color, retarded growth and tip necrosis (Bove, 2006). The most characteristic symptoms of HLB are a blotchy leaf mottle and vein yellowing that develop on leaves attached to shoots showing the overall yellow appearance. These foliar symptoms may resemble other diseases or a zinc deficiency although the green and yellow contrast is not as vivid with HLB as it is with zinc deficiency. Leaves with HLB have a mottled appearance that differs from nutrition related mottling in that HLB-induced mottling usually crosses leaf veins. Nutrition related mottles usually are found between or along leaf veins. Also, HLB-infected leaves may be small and upright (Halbert and Keremane, 2004).

Fruits from diseased trees are small, often misshapen, and typically some green color remains on ripened fruit. This is a key symptom, especially in the presence of aborted seeds, and is the origin of the common name “greening”. The preferred name is currently huanglongbing or HLB. Yields are almost non-existent, and the remaining fruit are rendered worthless due to small size, poor color, and bad taste (Timmer *et al.*, 2000; Halbert and Keremane, 2004; Bove, 2006).

Long distance spread of HLB occurs by grafting with diseased
budwood. Local spread of the disease may be due to grafting but is also attributed to two species of citrus psyllids. African citrus psyllid (*Trioza erytreae*) and the Asian citrus psyllid (*Diaphorina citri*) (Conant et al., 2007).

As the disease is transmitted through grafting, the budwood used from the parent tree should be free from greening. Controlling the vector (psyllids) population through sprays and insecticidal soil drenches can effectively check this disease in the field. The use of cultural methods for control of HLB has had some limited success. In South Africa, removal of infected branches and trees, removal of neglected trees, and the use of HLB-free planting material are used to reduce the impact of HLB (Halbert and Keremane, 2004). In this regard, clean nursery programs are essential.

**Foot Rot or Gummosis** (*Phytophthora* spp.) - The symptoms appear as yellowing of leaves, followed by cracking of bark and profuse gumming on the surface. The main source of infection is infected planting material. As a result of severe gumming, the bark becomes completely rotten and the tree dries owing to girdling effect. Prior to death, the plant usually blossoms heavily and dies before the fruits mature. In such cases, the disease is called foot rot or collar-rot.

In soils, which are poorly drained, forms of gummosis and root and crown rots may be a problem. Preventive measures like selection of proper site with adequate drainage, use of resistant rootstocks and avoiding contact of water with the tree trunk by adopting ring method of irrigation are effective. Alternatively the disease portions are scraped-out with a sharp knife and the cut surface is disinfected with Mercuric chloride (0.1%) or Potassium permanganate solution (1%) using a swab of cotton. Painting 1 m of the stem above the ground level with Bordeaux helps in controlling the disease. Also spraying and drenching with Ridomil MZ 72@ 2.75 g/L or Alieette (2.5 g/L) is effective in controlling the disease.

**Citrus Canker** - The disease is caused by a bacterium, *Xanthomonas axonopodis* pv. *citri* (Manner et al., 2006; Ladaniya, 2008). The disease symptoms appear on leaves, branches and fruit stalks. Canker lesions appear as yellowish spots,
which gradually enlarge and appear as raised, rough brownish pustules. These pustules are surrounded by a characteristic yellow halo.

Citrus canker occurs primarily in tropical and subtropical climates where considerable rainfall accompanies warm temperatures, but it can also occur in drier climates (Polek et al., 2007). Citrus canker becomes a serious disease when wet weather conditions occur during the periods of shoot emergence and development of young citrus fruits. Citrus canker is mainly a leaf-spotting and rind-blemishing disease; however, when conditions favor disease development, defoliation, shoot dieback, and fruit drop occur. It affects fruit appearance and renders it completely unfit for marketing (Ladaniya, 2008). Small circular-shaped (0.1-1 mm up to 3 mm in diameter) cankerous lesions in the form of raised pustules with a yellow halo develop on fruit surfaces, twigs, and leaves. It causes a rough texture on the fruit surface, but the internal part of fruit is not affected. Canker lesions on the fruits are confined to the rind only and do not penetrate into the flesh of the fruit. The market value of the canker-affected fruits is very much reduced. An infection occurs primarily through leaf stomata, other natural openings, and wounds. A combination of wind and rain increases the potential for the disease to be spread over short distances. Windbreaks surrounding citrus plantings, especially when facing the prevailing wind direction, can hinder or limit the natural spread of citrus canker by wind (Polek et al., 2007).

Pathotypes of citrus canker may vary in their severity, host range and location in the world (Polek et al., 2007). In general, grapefruit, Mexican lime, and trifoliate orange are highly susceptible to all pathotypes of citrus canker. Early oranges are moderately to highly susceptible; sour orange, lemons, and sweet orange are moderately susceptible; and mandarins are moderately resistant (Schubert et al., 2001).

Leaf and fruit spot of citrus (Phaeoramularia angolensis, syn. Cercospora angolensis) - The causal agent of leaf and fruit spot of citrus (also called Phaeoramularia fruit and leaf spot) is the fungus Pseudocercospora angolensis (formerly Phaeoramularia angolensis). The disease indiscriminately attacks fruits, young twigs and leaves of citrus trees (Eshetu Derso, 1999). The
disease has been observed on all citrus species, including grapefruit, lemon, lime, orange, pummelo, and mandarin. Grapefruit, orange, pummelo, and mandarin are very susceptible, lemon is less susceptible, and lime is the least susceptible (Seif, 2000).

Infection occurs through splash-borne conidia invading the underside of the leaf to produce an irregular necrotic spot up to 1 cm in diameter visible on the upper surface and surrounded by a chlorotic halo (Seif and Hillocks, 1997). Several spots may unite to cover much of the leaf area. Early infection of the fruit leads to abortion or mummification of the young fruit. Infection later in fruit development causes a circulator necrotic spot 1-2 cm in diameter, surrounded by an area of chlorosis. Lesions appear sooty black in wet weather due to sporulation of the pathogen. A single such lesion usually renders the fruit unsaleable. On young fruits, brown necrotic lesions form. These are usually circular, slightly sunken, with a surrounding ring of raised epicarp, giving the fruit a blistered appearance. During wet weather, the lesions sporulate and become black. In young fruits, a generalized necrosis sometimes forms, resulting in premature abscission of the fruit. Fruits and leaves are much more susceptible than stems, on which symptoms are rare. When infection of stems occurs, the lesions are dark-brown and usually occur as extensions of petiole lesions. They may join together resulting in stem die-back or the formation of corky internodal regions. The affected fruit produce poor quality juice, and thus are not suitable for processing or the fresh market.

Under natural conditions, *P. angolensis* probably spreads by air-borne conidia (asexual spores), although the possibility of transfer by insects cannot be discounted. Internationally, transfer on the leaves of planting material or on fruits seems the most likely pathway. Infection is apparently favored by wind-blown rains that occur when susceptible young leaves and fruit are present and temperatures are warm.

In Ethiopia it was first observed at Bebeka state farm (located in southwestern part of the country), and within a very short period of time, it spread to the wet regions of the south and south west parts of the country including Bebeka, Mizan, Metu, Jimma, Lemmu, Gibe, Wolkite and most parts
of Sidama zone (Mohammed et al., 2009). In these areas the disease has become a menace to citrus production and currently it has reached epidemic level. The economic losses of the outbreak have resulted from direct fruit damage and premature leaf fall. The disease has become so severe that, in some areas, farmers were forced to uproot citrus trees and replace them with other crops (Eshetu Derso, 1999).

Control of this disease may be achieved by using sanitary measures such as removing infested fruits and leaves; and eliminating dead branches and twigs by pruning operations so as to reduce inoculum density of the causative agent (fungus) (Mohammed Yesuf, 2013). Use of wind breaks also played a positive role on the reduction of wind borne inoculum of *P. angolensis*.

The efficacy of two chemicals (fungicides), namely chlorothalonil 75% W.P. and prochloraz 50% W.P. on control of the leaf and fruit spot of citrus has been tested at Bebeka state farm condition. According to Eshetu Derso (1999), the results of the chemical spray trial conducted at Bebeka, has shown relatively better control of the disease on plots treated with chlorothalonil 75% W.P., though there was no significant difference among the treatments compared. Control of the disease with proclaraz 50% was somewhat lower than obtained with chlorothalonil.

Kassahun et al. (2006) have studied incidence of the disease on five popular sweet orange cultivars viz., Washington Navel, Pineapple, Hamlin, Campbell Valencia, and Jaffa. They found out that Washington Naval is most susceptible while cultivar Jaffa scored the lowest mean disease incidence. Kassahun et al. (2006) also evaluated some fungicides against *Phaeoramularia* leaf spot. They reported that the systemic fungicide benomyl and non-systemic fungicides chlorothalonil and copper hydroxide reduced the incidence and severity of *Phaeoramularia* leaf spots over control significantly, when applied singly or in mixtures, similar result has also been reported by Seif (1995). However, the level of reduction varied among treatments. Application of benomyl @ 0.039% plus chlorothalonil @ 0.09% was the most effective fungicidal treatment for reduction of foliar symptoms of the disease.

There are a number of insects, which attack citrus but the severity of
damage varies with efficiency of predator populations (Rice et al., 1994). Among the most serious are scales including red scale, soft brown scale, soft green scale and wax scale. Many species of fruit flies such as the Mediterranean fruit fly are damaging. Mites, especially citrus red mite, thrips, aphids (especially black citrus aphid and brown citrus aphid) can reduce yield. The false codling moth, fruit-piercing moths and citrus psyllid make up the remainder of the serious pests.

In small citrus farm, most of the insects listed above do not cause serious damage due to the presence of predators, which feed on insect pests. Insecticides should not therefore be used to control scales and mealy bugs unless it has been determined that biological control system is not working or is not efficient.

Fruit flies - These insects, mainly of the family Tephritidae, are of economic importance (Ladaniya, 2008). Fruit flies attack mostly mature or maturing fruit. The life cycle starts as the female adult inserts eggs in the skin (lay eggs just under the epidermis) of the ripe or ripening fruit and larvae tunnel into fruit. Mediterranean fruit fly, Ceratitis capitata, is the main fruit fly pest of citrus. The major problem it poses is that it deposits its eggs in the fruit as soon as there is any color break, and the larvae burrow into the fruit and feed (Manner et al., 2006). The damage is recognized by the presence of sunken brown spots in the skin of large fruit. If the fruit is cut open, the region under the spot will be found to be liquid and with several white legless worms up to 7 mm long (Crowe and Shitaye, 1977). Infested fruit usually drops before it is completely ripe. This makes the fruit unpalatable as well as having the potential to introduce this pest, which cause serious damage to numerous agricultural products, into new areas. The fruit fly has not been seen infesting acid lime (Citrus aurantifolia Swingle) fruit, which are more acidic (usually 7-8% titratable acidity) than lemons (Ladaniya, 2008). Crowe and Shitaye (1977) suggested the following cultural and chemical control measures:

- Twice a week collect all fallen fruits and fruits that are still on the plants but are clearly infested and destroy in a manner which will
prevent emergence of the pest. Removal of host plants from around the orchard also is advisable to reduce fruit fly infestation.

- Spray with a mixture of 10 mL 55% fenthion EC in 10 liters of water with one week of safety period.

Citrus woolly whitefly (*A. flocococus*) - Sucks the sap from tender foliage and devitalize the tree (Goswami and Saxena, 1999). The flies secrete sugary substance on which black sooty mould develops which hinders photosynthetic activities of the plant. Avoiding dense planting and stress on the plants, and clipping-off and destroy the infested shoots at the initial stage of infestation (Singh, 2005) will help reduce the citrus white fly problem.

Citrus woolly whitefly (*A. flocococus*) is a newly introduced pest into Ethiopia and first recorded in 2000 and identified by the International Center of Insect Physiology and Ecology (ICIPE) in 2001 (Emana et al., 2001). The pest is well established and distributed in the central Rift Valley areas like Nazareth, Debre Zeit, Wonji, Melkassa, Meki, Merti (UAAIE) and Ziway and eastern Wollega (Nekemt area) (Ferdu et al., 2009).

False codling moth (*Cryptophlebia leucotreta*) is a major pest throughout Ethiopia (Crowe and Shitaye, 1977; Ferdu et al., 2009). Females deposit eggs singly or in small groups on the surface of smooth fruit and larvae burrow inward causing the decay and collapse of tissue. Feeding damage can also lead to the development of secondary infections by fungi or bacteria. Fruit damage caused by false codling moth is recognized by the presence of sunken spots on the green fruit surrounded by a prematurely ripened zone. Later a soft rot usually spreads from the spot and the fruit falls before fully ripe. False codling moth can be managed by collecting twice a week, all fallen fruit and fruit that are still on the plants, but that are clearly infested and destroy in a manner which will prevent emergence of the pest.

Adult fruit-piercing moths feed on mature fruits of citrus by inserting their mouthparts into the fruit. These moths are active at night and fly during the day when disturbed (Ladaniya, 2008). Punctures made by the mouth parts are
distinct holes, and decay organisms soon enter the affected fruits, which drop within few days. Secondary infection usually occurs which may cause fruits to rot and drop prematurely. Fruit sucking moths prefer fruits that are ripening or already ripened (Jeppson, 1989). Early harvest, where it doesn’t jeopardize maturity standards, will help to reduce losses. No satisfactory chemical control measure is known.

*Orange dog* - This caterpillar can do extensive damage to young trees and in citrus nurseries, where its feeding can result in the complete defoliation of a plant (Rice et al., 1994). The adult of the orange dog is the giant swallowtail butterfly (*Papilio crephontes*). Orange dog eggs are large, round, semi-translucent, orange in color, and easily recognized on the expanding terminals where they are typically laid. The developing larvae are shiny brown and white, resembling bird-droppings and feed preferentially on the new leaves. Under normal conditions, populations are sufficiently low, and the damage sufficiently dispersed, that there is little cause for concern (Lewis, 2012). However, situations can arise, when large numbers of butterflies deposit numerous eggs on very young trees that then suffer severe damage from developing larvae. However, damage can only be averted by chemical treatment if the problem is detected early, i.e., when the majority of larvae are still in early stages of development (Stansly et al., 2009). When larvae reach later instars, they are more resistant to insecticides and most feeding damage will have already occurred. Careful monitoring of young groves early in flush cycles is necessary for timely detection and treatment.

Usually the insect is only serious on young trees where hand collection gives adequate control. Therefore the insect can be collected by hand into tins partly filled with gas (Kerosene) or *nafta* (diesel fuel) (Adhanom Negasi, personal communication, 2013). Diseased or parasitized worms however should not be collected.

*Aphids* are sucking insects, which damage new growth and transmit tristeza virus. Black citrus aphid, *Toxoptera citricida* (syn. *Toxoptera citricidus*) has been found to be the most harmful vector for the spread of tristeza virus
Black citrus aphid is recognized by the presence of small, black, soft bodied insects clustered on soft young shoots and leaves (Crowe and Shitaye, 1977). Young leaves may be cupped, twisted or otherwise distorted. As with scale insects, ant control is the first step in controlling aphids. Population of this pest on citrus can be easily controlled by spraying the plants with Parathion (0.03%) and Malathion (0.03%) (Goswami and Saxena, 1999).

Citrus leaf-miner (*Phyllocnistis citrella*) - The citrus leaf-miner is a serious pest of almost all citrus species, though it prefers varieties with thick leaves and thin cuticle (Goswami and Saxena, 1999). Damage is caused by the larval stage, in which the larvae feed by creating shallow tunnels, referred to as mines, in leaves of citrus trees. The larvae mine inside the lower or upper surface of newly expanding leaves, causing them to curl and look distorted (Grafton-Cardwell, 2008). The larvae will not cross their own mine or the mine of another larva. The larvae continue to mine as the leaf fully expands. After the citrus leaf-miner emerges, the damage to the leaf caused by mining activity remains. Older leaves that have hardened off are not susceptible unless extremely high populations are present (Goswami and Saxena, 1999). Mining damage can cause a retardation of plant growth of young trees and nursery stock (Yadav, 2007; Grafton-Cardwell, 2008). According to Yadav (2007) severe infestation of the pest may cause defoliation. To keep the pest population under check, pinning of all the affected parts during winter should be done (Goswami and Saxena, 1999).

*Citrus scales* - High humidity and a decrease in light accompanied with dense vegetation favors growth of scale insects. These present in most citrus growing areas in the world (Ladaniya, 2008).

Crowe and Shitaye (1977) illustrated a general guide to the recognition and control of the more important pests of field and plantation crops in Ethiopia. Specific citrus pests and their control methods are discussed in two groups vis-à-vis Armoured and Non-Armoured Scale insects as follows:
Armoured Scale Insects

Armoured scales are covered with a hard shell-like covering which, in most species, can easily be lifted with a needle to reveal the body of the female below.

Goosens et al. (1981) reported 11 species of armoured scales recorded on citrus in Ethiopia. They may usually be distinguished in the field by a combination of the following characters:

- Size, shape and color of the armour of the adult female;
- The ease or difficulty with which the armour can be lifted from the body of the adult female;
- The color and shape of the body of the adult female;
- The presence or absence of eggs under the armour of the mature female;
- The distribution of the infestation on the tree (certain species, for example, are only found on leaves and fruits not branches or twigs).

1. Red Scale (California Red Scale), Aonidiella auranti

Recognition: Flat, circular, immobile insects, red or brown in color and up to 2 mm in diameter, on fruits, leaves and branches. A major pest of citrus in Ethiopia, but especially in the Upper Awash Valley.

Chemical control measures and safety period:

In very severe scale infestations one of the following synthetic insecticides may be used, either alone or mixed with 1.5% white oil:

- Diazinon (Basudin) 60% EC
  150 mL of the formulation in 100 liters of water (0.09% a.i.) with safety period of 7 days.
- Phenthoate (Cidial) 85% EC
  120 mL of the formulation in 100 liters of water (0.1% a.i.)
with safety period of 7 days.

- Malathion 50% EC
  250 mL of the formulation in 100 liters of water (0.125% a.i.)
  with safety period of 7 days,
- Methidathion (Supracide) 40% EC
  150 mL of the formulation in 100 liters of water (0.06% a.i.)
  with safety period of 21 days. (Note that the manufacturers recommend that methidathion should not be mixed with white oil)
- Formathion (Anthio) 33% EC
  600 mL of the formulation in 100 liters of water (0.2% a.i.). If mixed with white oil the rate can be reduced to 0.15.

Note: Don’t apply white oil sprays during hot sunshine (Adhanom Negasi, personal communication, 2013).

Biological control:

Predators: Only one species of predator is at all common on armoured scale infestation in Ethiopia. This is the ladybird beetle, *Chilocorus distigma* (Coleoptera: Coccinellidae).

Parasites: The primary parasites found from Red Scale samples collected from five farms were:

- *Aphytis* sp.
- *Habrolepis* sp.
- *Aspidiotiphagus* sp.

2. Oriental Scale, *Aonidiella orientalis* (Synonym: *Aspidiotus orientalis*)

*Recognition:* Circular in shape, brown or slightly reddish brown in color. It is found on leaves, twigs and large and small branches. It is common in the upper, middle and lower Awash Valley but, in Ethiopia, has not been recorded outside this area.
Chemical control measures and safety: The same as that of the Red Scale

3. Oleander Scale (Ivy Scale), *Aspidiotus nerii*

*Recognition:* Roughly circular in shape and strongly convex. The general color is white or light grey with a pale yellow central spot. Scales are found on green twigs and on the underside of the leaves. It is found in most parts of Ethiopia. Chemical control measures and safety periods: The same as that of Red Scale

4. Orange scale, *Chrysomphalus dictyospermi*

*Recognition:* Flat, circular, immobile insects, orange brown in color and up to 2 mm in diameter, on fruits and leaves.

Control measures and safety period: The same as that of Red Scales

5. Purple Scale, *Chrysomphalus aonidum*

*Recognition:* Flat, circular, immobile insects, dark brown or purple and up to 2.5 mm in diameter, on fruits, leaves and branches. In Ethiopia the Purple Scale has only been found in the upper Awash Valley where it is not a serious pest and the Erer Gota area near Dire Dawa where it is extremely damaging.

Chemical control measures and safety period: The same as that of Red Scales

Biological Control:
Parasites: Five species of parasites have been identified in Ethiopia:
7. GURUS

- Aspidiotiphagus sp. (Hymenoptera: Aphelinidae)
- Aphytis sp. (Hymenoptera: Aphelinidae)
- Habrolepis aspidioti (Hymenoptera: Encyrtidae)
- Tetrasticus spp. (Hymenoptera: Eulophidae)
- Marietta sp. (Hymenoptera: Aphelinidae)

6. Rufous Scale (West Indian Red Scale), *Selenaspidus articulates*

**Recognition:** Flat, circular with light brown color infesting leaves, twigs and branches.
There was only one record of Rufous Scale on citrus. This was at Ambo.

Chemical control measures and safety period: The same as that of red Scale

7. Latania Scale (Palm Scale), *Hetniberlesia lataniae*

**Recognition:** Roughly circular in outline, convex and about 1.8 mm in diameter. The general color is grey with a brown, more or less central spot. It feeds on the twigs and branches. There was one record from citrus in Ethiopia. Found on orange fruits at Gode by the Wabe Shebelle River.

Chemical control measures and safety period: The same as that of Red Scale

Greater Red Scale, *Neoselenaspidus silvaticus*

**Recognition:** Roughly circular and a similar red-brown color to that of the Red Scale. But the diameter of the armour is 2 mm or more and it can be easily be lifted from the pear-shaped body of the female. Greater Red Scale has been recorded in some parts of the country
(i.e., on citrus in Nazareth area and on ornamental palm in Meki area).

Chemical control measures and safety period: The same as that of Red Scale

8. Black Thread (Black lime Scale, Coffee Comma Scale), *Ischnaspis longirostris*

**Recognition:** This species is unmistakable because of the characteristic shape of the armour of the adult female. It is up to 3 mm long but only 0.25-0.50 mm wide. The color is black except at the anterior end which is brown. The shape may be straight, or more often, slightly curved like a comma. It feeds on leaves and twigs. In the upper Awash, it has been seen in very small number on mango and citrus trees causing negligible damage.

Chemical control measures and safety period: The same as that of the Red Scale

9. Mussel Scale (Purple Scale), *Lepidosaphes beckii*

**Recognition:** This species can easily be recognized by the characteristic mussel shell shape of the adult female. It is rounded at the posterior end and tapers to 1 mm. It may be straight or, more often curved like a comma. The general color is dark brown, purple or black. All parts of the tree can be attacked but the scale is most common on the upper parts of the fruit near the stalk. In Ethiopia, Mussel Scale has only been recorded from citrus. There were few records from Eritrea and it was also common in and around Jimma township but it has not been seen elsewhere in Ethiopia.

Chemical control measures and safety period: The same as that of Red Scale
10. Black Scale, *Parlatoria zizyphus*

*Recognition:* Flat, roughly oval, immobile insects, shiny black in color with white border up to 1.5 mm long, found on fruits, on both upper and lower surfaces of the leaves especially along the main veins. The preferred host plants are lemon and orange trees. Despite its slow rate of reproduction, it is a major pest not only because it can cause die-back as well as leaf and fruit fall but also because it is difficult to control with chemicals. It was recorded from Gibe Valley where the main road to Jimma crosses the river.

Chemical control measures and safety period: The same as that of Red Scale

**General Precautions:**

1. Use of Clean Planting Materials:

- Most of the scales described above are exotic pests that have been introduced into Ethiopia on infested plants. It is strongly recommended that strict plant quarantine measures be taken so as to provide protection to the agriculture of a country against the likely ravages of alien pests should they get introduced and established. Quarantine not only helps to ward off the threats of exotic pests, but also aims to eliminate and prevent further spread of pests with restricted distribution within the country (domestic quarantine).
- If grafted plants are needed, then certified disease-free root-stock seed (planting material) should be imported and grown in isolated nurseries.
- Budwood should be taken for grafting from trees free of virus and scale insects.
- Since female scales cannot fly at any stage in their life history, a scale-free orchard in an isolated area will remain scale-free for many years, perhaps forever. It is, therefore, very well worthwhile
to make sure that the initial planting material is clean.

- All ornamental plants, especially roses, should be carefully inspected for the presence of scale insects when they are planted on the same farm as citrus.
- If in doubt they should be dipped in a bath of 0.1% diazinon or other chemicals.

2. Ant Control

- Ant control is very important in citrus orchard. The ants nest in the soil but collect the food from the trees.
- They can be therefore easily seen running up and down the trunk.
- Ants are particularly interested in the honeydew produced by soft scales and aphids but their presence on a tree has a bad effect on the parasites and predators which are trying to attack soft and armoured scales.
- DeBach (1951) remarks “They attack nearly all natural enemies; if they cannot seize them, they constantly disturb them. Parasitism of the California red scale by Aphytis is considerably reduced on ant-infested tree”.
- On non-irrigated citrus, regular dieldrin-banding is essential for ant control.
- The insecticide is prepared by mixing 50 mL of 18% dieldrin EC with 950 mL of water.
- It is helpful, but not essential, to add 1 g of a water-soluble dye (e.g., rhodo’ in B, methylene blue) to the mixture because it is then easy to see if the band has been correctly applied.

3. Dust Control

- It has been observed with many species of scale insects on many tree crops that infestation are much more severe when the trees are covered with road dust.
- DeBach (1951) showed that citrus scales on dusty surfaces are less heavily parasitized than those on clean surfaces.
- It is therefore, strongly recommended that citrus trees should be kept as free of dust as is practically possible.
• Changing the farm road system so well-used roads do not pass through or near the citrus groves.
• Use of sprinkler irrigation on the roads in dry weather.
• Repeated application of old engine oil plus detergent to the road surface using a conventional sprayer.
• Planting of wind breaks in reducing wind-blown dust. For a narrower barrier along a canal, sugar-cane might be considered.

4. Pruning

• If scale-infested leaves, twigs, and branches are pruned from citrus trees, they should not be burnt immediately.
• They should be piled up a few meters outside the citrus orchard for two to three weeks so that parasites can emerge and fly back into the orchard.

Non-Armoured Scale Insects are those scale insects that do not have a hard shell-like covering. The following are Non-Armoured Scale Insects reported to inflict damage to Citrus spp in Ethiopia (Crowe and Shitaye, 1977):

1. Cottony Cushion Scale, Icerya purchasi

Recognition: Reddish-brown insects, each with a conspicuous white egg sac growing from the end of the body, clustered on leaves and branches. The egg sac has longitudinal ridges and may be more than twice as long as the body of the insect.

Physical and chemical control measures and safety period:

• Cut off infested branches, carry them out of the orchard and leave them on the ground so that parasites can emerge.
• Spray with a mixture of either 25 mL 50% malathion or 15 mL 60% diazinon EC plus 250 mL white oil in 10 liters of water with 1 week safety period. Use as high a nozzle pressure as possible. A full-grown orange tree will need about 3 liters of
spray mixture. Repeat this spray 3-4 weeks later if the attack is severe.

- Mix 50 mL 18% diesel in EC with 950 mL water. Add 1 g of a water soluble dye (such as rhodamin B) to the mixture. Paint a band round the trunk of the tree about 25 cm wide. Remove any weeds, low-hanging branches, etc., which would allow ants to reach the foliage of the tree without crossing the band.

The cottony cushion scale is a polyphagous insect attacking citrus and a number of crops across the country. A dozen of natural enemies including parasitoids (Metaphycus spp.) and predators (Rodolia spp.) were recorded on cottony cushion scale (Fekru et al., 2009). These natural enemies might have contributed for checking of the populations of this insect.

2. Soft Brown Scale, Coccus hesperidum

Recognition: Soft-bodied immobile insects, brown in color and oval in outline, feeding on green branches and leaves. The full-grown scales are 5 mm long. They are mostly found in rows alongside the main veins or in the grooves in green bark.

Control measures and Safety period: The same as the Cottony Cushion Scale

Citrus Psyllid, Trioza erytreae

Recognition: Leaves pitted on the underside. In a severe attack, the leaf may be cupped or otherwise distorted and yellow in color, especially when young.

Chemical control measures and safety period:

- Spray with a mixture of 10 mL 40% dimethoate Emulsifiable Concentrates (EC) in 10 liters of water with 2 weeks of safety
period
- Spray with a mixture of 10 mL 33% formathion EC in 10 liters of water with 2 weeks of safety period

Notes: Control is usually only worthwhile on nursery stock. Spray in periods of flush growth. The Psyllid is the vector of “greening” disease.

**Thrips** - In Ethiopia, the citrus thrips, *Seirtothrips aurantii* Faure, has become an important pest and well established in the fruit farms in the Rift Valley area and causes heavy scarifications on citrus fruits (UAAIE, 2006). The other species (*Seirtothrips citri* Moult) is a pest of serious economic importance (Ladaniya, 2008) elsewhere. Thrips are a serious pest on all citrus fruits, although they have some preferences. According to Ladaniya (2008) in acid limes, attacks of thrips are seen as negligible, whereas on mandarins, they are a serious pest with losses that can exceed 25% of fruit affected in unattended orchards. Thrips are controlled with timely sprays usually just before or just after flowering using systemic insecticides with residual effects of up to 15-20 days.

**Mites** - Several species of mites are pests of citrus, most notably the citrus rust mite, *Phyllocoptruta oleivora*, which causes minimal damage to foliage but extensive damage to fruit (Manner et al., 2006). They move from the leaves to the young fruit when it sets and extract the cell contents from the skin. Mites penetrate their stylet in cells and cause rupturing of the fruit surface or oil gland (Ladaniya, 2008). They also suck out cell content and inject a toxin in the tissue. The damage is generally minor in regard to production but causes a russetting of the fruit, making it unmarketable.

**Nematodes** are microscopic worms that live in the soil. Infestation of nematodes is one of the main factors responsible for slow decline of citrus (Goswami and Saxena, 1999). Over 15 species of nematodes attack citrus (Rice et al., 1994), the most serious of which are the burrowing nematode and the *citrus nematode*. The most common nematodes affecting citrus trees
are citrus nematodes (*Tylenchus semipenetrans*) (Goswami and Saxena, 1999; Hoffman, 2008). Citrus nematodes are ectoparasitic that feed on plant tissues from outside the plant. With their hindquarters buried in the soil, the larvae pierce the roots to feed, usually just behind the growing tips (Hoffman, 2008). Feeding on the roots does not kill the citrus tree. However, the root’s capacity to carry water and nutrients is impeded and yields are noticeably reduced early in the life of the tree. Nematode damage of the roots also promotes entry of secondary diseases. All varieties of citrus are attacked. However, some rootstocks, such as trifoliate orange (*Poncirus trifoliata*), are highly resistant to citrus nematode attack. Others such as Troyer and Carrizo citrange are moderately tolerant and some are highly susceptible (sweet orange). Different species of nematodes under certain conditions may cause deficiency of certain nutrients in the roots, leaves or entire plants of various species (Goswami and Saxena, 1999).

It is difficult to diagnose attack by citrus nematodes, since they cannot be seen with the naked eye. However, roots which have been attacked usually have a knobbly, gritty, dirty appearance when the soil is shaken from them. This is because soil adheres to the sticky egg masses extruded by the females (Hoffman, 2008).

Many nematodes occur naturally, at low levels, in most soils. Most plant-parasitic nematodes enter the garden through infested soil or infested planting materials. Control is difficult, so the orchard site should be tested for nematode prior to planting. When planting citrus trees, planting material should be obtained from a reputable source, preferably from an officially accredited nursery. Nematodes are a greater problem where conditions favor them, such as a long growing season, sandy soil and if plants are under stress (such as water or nutrient stresses). Citrus should not be replanted where it has grown previously, and only nematode-free nursery stock should be used. Available rootstock varieties may be tried against nematodes for different species, and tolerant stocks promoted for commercial uses (Rice *et al*., 1994).

Weed should be controlled in an area of 2 m in diameter around the base of each tree. Weed control can be accomplished through cultivation or herbicides. After the weeds have been killed, thick mulch will prevent new
weed growth and will also conserve moisture. The area between rows is best grassed and mowed so that erosion is minimized.

Climates that receive moderate to high rainfall, temperatures, and humidity will experience more insect, weed, and disease pressure (Manner et al., 2006). Regardless of the pest management program (IPM, organic, or conventional) the success of the program will be greatly influenced by selecting the proper variety (Inserra et al., 2003).

As with any plant, keeping citrus healthy and vigorous will reduce the effects of insects and diseases in two ways, making them less likely to be infested as well as more able to withstand the pest. This includes (Manner et al., 2006):

- Fertilizing plants on a regular schedule;
- Keeping weeds under control;
- Pruning to maintain vigor;
- Increasing air and light penetration;
- Removing any diseased wood;
- Providing an adequate and consistent supply of water;
- Not irrigating too frequently to avoid disease infestation;
- Observing trees for signs of insects, disease, or other problems.

Citrus require little pruning. Early tipping of main branches may be required to develop a balanced tree form. In later stages of growth, only branches which touch the ground should be removed, otherwise lower branches should be allowed to remain to protect the trunk from sunscald. Pruning of established citrus is primarily practiced with the objective of maintaining optimal balance between vegetative and reproductive growth and to allow access to the field. Pruning also aims at removing diseased or crossed branches and removing vigorous suckers which occasionally grow up through the center of the tree or from below the graft union.

Maturity of citrus fruit is indicated by color changes in the rind. Although it is commonly thought that citrus should be picked after turning color, this is not necessarily true, especially in tropical climates (Manner et
Many types of citrus fruits, such as grapefruits and mandarins, do not fully turn color when ripe, and commercial producers use special treatments to induce full color break to make the fruit more appealing to consumers. In other words, skin color is a poor indicator of ripeness. Also, waiting for the skin to fully turn color also can greatly increase fruit fly damage. The best way to check for ripeness is by tasting a fruit or two that appear to be fully developed.

Maturation of citrus fruit is classified as nonclimacteric, as the typical changes in fruit quality parameters are not associated with an increase in respiration rate and ethylene production (Watkins, 2002). Even though citrus fruit has very low ethylene production during maturation, application of ethylene is a common postharvest practice for degreening in many citrus cultivars. The peel of fruits of early harvested varieties or from warm climates remains green after the pulp has reached an optimum maturity index. Treatment with ethylene induces chlorophyll degradation and accumulation of carotenoids, and these effects are widely used in the packinghouses to induce color development and uniform color between shipments (Grierson et al., 1986). Ethylene treatment only affects external fruit coloration and does not significantly affect internal fruit quality. The development of citrus color is the result of coordinated changes in carotenoid content and composition, and chlorophyll degradation (Gross, 1987). Though the lack of coloring decreases the attractiveness of the fruit, flavor is unaffected.

The external appearance of the citrus is used by the consumer as an indication of quality, citrus fruit which doesn't have the correct color, will not be preferred by consumers. Degreening is thus becoming an important commercial aspect in the preparation of citrus for the consumer (Grierson et al., 1986). The external color of citrus fruit is more often related to climatic conditions than to internal maturity. Many cultivars still have an external appearance of immaturity with a green peel that are in fact internally mature.

The ratio of soluble solids/acidity (TSS/TA) is currently used as a maturation index (Ladaniya, 2008). A ratio from 7 to 10 is generally accepted as a measure of minimum maturity and from 10 to 16 is considered as an acceptable quality, although these values may vary among the different
markets. In lemon, the percentage of juice content is the main parameter used for maturity (Baldwin, 1993).

Budded citrus fruits start to flower very early but fruits should be allowed to form only in the 3\textsuperscript{rd} year. All flowers that develop before then need to be removed. Flowering begins at the onset of rains. Commercial yields start 4 to 5 years after transplanting. Citrus fruits are harvested by clipping using a sharp knife, taking care not to injure or bruise the fruit. Fruits can also be plucked or harvested by pulling them from the tree. However, plucking causes the stem to break close to the fruit and increases the chances of it becoming infected. Mandarins, lemons and limes are clipped while others are pulled with a slight twisting motion. Fruit should be handled carefully to prevent bruising.

After picking, fruit should be graded, washed and kept as cool as possible until consumed or sold. Damaged and irregularly shaped fruits should be discarded or used immediately. Ideal storage temperature is between 4°C and 6°C (Rice \textit{et al.}, 1994).

Losses in citrus are influenced by pre- and postharvest factors (Ladaniya, 2008). Preharvest factors include climatic conditions, especially relative humidity, rain, temperature, cultivation practices, tree health, stage of fruit maturity, and fruit type. Postharvest practices such as harvesting, handling, treatments, packaging, and marketing greatly influence fruit losses. Losses take place at various stages of handling, from harvesting until fruit reaches consumers. Usually higher losses are encountered in mechanically harvested citrus (Recham and Grierson, 1971). Losses are quantitative as well as qualitative.

In developing and underdeveloped countries, mostly in the tropics, high losses result from inadequate storage facilities and improper transport and handling (Ladaniya, 2008). In economic terms, losses are high since repacking of fruits (as a result of the decay of some fruits) increases costs and reduces profit margins.
Importance of rootstocks for commercial citrus fruits production

Citrus rootstocks have pronounced effects on scion vigor and size, fruit yield and size, juice quality, tolerance to cold, drought, flooding, salt, and alkalinity, and leaf nutrient content (Castle, 1987). The effect of rootstocks on longevity of scion varieties is also significant.

Scion vigor, yield, and juice quality generally are of greatest interest in rootstock development. Yield is the single most important factor because of its strong relationship to profit. Optimum performance of budded or grafted plants depends on the proper selection of desirable rootstocks for a given set of growing conditions. Criteria used for rootstock selection include (Marte, 1987): ease of budding, vigor, pest and disease tolerance or resistance, adaptability to soil conditions (salinity, waterlogged, etc.), the effect on scion (fruit size, fruit quality, etc.) and other desirable features. The selection of any of these, in particular as a rootstock, must be made on the basis of presence of the greatest number of desirable characteristics, in keeping with the requirements of orchard in which the tree will grow. It is therefore, important to thoroughly know about the characteristics of rootstocks and their compatibility with the scion variety.

In general stock/scion compatibility is expressed in morphological changes. A successful union involves the forming of new tissues produced by the cambia of the stock and scion and the inter-connecting of conducting elements to permit the movement of elaborated products of photosynthesis and of water and nutrients and possibly hormonal substances. There is considerable variation however in the movement of nutritive substances due to stionic (stock-scion) factors. In a highly compatible union the region of the graft is characterized by an even or tapering union without marked stock or scion overgrowths. Such morphologically smooth unions usually produce long-lived healthy trees. When scion overgrowths occur trees may be dwarfed and short-lived. Scion overgrowths have been attributed to a reduced ability of photosynthates to move across the graft union, to poor growth of the scion following accumulation of photosynthates, and to a reduced supply of nutrients and water from the poorly-developed stock root system. In the case of stock
overgrowths difference in size may be attributed to natural differences in growth rate, but more often to an enhanced growth of the stock with particular scions (Williams, 1975). Some of the main advantages of rootstocks for commercial citrus production are to:

- save the crop (scion cultivar) from economically important diseases and other pests, such as nematodes;
- secure adaptation to environmental conditions e.g., tolerance to relatively low and high temperature conditions, salinity, drought and wind; and adaptability to soils of different textures;
- control the ultimate tree size of the scion variety (e.g., trees budded on trifoliate orange are relative dwarf); and
- give better size and quality of the fruit of the scion cultivar (induce good yields of high quality).

Once the rootstock has been selected, the collection of fruits for seed must be done only from the selected trees in order to ensure that the seeds are not contaminated, and that they reflect to the characteristics of the rootstock species chosen. As a general rule, the fruit for seed must be picked directly from the tree. Fruits that have fallen to the ground are more subject to brown-rot and/or other fungal infections that may late contaminate the whole seedbed (Marte, 1987). According to Marte (1987), it is preferable to pick mature fruits from vigorous trees, if possible, from trees of 10 years old or more and most importantly from those free of pests and/or diseases of economic importance.

After harvest, the fruits should be transported to the nursery within the shortest possible time. Direct exposure of fruits to direct sunlight and/or a place where water may accumulate should be avoided as fruits under such conditions are more susceptible to disease infection.

**Important rootstocks used for citrus and their principal characteristics**

Principal characteristics of the important rootstocks used for citrus are given as follows:
Sour orange (*C. aurantium* L.) is a medium sized tree growing to a height of 10 m with a rounded top. It is the premier citrus rootstock, common throughout the world where tristeza (quick decline virus) does not preclude its use and especially valued as a rootstock for producing fresh market fruit (Castle, 1987). Trees on sour orange are highly susceptible to tristeza virus, and this susceptibility eliminates sour orange to be used as a rootstock for most scions except lemons which survive in tristeza areas on sour orange. Sour orange is susceptible to the burrowing and citrus nematode. This rootstock is well adapted to heavy, often wet types of soil partly because of its moderate resistance to Phytophthora foot rot (gummosis). Hence, sour orange can be used more successfully in heavier soils than sweet orange and rough lemon. It is adapted to soils with high pH. It grows quickly in the nursery, and the expected economic life of a plantation is 40-50 years. In Ethiopia this rootstock is commonly used for sweet orange and grapefruit cultivars.

Troyer citrange is a hybrid of trifoliate orange and the navel sweet orange. Citranges (‘Troyer’ and ‘Carrizo’), are developed from the same cross between ‘Washington navel orange’ (seed parent) and *P. trifoliata* (pollen parent) (Davies and Albrigo, 1994). Trees on this rootstock are vigorous, growing well on a wide range of soils. However, troyer citrange is not well adapted to soils with pH higher than 7.5. It is tolerant to tristeza, and foot rot gummosis resistant. The seedlings are slow growing in the nursery, and economic life of plantation, established on this stock, probably equals that of sour orange. It is a rootstock for sweet orange and grapefruit cultivars.

Carrizo citrange is also a hybrid of trifoliate orange and the navel sweet orange. It has more or less similar character like that of Troyer citrange. The primary difference between these two stocks lies in their nematode tolerance, and Carrizo seedlings were found to be tolerant to burrowing nematode (Ford and Feder, 1969; Davies and Albrigo, 1994).

Macrophylla, Alemow (*C. macrophylla* Wester) - Trees on Macrophylla rootstock are vigorous, precocious, and fruit heavily as young trees. This
rootstock is among the most tolerant of high levels of soil boron, chloride, and calcium (Bitters et al., 1972). It is considered *phytophthora* (foot rot gummosis) resistant but susceptible to tristeza. Intolerance to nematodes is other limitation to the use of Macrophylla. The seedlings are fast growing in the nursery. It is a rootstock for lemons and limes.

**Cleopatra Mandrin** (*C. reslni* Hort. ex Tan.) - Cleopatra is deep rooted with extensive lateral root development on sandy soils; but it thrives best on heavier soils or those with a clay layer close to the soil surface (Ford, 1959). It is tolerant to tristeza, salinity, and resistant to foot rot gummosis. Cleopatra is said to be an excellent rootstock for mandarin and related cultivars and ‘Pineapple’, ‘Hamlin’, and certain other sweet orange cultivars.

Cleopatra has two major faults as a rootstock. First, trees budded to Cleopatra are capable of achieving a large size, but they are often slow to bear; second, juice quality is excellent but fruit size is small, particularly with ‘Valencia’ scions. This rootstock may be used to reduce over-large fruit (edible part) size of grapefruit.

**Rangpur Lime** (*C. limonia* Osb.) - Trees on Rangpur, as those on rough lemon, are known to be vigorous and highly productive, particularly as young trees, and bear medium to large size fruit with low to moderate juice quality. Rangpur lime has excellent drought tolerance because of a deep, vigorous root system, but is sensitive to *phytophthora*, and is not tolerant to either the burrowing or citrus nematode (Cohen, 1970). This rootstock is tristeza tolerant. Like rough lemon, Rangpur is preferred stock for deep, sandy soils in humid climates, where grapefruit and sweet orange trees yield well. Juice quality from Rangpur lime-rooted trees is usually above that for rough lemon and has approached the quality of fruit from trees on sour orange and citranges (Wutscher, 1977).

**Volkamer Lemon** (*C. volkameriana* Ten. & Pasq.) is a hybrid of lemon and sour orange tolerant to *Phytophthora*. Volkamer lemon is said to possess many of the same characteristics as rough lemon, although trees on this stock have
often yielded more fruit with slightly higher juice quality than those on rough lemon. Even though sufficient information is not available about its performance in Ethiopia, it is one of the promising rootstocks for mandarins elsewhere.

**Rough lemon (C. jambhiri Lush.)** - Rough lemon rootstocks produce early bearing vigorous trees which are resistant to quick decline virus (tristeza) but are susceptible to foot rot gummosis, making it useful only on freely-draining soils. It is susceptible to the burrowing and citrus nematodes. In warm, humid areas with deep, sandy soils, trees on rough lemon grow rapidly and are long-lived and highly productive, yielding large fruit with low total soluble solids content; while in arid environments and clay soils, trees on this rootstock often decline prematurely (Bowman, 1956). Fruits from trees on rough lemon are prone to be coarse, thick skinned, and to dry out or granulate early. Such fruits do not store well on the tree. Rough lemon is used for sweet orange, grapefruit and lime cultivars.

**Sweet orange (C. sinensis L. Osb.)** - Sweet orange trees frequently slow growing with a shallow, dense, fibrous root system and perform best on sandy loam soils. Most commercial scion cultivars are long-lived and grow to a large size on sweet orange, producing crops often equal to or better than those from trees on sour orange (Bowman, 1956). Valencia and navel oranges, mandarins, and lemons on sweet orange are known to yield well, and give thin-skinned fruits of good size and juice quality. The primary drawback of sweet orange as a rootstock is its susceptibility to gummosis (*Pytophthora* spp.), making it useful only on well-drained soils.

**Trifoliate orange (Poncirus trifoliate L. Raf.)** - Trees on trifoliate orange stock are slow growing and normally do not achieve large size. It is considered as a dwarfing rootstock, and is best used on medium-textured soils. Scion cultivars budded on trifoliate orange grow poorly on infertile, sandy soils and are not drought-tolerant but grow quite well on moderately fertile sands; trifoliate orange is better adapted than most rootstocks to heavy, poorly drained soils (Davies and Albrigo, 1994). Cultivars budded on this stock are
known to bear small fruit size heavily but of excellent quality. Trifoliate orange is resistant to tristeza and foot rot gummosis, and can withstand low temperature conditions, i.e., borderline temperatures which are not very cold. Trifoliate orange is widely used as a rootstock for Satsuma mandarins and sweet oranges in some parts of the world such as Japan, China, and Australia, while in Ethiopia; it is not being used for large-scale production.

**Table 7-2. An evaluation of properties of the main citrus rootstocks.**

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>Foot rot</th>
<th>Tristeza</th>
<th>Exocortis</th>
<th>Nematodes</th>
<th>Drought and salt</th>
<th>Production</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sour orange</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Sweet orange</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Rough lemon</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Cleopara.mandarin</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Troyer citrange</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Trifoliate orange</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

0 = very bad, 1 = bad, 2 = moderate, 3 = good, 4 = very good
Source: Samson (1986)

When this table is studied horizontally as well as vertically, we may draw the following conclusions (Samson, 1986; Castle, 1987):

(a) Where foot rot is prevalent sweet orange and rough lemon should be avoided;
(b) If tristeza is a serious problem, sour orange cannot be used;
(c) Trifoliate orange and troyer citrange demand the use of exocortis-free budwood and disinfection of tools;
(d) Where fruit quality carries more weight than quantity, rough lemon should not be used as rootstock.

**Growing rootstock seedlings**

Seed propagation should not be recommended for commercial production simply because it does not guarantee true-to-type plants. In the course of time, citrus growers have, therefore, turned more and more to vegetative
propagation, which ensures continuity of species. Moreover, vegetative propagation provides fruits of uniform size and quality and trees commence bearing early (Goswami and Saxena, 1999).

Low yields, poor tree growth, and a lack of uniformity visible in orchards can also stem from poor rootstock performance. Inferior quality rootstock material in citrus can result from using seed source trees that do not produce true to type seeds, or, more usually, because of insufficient rogueing of zygotic (sexual) seedlings from seedling rootstock populations in the nursery.

Most citrus rootstocks in use are polyembryonic and the percentage of zygotic seedlings produced varies between rootstocks. More than one seedling emerge out of a seed. In view of this, seeds should be sown at sufficient distance to avoid crowding. Zygotic seedlings can be expected to perform poorly or out of character compared to true to type nucellar (or clonal) seedlings. The sexual seedlings usually lag behind in growth and remain weak and therefore, should be discarded.

Seed for raising rootstocks is obtained from physiologically mature fresh fruit, which is picked from the tree rather than from the ground just to minimize Phytophthora infection. The easiest way to extract the seed is to cut shallowly through the rind all the way around the fruit and then twist the fruit apart. The pulp can then be squeezed through a sieve and the seeds washed. Seeds must not be allowed to dry out otherwise germination will be sharply reduced. After extraction seeds should be placed in water at 47°C for 10 minutes (Rice et al., 1994) to kill any spores of Phytophthora citrophthora and Phytophthora parasitica which may be adhering to the seed coat. After such treatment, the surface of the seeds should be rapidly dried under shade to prevent drying of the inside, by spreading on absorbent paper and fanning. The seeds can then be treated with fungicide such as thiram or captan.

According to Rice et al. (1994), citrus seeds can be stored by placing them in sealed plastic bags and keeping at temperatures between 6°C and 10°C. In this way, the seeds can maintain viability for six to eight months.

Seeds are planted in containers or more commonly in seedbeds. The soil should be at least 30 cm deep, light in texture, and well drained. Seeds are planted 3-5 cm deep and covered with sand or other porous and light
Seed germination commences with the emergence of the radicle (primary root) through the mycropylar (pointed) end of the seed and is dependent on moisture and temperature (Davies and Albrigo, 1994). Germination is most rapid (often 10 days) when the soil temperature is between 26°C and 32°C, although seeds will still germinate, more slowly, providing the temperature is above 12°C. Seed germination is hypogeal, i.e., the cotyledons remain underground. When seedlings are 20-60 cm tall they should be lifted and transplanted either to individual containers (plastic tubes) or to planting rows/furrows in the nursery.

Seedlings are ready to be budded when they attain a pencil size thickness (1.25 cm in diameter). Among the various vegetative propagation methods used to perpetuate citrus, ‘shield’ or ‘T’ budding is the most common method practiced universally in citriculture (Goswami and Saxena, 1999), however, in high rainfall areas the inverted-T method is often used so that the union will shed rain and be less susceptible to rot. Budding can occur at any time when the bark is slipping (separating), that is to say, when plants are growing actively.

In the selection of trees from which the budwood is to be taken, one has to ensure that these trees meet the requirements of the future orchard. Some of the most important aspects to consider when selecting a citrus tree for budwood, are the following (Marte, 1987):

a) The primary choice should be virus-free plants.
b) Be sure that the characteristics of the tree correspond to the cultivar requested.
c) Avoid taking budwood from plants which show abnormal growth, or abnormal fruits.
d) Avoid taking budwood from plants with rapid or vigorous growth to reduce the probability of propagating undesirable mutations.
e) Only select trees with a record of good yields, and proven high quality fruits.
f) Avoid choosing any plant showing symptoms of diseases.
g) Give preference of adult trees (10 years and older) and reject any thorny budwood.
There are two types of citrus budwood: The sound budwood, from hardened twigs, which is usually preferred by propagators, and the "angled" budwood, which comes from less mature twigs. The latter is more used in the "microbudding" of small citrus seedlings. The best bud wood is that taken from wood below the last flush of growth (twigs). After budding trees (rootstocks) are cut about half way above the bud (to avoid apical dominance that inhibit bud growth) and the tops bent over to the ground to force the bud into growth.

Propagation tools such as, knife, scissors, must always be sterilized (e.g., in sodium hipochloride) every time the propagator moves from one tree to another. The budwood should be used immediately after it is collected, and must not be allowed to dry. If storage is required, the budwood should be prepared as normal by clipping off leaves and thorns. The budwood should then be cut in appropriate length (15 to 20 cm), arranged in small bundles, labeled and sealed in polythene bags. They should then be put in a refrigerator at 10 to 13°C. If a refrigerator is not available, the budsticks should be kept in sterilized sawdust (or any other appropriate material) and maintained in a cool, dark area.

Growing fruit plants from seedlings has now become a common practice in the tropics, including Ethiopia. Nevertheless, the use of budded plants is still confined to large-scale farms. The advantages (but also one great disadvantage) of using budded plants are summarized in Table 7-3.

Table 7-3. Comparison of budded and seedling citrus trees.

<table>
<thead>
<tr>
<th>Characteristics (of trees)</th>
<th>Budlings (budded plants)</th>
<th>Seedlings (unbudded plants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trueness to type</td>
<td>Great</td>
<td>Moderate</td>
</tr>
<tr>
<td>Thorns</td>
<td>Few, Small</td>
<td>Many, large</td>
</tr>
<tr>
<td>Bearing</td>
<td>From 3rd year</td>
<td>From 7th year</td>
</tr>
<tr>
<td>Habit</td>
<td>Spreading</td>
<td>Upright</td>
</tr>
<tr>
<td>Picking cost</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Reaction to foot rot</td>
<td>Resistant on suitable stock</td>
<td>Susceptible in most spp.</td>
</tr>
<tr>
<td>Virus diseases</td>
<td>Dangerous</td>
<td>Initially none</td>
</tr>
</tbody>
</table>

Source: Samson (1986)
With selection of proper site, cultivar and improved cultural practices, citrus fruits of excellent quality and good yields can be produced in Ethiopia. Citrus cultivars are classified according to their ripening season (early, mid and late season cultivars), shape, color, taste and other properties. This is advantageous, because the period of availability of fruits on the market can be extended by growing fruits of different maturity seasons. It is, therefore, essential to plant each cultivar within its range of climatic adaptation in order to produce fruit at the times of maximum market demand.

Citrus fruits of major economic importance in Ethiopia

Sweet orange (*Citrus sinensis* L. Osbeck)

Sweet orange trees grow to a height of 7-12 m, with a compact, conical head; thorns generally present, 1.25-5.0 cm long, sharp, stout/solid; leaves oval or ovate-oblung, smooth, shining, somewhat lighter below than above, margins entire, or very slightly serrate; petiole slightly winged; fruits mostly borne in singles, generally round (or subglobose) to oval in shape; tight skinned, rind is golden yellow to orange in color having red streaks when fully ripe; pulp yellow to orange or reddish; segments tightly attached to one another, fairly sweet, juicy, seeds few to many. Sweet orange is a highly polyembryonic species. The following are cultivars of sweet orange that are commercially important in Ethiopia:

*Valencia* - This is the most widely grown cultivar worldwide. Apart from its high fruit quality, it has a wide range of climatic adaptation. It is a late cultivar, that is, a period of a year or more may elapse between flowering and fruit maturation in the temperate zones.

The fruit is round or sometimes slightly oval; size medium to large; color deep golden orange; rind thin, smooth, though; acidity and sweetness well blended; rich in flavor and of excellent quality.

In Ethiopia, the so far experiences have indicated that commercial planting should be undertaken in the altitude range of 1,000 to 1,600 m if
fruit of high quality is to be expected. Valencia is very suitable for processing.

Nucellar budlines (clones obtained through the process of apomixis/nucellar embryony) of ‘Valencia’ exist: ‘Cutter’, ‘Frost’, ‘Olinda’ and ‘Campbell’. It should therefore be propagated from these budlines.

Washington Navel - Unlike Valencia, this cultivar has a narrow range of adaptation and is early maturing (as compared to Valencia). Washington Navel is less vigorous than other sweet orange cultivars and poorly adapted to the humid tropics, semi-tropics, or intense desert heat. In Ethiopia, its optimum range for planting probably lies between 1,500 m and 1,800 m.

The fruit is seedless because functional pollen is lacking and viable ovules are rare. It has large fruit (spherical to ellipsoid) with thick rind. Sometimes, there is secondary growth (navel) that protrudes at one end of the fruit. Orange or orange-yellow in color; rind smooth, tough, leathery; acidity and sweetness well blended; flavor rich and excellent quality. It is used primarily as a table fruit (eaten in the fresh form). The juice develops bitterness in storing and is thus unfit (less suitable) for processing.

Hamlin - It is an important early maturing cultivar. The fruit tends to be small unless grown in climates of relatively high temperature and humidity. However, it is not recommended for planting in the hotter part of the Valencia range.

In the tropics, it is probably best adapted to altitudes of 1,000 to 1,300 m in areas where humidity is reasonably high. The fruit is oblate, medium size; color deep golden yellow early in season, changing to orange-red with full maturity; rind very smooth and bright; acidity and sweetness well blended, and excellent flavor.

Pineapple - This is a mid-season cultivar which has recently been introduced to Ethiopia. The fruit is somewhat variable, from nearly round to slightly oblate; size medium to large; color deep orange, showing a reddish tinge when well-colored (fully ripe); rind smooth, bright and glossy; acidity and sweetness well blended; rich and excellent flavor.
Mandarin (*Citrus reticulata* Blanco)

The mandarins (also called “Loose-skinned oranges”) are ordinarily recognized without much difficulty. The trees are bushy and evergreen, upright; leaves are generally small and slender (narrow to ovate pointed), and have a characteristic scent; petioles slightly winged. The fruit is flattened or depressed globose; medium sized, generally smaller than the sweet orange, frequently reddish orange in color, and sweet in taste. The rind and segments are loosely attached; seeds are small, variable in number, and are generally green when cut open (i.e., embryo is green). Mandarin is a highly polyembryonic species.

It is generally recognized that mandarins have a wider range of adaptation than most of the sweet orange cultivars. In Ethiopia mandarins produce better color than oranges in warm climates. However, the fruit is more fibrous and have less desirable color compared to fruit grown in cooler climates. Unlike oranges, mandarins:

1. are prone to attack by fruit piercing moth and birds. The rind of mandarin fruit is very fragile, thus these fruits are very prone to bruises, cuts, and infections;
2. cannot be held for long on the trees after maturity without serious deterioration of quality;
3. have high losses from handling and transport damage.

Nevertheless, mandarins are very popular with consumers. Their popularity as “easy peelers” is increasing on overseas markets. To secure good fruit set, mandarins in general, often require cross-pollination and thus provision should be made for this in planning a new farm. Mandarins are more perishable than other citrus, therefore, in order to prevent heavy postharvest crop losses improvements should be made in harvesting and handling methods.

Mandarin cultivars grown in Ethiopia

The following are mandarin cultivars grown in Ethiopia:
**Satsiana** - This is the earliest mandarin cultivar but has a narrow range of adaptation and does not appear to be well-adapted to conditions in Ethiopia.

The fruit is *puffy* (i.e., skin loose fitting to juicy portion of fruit), very easily damaged and weak in flavor. This cultivar is not recommended for commercial production, except possibly for processing, provided it can be produced in the vicinity of the processing industries.

**Fairchild** - This is an early cultivar of high quality. It is a hybrid of Clementine mandarin and Orlando tangelo and is not yet expanded in the tropics. In Ethiopia, it has been reported to be a low yielder compared with Fremont and Dancy. The fruit quality of Fairchild budded on Cleopatra is said to be superior, but too acid on Troyer citrange.

**Fremont** - It is an early cultivar but said to be later than Fairchild. The fruit is of good quality and retains its quality well after maturity. It has been reported that in Ethiopia Fremont gives satisfactory yields on Troyer citrange rootstock.

**Dancy** - It matures mid-season, it is of excellent quality, productive but with a tendency to alternate bearing. This cultivar produces a brilliant orange-red color and has out-yielded all other cultivars in Ethiopia (at Melka Werer, 700 m a.s.l.). In arid or cooler climates, the flavor is said to be too acid and fruit size may be small.

The nucellar budline, *Frost Dancy*, is the clone most propagated in the South Western USA. Dancy is recently introduced cultivar to Ethiopia, probably its performance need to be examined on different rootstocks and growing conditions.

**Lime (Citrus aurantifolia L. Swingle)**

Lime is a shrub or small tree of straggling habit, with small, stiff, interlocking or drooping thorny branches, the thorns small, sharp, numerous; leaves elliptic-oval, glossy green, margin slightly indented; petioles margined/
winged; fruit rounded oblong or oblong, frequently mammillate, light yellow; rind thin; pulp greenish, as compared with the yellow pulp of the lemon; and juice highly acidic. Lime is a highly polyembryonic species.

The principal use of lime is processing (juice and peel oil), though considerable quantities are also marketed as fresh fruit. In Ethiopia the lime is more popular compared to lemon. There are two natural groups: acid (sour) limes, and acidless (sweet) limes. The two important cultivars of an acid limes in world production are described below.

The ‘West Indian’, ‘Mexican’ or Key lime - It is round, small-ruited (but is of superior quality aroma) moderately seedy and highly polyembryonic; it has a thin, smooth rind, greenish flesh and a citric acid content ranging from 7 to 8 per cent. The fruit drops from the tree when mature. Even though no yield trials have been carried out, in Ethiopia there are several commercial plantings, which have given good results (for example at Awara-Melka). Although this cultivar is susceptible to tristeza, it is usually grown from unbudded plant material (seedlings), as a satisfactory rootstock is unknown. However, in Ethiopia it is grown on Macrophylla rootstock.

‘Tahiti’, ‘Persian’ or Bearss seedless - The fruit is larger than the ‘West Indian’ and is seedless but the juice is of lower quality. It can be grown in cooler climates than Mexican, which requires rather high temperatures.

In Ethiopia, this cultivar is grown on Rough lemon stock. Even though yields obtained are promising, heavy losses of fruit have occurred through a physiological disorder known as stylar end breakdown, which causes brown rot of the fruit. For this reason the cultivar is not recommended for commercial planting.

Grapefruit (Citrus paradisi Macf.)

Sometimes it may be difficult to distinguish a grapefruit tree from a pumelo. The leaves of grapefruit (compared to pumelo) tend to be somewhat smaller, slightly lighter in color, and less leathery. The wings on the petioles are
smaller (Fig. 7-1). The leaves and young shoots have little, if any, pubescence. The fruit is generally smaller, has a thinner rind, more juicy, and has a somewhat different flavor. Both pumelos and grapefruit have varieties with pink or red pulp as well as pale yellow or grayish. Some grapefruits also have a pink blush on the outside.

Grapefruit tree grows 9-15 m in height, with a round or conical head; leaves ovate, blunt, pointed or rounded, emarginated, smooth, dark glossy green, leathery, margin crenate; petioles articulated, broadly winged; fruit large, oblate, light lemon or orange-colored; flesh grayish or pink; juice sacs large, spindle-shaped, closely packed together; flavor a mingling of acid, bitterness, and sweetness or subacid. Grapefruit is a monoembryonic species.

Grapefruit is not very popular in Ethiopia. However, there is a small market for fresh fruit of which the major consumers are foreign nationals. Seemingly there are opportunities for promoting consumption by natives and developing juice production.

Two groups of grapefruit are known: the pigmented and the white cultivars. In both groups seedy and seedless cultivars exist. In general seedy cultivars mature earlier than seedless ones; the former takes about eight months in favorable conditions, but over a year if there is insufficient heat. There are two economically important grapefruit cultivars grown in Ethiopia:

‘Redblush’ - In Ethiopia, this cultivar is grown on Sour orange and Troyer citrange rootstocks. The fruit stores well and is of excellent quality. Unlike ‘Marsh’ it is unsuitable for processing because the pigment is not retained. It matures earlier than ‘Marsh’.

‘Marsh’ - This cultivar has medium-sized fruit, flattened to spherical in shape, with few or no seeds. It is very juicy, has a good flavor, holds unusually well on the tree and ships and stores well. It is very productive and has a high heat requirement. Generally the fruit is better suited for juice production than the red-fleshed cultivars.
High temperature is necessary for the production of grapefruit of high quality. The highest altitude limit for commercial planting in Ethiopia is probably in the region of 1,200 m.

**Lemon (Citrus limon L. Burm)**

Lemon is a small tree, 3-6 m in height, with rather open head of short, round or angular branches, thorny; leaves evergreen, alternate, ovate-oval, sharp-pointed, light green, margin serrate; petioles entirely wingless; fruit ovoid or oblong and pointed at both base and apex, either smooth or rough, light yellow in color; rind thin; flesh light-colored; pulp acid; juice sacs long and pointed. Lemon is a weakly polyembryonic species.

The demand for lemons is not so great as for orange and mandarin. Lemon flowers throughout the year, and is very sensitive to extreme temperature (heat and cold) and thrives only in coastal locations with a Mediterranean-type climate. In Ethiopia, it has been observed that many mature lemon trees on various citrus farms appear unhealthy (suspected to be infected with “greening” disease). Until the root cause of this problem is identified, it would be safer to confine new commercial plantings of lemons to an altitude lower than 800 m, where symptoms of greening and presence of the insect vector have not been observed.

Lemons are not eaten as fresh fruits, but are widely used in the preparation of lemonade, squashes and for culinary and confectionery purposes as a flavoring and garnish. They are used in cosmetics and for the production of lemon oil, citric acid and pectin. Rough lemons are used extensively as rootstocks for sweet oranges, grapefruits and mandarins. Lemons are less important than limes in the tropics, but they are extensively used in temperate countries.

‘Eureka’, ‘Lisbon’ and ‘Villafranca’ are the most widely grown cultivars of lemon. In the past much citrus have been grown from seeds, but it is now customary to propagate them by budding. Due to the presence of zygotic embryos, cultivars do not reproduce true-to-type seed. Nucellar embryos
produce seedlings of the same genetic constitution as buddings from the same tree but they tend to be rather more vigorous, thornier, and are slower to come into bearing. Rootstocks, however, are grown from seeds. Seeds should be obtained from good, fully matured trees growing on vigorous, adult, healthy trees.

**Citron (Citrus medica L.)**

The citron (Citrus medica) is a fragrant fruit, prominent member in the genus *Citrus*, belonging to the Rutaceae subfamily Rutstroemioideae.

Citron is slow-growing shrub or small tree, reaching a height of about 2.4-4.5 m. It has irregular sprawling (irregular) branches and stiff twigs and long spines at the leaf axils. The evergreen leaves are green and lemon scented with slightly serrate edges. Ovate-lanceolate or ovate elliptic 6.25 to 17.5 cm long. Petioles are usually wingless or with minor wings. The flowers are generally unisexual providing self-pollination, but some male individuals could be found due to pistil abortion. The clustered flowers of the acidic varieties are purplish tinted from outside, but the sweet ones are white-yellowish. The citron tree is with almost no dormancy, blooming several times a year, therefore fragile and extremely sensitive.

The citron’s pulp is very dry containing only little insipid juice. Moreover, the main content of a citron is the thick white rind, which is very adherent to the segments, and cannot be separated from them easily. The citron is used for the fragrance of its outer peel (flavedo), but the most important part is still the inner rind (known as pith or albedo).

The citron fruit is usually ovate or oblong, narrowing up till the stylar end. However, the citron’s fruit shape is highly variable, due to the big quantity of albedo which forms independently according to the fruits’ position on the tree, twig orientation, and many other factors. This could also be the reason of its being protuberant, forming a “V” shape after the end of the segments till the stylar end. The rind is leathery, furrowed, and adherent. The inner portion thick, white and fleshy — the outer uniformly thin, and very fragrant.
References


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CHAPTER 8

BANANA (Musa spp.)

Banana belongs to the family Musaceae. The center of greatest diversity of wild Musa species, and the presumed center of origin of the group, is in Indochina and South East Asia and it is here that the earliest domestication is considered to have occurred (Simmonds, 1962; Prince, 1995). In Malesian area, Musa's wild ancestors are still found in the forests (Samson, 1986).

Next to citrus, banana is the world's leading fruit. It is cultivated in over 100 countries on over 10 million hectares producing nearly 90 million metric tons annually (Marin et al., 2003). Banana is one of the important food crops, especially in the tropics. It is one of the rare fruits which satisfy the definition of a good food, i.e., one that contains an ample proportion of nutritive constituents which are easily digested and absorbed, while available at reasonable cost (Aravindakshan and Pushkaran, 1996). It contains nearly all essential nutrients including minerals and vitamins and has several medicinal properties (Chattopadhyay, 1999). As starchy foods, banana, cooking banana and plantain (Musa spp. AAA, AAB and ABB groups) are important sources of high-calorie energy (Johnson, 1958). About 24 bananas weighing around 100 g each would provide the energy requirement (2,400 cal/day) of a sedentary person. They are major staple crops for millions of people in the tropical world (Dadzie, 1998).

Many small-scale farmers in Ethiopia grow bananas for household consumption and local markets. Most of this production is achieved with little or no external inputs. In backyards, bananas thrive due to the high soil fertility and soil organic matter from profusely dumped refuse and manure. The great bulk of banana fruit, which is sold in urban markets of Ethiopia, is of cultivars introduced comparatively recently (e.g., ‘Poyo’, ‘Giant Cavendish’). These
cultivars are mostly used for large-scale commercial production mainly grown in the Awash valley at Awara Melka and Melka Gedi (Jackson et al., 1985).

Botany

In Musaceae family there are only two genera, viz., Ensete and Musa. Under the genus Musa, five sections are known: (i) Eumusa, (ii) Rhodochlamys, (iii) Callimusa, (iv) Australimusa, and (v) Incertae sedis. A brief description of these as given by Pursglove (1975) is as under:

**Eumusa** - (having chromosome number; x = 11; 2n = 22 in wild spp., 22, 33, 44 in cultivated). Eumusa, consists the largest section with 13-15 species, pseudo-stems usually exceed 3 m in height; inflorescence pendent or semipendent; bracts usually dull in color; flowers many, in two series in each bract. The edible cultivated parthenocarpic bananas, except Fe'I bananas, belong to this section, which are derived from *M. acuminata* and interspecific crosses with this species and *M. balbisiana* (Samson, 1986).

**Rhodochlamys** - (x = 11; 2n = 22), consists of five to seven species. Pseudo-stem is less than 3 m high; inflorescence erect; flowers few, parthenocarpic absent. *M. ornata* and *M. textilis* are sometimes grown as ornamental plants.

**Callimusa** - (x = 10; 2n = 20), consists of five to six species. Plants of Callimusa are of small stature; usually with erect inflorescence and purplish bracts; parthenocarpic absent. *M. coleosperma* is grown as an ornamental plant.

**Australimusa** - (x = 10; 2n = 20), consists of five to seven species. Inflorescence pendent, semipendent or erect. Included here are *M. textilis*, abaca or Manila hemp, and the Fe'I bananas. Their fruits are parthenocarpic and predominantly female sterile; the skin is orange in color when ripe and the flesh is yellow.

**Incereae sedis** - There are a few species of doubtful affinity. These include *M.*
8. BANANA (*Musa* spp.)

*Banana* (*Musa* sp.)

*Musa* species are grouped according to "ploidy", the number of chromosome sets they contain, and the relative proportion of *Musa acuminata* (A) and *Musa balbisiana* (B) in their genome. A genome is defined as a set of chromosomes corresponding to the haploid set of a species (Lincoln et al., 1982). Simmonds and Shephered (1955) suggested the use of the term genome as a key for classifying banana cultivars. Using 15 key characters (Table 8-1), these authors categorized cultivars in terms of their relative similarity to the ancestral seeded species.

**Table 8-1. Characters used in taxonomic scoring of banana cultivars.**

<table>
<thead>
<tr>
<th>Characters</th>
<th><em>M. acuminata</em></th>
<th><em>M. balbisiana</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudostem color</td>
<td>More or less heavily marked with brown or black blotches</td>
<td>Blotches slight or absent</td>
</tr>
<tr>
<td>Pettiolar canal</td>
<td>Margin erect or spreading, with scarious wings below, not clasping pseudostem</td>
<td>Margin inclosed, not winged below, clasping pseudostem</td>
</tr>
<tr>
<td>Peduncle</td>
<td>Usually downy or hairy</td>
<td>Glabrous</td>
</tr>
<tr>
<td>Pedicels</td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>Ovules</td>
<td>Two angular rows in each loculus</td>
<td>Four irregular rows in each loculus</td>
</tr>
<tr>
<td>Bract shoulder</td>
<td>Usually high (ratio &lt; 0.28)</td>
<td>Usually low (ratio &gt; 0.30)</td>
</tr>
<tr>
<td>Bract curling</td>
<td>Bracts reflex and roll back after opening</td>
<td>Bracts lift but do not roll</td>
</tr>
<tr>
<td>Bract shape</td>
<td>Lanceolate or narrowly ovate, tapering sharply from the shoulder</td>
<td>Broadly ovate, not tapering sharply</td>
</tr>
<tr>
<td>Bract apex</td>
<td>Acute</td>
<td>Obtuse</td>
</tr>
<tr>
<td>Bract color</td>
<td>Red, dull purple or yellow outside; pink, dull purple or yellow inside</td>
<td>Distinctive brownish-purple outside; bright crimson inside</td>
</tr>
<tr>
<td>Color fading</td>
<td>Inside bract color fades to yellow towards the base</td>
<td>Inside bract color continues to base</td>
</tr>
<tr>
<td>Bract scars</td>
<td>Prominent</td>
<td>Scarcely prominent</td>
</tr>
<tr>
<td>Free tepal of male flower</td>
<td>Variably corrugated below tip</td>
<td>Rarely corrugated</td>
</tr>
<tr>
<td>Male flower color</td>
<td>Creamy white</td>
<td>Variably flushed with pink</td>
</tr>
<tr>
<td>Stigma color</td>
<td>Orange or rich yellow</td>
<td>Cream, pale yellow or pale pink</td>
</tr>
</tbody>
</table>

Source: Simmonds and Shephered (1955)
The genome with 11 chromosomes from *Musa acuminata* is designated as “A” and that from *Musa balbisiana* is designated “B”. In other words, scoring method is based on the contribution of the two species using 15 morphological characters, scoring 1 (*acuminata*-like) to 5 (*balbisiana*-like). Thus a score of 15 (1 x 15 characters) would be considered pure *acuminata* and a score of 75 (5 x 15 characters) would be pure *balbisiana*.

According to the recent system of classification recognized in the world, edible bananas or those grouped in the section Emusa have two wild species (*M. acuminata* and *M. balbisiana*) as their progenitors. Simmonds and Shephered (1955) have used a scoring technique to indicate the relative contribution of the two wild species to the constitution of any given cultivar. They identified 15 diagnostic morphological characters to distinguish edible banana cultivars (i.e., between *M. acuminata* and *M. balbisiana*). For each character in which the cultivar agreed with *M. acuminata*, a score of one was given and for each character in which the cultivar agreed with *M. balbisiana* a score of five was given. Intermediate expressions of the characters were assigned score of two, three or four according to their intensity. According to this scoring technique, the scores range from 15 (15 x 1) for *M. acuminata*, to 75 (15 x 5) for *M. balbisiana*. A cultivar would have a large score if it were derived from *M. balbisiana* and smaller if it were derived from *M. acuminata*.

<table>
<thead>
<tr>
<th>Ploidy</th>
<th>Score</th>
<th>Constitution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x</td>
<td>16-23</td>
<td>AA</td>
</tr>
<tr>
<td>3x</td>
<td>15-21</td>
<td>AAA</td>
</tr>
<tr>
<td>4x</td>
<td>15-20</td>
<td>AAAAA*</td>
</tr>
<tr>
<td>2x</td>
<td>46-49</td>
<td>AB</td>
</tr>
<tr>
<td>3x</td>
<td>26-46</td>
<td>AAB</td>
</tr>
<tr>
<td>59-63</td>
<td></td>
<td>ABB</td>
</tr>
<tr>
<td>4x</td>
<td>63-69</td>
<td>ABBB</td>
</tr>
</tbody>
</table>

* Not encountered in nature
Source: Shanmugavelu *et al.* (1992)
The edible bananas of the Emusa section were further divided into the diploids with genomic groups AA and AB, the triploids with genomic groups AAA, AAB and ABB, and the tetraploids with genomic groups AAAB, ABBB (Table 8-2). The natural tetraploid forms are rare though their identity (AAAB, ABBB, AABB) has been recognized (Shanmugavelu et al., 1992).

All *Musa acuminata* types and their hybrid clones have more or less sweet fruits and hence may be eaten uncooked. These are called “dessert bananas”. The association of “B” genomes to clones of hybrid origin confers increased starchiness and some degree of drought and disease tolerance (Chattopadhyay, 1999; Aravindakshan and Pushkaran, 1996; Stover and Simmonds, 1987). These starchy cooking bananas are often called “plantains”.

Most edible bananas originated from two species in the section Musa (formerly known as Eumusa), *M. acuminata* and *M. balbisiana* (Ploerz et al., 2007). The cultivars are either hybrids among subspecies of *M. acuminata* or between *M. acuminata* and *M. balbisiana*. These hybrids are diploid (two sets of chromosomes), triploid (three sets, the most common and important ploidy), or tetraploid (four sets). Most edible bananas are known to be triploids that can be described as AAA, that is, they carry three sets of chromosomes derived from *M. acuminata*. The plantains are generally triploid: AAB and ABB. Other combinations also exist, namely AA, AB, AAAA and ABBB (Samson, 1986; Stover and Simmonds, 1987).

*Banana* is a tree-like herb, perennial but monocarpic, 2 to 6 m high with milky juice in all parts. The entire plant is called a mat. The underground stem (corm) has short inter-nodes. The corm’s terminal growing point produces leaves in a spiral succession. The pseudostem, which reaches a height of up to 6 m, constitutes the functional trunk which supports the leaves and the flower, and fruit bearing stalk. New rolled leaves emerge through the center of previous overlapping leaf bases. The banana leaf consists of a long, tube-like structure called a sheath, a stout petiole (leaf stalk), and a lamina or leaf blade. The tight packing of numerous sheaths forms the pseudostem. After approximately 40 leaves have been produced (about nine months after planting the sucker) the plant enters a reproductive phase and the vegetative apex inside the leaf sheath changes to a floral apex.
Banana is monocarpic: a shoot flowers only once and dies after it has borne fruit. Yet the plant is perennial as the corm’s life is perpetuated by suckers; a whole clump may thus develop. After a sucker has formed a fixed number of leaves, its meristem changes into a flowering stem that begins to push up through the pseudostem. The process of banana flowering is called shooting. The flowers appear spirally along the axis of the inflorescence in groups of 10 to 30, covered by purplish-to-greenish fleshy bracts, which shed as flowering development progresses. The first flowers to emerge are functionally female. In the edible cultivars, the rapidly growing ovaries develop parthenocarpically (without pollination) into clusters of fruits, called “hands”. The fruit is a berry. It contains many ovules, but no seeds; the fruit develops by means of parthenocarpy, i.e., without fertilization. Although most banana cultivars produce seedless fruit, some are fertile and can set seed. In the wild seed productive species, pollination is essential for the development of the fruit (Simmonds, 1973). An entire hanging banana is generally called a ‘bunch’ while a fruit cluster is a ‘hand’ and the individual fruit is known as a ‘finger’. A bunch consists of eight hands of 15 fingers with an average weight of 150 g; the fruit (of one plant) thus weighs 18 kg and the entire bunch about 20 kg. However, bunch weights of 30 kg and more are not at all rare (Samson, 1986). Shape, size, colors of skin and flavor characteristics differ from cultivar to cultivar.

Ecological requirements

Bananas are adapted to a wide range of soil conditions but good drainage is essential and the crop is only slightly tolerant of salinity (Chattopadhyay, 1999). Deep, well-drained, friable loamy soil with adequate organic matter is ideal for its cultivation. Banana is one of the few fruits which have a restricted root zone. Therefore, depth and drainage are the two most important considerations in selecting the soil for banana. Soil pH between 4.5 and 7.5 is used, although 5.8-6.5 is recommended (Nakamone and Pauli, 1998).

Unlike citrus, the banana is predominantly a tropical crop (is a crop of the tropical lowland). Chilling injury occurs at temperatures below 12°C,
where latex coagulates. Short stemmed cultivars are the worst affected. Bananas are transported at temperatures between $12^\circ C$ and $13^\circ C$ when respiration is low. Growth begins at about $18^\circ C$, reaches an optimum at $27^\circ C$, then declines and comes to a stop at $38^\circ C$ (Fig. 8-1). Still higher temperatures cause sun-scorch.

![Figure 8-1. Relation between temperature, growth and other processes in banana culture. Source: Samson (1986).](image)

In Ethiopia the top altitude limit for commercial production of banana is around 1,000 m but Ducasse (also known as ‘Kenya’) variety may be grown as high as 1,700 m, provided there is no frost hazard (Jackson et al., 1985).

The crop has a high soil moisture requirement. A well-distributed rainfall of 1,750-2,000 mm is sufficient; otherwise supplementary irrigation will be necessary (Samson, 1986). Even though a banana plant is a very large user of water, it is unable to sustain any long periods of water lodging (Jackson, 2001).

Banana is very susceptible to strong winds; especially tall growing cultivars are very vulnerable to wind damage. Continuously windy weather may cause severe leaf shredding, drying of the leaves, and plant crown distortion. Winds in 17-36 km per hour (kph) will cause shredding of leaves, reducing productivity (Jackson, 2001). Tropical storms up to 72 kph cause
serious blow downs, and tall cultivars are more susceptible compared to the short ones. Whole plantations can be blown down to soil level by strong winds. Planting in blocks, which are not less than 100 m wide and surrounded, by two rows of the tall growing Ducasse cultivar, can minimize wind damage. In addition to this, properly designed tree windbreaks are required. The following are the banana cultivars widely grown in commercial farms in Ethiopia:

‘Payo’ is a leading cultivar, unlike ‘Dwarf Cavendish’ and ‘Giant Cavendish’, the male bracts fall off and the fruit is reported to be comparatively resistant to transport damage.

‘Dwarf Cavendish’ is better adapted to a cool climate than any other Cavendish cultivar. It was extensively planted; nevertheless, as of recent years its popularity has been declining owing to its susceptibility to burrowing nematode and cigar-end rot disease.

‘Giant’ Cavendish’ is a tall growing strain of Cavendish, which has largely replaced the “Dwarf” in commercial plantations. Unlike other cultivars, bracts and male flowers are persistent on the lower part of the male axis of ‘Dwarf Cavendish’ and ‘Giant Cavendish’.

‘Ducasse’ is locally called ‘Kenya’ banana in Ethiopia. It is a tall plant with wider ecological adaptation (i.e., grows well in warm and cooler climates). The so far experiences indicate that this cultivar can grow up to an altitude of 1,700 m a.s.l. The fruit is small, thin-skinned and rather starchy. It has good keeping quality; the flesh may remain firm and stay in good condition even after the skin has turned completely black. This cultivar is therefore popular with nomadic people. Because of the tall habit of the plant, it is often planted as a windbreak around blocks of other banana cultivars.

of banana have been released in 2006 (Asmare Dagnew, personal communication, 2013).

Crop husbandry

Banana and plantain are propagated principally by vegetative division (suckers or corm) and far more rarely by seeds (usually only for banana breeding, ornamental types and wild species). In addition, tissue culture has become standard for commercial plantations in recent years, primarily because of the advantage of starting with disease-free planting material, and resulting plantations are uniform, allowing for easier management (Chattopadhyay, 1999). Planting material for vegetative propagation consists of suckers or corm. The corm (Fig. 8-2) is an underground stem with numerous meristems (growing points) from which the pseudostems, flowering and fruiting stalks, and fibrous roots arise. The corm is covered with closely packed leaf scars, which form rings around the corm. The internodes are extremely short. Each leaf scar carries a bud. Ten to fifteen buds on each corm develop into suckers. Pieces of corm carrying such buds, called mini-setts, can be used as planting material, with one to three eyes.

![Figure 8-2. Corm of banana plant.](image)

Source: Moorhead and Oyetunde (1997)
A corm produces 10-15 branches called suckers or daughters. Suckers are lateral shoots from the main plant, and they can be used for planting. The whole unit of corm and suckers is called the mat or stool. Maidens, sword suckers, water suckers and peepers are different age groups of banana suckers used as a planting material (Fig. 8-3). These planting materials differ in the time to fruiting. This may be utilized in commercial production in timing the crop to a favorable marketing time or to avoid adverse seasons. The absolute time for shooting and maturity varies with climate but in general it seems that large shoots, including the corm and large swords mature slightly earlier (Williams, 1975).

Maidens are large suckers with foliage leaves and large corms. They are about to shoot a bunch (large but non-fruited ratoons).

Sword suckers are suckers bearing narrow sword-like leaves and attached to the mother rhizome. Sword suckers have a few linear leaves and are thick at the base and taper rapidly towards the top, which will develop into fruitful pseudostems at maturity.

Water suckers are suckers of superficial origin broad leaves, characterized by broad leaves when small. Water suckers are not well attached to the rhizome and generally produce weak plants and less fruit than sword suckers. They produce weak plants with small fruit. In Ethiopia, water suckers are undesirable as planting material.

Peepers are very young (small) suckers bearing scale leaves only, appearing just above the ground, showing very small pseudostems, that develop into either sword or water suckers.
Sword suckers are preferred to water suckers for planting new fields because of their superior vigor and eventual yield. Sword suckers have narrow, sword-shaped initial leaves and are attached to a healthy, fruiting mother plant. Water suckers are those young plants that no longer have a physical connection with a living mother plant. Water suckers do not have the sword-shaped initial leaves. The sword suckers (with narrow leaves) can be obtained from healthy mother plants that are devoted (either in full or in part) to the production of sword suckers. These sword suckers are not removed during the normal process of thinning out banana clumps, but are reserved for collection and subsequent planting. Suckers to be used for planting can be given extra light (by trimming overhanging leaves) and fertilizer before removing them from the mother plant to enhance their viability. Suckers are ready for removal from the mother plant when they reach a minimum of 15 cm diameter and 50 cm height above the soil (Stover and Simmonds, 1987). The sucker is removed (cut away and out) from the mother plant using a sharp tool such as a narrow-bladed, straight-sided shovel, making sure to
obtain an appreciable amount of corm with the sucker. It is not advisable to use “peepers” (suckers less than 30 cm tall) for propagation material because they are extremely slow-growing, may not survive, and if they do survive will produce small bunches the first year.

In Ethiopia suckers are normally used for banana propagation, and “sword” suckers are the most productive. The selected suckers should be uprooted using a very sharp shovel to reduce damage to the mother plant. At planting sword suckers should be cut back to about two thirds of their length, while maiden sucker is cut back just below the crown. *Bullhead* (corm from a plant which has been harvested) with or without a sword sucker, and *bullhead sections* (corm pieces with a budeye) are also used as planting material, usually for household production. Currently tissue culture plantlets are the ones most recommended for expansion of commercial banana production in Ethiopia. Dubois (2011) stated that banana plants produced by tissue culture (TC), because they are produced axenically in the laboratory, are material that is free from pests and diseases with the exception of fastidious bacteria and viruses. There are many added benefits to using TC plants: (1) they are more vigorous, allowing for faster and superior yields; (2) are more uniform, allowing for better marketing; and (3) can be produced in huge quantities in short periods of time, allowing for faster and better distribution of existing and new cultivars.

Plant population per unit area depends on cultivar, topography, soil fertility, desuckering, duration of planting and system of cultivation (Chattopadhyay, 1999). Nowadays, the tendency is towards closer planting, especially where bunches are sold by weight rather than number of hands. Tall cultivars need wider spacing than dwarf cultivars. Thus the density varies between 1,000 and 3,000/ha.

In Ethiopia, a plant spacing of 2.5 x 2.5 m (1,600 plants/ha) is sufficient to allow for mechanical cultivation in both directions. However, this would destroy the irrigation furrows, of which there should be one furrow running close to each plant row. Therefore, a spacing of 2.5 m between rows and 2 m between plants (2,000 plants/ha), which will allow mechanical cultivation in one direction, is recommended. Contours are followed on sloping
land, while on flat land the planting can be on the square, rectangle or triangle. A sucker is placed in each previously prepared planting hole and the soil pressed firmly around it.

The best time of planting is at or just before the beginning of a rainy season. The sucker is placed in the planting hole and its corm is covered, first with the topsoil, mixed with manure and then topped up with the subsoil. If the land is sloping, the sucker should be so oriented that the future ratoon emerges against the slope. If there is no rain, irrigation should follow the planting as soon as possible. Four to six weeks after planting a careful check of all plants should be made; dead suckers need to be replaced, preferably by big maiden suckers. As a rule, no more than 10 per cent of the plants set out have to be replaced.

Weed management - If weeding is done by hand, the weed residues should be heaped together in the plantation so as to confine the weed seeds in one or a few places. Although it is laborious, hand weeding is better than hoe weeding as it is less destructive to the delicate banana roots and soil structure. It is however most applicable where weed density is very low, such as in mulched plantations. Otherwise, high-density weeds can be removed faster by hoe weeding and fastest by spraying with appropriate herbicide. Note that hoe weeding is not recommended because of the damage it causes to the feeder roots. Mulching reduces the amount of weeds in a plantation by suppressing the established weeds and denying light to those that require it for germination. Additionally, mulch helps water to penetrate deeper into the soil and it prolongs its retention. It also returns nutrients to soil as it rots, thus improving soil fertility. Usually banana plant residues are used as mulch. Old (senescent) leaves are pruned off and spread between rows of the banana plants. Pseudostems of harvested, pruned and toppled plants are split and are placed between rows. Annual crop residues, grasses of different type (chopped and dried) are also used as mulch. It is important to note that mulching sometimes provides good homes for pests such as the banana weevil (Tushemerehi et al., 2001). Mulches should therefore be placed away from the base of the mat so as to reduce the population of weevils that may get in
contact with the plants. The recommended distance is 50 cm from the mat.

In commercial banana plantations, herbicides are commonly used to control weeds. When spraying, precautions must be taken to avoid herbicide drift to the banana plants. It is advisable to avoid spraying on a day with high winds and immediately after rain (i.e., after rain at least three hours need to elapse before beginning spraying). Herbicides commonly used in Ethiopia include Roundup and Gramoxone. It is important to note that the rate (amount of herbicide to mix with water in a sprayer pump) may change according to weed type (e.g., grass type), age, thickness, etc.

**Fertilizer application** - Banana plants need fertile conditions and an abundance of soil moisture for best growth and production. The type of development the plant makes in the first 3 to 4 months determines the weight of the bunch and the number of hands. Consequently, it is essential to provide the best of care during this period. Obviously fertilization should be related to natural soil fertility and newly-cleared lands are more likely to be sufficient in plant nutrients. Continues cropping, however, calls for the use of fertilizers to replace those removed by the crop and lost by leaching and erosion, and to obtain maximum economic yields. Heavy applications of organic manure’s or fertilizers are considered necessary in order to produce high yields and to extend the life of the plantation, even on fertile soils. The following dressing is recommended, to be applied twice a year to each mature plant or stool (Jackson *et al.*, 1985):

- Sulphate of ammonia - 600 g
- Superphosphate - 600 g
- Sulphate of potash - 450 g

If farmyard manure is available, 3-5 kg may be worked into the soil around each sucker after planting.

**Pruning (clump management)** - Clump (sucker) management (also called desuckering) is an essential step to remove unwanted suckers developing from
the base of the parent rhizome and to select a suitable sucker to produce the ratoon crop (Nakasone and Pauli, 1998). Sucker management aims at maintaining a balance between growth and yield. Selection is carried out in a manner to ensure that the shortest possible time pass between harvests from each mat, while still yielding the largest possible bunches. The suckers that are chosen to remain are called "crop suckers". When unwanted suckers are not pruned, they use up expensive fertilizer, which makes less of the nutrients available to develop the bunch in the shortest possible time (Conie and Young, 2003). Therefore, the bunch size and weight are small and the time period between harvests is long. Too many suckers make the fields over-crowded and lower the yield.

Competition between suckers depletes soil fertility very fast and results in weak plants which are very susceptible to infections. About 3 to 4 suckers should be maintained per stool (Fig. 8-4) in order to ensure strong plants and good yields. Any extra suckers should be removed when they are still young. Suckers at different growth stages (mother, daughter and granddaughter) on the opposite side of the mother plant, should be chosen, also to avoid competition for light. De-suckering should be done well, so that pruned suckers do not grow up again. The sucker pseudostem should be cut off near its corm and the sharp point of the knife twisted into the growing point to kill off the sucker permanently. During this operation, care must be taken not to harm other daughter plants.

Desuckering is done by hand by cutting and rouging every 4-6 weeks, and paraffin-oil injection so that suckers do not use too many of the resources available to the parent. Selection of ratoon suckers is critical to maintain yield, production and appropriate plant spacing (Nakasone and Pauli, 1998; Chattopadhyay, 1999). A sucker on the most open side is usually selected as the daughter plant and left as the follower, taking into consideration field spacing. In Ethiopia, a common practice is to maintain a cycle of three suckers per stool, one of which is flowering or fruiting (the "mother"), the second being half-grown (the "daughter" or a follower of the mother), and the third is of small size (the "grand daughter" or a follower of the daughter). If these three plants were left standing in a straight line, linear
succession, the original spacing would soon be disrupted. Therefore, a rotating succession is preferred. The cycle may be continued for as many years as yields remain economic (Samson, 1986).

![Diagram of a banana plant with labels](image)

**Figure 8-4.** Practice of maintaining a cycle of three suckers per stool.

**Propping (provision of support)** - Propping serves to protect bearing plants from falling over and from wind damage. As banana plants are non-woody they easily break when exposed to heavy winds. Bunches falling from the plant or the whole plant falling over can lead to considerable bunch damage. Lodging is caused by poor anchorage, poor planting material or very large bunches (Nakasone and Paull, 1998). The problem is reduced if single or double poles are wedged against the throat of the plant under the curvature of the peduncle. Provision of support (especially, at the time of bunch
emergence) is necessary because the weight of the bunch is heavy enough to pull the plant out of balance.

Earthing-up - This practice is carried out sometimes as a protection against wind and when the roots and parts below the ground are exposed by erosion. Earthing-up reduces crop losses by 30 to 50 per cent (Samson, 1986). Earthing up should be done during the rainy season to provide drainage, and to avoid waterlogging at the base (Chattopadhyay, 1999).

“Dehanding” in the field refers to the removal of the false hand alone or two of the last apical hands at the time of bagging. It is designated “F” (removal of the false hand only), “F”+1 (removal of the false hand plus one apical hand) or “F”+2 (removal of the false hand plus two apical hands). Cutting the last, so-called false hand(s) of a bunch soon after bloom is generally practiced to increase the size/weight of the remaining hands, and is commonly followed in banana production meant for export market.
Bagging - Covering of each bunch before it reaches maturity is claimed to have great advantages in improving fruit quality as it protects the fruit against frost (in marginal climatic zones), sunburn, dust, spray residue, insects (e.g., thrips, mite, and scarring bettle), and birds (Samson, 1986; Nakasone and Paull, 1998; Chattopadhyay, 1999). Polyethylene bunch covers (30-40 μm thick) are almost universally used to improve yield and maintain fruit quality (Nakasone and Paull, 1998). The covers produce a microclimate around the bunch and prevent fingers inside the bunch covers from being chafed by leaves and covered in dust. For tropical areas, perforated covers (for aeration and cooling) are used. Covers are applied after the bracts have fallen and should hang about 15 cm below the distal hand (Nakasone and Paull, 1998).

Polythene bunch covers should be open on both sides and are loosely tied above the first hand of the bunch. Thicker covers are used in the tropics, where wind is less of a problem. Bunch covering with dry leaves is also a common practice, for instance in India (Chattopadhyay, 1999) which, however, may be a source of inoculum for postharvest diseases. Blue polythene tubes/bags are commonly used and sometimes newspaper is used to cover the upper fruits to reduce sun-scorch. Various pests attack banana and the following are some of the most serious damage causing diseases and other pests:

**Banana bacterial wilt disease**, caused by *Xanthomonas campestris pv musacearum* (Tshemereirwe *et al.*, 2003; 2004) is one of the major banana diseases in Ethiopia (Mohammed *et al.*, 2009). The same organism causes Ensee wilts (Yirgou and Bradbury, 1968; 1974). This disease causes total yield losses in affected plants (Ssekiwoko *et al.*, 2006). It mainly manifests itself as premature fruit ripening and wilting. First the male buds of the affected fruited plants wilt and die; the fruits ripen prematurely, eventually the leaves wilt, starting with the young ones and the plant finally dies. Non fruited plants externally exhibit leaf wilting symptoms.

The pathogen is thought to be transmitted from flower to flower by contaminated foraging insects (Ssekiwoko *et al.*, 2006). It is also transmitted on contaminated cutting garden tools (Yirgou and Bradbury, 1974; Tshemereirwe *et al.*, 2003). Disease control is achieved through male bud
removal of flowered plants, sterilization of introduction of foreign plant materials into gardens and destruction of diseased host plants (Ssekiwoko et al., 2006).

**Banana wilt or vascular wilt** (also known as Panama disease), caused by *Fusarium oxysporum cubense*, is a soil-borne fungal disease and gets entry in the plant body through roots (Chattopadhyay, 1999). It is most serious in poorly drained soil. The organism attacks the roots and underground portions of the plant giving rise to wilting of the foliage and death of the plant. Leaves of infected plants turn yellow from the margins and dry up. All leaves, even the young ones, will die but the pseudostem remains standing until it decays (Arya, 1993). Internal symptoms consist of purplish stains in the vessels and very often, diseased stems, smell strongly of rotten fish when cut. Infected soil, planting material, tools and water easily spread the pathogen. Young plants are more susceptible than old and heavy soils with poor drainage combined with high rainfall favor attack, apparently because of reduced host vigor under these conditions (Williams, 1975). The most important way of reducing the disease is by the planting of resistant clones (e.g., Cavendish) (Arya, 1993). Care in cultivation, avoiding root injury and control of nematodes would also prove helpful in the control of the disease.

**Cigar-end rot (Cigar end tip rot)** (*Verticillium theobromae*, *Trachysphaera fructigena* and *Gloeosporium musarum*) - The fungus infects the dry flower parts and from there it penetrates the fruit skin. A black necrosis spread from the perianth into the tip of immature fingers. It develops into a dry rot, which affects mainly the tip of a fruit. The corrugated necrotic tissues become covered with fungus and resemble the grayish ash of a cigar end (Chattopadhyay, 1999). Some cultivars (e.g., ‘Dwarf Cavendish’) are very susceptible and it has been observed that damage occurs mainly in areas where night temperature prevails. Removal of the pistil and perianth by hand as soon as the fingers emerged and spraying the bunch with Dithane M-45 or Topsin M (0.1%) and covering of bunch controls the disease effectively (Chattopadhyay, 1999).
Leaf spot (Leaf streak or Sigatoka disease). This disease is caused by the fungus *Cercospora musae*, which is largely specific to bananas and the symptoms include appearance of yellow or pale yellow streaks, clearly visible on both the leaf surfaces (more prominent on upper surface) (Arya, 1993). It produces yellow and then necrotic leaf lesions. Since the lesions take several weeks to develop the older leaves appear most infected. The more humid regions of the tropics are most susceptible to this disease since the spread of the fungus and infection is favored by high humidity and temperature. The major commercial cultivars of banana (e.g., Cavendish group) are all highly susceptible to leaf spot disease (Chattopadhyay, 1999).

Some recommended control measures include (Arya, 1993; Chattopadhyay, 1999):

1. Removal and destruction of the infected leaves.
2. Treatments with mineral oils (both preventive and curative); and Dithane M-45 (Mancozeb) WP (in foliar-water emulsion) and Dithane M-45 F (in water only).

Crown rot (*Colletotrichum musae*, *Rusarium* spp., *Vetricillium theobromae*, *Botryodiploidia theobromae* and *Nectrospora sphaerica*) - Blackening of the crown tissues is the characteristic symptoms which spreads to the pulp through the pedicle resulting rotting of infected portion and separation of fingers from the hand. Occurrence of the disease is closely linked to poor cultural and disease management practices in the banana field, unclean packinghouses and improper postharvest handling (Timpo and Run, 2010). The infections reduce fruit quality, shelf life, and marketability. For packing is recommended to manage the disease.

Anthracnose - The disease is caused by *Gloeosporium musarum*, and it attacks the plant at all stages of their development (Arya, 1993). The disease cause a
transport and ripening trouble. Dark, blotchy areas appear on the skin of the ripening fruit and enlarge rapidly. At first only the skin is affected, but later a soft water-soaked condition extends into the pulp and greatly hastens what is commonly called the over-ripe condition. Black end of fruit stalk rot also affects the ripening fruit and occurs principally when the hands are broken into singles for packing. As the fruit ripens a soft, black and usually wet rot commences at the broken end of the fruit stalk. Spraying with Bordeaux mixture or Dithane Z-78 (0.2%) gives good control (Arya, 1993).

**Nematodes** - Bananas suffer greatly from nematodes, and heavy infestation of the burrowing nematode will cause a dramatic decline in yield. Affected plants show yellowing leaves, growth is stunted and rhizome development can be retarded. A total of 71 species of nematode belonging to 33 genera are reported to infest banana of which six are parasitic (Chattopadhyay, 1999). The most important nematode species in *Musa* production in Tropical Africa is *Radopholus similis* which is present in nearly all the dessert banana plantations and in many cooking banana production areas. Nematode damage to roots results in reddish, elongated flecks parallel to the root axis. The discolored areas enlarge as the nematodes and progeny feed. The older parts of the lesions turn black and shrink, while the advancing margins remain red. Continued feeding causes extensive, deep lesions on roots and rhizome. The root systems are reduced, severely damaged and unable to uptake water and nutrients, thus the plants lack vigor, are stunted, and, because of poor anchorage, are prone to toppling under bunch weight or to being blown over even by not so strong winds.

The dissemination of *R. similis* throughout Africa is mainly due to the distribution of nematode infested rhizomes used as planting material (Sarah, 1989); therefore use of nematode free planting material is one of the important control measures (Mohammed *et al.*, 2009). Nematode-free banana and plantain crops can be produced by using clean (uninfested) planting materials (properly pared corms, or micro-propagated plantlets). These are planted in new areas, or in fields, which are free of plant nematodes, having been left fallow for at least six months to ensure the breakdown of infested
roots and elimination of the nematode, and which were kept free of weeds that could harbour *R. similis*.

**Banana thrips** - A serious insect pest to affect high-grade fruit production. The dark-brown adults and nymphs feed on the skin of banana fruit, producing silvery patches which later turn brown and cover the whole fruit. Young fruits may crack and there will be no proper yellow color development.

**Harvest and postharvest handling**

Banana fruit will develop its full characteristic flavor, taste and color during storage if it is picked during an optimum period. In the banana industry, bananas are usually harvested at a physiologically mature green stage, packed and transported or exported to distant markets where they are ripened. During the period between harvesting and ripening, the fruit should remain firm and green without marked changes in skin color, texture or composition for extended periods of time (depending on the temperature and humidity) before the onset of ripening. This well defined period after harvest, during which the fruit remains green and firm, is called the pre-climacteric life or green-life (Marriott *et al.*, 1979). The process is irreversible once the green-life ends and ripening has been initiated, which means that any fruit in this condition will be overripe at the handling and marketing stage.

Fruits harvested at an early stage of maturity are more susceptible to shriveling and mechanical damage and are of poor quality upon ripening, despite having a long storage life. On the other hand, harvesting at an advanced stage of maturity is unsuitable for fruits intended for long distance shipment due to their shorter storage life (Harman, 1981; Kader, 1994). Therefore, it is important to carry out harvesting at the right maturity stage to suit the purpose. Fruit at advanced stages of maturity are harvested and sold in local or nearby markets, while those destined for distant markets are usually harvested at less advanced but physiologically mature stages (Marriott, 1980). The fruit should arrive firm and green at the final destination before
being ripened with ethylene. Traditionally, the stage of banana ripening is closely linked with changes in peel color (Palmer, 1971). Under high temperature and low relative humidity conditions, the peel can remain green even though internal ripening has already commenced, and in such cases peel color does not reflect the internal status (Dadzie, 1998).

Maturity at harvest is an important factor affecting quality perception and the rate of change of quality during postharvest handling. During maturation, morphological changes occur in the fruit, i.e., fruit characteristics such as fruit weight, girth relative to length and the pulp to peel ratio can increase. These changes occur concomitantly with other visual changes in the fruit, such as, size, shape, angularity, skin color and nature of the stylar end. The extent of changes in fruit characteristics during maturation are generally hybrid/cultivar-dependent (Dadzie and Orchard, 1996). Therefore, it is important to identify key indicators or indices of maturation for banana that would ensure the best eating quality to the consumer and provide the needed flexibility in marketing. In Ethiopia, the dessert banana is all in all consumed out of hand at the fresh ripened stage.

Whole bunches are harvested when the fruit is at the green mature stage. Mature fruit is less angular and more rounded (“full”). Under optimal conditions it takes nine months from planting to the harvest of the crop; this period may be as much as 18 months, depending on climate, cultural practices and cultivar. From bloom to harvest it takes 80-95 days under good conditions and may extend up to 120 days under sub-optimal conditions (in subtropics it even lasts longer).

The weight of a bunch increases considerably during the last two or three weeks of maturity period and it is the producer’s advantage to postpone cutting as long as possible. However, a full bunch is very vulnerable in transport; the longer the transport distance, the earlier the bunch must be cut. Experience is necessary to determine the optimum stage for harvesting. The pseudo-stem, which has borne the bunch, is cut off at the base and used as soil mulch. Bunches are carried by hand to the nearest road for transporting to the pack-house or marketed by vehicle. Heavy losses of fruit occur during transport, particularly when the whole bunches are conveyed to market. Losses
of up to 40% (Dadzie and Orchard, 1996) have been reported. Bunches arriving at the pack-house are dehanded and the separate hands are dipped in fungicide solution (e.g., in maneb) to reduce infection by decay organisms. After drying, individual hands are packed in cartons and enclosed in plastic bags.

In the port of destination or on arrival at urban markets, the fruit is unloaded and taken to specially constructed banana ripening rooms. Here they are subjected to intermediate temperatures, usually 18-20°C, high humidity and an ethylene treatment. The exact conditions depend on the cultivar, the picking stage, outside temperature, lapse of time from harvest to arrival or consumption.

Local experiences indicate that temperature in the ripening room should be 19-24°C. In ripening, the skin changes color from dark to light green and greenish yellow to bright yellow. Meanwhile the pulp softens outwards from the core and also from tip to stalk. Generally, not all the bananas on a stalk ripen simultaneously allowing consumption of the fruit over an extended period of time. If left too long the pulp becomes watery, the skin turns brown and finally the whole fruit rots away. There are seven ripening stages (Fig. 8-6) according to the progressive color changes of the fruit and pedicel [http://postharvest.ucdavis.edu] : (i) green, (ii) green with some yellow, (iii) more green than yellow, (iv) more yellow than green, (v) only a green pedicel, (vi) yellow and (vii) yellow with brown spots.

Figure 8-6. Banana ripening stage chart.
Bananas should not be refrigerated prior to ripening as this will cause chilling injury. Chilling injury in bananas is a postharvest disorder which can result in great loss in the quality and shelf life of the fruit. Classic symptoms of chilling injury in bananas are subepidermal vascular browning, peel discoloration, delayed or abnormal ripening, and sometimes failure to ripen (Morrelli et al., 2003). According to the authors, speciality banana cultivars and plantains appeared to be more tolerant of temperatures below 13°C than the traditional Cavendish-type bananas, and thus have lower minimum safe temperatures for transport and storage.

Cooking banana (AAB group) and plantain (ABB group), unlike dessert bananas (Musa spp. AAA), are much starchier and can be eaten either ripe or unripe; they are boiled, steamed, fried or roasted. In world trade plantains are insignificant, but for home use they are as important as bananas. Cooking bananas and plantains were recently introduced to Ethiopia and are a potential carbohydrate source for our society. Currently various cultivars of cooking banana and plantain are being evaluated at Melkassa, Jimma and other Agricultural Research Centers for their adaptation to different agro-ecological zones of the country (Seifi Gebremariam, personal communication, 1999). Plantain fruits are not ripened artificially. Green fruits of plantains and cooking bananas are boiled, peeled and eaten as such or mashed and mixed with spices, fish or other food (Aravindakshan and Pushkaran, 1996). Yellow, unpeeled plantain fruits can be roasted while peeled ones are sliced and fried in palm oil. Overripe plantains and cooking bananas can be eaten raw.

References


CHAPTER 9

GRAPES (Vitis spp.)

Grapes, belonging to the Vitaceae family, are one of the world's major fruit crops. The European grape (Vitis vinifera L.) is believed to have originated in the area between the Black and Caspian Seas, where it still grows wild. About 18 species of grapes, important to viticulture (either as fruiting or rootstock), are native to North America. Although grapes are used mostly for wines and juices making, considerable amounts are consumed as fresh (table) grapes, jams, jellies and dried raisins. Over 90% of the world's grape production comes from V. vinifera cultivars.

Grapes are cultivated in all the continents, except Antarctica, and are among the most widely distributed fruit crop (Williams et al., 1994) in the world. This widespread distribution of vines is due to the large genetic diversity of available vine species and cultivars, as well as the relative low chilling requirement of buds to overcome winter dormancy. The most widespread vine species, V. vinifera L., is basically a temperate climate plant, adapted for warm summers and cold winters.

The origin of grapes being in the Caspian Sea region, with its cold winters, dormancy in the winter is a genetic necessity for the grapevine and a rest period is essential in the growth cycle of the grapevine. However, in the warmer cultivation regions of the world, this chilling requirement is not necessarily met and the resulting spring growth is often not satisfactory. Consequently, this leads to uneven and low budbreak percentages in spring, which causes management problems later in the growth season, resulting in reduced yields.

Grapes are an early introduced to Ethiopia, probably from the Mediterranean area, though reliable records are not available. Commercial
grape production, largely for the manufacture of wine, was started during the first half of the 20th Century by various entrepreneurs who established vineyards in “Shoa”, central part of Ethiopia (Jackson et al., 1985). Currently, over 100 cultivars, both introduced and local selections, are established at the Melkassa and DebreZeit Agricultural Research Centers, and Merti State Farm (Seifu Gebremariam, personal communication, 1999).

It is believed that Ethiopia has enormous potential for the successful production of grapes. Unlike in temperate countries, where the crop is widely grown, it yields two crops a year in many parts of Ethiopia, if proper pruning procedure and irrigation schemes are followed.

The tradition of wine making has been started a long time ago. Currently, different types of red and white wines are brewed in the country for local and export markets. However, the overall annual production has not yet satisfied the present local demand for grapes (i.e., fresh market as well as raw material for wine making industries).

**Botany**

The root system of the cultivated vine is spreading. Under conditions that favor growth, the roots spread over a wide area, penetrating the soil mass to a considerable depth.

The shoot system consists of the aboveground parts of the vine. These parts are the trunk, the arms, the shoots (canes, when mature), and the leaves (Fig. 9-1). The succulent growth arising from a bud is called a shoot. When the shoot becomes woody, matures, and drops its leaves, it is called a cane. The shoot of a vine is divided into several distinct parts: the growing tip, the nodes, the inter-nodes, the buds, the tendrils and the laterals.
Figure 9-1. A horizontal bilateral cordon: (a) trunk (b) arm (c) bearing unit/shoot (cane when mature)
Adapted from: Winkler et al. (1974)

A bud of the vine usually consists of three partially developed shoots, with rudimentary leaves or with both rudimentary leaves and flower clusters. These are compound buds, often called “eyes” (Fig. 9-2) (Babrikovet al., 1989).

Figure 9-2. A cross section of grape bud: (1) main/primary bud (2) reserve buds (or a substitute of the main bud) (3) tendril
Under normal conditions, only the middle one of the three partially developed shoots (the primary growing point) of the bud grows when the vine leaves out flush in the following spring. If it is destroyed, the more advanced lateral growing points will grow. Under abnormal conditions (such as over-severe pruning, destruction of part of a vine, or a boron deficiency), two or even all three of the growing points may burst grow. The buds of the vine may be classified according to (a) the nature of the structures they contain, or (b) their position on the shoot or arm.

As to the nature of the structures they contain, buds in grapes may be leaf buds or fruit buds (Winkler et al., 1974). The leaf bud is a rudimentary sterile shoot; it elongates into a shoot that bears only leaves and tendrils. Thus, a shoot arising from a leaf bud cannot bear fruit.

A fruit bud contains a shoot having both rudimentary leaves and flower clusters (Fig. 9-3). When a bud of this type unfolds (grows), it produces a leafy shoot that bears one to four (usually two) flower clusters opposite the leaves at the third and fourth, fourth and fifth, or fifth and sixth nodes from the base, depending on the cultivar. In the vine, the flowers are borne in a cluster or bunch. In position and origin, the cluster very closely resembles the tendril. The fruit of the grape is a cluster consisting of stems like rachis, branches, pedicels and berries. The seeds constitute up to 10% of the weight of the fruit. They are rich in tannin. The seeds are generally undesirable in table and raisin grapes.
Most *vinifera* varieties (European type grapes) have perfect or hermaphroditic flowers that have both a functional pistil and stamens (Fig. 9-4). Female or pistillate flowers have stamens that are short and more or less reflexed, and produce pollen that is generally sterile. These types are found in many varieties of European grape as well as in certain American varieties (Weaver, 1976). Male or staminate flowers have an undeveloped pistil that has neither a stigma nor a style, but contains only a small ovary which cannot be fertilized. To ensure good set of bunch, it is necessary to cross-pollinate the flowers of the self-unfruitful varieties with the flowers of self-fruitful varieties, which should be inter-planted among the rows of self-unfruitful variety.
Commerciaally, grapes may be classified into five main categories depending upon their purposes (Jindal, 1999; Pandy and Pandy, 1996). These are (i) Table grapes, (ii) Raisin grapes, (iii) Wine grapes, (iv) Juice grapes, and (v) Canning grapes. There is specific variety most suited for each purpose, and certain varieties qualify for more than one purpose. The grapes are also used for the preparation of vinegar and winery by-products for local uses.

**Table grapes** - The grapes that are used either for fresh consumption or for decorative purpose are designated as table grapes. The table grapes should be attractive, with good taste and excellent shipping quality. The berries should be large, uniform in size, shape and color. Grapes with Muscat flavor, thin skin, firm flesh, and seedless are preferred, e.g., ‘Thompson Seedless’, ‘Perlette’, ‘Muscat of Hamburg’, etc.

**Raisin grapes** - The grapes that produce acceptable dried fruits are included in this category. Seedless grapes possessing soft texture, a marked and pleasing flavor, large or small size after drying (depending on market demand), and little tendency to become sticky during storage are considered as good raisin grapes. ‘Thompson Seedless’, ‘Muscat of Alexandria’, and ‘Black Corinth’ are the examples of raisin grapes.

**Wine grapes** - Grapes with moderate or high acidity and low sugar content are suitable for dry or table wines, while sweet or dessert wines are prepared from grapes with high sugar content and moderately low acid contents, e.g., ‘Beauty seedless’, ‘Early Muscat’, ‘Perlette’, ‘Red Prince’, etc.

**Juice grapes** - Grapes that produce acceptable beverage when preserved by pasteurization, germ-proof filtration or other means. The juice must retain fresh grape-flavor. ‘Concord’, ‘Beauty seedless’, ‘Early Muscat’, etc. are examples of juice grapes.

**Canning grapes** - Seedless grapes, such as ‘Thompson Seedless’ are canned alone or in combination with other fruits, in fruit salad and fruit cocktail.
Ecological requirements

Soils can play an important role in grape production and potential wine quality. Grape requires a deep, loamy, well-drained, not over fertile soil, with good structure. It must contain organic matter with ideal pH range between 6.5 and 7.5.

In Ethiopia, the highest altitude limit for commercial production of grape was reported to be 2,000 m (Jackson et al., 1985). The lower limit has not been defined, but at localities like Abisir (1,000 m above sea level); grapes have been grown successfully for a number of years. From about 1,800 to 2,000 m, only one crop harvest a year can be produced but rain-fed production is possible provided precipitation is not less than about 800 mm/year. Supplementary irrigation is necessary to obtain higher yields. Below about 1,700 m, the temperature is high enough to produce two crops in a year, because the growing period is shorter. However, supplementary irrigation is essential in order to produce two crops.

At Koka (1,600 m a.s.l.) two prunings per year are practiced. The first pruning is done in August. This month is considered to be appropriate for pruning because it is on the offset of the main rainy season and also is cooler during which the plants will respond for such unfavorable weather condition and automatically proceed to dormancy to escape the season more in a slow-down of metabolism. Moreover, downy mildew prevalence is also getting lower at this month of the year due to lower relative humidity. The second pruning is done in January. This is done to prepare harvest of the crop prior to the main rainy season. At the same time January is also relatively cooler during which plants enter into dormancy. For dormancy breaking Dormex (cyanamide) at 10 liter/ha, is used (Adhanom Negasi, personal communication, 2013).

Grapes grown in the cooler climates are of better quality for wine making as they develop more color and have higher tannin content; on the other hand, grapes grown in warmer areas have higher total soluble solids (Jackson et al., 1985; Asfaw Zelleke, 2013).

Optimum temperature conditions for growing grapes are where mean
temperature fall within the range of 20-25°C with low to medium atmospheric humidity. Humid climates favor the development of diseases such as downy mildew.

Crop husbandry

Grape vines may be propagated from seeds, cuttings, layers, or grafts. Since most seedlings are inferior to the parent vines in vigor, productivity, and quality of fruit, propagation of vines by means of seed is not common. The seeds are useful, however, in producing new varieties (i.e., for breeding purpose). Propagation by cuttings, layers, buds, or grafts, in contrast, produces vines identical with the parents in all varietal characteristics. Nearly all grape cultivars, whether for fruiting or rootstocks, are multiplied by cuttings.

Layering as a means of propagating vines is recommended under two conditions (Winkler, 1974; Weaver, 1976): (a) to multiply cultivars whose cuttings can be rooted only with great difficulty, or (b) to replace occasional missing vines in an established vineyard.

Grape vines are grafted for the following purposes:

1. to obtain vines of the desired fruiting cultivar resistant to nematode or phylloxera (not reported in Ethiopia so far);
2. to correct mixed cultivars in an established vineyard;
3. to change the cultivar of an established vineyard;
4. to increase a supply of new or rare cultivars rapidly; or
5. to obtain vines on roots tolerant to certain adverse soil conditions such as high lime.

In Ethiopia grapes are propagated by stem cuttings of mature brown wood. Cuttings should be taken only from healthy, vigorous and high-yielding mother plants, which should be selected and marked before harvest, so that they can be recognized at pruning time. About 23-30 cm long cuttings of pencil thickness, preferably having four nodes, are prepared by giving circular cut just below the node on the lower portion and a sloping cut on the upper portion (Fig. 9-5). Recommended spacing in Ethiopia is 2.5 x 1.5 m, which
allows planting of 2,700 plants/ha. However, spacing could vary depending on the systems of training, pruning and trellis to be followed in the vineyard.

Vine spacing, the distance between vines within the vine row is a combination of vine genetic vigor, soil capability and climatic factors. Vineyard sites that are fertile and productive need larger distances between vines.

Genetic vigor variation among varieties also plays an important role with vine spacing. Genetically vigorous varieties typically require more distance between vines than less vigorous varieties. Vineyards in cooler sites generally have less growth (vigor) than warmer sites and therefore narrower spacings are more suitable.

Figure 9-5. Grape cutting (23-30 cm) with sloping cut at the tip end to ensure proper orientation.

Grape vines cannot be grown satisfactorily without some kind of support/trellis. The supports needed are of two kinds, temporary and permanent. Both kinds help to obtain, a well-formed vine with a strong, straight trunk, a vine that does not interfere with cultivation and other vineyard operations, and that is free of the defects and large wounds which otherwise diminishes vigor and longevity.

Trellising and training go hand in hand. Training is the strategic
development of grapevine structure and the trellis supports that vine structure. The basic goal of trellising and training is to maximize production, facilitate cultural operations (i.e., spraying, tillage, pruning, harvesting), improve canopy microclimate and to support the mechanical load of the vine.

Vineyard potential, variety vigor, and canopy spacing are the most important considerations when selecting trellis system (Hamman et al., 1998; Richard et al., 1998). These considerations are to a lesser degree economic factors. Vineyard potential would include environmental factors (i.e., temperature, topography, soil, rainfall and wind) and cultural management decisions (shoot thinning, fertilization, irrigation, etc.). Variety of vigor can often determine the choice of trellis system. For example, choosing a single wire trellis as compared to multi-wired trellis system may be sufficient for varieties with low vigor. Vines with excess vigor (long shoots, lateral growth, and shading) may need a more extensive trellis system. The high vigor trellis systems usually divide the canopy to support a higher number of buds and thus increasing canopy surface area.

Canopy spacing is a combination of row spacing and vine spacing. As a general rule of thumb, row-spacings should not be planted closer than the height of the trellis (shading can occur).

A great variety of trellis and training systems are in use in different grape growing countries in the world. Trellising and training go hand in hand. Training is the strategic development of grapevine structure and the trellis supports that vine structure. The basic goal of trellising and training is to maximize production, facilitate cultural operations (i.e., spraying, tillage, pruning, harvesting), improve canopy microclimate and to support the mechanical load of the vine (Hamman et al., 1998).

Trellis is needed for most of the common training systems, and its construction is similar to that of a fence. The initial choice of a trellis system is critical because vineyards are long term and usually trellised only once. Converting a vineyard to an improved trellising system is possible during the dormant season but can be very costly (Hamman et al., 1998). Care should be taken that the trellis is strong and adequately braced, as crop load of grape plants are very heavy. It is best to construct the trellis in the first or
second growing season so that training of vines can be started early (Strik, 2006).

The type of trellis the grower needs to construct varies with the training system used. However, all trellis systems have certain common characteristics. End posts should be strong and well anchored. Wooden posts should be treated with appropriate chemicals, such as copper-based wood preservative. Concrete posts, steel posts, or sound, used railroad ties also are suitable (Strik, 2006).

The system, which has been commonly used in Ethiopia, is the three or four wire trellis for supporting the bilateral cordon. Grapevine, in nature, is a robust climber, having strong apical dominance. However, this phenomenon can be modified to a desired shape by means of proper training system. Apical dominance can be modified by bending the canes to a position lower than the arm level. That is, the vine is trained parallel to the ground or bent towards bottom to regulate the optimum growth and fruiting. The regularity of bearing, yield, and quality of grapes depend largely on proper training and pruning of vine.

The training operation in grapevine normally begins when the newly planted cuttings start growing. A shoot is selected when it is about 15 cm long and all the other side shoots are removed. Remove only the lateral side shoots at each leaf axil, not the leaves. The chosen shoot is carefully tied to a support as it grows so that a straight trunk is formed. When this (single-stem) vine attains certain height, the growing point of it, is cut back to desired height. The height for cutting back is usually decided taking into account the system of training to be followed in the vineyard.

Pruning comprises the judicious removal of living canes, shoots, leaves, and other vegetative parts of the vine. Grapes generally are pruned more heavily than other fruit trees. The objectives of pruning of grapes are to (Winkler, 1974; Hamman et al., 1998):

1. help establish and maintain the vine in a form that will save labour and facilitate vineyard operations, such as cultivation, control of diseases and insects, thinning and harvesting;
2. distribute the bearing wood over the vine, among vines, and over
the years in accordance with the capacity of the spurs (or canes) and vines, so as to equalize production and get large average crops of high-quality fruit; and
3. lessen or eliminate thinning in the control of crop. Pruning is the cheapest way of reducing the flower clusters.

Proper pruning and training is essential for the production of a good yield of high-quality fruit and to maintain a balance between vegetative growth and fruiting. The number of buds (or length of bearing units) to remain after pruning depends on the vegetative growth of the plant and the sprouting rate. The number of buds, the number of shoots (bearing units) and the number of fruit clusters (grapes) per vine are positively correlated with each other (Winkler, 1974). It is therefore very important to find the right balance between vegetative growth and yield. The appropriate number of shoots is 8-10 per m², but because of the poor sprouting (bud-break) rate under tropical conditions, one has to prune to 10-15 shoots per m² (Jackson et al., 1985).

The most common problem in grape production is that vines aren’t pruned hard enough. When vines are pruned, growers must remove the majority of wood produced the previous season (about 90 per cent is pruned off) (Strik, 2006). Relatively little wood is left to produce the following season’s crop. Vines are pruned when they’re dormant. There are two methods, cane pruning and spur pruning (Strik, 2006).

Depending on positions of fertile buds on the canes, the following pruning methods (spur and cane pruning) are recommended in Ethiopia (Jackson et al., 1985):

**Spur pruning** - This pruning method is recommended for cultivars, which have their most fertile buds at the basal part of the cones. It is a very successful method for tropical viticulture; since apical dominance is not very pronounced. In this type of pruning, fully matured canes are pruned to two bud spurs (Fig. 9-6), which should be distributed regularly all over the plant. Single bud spurs should be selected close to the trunk for renewal purposes.
Short cane pruning - This pruning method is recommended for cultivars, which have their most fertile buds at the middle part of the canes. The bearing units are pruned to 4-8 buds. In addition, 1-2 bud spurs are necessary for renewal purpose.

Long cane pruning - It is recommended for cultivars, which have their most fertile buds at the apical part of the canes. This method is very difficult to manage due to apical dominance. Generally, fully matured canes are pruned to 8-12 buds (Fig. 9-7). In addition to these, long canes: 1-2 bud spurs are needed for renewal purposes.
Under tropical and subtropical conditions, the time of pruning and consequently the time of the vegetation season should be chosen according to climatic and economic aspects. The rainy season should not coincide with the development of young shoots, flowering and the harvesting period due to disease prevalence and fruit droppings.

In addition to pruning and training, flower-cluster and berry thinning, girdling, topping and pinching, and the use of plant growth regulators are practiced to improve grape quality.

It is important for growers to recognize the major grape diseases. Proper disease identification is critical for the correct disease-management decisions. It is imperative that growers should develop a basic understanding on pathogens' biology and disease cycles for the major grape diseases. The more one knows about the biology and disease cycles of important pathogens, the better to make sound and effective management decisions. Climatic factors have important roles in disease development and occurrence. The warmer and wetter the climate, the more favorable for numerous and severe diseases to prevail for the grape grower (Hamman et al., 1998).

The major diseases of grapes in Ethiopia are downy mildew, powdery mildew and cluster botrytis rot (Asfaw Zelleke, 2013).
**Downy mildew** - caused by the fungus *Plasmopara viticola*, is a very serious disease, which attacks all the succulent tender parts of the vine (leaves, shoots and clusters), leading to a partial or total destruction of the foliage, dwarfing and killing of the shoots, and cracking and rotting of the berries (Arya, 1993). The fungus causes direct yield losses by rotting inflorescences, clusters, and shoots. Indirect losses can result from premature fruit dropping. The fungus spreads rapidly; with profuse downy growth on the undersurface and corresponding greenish patches on the upper surface, which turn chlorotic with age. The mildew growth may cover the entire leaf blade which turns brown and withers. The disease may also involve floral parts and the fruit. Infected flowers die and drop off. Downy mildew is a problem during moist weather. Grapes grown in humid areas are therefore prone to this disease. The disease spreads very fast when the rains are frequent with cloudy sky. The disease is carried from year to year in the form of oospores.

Control measures of downy mildew include the following (Arya, 1993; Jindal, 1999):

1. Sanitary measures, such as cutting the primary source of infection by deep cultivation and ploughing, thus preventing the germination of oospores, are desirable practices.
2. Removing and burning the diseased leaves, shoots and berries that may contain hibernating oospores help in preventing epidemics.
3. The disease can be effectively controlled by spraying with 1% Bordeaux mixture repeatedly at 6-7 days interval.

**Powdery mildew** is another serious disease on grapes caused by the fungus *Uncinula necator*. It is an important disease in almost all grape growing regions of the world, but it is the most important in relatively dry climates (Hamman *et al.*, 1998). Powdery mildews are unique among fungal pathogens in that they do not require free moisture for spore germination or for penetration of the host plant. The spores are spread by wind. Almost any green tissue of a grapevine is susceptible to mild infection including tender parts of the shoot, blossoms, leaves, berries, the rachis and pedicles (Hamman
et al., 1998; Jindal, 1999). The presence of white, powdery mycelia on the surface of the leaves or any green part of the vine signals the disease, which is spread by wind-borne spores that germinate when leaves are dry. If the disease is not controlled on susceptible cultivars, the disease can reduce vine growth, yield and quality. Disease losses due to fruit infection can be severe and can result in complete loss of the crop.

The key to a successful powdery mildew control program is the assumption that mildew is always present in the vineyard and must either be prevented from spreading or repeatedly killed back so the epidemic does not develop to levels that will damage the crop (Hamman et al., 1998). The control measures include spraying of wettable sulphur (0.2%) or dusting sulphur at 5-7 days interval during infestation (Jindal, 1999). Sulfur is a completely preventive fungicide and is only effective immediately in the vicinity of the particle. Excellent coverage is necessary for control with sulfur. Sulfur is available either as a dust or as a wettable powder for water application. Once the disease has begun benomyl or wettable sulphur sprays are used for control. Failure to provide adequate control of powdery mildew early in the growing season can result in increased levels of other fruit rots such as Botrytis bunch rot.

*Cluster botrytis* (grey-mold) rot, caused by the fungus *Botrytis cinerea*, is another serious damage causing disease on clusters of grape. The fungus causes blight of leaves, shoots, and blossom clusters. It causes the grape skins to crack and the berries to turn brown and dry into a sort of moist raisin. The disease may occur on ripe grapes in the vineyard (before harvest), in transit, or in cold storage. Cluster botrytis rot is especially severe in grape cultivars with tight, closely packed clusters of fruit. Control can be obtained through two nonchemical management options (Hamman et al., 1998). Leaf removal around the developing fruit clusters will increase air circulation and decrease humidity levels within the canopy. This will reduce the likely-hood of bunch rot getting started. Secondly, varieties with very tight clusters may be cluster thinned by removing selected berries when young; this opens up the clusters to allow more air movement through them and thus reduce the potential for bunch rot.
Estimating grape yields

Crop estimation, also called crop yield prediction, is the process of projecting as accurately as possible the quantity of crop that will be harvested. Components of yield vary each year depending on the year, site, variety and cultural practices followed. The following factors are considered to estimate grape yield with reasonable accuracy (Hamman et al., 1998):

1) **Actual number of bearing vines per given area** (e.g., hectare): the maximum number of vines per hectare is determined by the row and vine spacing.

2) **Number of clusters per vine**: this number will depend on how many nodes (buds) are left after pruning. The number of clusters per vine can be counted as soon as they are visible (i.e., two weeks before bloom) or as late as berry set. The advantage of doing an early count is that clusters are readily visible and are not obscured by leaves. The number of vines on which to count clusters depends on vineyard size and uniformity.

3) **Cluster weight**: this is the component of yield that varies the most from year to year. It is influenced by environmental conditions. For example, wet weather during bloom could cause poor set and may lead to low cluster weight; also a dry summer tends to reduce berry size and thus may decrease average cluster weight. Other factors that may affect cluster weight include cultural practices (irrigation, fertilizers), diseases, insects, and birds. Cluster weights at harvest are a key part of any yield prediction program. The goal of obtaining cluster weight at harvest is not to predict the yield that year, but to provide records for yield prediction in subsequent years. Clusters can be collected from picking bins after harvest. This is an easy way to sample clusters from the bin but not as accurate as sampling clusters from the vines. The same vines used for cluster counts could be used for cluster weights. Clusters from each sample vine are picked and then weighed. The average cluster weight is obtained by dividing the total cluster weight per vine by the
Yields obtained in Ethiopia are relatively low. For example, at Koka, 3 tons/ha/harvest is recorded for table grapes which is way below the world average (20-25 tons/ha) and 13-16 tones/ha/harvest for wine grapes is an acceptable value (Adhanom Negasi, personal communication, 2013). This yield of table grape is far below as compared to those obtained elsewhere (20-25 tons/ha). The reason for this low yield is partly due to poor agronomic management practices and lack of Downy Mildew control practices.

Harvest and postharvest handling

Grapes are non climacteric fruit, and therefore they should be harvested at optimal ripening stage. The stage of maturity at which grapes are harvested depends on their end uses, which in turn usually depend on three parameters (Hamman et al., 1998): sugar content, acid content and pH. All of these change over time, and the rate at which they change is based largely on the temperature regime in which the grapes exist.

The acid and sugar content are the best measurements of maturity and occasionally color estimates or measurements are also useful (Weaver, 1976). Table grapes should be picked when they are attractive, where clusters are fully formed, berries are uneasy to loose, compact and have natural color particularly at stem end junction and have good taste quality. The sugar content of ripe grapes can be measured with a hydrometer or refractometer. These instruments are generally calibrated in the °Brix scale and read directly in percentage sugar by weight.

A reliable method of determining harvest maturity is by taking representative samples of berries from clusters at random from various vines, mash (crush) the grapes, and expressing the juice, and measuring the total soluble solids content (TSS) by means of a hand refractometer or hydrometer. The percentage soluble solids and refractometer reading is the same value as the °Brix.

The proper picking time for wine grapes depends mainly on the kind of wine to be made. While in raisin grapes, harvesting should be made when
the fruits attain the highest possible degree Brix as this helps to prepare better quality raisins. The TSS in degree Brix of grapes at harvest maturity for different end uses is shown below (Jackson et al., 1985):

Table grapes (grapes for fresh consumption) 16 °Brix
Raisins.................................................. ...18-20
Light white wine ........................................... ...17-18
Heavy red wine............................................. ...22-23

Sampling is critical in determining crop maturity. To make an accurate estimate of the sugar, acid and pH of a crop, a representative sample is taken from as many parts of the block, as many vines, and as many clusters in different sun exposures as possible. Younger vines and vines that are somewhat more water stressed will have higher sugar and lower acid (Hamman et al., 1998). Clusters exposed to the sun will be higher in sugar and lower in acid than those on the inside of the canopy. According to Hamman et al. (1998), in order to get a good estimate for picking, it is recommendable at least 200 berries be plucked with an effort to spread the sample across all the variations which might exist. It is easier to sample exposed clusters and exposed berries, so one tends to overestimate sugar content and underestimate acidity. It is also important that the grapes be squeezed to approximately the same degree to which they will be when actually pressed since higher sugar juice is released with only mild crushing.

Harvest maturity in grapes can also be determined based on the heat summation (degree-days) of the growing area. Time from blooming to ripening is largely determined for each cultivar by the effective heat summation which, for a given place, is calculated by subtracting 10°C (50°F) from the mean temperature for each day and adding together algebraically the quantities thus obtained (Winkler et al., 1974; Shoemaker, 1978). For whole months, the same result (degree-days) is obtained by multiplying the monthly mean by the number of days in the month.

Earliest cultivars need 871°C degree-days (1,600°F degree-days); the latest need at least 1,927°C degree-days (3,500°F degree-days). Thompson
Seedless, for instance, has been reported to ripe for table use at 18°Brix, and fully ripe for raisins at 25°Brix when the heat summation above 10°C, beginning at full bloom, reaches 1093 and 1,649°C degree-days, respectively (Jacob and Winkler, 1950).

Fruits for fresh consumption (table grapes) should be handled carefully so that the bloom on the skin of the berries is not damaged. Cool storage temperature (0°C) and 95% relative humidity for periods of up to six months with periodic fumigation to control disease are recommended.

Grapes for wine making do not require so much care in harvesting. They should be harvested into bulk containers, which are moisture proof and transported to the winery as fast as possible and under cool conditions to avoid fermentation.

Many factors contribute to and ultimately determine grape fruit quality, particularly in the case of wine grapes. Visual attributes, such as color, berry size, and cluster size are critical for acceptance of table grapes and in some cases wine and juice grapes (Owens, 2008).

References


Avocado belongs to the family Lauraceae. Central America, specifically Mexico and Guatemala, probably are centers of origin of the cultivated avocado varieties. It is a very nutritious fruit, containing 3-30% oil similar in composition to olive oil, and much vitamin B (Samson, 1986). The fruits are high in protein, fats (mono and polyunsaturated), several minerals and vitamins. The Guinness Book of Records lists the avocado as the most nutritious fruit in the world (McCarthy, 2001). The author further stated that avocado is suitable for infants through to the elderly and does not contain any cholesterol.

Botany

Avocado, a medium (9.1 m) to large (19.8 m) tree, is classified as an evergreen, although some varieties lose their leaves for a short time before and during flowering (Morton, 1987; Crane et al., 2007). Free-standing avocado trees typically have a rounded canopy with dense foliage. The tree canopy ranges from low, dense and symmetrical to upright and asymmetrical. Limbs are easily broken by strong winds or heavy crop loads. Its growth habit differs considerably between cultivars and according to the propagation method used. Trees raised from seed tend to grow erect and vertical, owing to strong apical dominance. Those grafted onto rootstocks have variable habits, which may be erect, round, goblet-shaped, or in the shape of a pyramid.

There are differences in flushing synchrony among cultivars and in general, new flushes tend to be from the tree periphery, continually adding to tree size (Sora et al., 2002). Different flushes on a particular branch are
easily recognizable, as the approach of a period of quiescence is marked by shorter internodes and then a ring of closely spaced buds (the intercalation) immediately distal to the resting terminal bud (Davenport, 1990). In avocado all branches are monopodial, and therefore indeterminate and ending in a vegetative bud (Sora et al., 2002; Crane et al., 2007).

Leaves are arranged in spirals, coming out in flushes, 7.6 to 41.0 cm in length and variable in shape (elliptic, oval, lanceolate). They are often hairy (pubescent) and reddish when young, then become smooth, leathery, and dark green when mature.

The inflorescence is most often simply called a much-branched panicle, and a single tree may have hundreds of panicles, each potentially with hundreds or thousands of flowers (Sora et al., 2002). Inflorescences arise most often from terminal buds, but also from sub-terminal buds in vigorous shoots. All inflorescences, at least initially, are subtended by a terminal vegetative bud, which may abort or grow out to compete with setting fruitlets. The terminal vegetative bud is not part of the inflorescence, and all avocado inflorescences are determinate and sub-terminal.

Flower primordia can usually be found in terminal and sub-terminal buds, from both spring and summer-grown shoots, from 4-5 weeks up to 2 months or longer before anthesis. Timing of flowering in avocado is a function of complex interacting factors, and is less well synchronized than for example in citrus trees. Generally, Mexican cultivars flower earliest, West Indian cultivars next, and pure Guatemalans last (Sora et al., 2002).

The flower of avocado is complete, but behaves in a unique way called ‘protogynous’ diurnally synchronous dichogamy in which its male and female organs do not function simultaneously (Ish-Am, 1991). The dichogamy is protogynous, meaning the stigma is receptive before the pollen is shed. The pistil matures before the stamens and all flowers of a group are synchronized to be functionally female at one time of the day and functionally male at another time. This way, self-pollination (of the same flower) is avoided. However, flowers on an entire tree are in different stages, and self-pollination does occur occasionally, but the young fruits fall from the tree prematurely, alluding to a possible post-zygotic self-incompatible mechanism (Boyle, 1980).
Pollination of the flowers is mainly by bees.

All avocado cultivars and seedlings, irrespective of race, fall into one of two complementary groups, designated “A” and “B” (Nakasone and Paull, 1998). The many-flowered lateral inflorescences (structures that hold the flowers) are borne in a pseudoterminal position. Flowers are perfect, yellowish-green, and 1.0 to 1.3 cm in diameter (Crane et al., 2007).

The avocado cultivars are divided into two complementary flowering groups, according to their daily flowering sequence. ‘A type’ cultivars bear, in warm weather, open female-stage flowers (Fig. 10-1A) from the morning till noontime, and the next day reopen these same flowers at the male stage (Fig. 10-1B) from noon throughout the afternoon. ‘B type’ cultivars, on the other hand, bear open female stage flowers throughout the afternoon, and reopen them at the male stage on the following morning till noon. Thus, a daily efficient overlap occurs between the female A-type flowers and the male B-type ones in the morning, and vice versa at the afternoon.

![Figure 10-1. Schematic longitudinal section of avocado flower. A-Female stage, with stigma receptive, but stamens bent outward and anthers not dehisced. B-Male stage, with stigma no longer receptive, but stamens upright and anthers dehisced. Source: Davenport (1986).](image-url)
Therefore, every morning A-pistils can be pollinated by B-pollen, while during afternoons B-pistils are ready to receive A-pollen (Fig. 10-2, 10-3 and 10-4). This means that, to ensure success, each orchard should be stocked with at least two cultivars, one from each group, both flowering during the same period of the year.

![Diagram](image-url)

Figure 10-2. Dichogamous flowering in the avocado.
Source: Samson (1986)

The periodicity of the flowering cycle is not always as marked as has just been described (Samson, 1986; Ish-Am, 1991). Climatic factors, especially changes in temperature, trigger significant offsets in the flowering rhythm of most of the avocado cultivars, leading to a daily regular self-overlap phase of male and female-stage flowers of the same tree (and cultivar), which takes place for a period of 1-3 hrs (Ish-Am, 1990).
Figure 10-3. ‘A’ and ‘B’ types of avocado according to the time of day when the female and male flower parts become reproductively functional. Source: Crane et al. (2001)

In cool weather there is a delay of the female and the male opening times, which may result in a complete reversal as to the part of the day female and male-stage flowers are open. Some cultivars (e.g., ‘Hass’) are known to fruit well in monoclonal stands (Samson, 1986).

The unique behavior of the avocado flower (Bergh, 1977) (Fig. 10-3) means that, in nature, the flowers are nearly always cross-pollinated. Self-pollination requires unusual flower behavior or a specific bee (or other insect) inter-flower movement during brief periods of overlap or rather lengthy pollen carryover on the bee’s body (Papademetriou, 1975).

Benefits are greatest when the mutually cross-pollinating cultivars are of opposite (A and B sex-stage) flower type (Bergh, 1977). The two complementary cultivars should have their branches close together and preferably overlapping. This can be achieved by having a small branch of one cultivar grafted into the second major cultivar or by adjoining rows in the orchard. When two rows of one cultivar are alternated with two rows of the other, orchard transportation rows and other gaps should be within, rather than between cultivars.

Field trials and grower observations continue to support the need for cross-pollination for avocados if maximum production is to be attained.
Cross-pollination has three prerequisites:

1. varieties of both A- and B-type flowers must be present;
2. both varieties must bloom during the same period;
3. either bees or other large insects must be present.

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**Figure 10-4.** Morphological stages of the avocado flower (B1, B2, B3, and C; represent functionally female stages, that is, from opening to closing of flower; while D1, D2, D3, D4 show different stages of functionally male flower. Note the orientation of stamens, in relation to pistil, at different morphological stages.)

Source: Ish-Am and Eisikowitch (1991)

There are three commercial avocado races, which may be best classified taxonomically as equally distinct botanical varieties: West Indian, *Persea americana* var. *americana*; Guatemalan, *P. americana* var. *guatemalensis*; and Mexican, *P. americana* var. *drymifolia* (Bergh et al., 1973; Bergh, 1976).
The Mexican race (*Persea americana var. drymifolia*)

This race is adapted to low temperatures. It is the most cold hardy of the avocado races; also more resistant to heat and low humidity. Its leaves have a pronounced anise scent when crushed, under-surfaces more hairy, glaucous (whitened with a bloom). Flowers generally are more pubescent (hairy); bloom earliest in the season; the period from flowering to harvest is six months. The fruits are small, rarely weighing more than 250 g; their skin is very thin and smooth; the oil content is fairly high (over 15 per cent). Fruit pulp is commonly rich to strong in flavor, sometimes with anise aroma and often fibrous. The seed is usually large and sometimes loose fitting (not adhering to flesh). Plants of this race are highly sensitive to soil salinity (Table 10-1).

The Guatemalan race (*P. americana var. guatemalensis*)

This race is characterized by larger leaves, both sides of which are a uniform deep green, rarely anise-scented. Young foliages are more commonly reddish. In adaptation and tolerance to soil and climate, Guatemalan race is intermediate between the Mexican and West Indian races. The fruit is usually larger in size than in the Mexican race. The fruit skin is usually thick and leathery to woody, sometimes over 6 mm. The seed, which also tends to be large, is almost always set tightly in the cavity. Oil content is medium (about 10 to 20 percent). The gap between flowering and harvest is usually eight to ten months.

The West Indian race (*P. americana var. americana*)

It is characterized by its large leaves, which are a lighter shade of green than in the Guatemalan race, with no anise leaf scent. The fruit is usually large. The skin is relatively thin, smooth and translucent, and delicate shade of green, turning yellow-green or reddish at maturity. At point of fruit attachment, the pedicels have a unique nailhead configuration. The flesh is watery, with low oil content (less than 10 per cent). The large seed is often loose fitting and mottled. This race is the most susceptible of the three to
cold and drought. However, it is the most tolerant of salinity (Table 10-1). The period between flowering and harvest is five to seven months. The fruits of this race are easily bruised, often suffering from chilling injury during storage and transport at the temperatures typically used for other species (6-8°C).

The avocado fruit is botanically a oneseeded berry containing two fleshy cotyledons and a small embryo. It is very variable (Table 10-1) in size, shape (round, oval, pyriform), rind characteristics (thickness, surface features, color), flesh, and seed characteristics (size, tightness in cavity, etc.) (Sora et al., 2002). Seedless avocado fruits (the result of stenospermocarpy) often set but do not reach the normal size of fruits with normal seeds. According to Sora et al. (2002), the seedless fruits are usually much more elongated and are commonly known as ‘cukes’ or ‘cocktail avocados’.

Table 10-1. Distinguishing characteristics of the three avocado races.

<table>
<thead>
<tr>
<th>Character</th>
<th>Mexican race</th>
<th>Guatemalan race</th>
<th>West Indian race</th>
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<tbody>
<tr>
<td><strong>Tree</strong></td>
<td></td>
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<tr>
<td>Climatic adaptation</td>
<td>Subtropical to Mediterranean</td>
<td>Subtropical</td>
<td>Tropical</td>
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<td>Cold tolerance</td>
<td>Most tolerant</td>
<td>Moderately tolerant</td>
<td>Vulnerable</td>
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<tr>
<td>Salt tolerance</td>
<td>Vulnerable</td>
<td>Fairly tolerant</td>
<td>Tolerant</td>
</tr>
<tr>
<td>Tolerance to root rot</td>
<td>Slight</td>
<td>Vulnerable</td>
<td>Highly vulnerable</td>
</tr>
<tr>
<td><strong>Fruit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shape</td>
<td>Elongated</td>
<td>Round</td>
<td>Elongated</td>
</tr>
<tr>
<td>Size</td>
<td>Small</td>
<td>Variable</td>
<td>Variable to larger</td>
</tr>
<tr>
<td>Color</td>
<td>Brown</td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td>Skin</td>
<td>Thin, waxy</td>
<td>Thick, rough</td>
<td>Thin, shiny</td>
</tr>
<tr>
<td>Oil content</td>
<td>High</td>
<td>Average</td>
<td>Low</td>
</tr>
<tr>
<td>Fibrous</td>
<td>Often</td>
<td>Seldom</td>
<td>Seldom</td>
</tr>
<tr>
<td>Cold storage</td>
<td>Excellent</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Seed</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotyledons</td>
<td>Large, sometimes loose, smooth</td>
<td>Small, tightly fitting, smooth</td>
<td>Large, sometimes loose, rough</td>
</tr>
<tr>
<td>Flowering to harvest</td>
<td>7-9 months</td>
<td>10-12 months</td>
<td>5-7 months</td>
</tr>
</tbody>
</table>

Source: Gaillard and Godefroy (1995)

In Ethiopia, some standard cultivars, introduced from California: ‘Hass’, ‘Pinkerton’, ‘Ettinger’, ‘Nabel’, ‘Bacon’ and ‘Fuerte’ are established at
Melkassa and Jimma Agricultural Research Centers and are being evaluated for their performance (Seifu G., personal communication, 1999). Distinguishing characteristics of these cultivars are presented in Table 10-2. In addition, there are two local selections namely; ‘Wondo Genet I’ and ‘Wondo Genet II’.

Table 10-2. Characteristics of some avocado varieties grown in Ethiopia.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Race</th>
<th>Flower type</th>
<th>Weight (g)</th>
<th>Oil content (%)</th>
<th>Shape</th>
<th>Color</th>
<th>Appearance</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacon</td>
<td>GxM</td>
<td>B</td>
<td>250-300</td>
<td>16-18</td>
<td>Obovate</td>
<td>Shiny green</td>
<td>Smooth</td>
<td>Thin</td>
</tr>
<tr>
<td>Ettinger</td>
<td>GxM</td>
<td>B</td>
<td>250-300</td>
<td>18-22</td>
<td>Narrow obovate</td>
<td>Shiny pale green</td>
<td>Smoothish</td>
<td>Thin</td>
</tr>
<tr>
<td>Fuerte</td>
<td>GxM</td>
<td>B</td>
<td>250-400</td>
<td>16-18</td>
<td>Obovate</td>
<td>Mat dark green</td>
<td>Smooth</td>
<td>Medium</td>
</tr>
<tr>
<td>Hass</td>
<td>A</td>
<td>A</td>
<td>250-350</td>
<td>18-20</td>
<td>Pear-shaped</td>
<td>Dark green to brown when ripe</td>
<td>Warty</td>
<td>Thin</td>
</tr>
<tr>
<td>Nabal</td>
<td>G</td>
<td>B</td>
<td>300-500</td>
<td>15</td>
<td>Spheroid</td>
<td>Dark green</td>
<td>-</td>
<td>Very thick</td>
</tr>
<tr>
<td>Pinkerton</td>
<td>GxM</td>
<td>A</td>
<td>270-400</td>
<td>18-25</td>
<td>Pear-shaped</td>
<td>Dark green</td>
<td>Warty tough</td>
<td>Medium</td>
</tr>
</tbody>
</table>


Based on flowering type, Hass and Pinkerton varieties belong to A-type while ‘Ettinger’, ‘Nabel’, ‘Bacon’ and ‘Fuerte’ to B-type (Lahav and Gazit, 1994). Avocado is grown in several agro-ecological zones of the country mainly by small-scale growers who grow it for subsistence and local markets.

Ecological requirements

The avocado is a sub-tropical fruit and is adapted to the same ecological conditions as citrus. It requires a pronounced dry season to induce effective flowering. In the humid tropics, where the dry season is short and unreliable, flowers are less abundant and the flowering period is more staggered. Average temperature for avocado varies from 12.8 to 28.3°C, evenly distributed annual precipitation more than 1,000 mm is sufficient for rainfed production of avocado (Gaillard and Godefroy, 1995). Avocado trees are frost susceptible, particularly when young, so they are best suited to frost free locations. They
are also susceptible to wind damage and galearm (McCarthy, 2001). It has been suggested that in Ethiopia, avocado should not be planted at altitudes higher than 1,800 m as in these areas frost should occur.

Avocados are sensitive to water logging. This is because water logging is associated with the presence of *Phytophthora* fungi, leading to root or stem end rot. Because of the avocado trees' high susceptibility to root rot pathogens, the main requirement is that the soil is free draining and of a good depth, at least 1 m, preferably 2 m (McCarthy, 2001). Gentle mounding can be employed to improve soil depth and drainage where necessary. The optimum pH is between 5 and 7, and irrigation water should be of low salinity.

**Crop husbandry**

The avocado can be propagated by sexual or asexual means (Bender and Whiley, 2002). Due to low cost, vigor of seedling growth and ease of propagation, most countries are still using seeds to produce rootstocks for grafted avocado trees despite their genetic variability (Ben-Ya'acov and Michaelson, 1995). Seeds should be harvested directly from the tree when mature, avoiding contact with the ground (Bender and Whiley, 2002). Planting of seeds should be made soon after removal from fruit or stored in a manner that prevents dehydration, as a high mortality will result if seeds are allowed to dry out (Storey et al., 1986; Whitsell et al., 1989). Avocado seeds often germinate slowly and irregularly, which can be due to either their postharvest treatment or the seedling line chosen (Leal et al., 1976).

Most avocado varieties do not come true from seed (i.e., a seed will not render the same variety), so they must be propagated vegetatively (Crane et al., 2007). Vegetative propagation is primarily used to perpetuate the unique genetic characteristics found in a rootstock or variety that make it valuable in a production system. Vegetative propagation involves cuttings, layering, grafting or in vitro tissue culture. Grafting is by far the most common method. Standard varieties must be propagated by grafting scion onto a seedling rootstock and trees normally start bearing within 3–4 years of being planted.
Poor seedling trees and unsatisfactory cultivars can be top-worked using cleft grafting. Avocado trees are also commonly top-worked in the field if a pollinizer or change in cultivars to meet market specifications is required. Varieties belonging to opposite ‘flower groups’ that can provide cross-pollination to improve yields of the main variety are commonly introduced into orchards through top-working a branch or selected trees (Bender and Whiley, 2002). Healthy trees are fairly easy to top-work, grow faster than replant nursery trees, and begin to produce fruit 2-3 years after grafting. The most common method of top-working is to cut the tree to a stump and insert scions beneath the bark in contact with the cambium tissue.

Selection of good propagation material (e.g., scion) is one of the most important tasks for the propagator (McCarthy, 2001; Bender and Whiley, 2002). Suitable buds are found on mature terminal growth that is quiescent. Terminals carrying plump, dormant buds with a dark green color are best selected. Scion wood with extra large buds during the early winter through to spring may be floral and not produce vegetative growth. Other buds to avoid are those that are slim and elongated with a small leafy growth at the end, as these are not mature (Whitsell et al., 1989).

The best wood is generally found on young trees, or older trees that have been cut back to force strong new growth. However, if the growth has been too vigorous the budwood may have central soft pith that contributes to drying of the wood (Bender and Whiley, 2002). Budwood should be firm and not rubbery. It is sometimes helpful to prune rubbery, immature tips a week before cutting scion wood as this will usually hasten the growth and maturity of the more basal buds (Whitsell et al., 1989). Scion wood that has brownish bark, internal browning in the wood or abscised buds is not suitable for propagation.

During the grafting operation, budwood should be stored in a box lined with wet burlap or wet newspaper and covered with a damp cloth to prevent desiccation. Scions stored in polythene bags should be kept out of sunlight as heat will build up quickly and kill the material (Bender and Whiley, 2002).

Budding with a ‘shield’ bud is the oldest method of asexual
propagation used in commercial avocado nurseries. It is still used when budwood is scarce or expensive, but is limited to times when bark slips easily from the rootstock (Bender and Whitley, 2008).

Spacing varies with climate, soil and cultivar from 6 to 12 m on the square. Recommended spacing for grafted avocado trees is 7 x 7 m, which gives a plant population of 204 trees/ha. Seedling trees are more vigorous and should not be planted closer than 9 x 9 m (Ethiopian experience). The modern practice in California is to plant at 5 x 5 m and gradually thin to ultimate spacing.

Seedling avocados begin bearing at 5-6 years. As mentioned before, vegetatively propagated plants usually come into bearing earlier, but it is usual to remove the fruits (defruiting) until the tree is 3-4 years old. Mature fruits can remain on the tree for some time before harvesting. Maturity can be tested by the oil content or by picking a few fruits to test ripening. Immature fruits will not soften and ripen properly.

Fertilizer use on avocado is not much different from that in citrus, but nitrogen requirement is lower.

Avocado trees must be pruned at an early stage. Formative pruning during the first 2 years may be desirable to encourage lateral branching (and growth) and the formation of a good framework. Selectively removing a few upper limbs back to their origin (crotches) each year will help prevent the loss of the lower tree canopy due to shading by the upper canopy. In addition, maintaining a smaller tree facilitates tree care and fruit harvest, makes it easier to spray the tree. The top may have to be cut back in cultivars with an upright habit, but this must be done carefully; as severe pruning reduces yields. Lower tree branches (limbs) are not removed. However, lower limbs are removed only if they interfere with irrigation and fertilization (Nakasone and Pauli, 1998).

Fruit production involves the capture and conversion of light energy into fruit biomass (dry matter). The main controlling factors here are the amount of incoming radiation, the percentage of that radiation which is intercepted by the tree, and how efficiently the tree converts that energy into fruit (Wünche and Lakso, 2000).
Canopy management, particularly tree training and pruning, also affects the percentage of sunlight intercepted by the tree, as tree shape determines the presentation of the leaf area to incoming radiation. Generally a narrow tree that is wider at its base than its top will have the greatest area of leaves exposed to sunlight. It should come as no surprise then that this is the preferred tree shape for most tree fruit crops.

Like in apples (Tustin, 1990), the objective of canopy management of avocado trees is to start with single axis trees provided by the nursery and to have minimal pruning in the first years so that the trees naturally produce a single dominant trunk. With the emphasis on minimal pruning, maintenance pruning involves only the removal of side branches likely to reduce the dominance of the central leader, and thus to promote the development of a slender fruiting canopy.

Various diseases are known to attack avocado, the most serious being root rot (Nakasone and Paull, 1998; Crane et al., 2007).

**Avocado root rot** (*Phytophthora cinnamomi*) - In areas subject to flooding and on poorly drained soils, trees of any size and age are likely to be infected by fungus. Trees affected by this disease lose vitality, become sparsely foliated and do not produce the expected crop. The pathogen primarily causes a rot of the fine feeder roots that blacken, become brittle and eventually die (Palmateer et al., 2006). As the disease progresses, feeder roots are reduced resulting in reduced; soil beneath the trees remains wet. Severely infected trees show sparse foliage with pale green, often wilted leaves and dieback occurs in advanced stages. Feeder roots become darkened and decayed, and trees will eventually die prematurely. The fungus can be spread to new areas with infested planting material, soil and irrigation water.

In Ethiopia, avocado root rot or decline was observed in avocado orchards in the early 1990s at the Jimma Research Center (JARC). Surveys conducted since then confirmed that avocado root rot is widely distributed in all districts of Jimma, Illubabor and Wellega zones (southwestern Ethiopia) causing heavy crop damage (Mohammed et al., 2009).

For managing this disease, only disease-free nursery stock should be used, and no planting should take place in areas that are subject to flooding.
Introduction of soil or water from infected areas to clean fields on equipment or plant stock should also be avoided (Palmateer et al., 2006).

Anthracnose (Colletotrichum gloeosporioides) - Anthracnose is a serious disease of avocado fruit, causing dry and rotted fruit and reducing shelf life during storage and transport (Palmateer et al., 2006). Anthracnose is the most common rot of mature fruit, but also affects leaves, twigs and young fruit under favorable conditions. Infections occur through lesions caused by other organisms such as scab and Cercospora spot or mechanical injuries (Crane et al., 2007). The fungus does not develop in actively growing fruits but causes a rot as the fruit ripens. Fruit lesions start as circular brown to black spots which enlarge, become sunken and crack. It is recommended that wind and insect damaged trees be treated with a fungicide such as azoxystrobin or copper to prevent infection by the fungus (Palmateer et al., 2006).

Cercospora spot (Cercospora purpurea) - Infection appears on fruits and leaves as small, angular, dark brown spots which combine to form irregular patches. These spots have a yellow halo. Fruit lesions are frequently the point of entry for other decay organisms such as the anthracnose fungus. Infection usually occurs during the dry months.

Avocado scab (Sphaceloma persea) fungus readily infects young, succulent tissues of leaves, twigs and fruit (Crane et al., 2007). These tissues become resistant as they mature. Lesions appear as small, dark spots visible on both sides of the leaves. Spots on leaf veins, petioles and twigs are slightly raised, and oval to elongated. Severe infections distort and stunt leaves. Spots on fruits are dark, oval and raised and eventually coalesce to form cracked and corky areas which impair the appearance but not the internal quality of the fruit. Many avocado varieties are resistant or moderately resistant to scab and no control is necessary. Efficacy trials in Florida indicated that copper fungicides seem to give good control and Folpet is also labeled for controlling avocado scab (Palmateer et al., 2006).

Harvest and postharvest handling

Identification of proper maturity is difficult in the case of avocado fruits, as maturation is not accompanied by significant changes in external appearance.
Experience is therefore required in harvesting avocado at the correct stage of maturity. An avocado fruit of insufficient maturity is likely to shrivel and rot during softening and will in any case lack the desirable flavor found in more mature fruit (Marriot and Proctor, 1984), whilst late harvested fruit will become soft and over mature before it reaches the consumer.

An experiment conducted at Jimma (Southwest Ethiopia) to determine stage of maturity at harvest indicated that the fat and dry matter contents of avocado fruits tended to increase as the fruit matures on the tree (Table 10-3) (Maru et al., 2011). Optimum quality was observed towards the later days of harvest and advantages could be obtained by timing the picking. The highest value of fat (18.72%) was observed for the third harvesting date (8 months after flowering), while the lowest fat value (16.23%) was observed for the first harvest date (6 months after flowering). According to Maru et al. (2011), the best parameter to be used as a maturity index for avocado fruit was found to be the calendar (harvest dates expressed in terms of days after flowering).

Table 10-3. Average fat content (%) of six varieties at four different harvesting dates.

<table>
<thead>
<tr>
<th>Harvest date(days)</th>
<th>Fat (%)</th>
<th>Dry matter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>16.23a</td>
<td>22.82ab</td>
</tr>
<tr>
<td>210</td>
<td>17.40a</td>
<td>18.50ac</td>
</tr>
<tr>
<td>240</td>
<td>18.72b</td>
<td>25.11ab</td>
</tr>
<tr>
<td>270</td>
<td>18.44b</td>
<td>28.98b</td>
</tr>
<tr>
<td>G. Mean</td>
<td>17.70</td>
<td>23.85</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>2.32</td>
<td>9.79</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different at P≤0.05

Commonly avocado fruit is considered to be mature when a certain minimum oil content (e.g., 15% for the Mexican varieties) and size, typical for the variety, is reached. A study conducted at Jimma (Southwest Ethiopia) indicated
the existence of significant (P<0.01) variation in fat content among six avocado varieties (Maru et al., 2011). The highest fat content was observed for the variety ‘Bacon’ (19.44%), while the lowest was observed for the variety ‘Pinkerton’ (15.30%) (Table 10-4).

Table 10-4. Mean values of fat and dry matter contents (%) for six avocado varieties at Jimma (Southwest Ethiopia).

<table>
<thead>
<tr>
<th>Variety</th>
<th>Fat (%)</th>
<th>Dry matter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacon</td>
<td>19.44 a</td>
<td>27.35</td>
</tr>
<tr>
<td>Ettinger</td>
<td>19.37 a</td>
<td>29.22</td>
</tr>
<tr>
<td>Fuerte</td>
<td>18.02 b</td>
<td>27.05</td>
</tr>
<tr>
<td>Hass</td>
<td>18.14 b</td>
<td>21.67</td>
</tr>
<tr>
<td>Nabal</td>
<td>15.92 cd</td>
<td>17.10</td>
</tr>
<tr>
<td>Pinkerton</td>
<td>15.30 d</td>
<td>20.73</td>
</tr>
<tr>
<td>G. Mean</td>
<td>17.70</td>
<td>23.85</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>3.18</td>
<td>NS</td>
</tr>
<tr>
<td>CV (%)</td>
<td>3.47</td>
<td>26.09</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different at p<0.05.

Avocado fruits should be clipped from the tree. Fruits ripen best at temperatures of 15-24°C and should be stored or transported at 13°C (West Indian varieties) or at temperatures not lower than 5°C for hardier ones (Samson, 1986). If picked when full grown and firm, avocados will ripen in 1 to 2 weeks at room temperature (Morton, 1987). The best place to keep fruit until used is on the tree. Some avocado varieties hold their fruit satisfactorily for several months, others for only a relatively short time. This is a varietal and seasonal characteristic. Picking only a few fruit at a time when needed may extend the harvest period many months (Anonymous, 2000).
References


Mango belongs to the Anacardiaceae family and is originated from the South-East Asia, Indo-Burma region (Samson, 1986; Sadhu, 1999).

Botany

The mango forms an erect, branched, evergreen, large tree with a wide crown (dome-shaped canopy). Most cultivated mango trees are usually between 3 m and 10 m tall when fully mature, depending on the variety and the amount of pruning. Trees (seedling trees) can reach heights of 15-30 m when found in favorable climates, and in some forest situations. The leaves are simple, exstipulate, and alternate with petioles of 1-12 cm long. The leaves are variable in shape and size, but usually oblong with tips varying from rounded to acuminate. New leaves emerge in flushes of 10-20 leaves. Young expanding leaf color varies between varieties and can be from light tan/chocolate to deep purple, and can be used as a distinguishing character among varieties. Mature leaves are dark green with a shiny upper surface and glabrous lighter green lower surface; they remain on the tree for over a year. Vegetative flushing usually continues throughout the wet season, slowing as the climate and soil dry out. The leaf-flushing period can have one to five flushing events, with the whole canopy flushing in synchrony or in patches. In years of poor flowering and cropping, several leaf flushes can occur during the flowering and fruiting period. Although mango is an evergreen tree, large quantities of old leaves are shed during vegetative flushing. The fallen leaves become mulch under the tree, where nutrients are recycled from old leaves to the new leaves.
According to Bally (2006), in a typical tree there are two periods of dormancy. The first is immediately after harvest or ripe fruit drop, when the tree becomes dormant for 2-8 weeks, depending on the soil moisture conditions and previous crop load. The second dormant period is after the summer flush period, when dryer conditions set in. The second dormancy period is critical for floral bud development.

Mango flowers are born on terminal inflorescences (panicles) that are broadly conical and can be up to 60 cm long on some varieties (Bally, 2006). Inflorescences usually have primary, secondary, and tertiary pubescent, cymose branches that are pale green to pink or red and bear hundreds of tiny flowers. There are two types of flowers, male and perfect (hermaphrodite). The number of panicles in mango varies from 200-300 per tree. The panicles may have 300-1,000 flowers in each panicle. Out of these flowers only few fruits are formed depending upon the season and variety. The proportion of male and hermaphrodite flowers (sex ratio) on panicles may be 1:4, 1:1, 2:1 (Bal, 2002). This proportion (the percentage of perfect flowers) varies according to the variety and season (environmental conditions) of flowering (Joubert et al., 1993). During cooler seasons, the percentage of hermaphrodite flowers is relatively less. Studies indicate that although the total number of flowers is substantially less in the distal half of panicles, there is a greater proportion of perfect flowers in this part (Davenport and Núñez-Elisea, 1997); however, this condition may be reversed in some cultivars (Hussein et al., 1989). Perfect flowers tend to form in the terminals of individual inflorescences while staminate flowers are displayed in the earlier forming flowers located closer to the panicle axis. When panicles begin to elongate in the lower inflorescences, only staminate flowers form and the perfect flowers form at the terminus of each lateral inflorescence. As more distally located lateral inflorescences begin elongation and anthesis, they too first display staminate flowers before perfect flowers. These inflorescences are progressively shorter than previously formed proximal inflorescences, and there are fewer staminate flowers. The final vertical spike of the panicle is composed almost exclusively of perfect flowers. Each flower has only one full-developed stamen and if the cloudy weather occurs while the trees are in blossom; the flowers mostly wither and
fall off without fertilization. Flowers begin to open early in the morning and anthesis has generally been completed by noon. The greatest number of flowers opens between 9 and 10 a.m. (Iyer and Schnell, 2009). Mango is cross-pollinated, which is carried out by insects such as the common housefly, honeybees and thrips, and possibly by other insects although to a lesser extent. The initial fruit set is directly related to the proportion of perfect flowers though the final fruit set doesn’t depend on it (Iyer et al., 1989).

Mango flowering occurs during the coolest months of the year. Flowering requires 4-6 weeks of shoot dormancy and cool night temperatures to trigger floral induction of the terminal buds. The absolute temperature needed for floral induction varies among varieties and climates, but night temperatures between 8°C and 15°C with day temperatures around 20°C are typically needed. Better flowering is seen in trees growing in the subtropics where the seasonal temperature differences are stronger and more reliable than in the hot tropics. Flowering in mango continues in two or three distinct flushes for a period of six to eight weeks in different branches or trees, and it takes about five months for the fruit to mature and ripen after flowering.

Mango is a highly cross-pollinated crop and pollination takes place mostly through insects (Ram et al., 1992) such as wasps, ants, flies, bees, and wind. Temperatures below 10°C during flowering are not conducive to production of viable pollen, and temperatures below 15°C during pollination can prevent effective pollen tube growth and fertilization of the ovary. Pollen is generally compatible within and between varieties.

In mango, initially, hundreds of fruits can be set on each flowering inflorescence. The tree naturally thins the crop by shedding fruit throughout the fruit development period. At full fruit maturity on heavy cropping trees, most mango varieties will hold one fruit for every two or three inflorescences (Davenport, 2009). Mango fruits can take 3-6 months to mature, with temperature being the primary influence on maturity timing. Fruits grow faster and mature earlier in warmer climates. The variety of mango also has an influence on maturity timing, with varieties being classified as early, mid- or late season. The mango fruit is a broad, fleshy drupe with edible pulp (mesocarp) and a stony layer around the seed. Fruit size, shape, color, flavor
and taste vary according to variety. Seedling trees are known to live a long time, over 100 years, grafted trees may live for 80 years.

Mangoes can be classified into two groups, as having either monoembryonic or polyembryonic seed embryos (Bally, 2006; Mukherjee and Litz, 2009). Monoembryonic mango seeds contain only one embryo that is a true sexual (zygotic) embryo, as a result a single plant grows from a seed of a monoembryonic cultivar. Fruit grown from monoembryonic seedlings will often vary from the parent trees, so propagation by grafting is used to produce true-to-type monoembryonic trees. Sexual seedlings are generally of the breeder’s interest as they help in the selection of new improved rootstocks.

Polyembryonic mango seeds commonly contain several embryos, many of which are asexual (nucellar) in origin and genetically identical to the maternal parent. Polyembryonic seeds also usually contain one zygotic embryo (Mukherjee and Litz, 2009). Approximately three to eight seedlings normally originate from a single polyembryonic seed (Garner and Chaudhri, 1976, cited in Ram and Litz, 2009). The zygotic seedling usually has lower vigor than the nucellar seedlings. In some varieties this is reversed and the zygotic seedling is the most vigorous. The nucellar seedlings behave like the female parent and are comparable to vegetatively propagated plants, while the seedlings resulting from the sexual union exhibit variations. Nucellar seedlings are preferred for the propagation of mango rootstocks because of their uniformity. The uniformity of nucellar rootstocks would help in standardizing the performance of the scion trees and avoid the variability inherent in monoembryonic rootstocks. Therefore, elimination of sexual seedlings (off types) from the nursery bed would ensure the retention of the nucellar seedlings. Mango seeds are considered to be recalcitrant and cannot survive for more than a few days or weeks at ambient temperatures (Parisot, 1988, cited in Mukherjee and Litz, 2009).

Ecological requirements

Mango grows over a wide range of frost-free climates. The trees produce best in climates that have a well defined, relatively cool dry season with high heat
accumulation during the flowering and fruit development period. There must be a marked dry season to induce flower formation. Rain or free moisture (high humidity, heavy dew, and fog) during the flowering and fruiting period is conducive to the development of fungal diseases that cause flower and fruit drop (Bally, 2006). Temperature is probably the most important environmental variable to consider when selecting mango cultivars for particular sites. The mean temperature range for optimum growth of mango is about 24-30°C (Whiley et al., 1989). However, mango trees can tolerate temperatures up to 48°C for short periods (Mukherjee, 1953). Mango trees have limited tolerance to cold and trees are usually severely damaged or killed after a few hours at temperatures < 0°C (Campbell et al., 1977). In areas where optimum temperature ranges do not prevail, cultivation of mango on a commercial scale could be risky. Mango grows best in full sun because its flowers and fruit are produced at the edge of the canopy (the outside of the tree) in full sun. Light interception and utilization within tree canopies is a primary consideration in orchard design. Thus, tree spacing as well as pruning practices in orchards are primarily based on maximizing light for photosynthesis. The best fruits are from sun-exposed branches (Bally, 2006).

Though a tropical fruit, the mango is adapted to fairly high altitudes. In Ethiopia, sporadic mango plantations are found from 500-1,800 m a.s.l., but in upland areas (above 1,200 m) production is often poor. Gambella (500 m a.s.l.), and Assosa areas (about 1,200 m a.s.l.) are known to be suitable for the production of better quality mango.

High temperature, together with low humidity and a strong wind, is injurious; the plant cannot cope with the increased transpiration, otherwise trees may die out, be prone to leaf scorch, seed abortion, and fruit fall. Mangoes require a lot of light.

Rainfall requirements vary from very little, where irrigation is possible, to a lot, if the soil is permeable. Rain fed production is possible with 900 mm rainfall or more, provided that it is well distributed throughout the year. Good yields are unlikely below this level unless supplementary irrigation is provided. Rainfall at the time of flowering would interfere with pollination and could favor mildew that attacks the inflorescence, which
subsequently results in a poor set of fruit. Adequate soil moisture during fruit setting is of importance.

Dry and cloudless weather, before flowering, has been found conducive to profuse flowering. Strong winds and heavy rains during the fruiting season can cause immense damage by shedding the fruits. The frequency and speed of winds should therefore be taken into account while selecting site for mango orchards. In addition, strong winds cause shedding of flowers and fruits, and in worse cases cause serious damage to scaffold branches (or trees). However, the damage that may be caused by wind can be minimized by planting tall and hardy trees (windbreak) around mango orchard. Provision of suitable wind break, especially benefits the grafted trees, which are more vulnerable to speedy winds compared to that of seed propagated ones.

Mango is not a highly demanding plant with regard to soil fertility. Soil with good drainage, permeability, fair water holding capacity, and ground water at a depth of 3-4 m is an ideal mango soil. A pH of 5.5 to 7.0 is preferred. Very poor, shallow, alkaline, rocky and waterlogged soils should be avoided (Samson, 1986).

Crop husbandry

Mango reproduces naturally by seed, although this is rarely a horticultural practice, particularly for monoembryonic cultivars (Ram and Litz, 2009). Except in the case of apomictic (nucellar) seedlings that originated from polyembryonic seeds, plants must be propagated vegetatively to produce clonal material, true-to-type. Polyembryonic seeds give rise to several seedlings which can be separated from one another after germination and planted as independent plants.

Mango seeds loose viability very quickly, if not properly stored; it is best sown fresh. Maximum viability is obtained in freshly extracted seed, which decreases gradually with age (Sadhu, 1999). Seeds obtained from fresh ripe fruit, may also be stored in moist charcoal for 100 days, but better sown within a few days after harvest. Freshly extracted mango seeds from ripe fruits germinate with higher frequency (76-91%) than those from overripe,
firm or green fruits (Shant and Samoo, 1977 cited in Ram and Litz, 2009). The seed is sown 5 cm deep and germinates within 20 days. It is easier and cheaper to look after plants in a nursery than sowing seed directly in the field.

Most mango varieties are monoembryonic and do not breed true to their parents when grown from seed. Therefore, they have to be propagated by the asexual method. Vegetative propagation is utilized to preserve the unique phenotypes of superior selections, and has been based upon grafting and rooting methods, growing plants from nodular seedlings of polyembryonic mangoes and micropropagation (Ram and Litz, 2009). Budding and grafting are the most popular vegetative propagation methods of mango. Several vegetative propagation methods such as approach grafting, veneer grafting, epicotyl/stone grafting, patch budding, shield budding, air layering etc., are practiced in mango multiplication. Grafting or mango can be either attached or detached. In the attached method of grafting the scion is not severed from the mother plant until its union with the rootstock is complete, i.e., approach grafting, tongue and saddle grafting. In the detached method, the scion is removed from the mother tree and then joined with the rootstock, and both are allowed to grow prior to cutting of the rootstock above the graft union. Detached methods include cleft or wedge grafting, whip or splice grafting, side grafting, veneer grafting, 'T' or shield budding, patch budding, chip budding, etc. Rooting methods include layering and cutting techniques (Ram and Litz, 2009). Unlike grafting, budding is cheaper, quicker and an easier method. Rootstocks must be uniform in size, possess tolerance to soil-borne diseases and induce regular bearing. Old, or puffy and unproductive trees may be renovated by top working, using approaech, side or cleft grafting.

Grafted or budded mangoes usually produce a few fruits in the 4th or 5th year (in some cases even in the 2nd or 3rd year) after planting and yields gradually increase until the tree reaches its full bearing age. To avoid early bearing that may weaken the tree, any flower buds that develop during the first five years (from planting) need to be removed (Sadhu, 1999). Trees of vegetatively propagated mangoes are generally smaller than seedling trees. Seedling mangoes take longer (usually 5-10 years) to come into bearing, depending on cultivar and growing location.
Mango produces flowers and bears fruits mostly on the terminal buds of its shoots and very rarely on the auxiliary buds. Dry weather stimulates flowering while cloudy weather or rains tend to retard it. The chief internal factors that govern the entire phenomenon of flowering in mango are the maturity and age of its seasonal vegetative growth (leafy shoots) which are produced in distinct flushes at certain time of the year (Sadhu, 1999; Bal, 2002).

Grafted trees are usually set 8-10 m apart, while seedling trees need more room: a density of 100 trees/ha is common. However, better yield is obtained when a medium spacing of 7 x 7 m (204 trees/ha) is employed. The best time for planting is at the beginning of the rainy season. Owing to the wide spacing mango can be inter-cropped for five to six years with banana, papaya, pineapple, vegetables and other short-lived crops.

Mango fruit yields are generally low compared to other tropical and subtropical fruit species. The yields often reflect irregular annual bearing patterns, and they vary greatly from season to season. The yielding capacity of a tree is dependant on variety, tree age, tree size, seasonal conditions, and previous cropping history (Litz, 1997).

In Ethiopia, ‘Apple mango’ (introduced from Kenya in 1974) and ‘Sodere II’ cultivars are now recommended for general cultivation. These cultivars are fiber-less, fleshy, and juicy compared to other locally grown cultivars. Other cultivars, recently introduced from Israel namely; ‘Haden’, ‘Tommy Atkins’, ‘Zill’, ‘Keitt’, ‘Kent’ and ‘Irwin’ are established and being evaluated at the Melkassa Agricultural Research Center (Asmare Dagnew, personal communication, 2013).

According to Samson (1986) one of the most pressing problems in mango growing is alternate bearing (irregular bearing); during the “on-year” very many small fruits are set whose development exhausts the tree. In one or more subsequent “off-years” there is little or no harvest. Stripping flowers or thinning fruitlets in an “on-year” can reduce such problem. This can be done either by hand, or by means of chemicals such as naphthalene acetic acid (NAA) and dinitro-orthocresol (DNOC). Application of fertilizers may also help, particularly if they contain magnesium, zinc and manganese.

Mango is also characterized by a heavy fruit drop at all stages. Litz
(1997) has pointed out that less than one out of a thousand perfect flowers develops into a mature fruit. Rain, high humidity, attacks by fungi and insects, a low C/N ratio of fruit, mineral deficiency, a low percentage of perfect flowers and hormonal imbalance have been blamed for alternate bearing.

The following measures have been proposed to control alternate bearing; even though none of these measures are entirely successful (Samson, 1986; Litz, 1997): (1) Avoid cultivars that are known alternate bearers, (2) Plough, manure and irrigate during the on-year, (3) Double the amount of N during on-years, (4) Irrigate immediately after fruit setting, (5) Deblossom partly (flower thinning) in on-years, or (6) Ring (girdle) branches.

No information is available on fertilizer application of mango under Ethiopian conditions. Generally, it is recommended to apply nitrogen when the trees are bearing heavy crop (fruits) so as to stimulate shoot and flower bud growth for the next crop (season). Fertilizer regime that is recommended for citrus may also work for mango (Jackson et al., 1985).

In mango, regular pruning is not necessary, except for removing crossing branches, dead wood, and parasitic plants.

Some important diseases and insect pests of mango are presented below:

**Anthracnose** - This is a serious mango disease caused by *Colletotrichum gloeosporioides*. It attacks young leaves, flowers and developing fruits during high relative humidity as a result of long rainy days. Where mango flowering coincides with or is followed by wet weather, anthracnose can become established on panicles, virtually destroying them (Nelson, 2008). Or, should the panicles make it through the season without being destroyed by anthracnose, the fruits produced may still be seriously affected by the disease when they are young, and symptoms appear especially during and after ripening of the infected, mature fruit. The presence of shot-hole spots on the matured leaves and black sunken spots on the fruit are typical symptoms of the disease. Infections on the flower and panicle appear first as minute brown or black spots, which gradually enlarge, and (if uncontrolled) can lead to
flower-drop and total crop failure.

Powdery mildew is caused by *Oidium mangiferae*. Worldwide, mango powdery mildew is a sporadic but very severe disease of mango leaves, panicles, and young fruits; up to 90% crop loss can occur due to its effect on fruit set and development (Sadhu, 1999; Nelson, 2008). Powdery mildew infected flowers, young fruit and leaves are covered with the whitish powdery growth of the fungus. The affected leaves curl and become distorted. Blossom infection and subsequent failure of fruit set due to this disease is a real threat to the mango industry. Its incidence is favored by cool, cloudy, and dry weather.

The disease can be kept under control by spraying wettable sulphur (0.2%) or Kerathane (0.1%). Bavistin (0.1% carbendazim) or Benlate (0.1%) at pre-bloom stage, followed by two more applications at full-bloom stage and fruit-set stage. In case of severe infection, the interval between sprays may be reduced to 7 days (Sadhu, 1999). Control of the disease, using appropriate fungicides, must start immediately before flowering and application should be repeated fortnightly, especially if adverse weather conditions persist (Samson, 1986).

Fruit fly - This is a very serious pest of mango, making the fruit completely unfit for consumption (Sadhu, 1999). The female lays eggs under the surface of the fruit skin. After 2-3 days, the maggots hatch out, and penetrate the flesh and destroy the fruit from the inside. The infested part becomes mushy and causes premature coloring of the infected fruit. Sadhu (1999) suggested the following control measures: (i) prompt collection and destruction of the damaged fruits, (ii) bait sprays of Carbaryl 0.2% + 0.1% protein hydrolysate or molasses during egg-laying period.

Harvest and postharvest handling

The fruits are generally picked when they begin to change color or after a few ripe fruits have dropped from the tree. Fruit to be transported long distances by train or ship should be picked when still green and firm. For
local market one may wait until the fruit is becoming soft. According to Samson (1986), more precise standards for picking are: (a) total soluble solids of at least 12°Brix, (b) a specific gravity of 1.01 to 1.02, and (c) the ability to withstand a pressure of 1.75 to 2 kg/cm².

Picking is done by hand. After picking, any latex, which has oozed from the pedicel onto the fruit, must be carefully wiped off. The ripening temperatures are 21-24°C. Mangoes are susceptible to chilling injury. Therefore, it is important that the optimum storage temperature be determined for each cultivar. The safe cool-storage temperature for many mango cultivars is 12°C and most cultivars can be stored for 2-3 weeks at this temperature. Waxing the fruit increases storage life.

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CHAPTER 12

PAPAYA (Carica papaya L.)

The papaya, Carica papaya L., is a native of Central and South America and is now widely grown in the tropics. It is a fast-growing tree-like herbaceous plant in the family Caricaceae. Until recently, the Caricaceae was thought to comprise 31 species in three genera (namely Carica, Jacaratia and Jarilla) from tropical America and one genus, Clyicomorpha, from equatorial Africa (Nakasone and Pauli, 1998). However, a relatively recent taxonomic revision proposed that some species formerly assigned to Carica were more appropriately classified in the genus Vasconcella (Badillo, 2002). Accordingly, the family’s classification has been revised to comprise Clyicomorpha and five South and Central American genera (Carica, Jacaratia, Jarilla, Horovitzia and Vasconcella) (Badillo, 1971), with Carica papaya the only species within the genus Carica (Badillo, 2002), which is the most economically valuable, and is widely cultivated for its edible fruit.

Botany

The papaya plant is characterized by tree or shrub that is erect, small, soft-wooded and fast-growing. Papayas normally grow as single-stemmed trees with a crown of large palmate leaves emerging from the apex of the trunk which give the tree a palm-like appearance, but trees may become multi-stemmed when damaged (Villegas, 1997). Trees grow to a height of 3-6 m (sometimes tree height can reach 8-10 m), but in cultivation, they are usually cut down when they reach heights that make harvesting of fruit difficult. The stem and the leaves produce a milky sap when wounded, a feature found in all members of this family (Purseglove, 1968). The main
stem is hollow with prominent leaf scars. The leaves are large, flat palmately lobed or entire. As the leaves mature they dry off and fall, so the leaves are only found at the top of the tree. Flowers are produced in the axils of the leaves. The inflorescence is a modified cyme. The type of inflorescence depends on the sex of the tree. Fruit is usually "melon shaped" but may be round, long pyriform or oval and usually has 5 carpels. Flesh color ranges from pale orange to bright red. The fruits have many hundreds of small seeds. The crop is one of the few fruit crops planted from seed.

In general, papaya plants occur in one of three sexual forms (Fisher, 1980; Chia and Manshardt, 2001): male, female, or hermaphrodite (bisexual). These forms are expressed in the plant's flower.

Male flowers (Fig. 12-1) have no ovary and do not produce a fruit. They are smaller and more numerous and are born on 60-90 cm long pendulous inflorescences (Nakasone and Paull, 1998). Male flowers are conspicuously different from those of the other types because they are borne in large numbers on a branched, drooping flower stalk (peduncle). They contain stamens bearing pollen that can pollinate a papaya flower with an ovary, causing it to produce a fruit.

Figure 12-1. A male papaya plant.
Female papaya flowers (Fig. 12-2) have an ovary and are borne on the stem of the plant, where the leaf is attached (that is, in the axil of the leaf petiole). The flowers are held close against the stem as single flowers or in clusters of 2-3 (Chay-Prove et al., 2000). Female flowers are bulbous at the base and, before they open, pointed at the tip. The ovary of the female flower must receive pollen from another plant (either a male or hermaphrodite type) before it can be fertilized and produce a fruit containing viable seeds. The pollen is carried in the wind or on an insect.

![Figure 12-2. A female papaya plant.](image)

Hermaphrodite flowers have both an ovary and stamens bearing pollen. According to Nakasone and Paull (1998), bisexual flowers are intermediate between the two unisexual (male and female) forms. They are borne in the leaf axils, like the female papaya flowers, and can pollinate themselves and do not require the presence nearby of another papaya plant. The hermaphrodite plant is the preferred type of papaya plant for dependable fruit production, but under certain conditions its flower morphology is unstable (Chia and Manshardt, 2001) and subject to "sex reversal". According to these authors, cool weather or high soil moisture can lead to a shift toward
femaleness, where the stamens fuse to the carpels or ovary wall. The resulting fruits become severely ridged (carpelloid, or "cat faced") and hence are deformed and unmarketable. High temperature and water stress can lead to a shift toward maleness, in the form of a reduction in the number of carpels (normally five) comprising the fruit.

According to Fisher (1980), staminate and hermaphrodite plants may be: (a) phenotypically stable, or (b) phenotypically ambivalent, going through seasonal "sex reversal", during which they produce varying proportions of staminate, perfect and pistillate flowers. With controlled cross-pollinations between flowers of each sex, the ratio of female, hermaphrodite and male offspring are predictable, as summarized in Table 12-1.

Table 12-1. Summary of sex ratios following pollinations between male (M), female (F) and hermaphrodite (H) of *papaya* sex forms.

<table>
<thead>
<tr>
<th>Pollination</th>
<th>No. of resulting Females</th>
<th>No. of resulting Males</th>
<th>No. of resulting Hermaphrodites</th>
</tr>
</thead>
<tbody>
<tr>
<td>F x M</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>F x H</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>M x M†</td>
<td>1</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>H x H</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>H x M</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>M x H</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

† Note that because of sex reversals or alternations, 'males' may bear functional carpels and set fruit.


The genetic or chromosomal basis for the sex ratio of papayas is poorly understood (Villegas, 1997; OECD et al., 2003). However, as summarised by Somsri et al. (1998), a common hypothesis is that sex is controlled by a single locus with three alleles - M1 (male), M2 (hermaphrodite) and m (female). Male (M1m) and hermaphrodite plants (M2m) are heterozygous whereas female plants (mm) are homozygous recessive. Combinations of dominants, namely
M1M1, M1M2, or M2M2 are lethal, leading to post-zygotic abortion of such ovules. Accordingly, this hypothesis predicts that viable males can only be M1m and viable hermaphrodites can only be M2m.

"Sex reversal" in papaya occurs in response to climatic changes during the year (Ray, 2002). Environmental variables including temperature, humidity, soil nutrients may modify the functional sex of plants (OECD, 2003). In hot (> 35°C) and dry conditions, for example, bisexual flowers may become functionally male, with poorly developed and non-functional female parts (Watson, 1997; Nakasone and Pauli, 1998). At low (< 20°C) temperatures, by contrast, bisexual flowers may become functionally female because of carpelloidy, a condition in which the stamens resemble carpels but remain associated with the developed fruit, leading to distorted fruit shape (OECD, 2003). Unlike bisexual and male sex forms, femaleness is the most stable character, least affected by seasonal variations (Ray, 2002). However, Ram (1996) reported that female plants rarely can produce bisexual flowers. Bisexual flowers of variety 'Solo' may produce 100% carpelloidic flowers when minimum temperatures are less than 17°C (Nakasone and Pauli, 1998). Such changes in functional sex can be either temporary or permanent.

Sex of papayas cannot be distinguished at the seedling and vegetative stages of growth. Therefore, the selection of the appropriate sex type of the progeny for commercial planting would be beneficial, since only the female and hermaphrodite plants are grown for fruit. The sex type of a papaya plant can only be identified 3-6 months after transplanting, when the flowers develop. Several morphological characteristics such as seed coat color and root morphology have been associated with the sex type of papaya (Magdalita and Mercado, 2003). Female papayas have been described as having a seed coat which is lighter in color and branched root morphology, while males are believed to have darker seed coats and straight root morphology. However, these claims have not been proven scientifically.

At bloom, the male type of papaya is easily determined by the flower clusters borne on long peduncles arising in the axils of the leaves. These trees are generally cut out as soon as the sex can be determined since they do not bear fruits. In female type of papaya, the trees produce female
flowers, which produce fruits. These develop in the leaf axils, singly or in short clusters. Such flowers rarely have stamens. The hermaphrodite type of trees has perfect flowers with both male and female flowers. Hermaphroditic types are easily self pollinated but can be also cross pollinated. Fruits developing from the hermaphrodite type plants (e.g., ‘Solo’ variety) are preferred since they have a desirable pear shape. In case of the female type, a male plant should be planted (or maintained) at a ratio of 1:10 (male: female). If plants are densely spaced, the male: female ratio may go upto 1:25. The male to female ratio should be decided based on local conditions, considering mainly plant density and climatic condition.

Papaya flowers are pollinated by natural agents. They may be wind-pollinated, since the pollen is light and abundant. A few insects, including thrips and moths, can assist in pollinating the sweet-smelling flowers (Purseglove, 1968). The stigma is receptive prior to anthesis, and remains receptive for several days or until the stigmatic lobes turn brown. The pollinated fruit is ready for harvest 4-5 months after pollination depending on cultivar and temperature. Fruits that develop from hermaphrodite flowers are generally elongated, cylindrical, obvoid or pyriform, depending on the variety, while those from female flowers are rounded or spherical to oval in shape. Papaya fruits develop in the axils of the leaves arising around the top of the tree. As the trees grow older- and taller - the fruits become difficult to harvest, so they are cut out and replaced with new planting. Botanically the papaya fruit is a berry. The edible part is the soft fleshy mesocarp and endocarp of the ovary wall. Fruit production occurs year-round since flowering is continuous; and plants begin bearing in 8-12 months, depending on cultivar and temperature.

**Ecological requirements**

Papaya grows best in a well drained, well aerated and rich organic matter soil, pH 5.5-6.7 (Morton, 1987). The plants are very sensitive to waterlogging, which may in turn favor an outbreak of fungal diseases and induce suffocation of roots. Waterlogging of soils often results in the death of trees
PAPAYA (Carica papaya L.)

The plants are frost-sensitive (Litz, 1984). It is possible to produce papaya up to an altitude of about 1,800 m a.s.l., otherwise the trees can be killed by frost at the higher altitudes in this range. Papayas are locally important throughout the tropics where they thrive in frost-free areas below 1,500 m elevations.

Though the production of fruit of the best quality requires high temperature (as expected at an altitude lower than 1,500 m in tropics), in Ethiopia, fruit of better quality is produced in areas up to 1,800 m. Temperatures below 12-14°C strongly retard fruit maturation and adversely affect fruit production (Nakasone and Paull, 1998). Papaya is extremely sensitive to frost, which can kill the plant.

Papaya cannot tolerate strong winds and needs to be protected. The trees can be completely destroyed by hail; therefore areas where hail is prevalent are unsuitable for commercial scale planting. Once established, papaya is tolerant of drought. However, a pronounced dry season can significantly reduce the fruit set.

In areas where rainfall is inadequate, the trees must be irrigated. Irrigation will increase yields in low rainfall areas, but uncontrolled excessive irrigation has a disadvantage in that the flavor of the fruits may be poor.

As the economic life of papaya is not more than three years, it may worthwhile to inter-crop in newly planted fields. This gives an opportunity to efficiently use the space and minimize the cost of weed control.

Crop husbandry

Papayas are usually grown from seeds. Unlike the seed of many tropical species, papaya seed is neither recalcitrant nor dormant and are classified as intermediate for desiccation tolerance (Ellis et al., 1991). Germination occurs within 2-4 weeks after sowing. While seeds may be sowed directly in the orchard, some orchards are started with established seedlings (6-8 weeks after germination). Whether direct seeding or transplanting is practiced, a number of seeds or transplants are sown per planting site since the sex of a given plant
cannot be determined for up to 6 months after germination (Gonsalves, 1994). Papaya seeds germinate within two to four weeks after sowing provided that the soil is warm and moist. To obtain plants of the best quality, seed should be obtained from vigorous plants that possess the desired quality.

Since plant sex cannot be determined in seed or seedling stages, several plants or seeds are planted at a single site in the field, roguing all but the bisexual or female plants once they flower. In the ‘Solo’, which is the most important commercial cultivar, seed should be obtained only from hermaphrodite plants, which have been self-pollinated or crossed with another hermaphrodite. Propagation by cutting is possible but only entire branches including the basal swelling should be used. These should be taken early in the growth cycle. Due to the non-branching growth habit of the papaya, trees produce few cuttings and commercial scale propagation by means of cutting is therefore impractical. Patch budding, in which a rectangle of bark containing a bud is placed on the stock in an identical sized rectangle from which the bark has been removed, is the most successful technique used.

In Ethiopia, propagation of papaya by seed is still the most practical method of raising the crop, because it is efficient and economical. Seeds are extracted from well matured good quality fruits. The seeds are enclosed in a gelatinous sarcotesta (or aril) and are attached to the wall of the ovary in five rows (Purseglove, 1968). Reyes et al. (1980) and Yahiro and Yoshitaka (1982) isolated “germination inhibitors” in the sarcotesta and inner seed coat but not in the embryo and endosperm. The seeds are, therefore, washed to remove gelatinous material and are allowed to air dry. Seeds germinate in 3-5 weeks, but this can be reduced to 2-3 weeks if the sarcotesta is removed. Attention is always given to damping-off diseases. Once seedlings have attained a height of 15-20 cm, they are ready to be transplanted to the field.

Usually about 5 plants are allowed to grow on one planting position for 6 months until the sex can be determined on flowering. At flowering, plants are thinned to achieve the desired sex ratio and to reduce competition between plants, which would later affect fruit production (Chia et al., 1989). For dioecious varieties, a ratio of one male to 8-10 female plants is recommended to maximise yield (Nakasone and Paull, 1998; Chay-Prove et
al., 2000) whereas one bisexual plant is left in each planting position. Jackson et al. (1985) however have suggested possibility to leave one female plant per hill and one male plant for every 25 female plants.

In planting hermaphrodite cultivars such as ‘Solo’, it is customary to remove the female plants so that fruits of uniform size and shape are produced. Planting distances in the field are 3 m in the rows and 3 m between rows but nowadays the tendency is towards narrower spacing.

‘Solo’ (small fruited monoecious) and ‘Coorg Honey’ were the first cultivars tested in Ethiopia. Seeds of these cultivars were produced at Werer Agricultural Research Center and distributed to users. At Melkassa Agricultural Research Center, ‘Solo’ gave a yield of 18.7 tons/ha per year while the large-fruited ‘Coorg Honey’ provided yield of 20.4 tons/ha per year (Asmare Dagnew, personal communication, 2013).

Trees come into bearing at 9-14 months. Although trees may live for many years, yields decline with age. For fresh fruit and papain production the productive life is usually 3 years, there after the trees get too high for easy picking of fruits and yields (especially of latex) decline.

In many parts of the world, good results have been obtained from the use of organic manures and nitrogenous fertilizers. Papaya which is planted on Ethiopian soils known to be deficient in nitrogen or phosphorous, should receive dressings at the rate of 0.5-1.0 kg/tree/year of DAP. Urea may also be applied at the rate of 50-100 kg/ha if the trees show symptoms of nitrogen deficiency (Jackson et al., 1985).

Economically important diseases of papaya include:

**Anthracnose** - The disease is caused by fungus (*Colletotrichum gloeosporioides*) and attacks not only the fruit but also the petioles of lower and older leaves. The first symptoms are small, round, water-soaked areas on ripening portions of the fruit. The spots enlarge rapidly and the fungus also advances into the fruit, which starts rotting and is no longer suitable for marketing. Anthracnose is favored by wet weather conditions.

**Black spot** - This disease is caused by the fungus *Asperisporium*
caricae and infects both leaves and fruits. It does not develop into fruit rot. Symptoms of this disease are irregular dark brown to black fungal spots on the lower leaf surface of older papaya leaves (Ogata and Heu, 2001). On the upper leaf surface, the infection causes slightly sunken tan spots to occur. Black spots have also been observed on the surface of fruits, though not nearly as heavy as that found on the foliage. According to Ogata and Heu (2001), periods of wet weather may increase the development of the disease on both papaya foliage and fruits. The authors further indicated that damage on papaya fruits has mainly been cosmetic and there have been no indications of reduction in fruit quality by the disease.

Black spot disease of papaya caused by A. caricae is not to be confused with "black spot of papaya" caused by Cercospora papayae. Leaf spots of C. papayae are grayish white (Nishihara, 1993) compared to the dark brown to black spots of A. caricae.

Powdery mildew - This fungus is found mainly on the underside of the leaves where it develops typical powdery white growth. Severely infected leaves turn yellow and drop prematurely. Cool and cloudy weather favors the infection.

Papaya ringspot virus (PRSV) is an aphid-transmitted plant virus. It is a devastating viral disease which is most serious on young plants. This disease derives its name from the striking symptoms that develop on papaya fruit. These consist of concentric rings, spots or c-shaped markings. The top young leaves of the diseased plant are much reduced in size and show blister like patches of dark green tissue, alternating with yellowish-green lamina and puckering. The leaf petiole is reduced in length and the top leaves assume an upright position. The fruits on diseased plants develop circular water-soaked lesions with a central solid spot. The fruits are elongated and reduced in size; they do not attain full maturity and are spoiled being exposed to the sun (Arya, 1993). The only way to stop the further spread of this devastating disease is by controlling the movement of papaya (Gonsalves, 1998).

Breeding for resistance is the only satisfactory method, though hygiene and quarantine procedures and vector control mainly aphid species, Myzus persicae Sulz. (Williams, 1978; Arya, 1993) may help in minimizing the
spread of disease.

Harvest and postharvest handling

Papaya fruit is ready for harvesting as soon as it starts to develop some pale green or yellow color. At this stage, it is still hard and is relatively easy to transport. After a few days the fruit softens and is then ripe for eating. Papayas develop their highest eating quality when the skin is 80% yellow in color. The fruit skin is very delicate and is very easily damaged.

Fruits are hand harvested carefully to avoid scratching the skin, which would release latex and stain the skin. On taller plants, harvesters use poles or hydraulic lifts to reach fruit. Harvest is a continuous process once plants reach fruit bearing age. Fruits must always be handled with great care. Papaya intended for export should be carefully packed in padded or divided cartons and stored at cool places (7°C) as soon as possible. In this way, the fruit can be safely stored for about 2-3 weeks. Lower temperature will cause chilling injury and fruits will fail to ripen properly. Papayas are extremely perishable; shelf life at room temperature ranges from 3 to 8 days, depending on storage atmosphere.

Storage temperature depends on the type of papaya cultivar. The storage temperature usually ranges between 10-13.5°C. According to Chen and Paull (1986), papaya harvested at color break stage can be stored in cold storage at 7°C for 14 days and will ripen normally when transferred to room temperature. Storage below 10°C is known to cause chilling injury (Maharaj and Sankat, 1990).

Papaya is a climacteric fruit and exhibits a characteristic rise in ethylene production during ripening which is accompanied by softening, change in color, and the development of a strong and characteristic in aroma. Ethylene treated papayas ripened faster and more uniformly in terms of de-greening, softening and flesh color development. To induce ripening in papaya, fruits must be stored between 18°C and 25°C and treated with ethylene gas at 100 ppm for 24 hrs. Under this condition, fruit will take 3-4 days to develop full yellow skin (Ann and Paull, 1990). Severe weight loss
and external abnormalities become more prominent at temperatures higher than 27°C. Delaying the process of fruit ripening helps to control the release of ripe fruit to the market.

Production of papain

Papaya plants are also produced for papain and chymopapain two industrially important proteolytic enzymes found in the silky white latex exuded by fruits. In general, female fruits tend to exude more papain than hermaphrodite fruits (Madrigal et al., 1980). Green fruits are generally better sources, containing more papain than ripe fruits. The latex of the papaya plant and its green fruits contain two proteolytic enzymes (enzymes helpful in digestion of proteins), papain and chymopapain. The latter is most abundant but papain is twice as potent (strong). Small latex vessels extend throughout the tree and are particularly abundant in fruit, which has reached full size, but has not yet begun to ripen.

One of the best known uses of papain is in commercial products marketed as meat tenderizers, especially for home use. Papain has many other practical applications. It is used to clarify beer, also to treat wool and silk before dyeing, to de-hair hides before tanning, and it serves as an adjunct in rubber manufacturing. It enters into toothpastes, cosmetics and detergents, as well as pharmaceutical preparations to aid digestion. The latex also serves for treatments of gangrenous wounds or burns (Starley et al., 1999; Hewitt et al., 2000), and is used in cosmetic products (Singh and Sirohi, 1977; Knight, 1980), and food processing.

The latex is obtained by making incisions on the surface of the green (unripe) fruits (Baeza et al., 1989) early in the morning and repeating every 4 or 5 days until the latex ceases to flow. The tool is of bone, glass, sharp-edged bamboo or stainless steel (knife or razor blade). Ordinary steel stains the latex. Tappers hold clay cup, of glass, porcelain or enamel pan beneath the fruit to catch the latex, or a container like an “inverted umbrella” is clamped around the stem. When handling fresh latex, care should be taken to ensure that it does not come into contact with skin as it will cause
burning. Neither should it come into contact with heavy metals such as iron, copper or brass as this causes discoloration and loss of activity.

Fresh latex does not keep well and should be dried to below 5% moisture (when it will have a dry and crumbly texture) as soon as possible. For best results, it is spread on fabric and oven-dried at a low temperature, then ground to powder and packed in tins. Sun drying gives the lowest quality product as there is considerable loss of enzyme activity and the papain can easily turn brown. However, in many countries sun drying is still the most common processing technique for papain. The latex is simply spread on trays and left in the sun to dry.

The lanced (incised) fruits may be allowed to ripen and can be eaten locally but have very little sale value because of their scarred appearance. The fruits can also be used for making dried papaya “leather” or powdered papaya, or may be utilized as a source of pectin.

**References**


The pineapple (*Ananas comosus* L. Merr.) belongs to the Bromeliaceae family and is originated from the American tropics (Samson, 1986; Chadha *et al.*, 1998; Mitra, 1999). Pineapple fruit is a rich source of vitamin C apart from vitamins A, B and minerals like calcium, phosphorus and iron. The fruit also contains bromelin, a proteolytic (protein digesting) enzyme. It is an important fruit in world trade both as a fresh (table) fruit and for processing. By far the greater part of the world’s pineapple product is canned (Samson, 1986).

**Botany**

Pineapple plant is a perennial, monocarpic herb, about 1 m high and 1.5 m wide, with spreading leaves, which give the plant a rosette appearance. The main morphological structures of the plant are the stem, the leaves, the peduncle (stem which bears fruit), the multiple fruit or syncarp or sorosis (fusion of many fleshy fruitlets), the crown, the shoots and the adventitious roots (Coppens d’Eeckenbrugge and Leal, 2003). The plant bears a single fruit terminally on a peduncle, protruding out from the center of the rosette. As in banana each stem flowers only once and then dies after fruiting, a side shoot then takes over. These vegetative branches come to maturity and produce fruit while still attached to the old plant, through which they obtain most of their nourishment. The same plant may thus give a sequence of various production cycles. The crop from the plant growing from a separated vegetative shoot is commonly called as a *plant crop* and that from the plant produced from auxiliary branch (side shoots) is a *raison crop*. 
The root system of pineapple is shallow and limited; rarely extend below 30 cm depth. Under ideal conditions, the soil root system may spread up to 1-2 m laterally and 85 cm in depth (Coppens d’Eeckenbrugge and Leal, 2003). The leaves are long and narrow, arranged in a spiral on a short stem, forming a “rosette”. They increase in size toward the top of the plant. Individual leaves range in length from 5-20 cm long for new plants and up to slightly more than 1.5 m long on mature healthy plants. The form of the leaves varies and depends on its position on the stem and age. Depending on variety, the leaves either have smooth edges with a few spines just below the tip, or have spines all along the margins. The tip is elongated, ending in a finer point.

The stem is 20 to 30 cm long, narrow at the base and wider on top. The base is curved in slips, but straight in other propagules (crowns and suckers). The meristem produces 70 to 80 leaves, unless it is prematurely induced to bloom. Once the plant has produced between 70 and 80 leaves, it is ready to flower. The peduncle and inflorescence develop from the apical meristem. The stage of inflorescence emergence is called ‘red heart’ because of the five to seven reddish peduncle bracts at its base (Coppens d’Eeckenbrugge and Leal, 2003). These bracts are shorter and narrower than the ordinary leaves. The peduncle elongates after flower formation. In addition to its bracts, it bears, in many cultivars, a variable number of slips, which can be positioned more or less regularly between the stem and the fruit, at the axis of the peduncle bracts, or grouped just beneath the fruit. The flowers, 100 to 200 in number, are hermaphrodite, each sitting in the axil of a bract: 5-10 flowers open every day, from the base up, over a period of 10-20 days. Both pollen and ovules are functional, yet they set no seed unless cross-pollinated (principally by humming birds) (Samson, 1986).

The fruit is a terminal, cylindrical, compound structure (multiple fruit) at the apex of the stem and is formed by the fusion of the berry like fruitlets that develop from the flowers. At its apex, the fruit bears a compressed, leaf shoot called a crown. When fruits are mature (ready to pick), the individual fruitlets flatten and the peel color begins to change from green to yellow progressively from the base to the top of the fruit. It takes 5-6 months to
The fruit tapers towards top and bears crown. Growth of the crown continues during fruit development, but ceases when fruit matures.

Ecological requirements

The pineapple, being tropical fruit, cannot tolerate frost. It needs a sunny frost-free climate. Intense solar radiations associated with very low humidity are not favorable for pineapple cultivation. Such climate may cause sun-scalding of fruits, hence, partial shade is desirable in areas receiving high intensity of sunlight. In high-density planting (close planting), leaves normally show upright and overlapping orientation, providing natural shade to fruits (Chadha et al., 1998).

Pineapple is a true xerophytic crop; it has many features to adapt to drought (Samson, 1986). One of these is the behavior of the stomata opening and closure. Stomata are kept closed during the hot hours of the day, when evapotranspiration rate would be high.

For commercial production relatively high altitude (up to 1,800 m for instance in Ethiopian condition) are preferable in the tropics. In general, pineapple plants should be planted in full sun for best growth and fruit production. Avoid planting near other trees, buildings and structures. Production in climates with high temperature and humidity results in over-sized, coarse fruits, with a low acid to sugar ratio, which are not suitable for canning, though they may be acceptable as fresh fruit. Soil requirement specifications are minimal for pineapple cultivation. The plant is particularly sensitive to soil being waterlogged; hence ensuring proper drainage is essential while laying out pineapple plantation. Medium to light soils, with a pH of 5.0 to 6.0 are the more suitable. Alkaline soils are not considered suitable for pineapples.

The cultivar, which has the greatest worldwide importance, is ‘Smooth Cayenne’. The plant is stocky and robust, with almost spineless leaves (with a few spines near the tip “spiny tip”). Fruit is cylindrical in shape with slight upward taper and flat eyes; thus it is better adapted to canning compared to ‘Red Spanish’ and ‘Queen’ cultivars. Fruit weight is 2-3 kg on the average.
As the fruit ripens, it acquires a deep-yellow to coppery-yellow color, sweet, mildly acid, with low fibre and a tender juicy texture. In addition to canning, the fruit is good for fresh consumption. 'Smooth Cayenne' is the principal cultivar grown in Ethiopia. However, it is very susceptible to mealy bug wilt. Other cultivars of lesser importance grown the country are 'Red Spanish' and 'Queen'.

'Queen' - The plants are characterized by dwarf, compact habit of growth. The leaves are short, stiff, and spiny along with the margins. Fruits are smaller (0.5 to 1.1 kg), conical in shape, with deep eyes. When fully mature, the fruit is golden-yellow and internal flesh is deep golden-yellow, sweet, and less acid than 'Smooth Cayenne' and low in fibre. It is grown primarily for fresh consumption. This cultivar is known to be more disease resistant than 'Smooth Cayenne'.

'Red Spanish' - The plant and fruit size is intermediate between 'Queen' and 'Smooth Cayenne'. Fruit weighs 0.9-1.8 kg on average, globose in shape, with large deep set eyes, when ripen rind is deep reddish orange colored, flesh pale-yellow to white with a spicy-acid taste and fibrous texture. The leaves are long and spiny (semi spineless when compared with the 'Queen' cultivar). Peduncle is long and slender, and is often not able to support the fruit upright. Fruitlets are few, larger than 'Smooth Cayenne'. It is primarily grown for fresh consumption.

Crop husbandry

Pineapple is propagated by vegetative means using different propagules (suckers, slips, crowns) (Fig. 13-1). Suckers (or rations) are the lowest offsets coming out from below ground level or those attached somewhat higher on the main stem; leafy branches attached below the fruit, on the peduncle, grouped near the base of the fruit, sometimes produced from basal eye of the fruit are known as slips. Sometimes, they are produced from the basal eyes of the fruit (collar of slips). Slips are curved at their base. As they are numerous in most cultivars, they are useful for rapid propagation. Crown is the terminal rosette, the short stem and leaves growing from the apex of the fruit. The use
of crown for propagation is feasible when the pineapple fruit is processed. Some plants may lack a crown or, on the contrary, produce multiple crowns. Also, crownlets may grow at the base of the main crown or from some of the upper fruitlets (Coppens d'Eeckenbrugge and Leal, 2003).

![Figure 13-1. Parts of the pineapple plant showing the three major types of asexual planting material: crowns, suckers and slips. Source: Samson (1986); Chadik et al. (1998)](image_url)

Pineapple can also be propagated by stump, stem-bits and from split crowns (Mitra, 1999; Bal, 2002). Performance of plants as characterized by vigor, growth rate, time taken for bearing, and fruit size and quality varies with the type of planting material used. In addition, the type and size of the planting material also results in the variation in the performance of the subsequent plants. Therefore, in pineapple cultivation, different types of planting materials should be kept separately and must be sorted according to their size so that a field is planted with uniform material (Ray, 1996). Mixed stands will crop unevenly and the cycle will be unprofitably prolonged. Crowns and slips are preferred to suckers. Slips are the most popular type of planting material for commercial use. If the slips are all about the same size and age when planted, they will flower and fruit at approximately the same time. Suckers
tend to produce less even crops and produce prematurely and worthless fruit of more than about 600 g in weight. Suckers produce first crop in 15-18 months after planting while it takes 20-22 months for slips and 22-24 months for crown (Ray, 1996; Mitra, 1999; Bal, 2002). Before planting, all types of planting materials must be cured or dried for one to several weeks after they are separated from the mother plant. This allows a callus layer to develop over cut surface, reducing losses from decay organisms after they are planted.

When planting, ensure that the “heart” of the plant is above soil level otherwise rotting will occur, particularly if the soil is wet. Either the single or double-row system can be used. However, the double-row system is commonly followed system of planting. Commercially pineapples are planted in a double row spacing of 90 x 60 x 30 cm i.e., 90 cm between beds (double rows), 60 cm between rows and 30 cm in the rows (Samson, 1986). A simple way to figure out the planting density for this spacing is: each plant takes up $(0.9 + 0.6) \times 0.3 \ m = 0.225 \ m^2$; the density therefore is $10,000: 0.225 = 44,444$ plants per hectare. The double row planting system has several advantages, allows maximum use of land, less weed infestation, protection from sunburn and no logging of fruits (as plants are having mutual support). In rows, planting is usually done on rectangular system, however, triangular system of planting showed high percentage of flowering and increased yield compared to rectangular system (Roy et al., 1980). In a rectangular planting, it has been found advantageous to set the individual plants in a zigzag fashion (Fig. 13-2) so that the plants can get sufficient space.
A crop cycle usually lasts from three to four years. Normally, after the first fruit has been harvested (plant crop), two or sometimes more new shoots will be produced at the bases of the plant. Each will produce fruit in about a year and are called the first ratoon crop. A second ratoon crop will follow in the same fashion if the plant is vigorous. However, in most instances, the plant will either be too weak to produce an economic second ratoon crop or will be so poorly anchored to the soil that they cannot support the weight of the whole shoots of the second ratoon. Whether or not to allow the plants to produce the second ratoon is a decision which should be based on the condition of the plants. It should also be realized that fruit size in the first ratoon crop is smaller than that of the plant crop and will become smaller with subsequent ratoon cycles (Jens d’Eeckenbrugge and Leal, 2003). In most commercial plantings, the plants are not allowed to produce more than 2-3 crops due to reduction in fruit size and uniformity (Coppens d’Eeckenbrugge and Leal, 2003). Then a new plantation must be established through regular procedures using vegetative propagules.

Flower initiation takes place at the terminal axis of the stem. This occurs naturally on short, cool days. The inflorescence is not externally visible for 45-60 days, when it appears in the center (heart) of the plant. Stages of
development after its appearance are called “half-inch open heart” and “one inch (2.54 cm) open heart” (Bartholomew et al., 2002). At these stages, the center is open approximately 1.25 and 2.5 cm, respectively, and the red inflorescence is clearly visible below the opening. Three to four weeks after the “one-inch open heart” stage, blue flower petals can be seen at the bottom of the cone-shaped inflorescence. Before all flowers have opened, the earliest petals will have begun to dry. After all petals have dried, the inflorescence is said to be at the “dry petal” stage. Its surface is dull, individual fruitlets (“eyes”) are pointed, and a crown has just begun to develop. *A. comosus* var. *comosus* flowers are normally self-sterile and fruit development is parthenocarpic (Py et al., 1987).

Under natural conditions flowering in pineapples is highly irregular and some plants may fail to produce fruit (Ray, 1996). Thus in commercial practice, various growth regulators are used to force plants to flower uniformly. Artificial flower-induction, “forcing”, is a procedure that utilizes synthetic hormones to induce plants to flower. Pineapple responds readily to artificially induced flowering. This characteristic of pineapple plays a highly significant role in production planning. Additional benefit is obtained when artificial flower induction results in fruits complying with marketing standards. This implies that the exact stage of growth at which flower induction is to be carried out must be determined with respect to the desired type of fruit (Bhugaloo, 2003). Some growth regulators have been widely used since the past 15-30 years with suitable modifications in respect of dosage, time and stage of application, depending upon the climate and local needs (Chadha et al., 1998). Artificial flower-induction may be done at any time of year if the plants are large enough (at least 1.5 kg fresh weight). This permits scheduling of planting and flowering so that harvests can be spread throughout the year (Bhugaloo, 2003). The process works best when the following criteria are fulfilled: The plants in the block to be treated should be homogeneous in size and not less than 12 months old or possess less than 25 leaves. Young and unhealthy plants should not be induced to flower since they will produce small fruits, (unless small fruits are specifically required for a particular market). Forcing is sometimes not completely effective during hot weather.
Therefore treatment should take place in the cool part of the day, early morning or late afternoon, with preference for the latter. The main products used to induce flowering are Naphthalene Acetic Acid (NAA) and Ethrel.

Pineapple plants are slow growing and do not cover the ground well enough to suppress weeds from developing. Weeds compete with the pineapple plant not only for nutrients, but also for water and sunlight and can cause considerable reduction in the growth of the pineapple, resulting in poor crop yields. Weeds can be controlled manually by cutlassing, hoeing, etc., mechanically with tractor drawn implements, or by use of chemicals. In practice, however, it is a combination of these operations that is usually conducted.

Mulching is widely practiced in pineapple growing. Green manure and organic refuse, such as sugarcane bagasse, may be used. In heavy rainfall areas this provides an environment for parasitic fungi that attack the pineapple. Mulching paper and black polythene is also used to acquire the same advantages: to warm the soil, protect against erosion, prevent weed growth, reduce leaching and increase yields.

Except on soils of very high fertility, heavy applications of nitrogenous fertilizers are necessary in order to produce a profitable crop. The recommended dressing for one cycle of pineapple is about 3,000 kg of sulphate of ammonia (20.6% N)/ha. Sulphate of ammonia is recommended in preference to urea, because of its acidifying effect on the soil and because there is less danger of burning the plants (Jackson et al., 1985).

The pineapple mealy bug attacks leaves, roots, and fruits of pineapples and is a serious pest in many pineapple-growing regions. Infestations by mealy-bugs results in yellow spots appearing on the leaves but, more importantly, the insects spread black spot (Penicillium funiculosum and Fusarium moniliforme) and are also responsible for mealybug wilt, which is thought to be due to a toxin produced by the mealy bug. Mealy bugs, and consequently the diseases associated with them, can be controlled with insecticides. 'Red Spanish' and 'Queen', unlike 'Smooth Cayennee', said to be resistant to mealy bug infestation.

Nematodes, particularly the root-knot nematode (Meloidogyne spp.)
may become a problem where pineapples have been grown for several years on the same field. Although they have not yet become serious in most areas of smallholder production, rotations with nematode-resistant crops must be followed or pineapple yields will decline. Where nematodes are present initially, the soil should be fumigated prior to planting.

**Harvest and postharvest handling**

The point at which a fruit is considered ready for harvest depends on its ultimate destination (cannery, export, local market). Fruit for the cannery must be picked ripe and this is judged by the color.

Fruit for export is picked in a half ripe state. The maturity is judged on the basis of external color, but this depends on cultivar, fruit size and weather. Overripe fruits are deficient in flavor and highly perishable. Sunburn (Sun-Scald) is common during hotter periods (> 35°C), when the fruits are not shaded. Sun scorched fruits show a bleached yellow-white skin, which turns pale grey or brown, and damage to the flesh underneath. Sun-Scald especially results when plant leans or falls over to one side, thus exposing one side of the fruit to direct sunlight. The cells of the exposed surface get damaged. Later shell surface assumes a brownish to black color and cracks may appear between fruitlets. Affected fruits soon rot and become infested with pests. They must be cut as soon as noticed and safely disposed of where they will not contaminate other fruits. In high-density planting, intensity of sun-scald is very much minimised. Under favorable climates where leaf growth is luxuriant, leaves can be tied around the fruits to protect them from sunscald. The other method is to cover sun-exposed portion of the fruit with dry straw or grass or with any other locally available materials.

Harvesting pineapple fruits early in the morning or late in the evening or during the night would provide protection from the sun and this could reduce the heat load on harvested fruits during precooling. Pineapple fruits are harvested by bending them over and twisting to remove fruits from the stalk. Transportation of fruits packed in a horizontal position is more liable to lateral shocks. Absorbent pads are placed at the bottom of the carton
and between layers if fruit are alternated horizontally within the carton. A yield of at least 40 tonnes/ha may be expected in a well-managed pineapple plantation: under optimal conditions the yield goes up to 70 tonnes/ha and even more (Samson, 1986). The yield per unit area is associated with density of plants and is usually high in increased population density (Bal, 2002).

Production of Bromelain

Bromelain is a crude, aqueous extract from the stems and immature fruits of pineapples (Maurer, 2001). Stem bromelain is the major protease present in extracts of pineapple stem while fruit bromelain is the major enzyme fraction present in the juice of the pineapple fruit (Kelly, 1996). The commercially available product is most often made from stem bromelain, whereby the extract is removed from cooled pineapple juice through centrifugation, ultrafiltration and lyophilization (Corzo et al., 2011, cited in Bala et al., 2012).

Bromelain is a complex mixture of sulfur-containing protein-digesting enzymes called proteolytic enzymes or proteinases. A mixture of proteases, isolated from the pineapple plant is capable of hydrolyzing both plant and animal proteins to peptides and amino acids.

Bromelain has been extensively used in food industry; for meat tenderization, baking processes, and in prevention of browning of apple juice (Bala et al., 2012). It is suggested to eat the fresh or frozen (not canned) pineapple to obtain any potential health benefits from proteolytic enzymes in pineapples (Hale et al., 2004).

References


Guava, often referred to as “apple of the tropics”, is one of the most well-known edible tree fruits of the tropical and subtropical climates. It belongs to the genus *Psidium* of the family Myrtaceae, to which *Eucalyptus* spp., an important source of timber, and *Syzygium aromaticum* L. Merr. and Perr., the clove, a spice plant, also belong. The guava tree is native to tropical America, but it is cultivated in every tropical and subtropical country of the world (Samson, 1986). It is a delicious fruit that is highly nutritious and exceptionally rich in ascorbic acid (vitamin C) and several minerals useful for human health (Wilson, 1980).

**Botany**

The Genus *Psigium* contains about 150 species, most of which are fruit-bearing trees native to tropical and subtropical America. The guava plant, which grows symmetrically dome-shaped with a broad, spreading, low-branching canopy, is a shallow-rooted small tree 3 to 10 m in height, branching close to the ground, and often heavily suckering from the base of the trunk. The smooth and green to reddish-brown bark on older branches and trunk peels off in thin flakes. The four-angled young twigs of guava plants are easily recognizable. The simple leaves are always opposite, 10 to 15 cm long, oval to oblong-elliptic, smooth, and light green. The bisexual or perfect flowers, measuring from 25 to 30 mm in diameter with four incurved white petals and a large tuft of white stamens tipped with yellowish anthers, are borne solitary or in clusters of two or three in axils of leaves on new growth from mature wood. The guava flower produces numerous stamens and plentiful pollen.
Self-pollination is conspicuous (60 to 75%) since even isolated trees produce satisfactory crop; however, the distribution of cross-pollination, which is carried out mainly by bees and other insects, is estimated to be approximately 35% (Menzel, 1985). In rainy climates, the tree yields two crops; conversely, in climates with more differentiated seasons, only one crop is produced.

The fruit is a berry, surmounted by a persistent calyx. Depending on the variety, the fruit may be round, ovoid or pear-shaped, 3-10 cm in length, usually yellow, with flesh varying from white to dark pink and salmon pink. It contains a large number of small, hard, reniform seeds imbedded in the pulp. Seedless cultivars of guava are also available in many countries around the world. These cultivars have great potential for becoming popular in the years ahead.

Ecological requirements

Guava requires tropical and subtropical climates. It can be grown in the plains as well as in the sub-mountainous tracts provided sufficient care to shelter the trees against frost and cold winds during early stage of growing. Under humid conditions, guava trees grow luxuriantly resulting in poor quality fruits. In tropical regions optimum production of guava occurs up to 1,300 m of elevation where the soil is fertile and rainfall is regular. It will however tolerate drought, low soil fertility levels, and waterlogged conditions. Guava is one of the few tropical and subtropical fruit crops, which have tolerance to salinity and can be grown on marginal lands with minimum care. Though, it thrives well in varieties of soils having pH range of 4.5 to 9.5, the best results are achieved in sandy loam with an optimum pH range between 5.0 to 7.0 (Singh, 2007). Guava being hardy crop can be planted in various types of soils and agro-climatic conditions, but it shows good response to manuring in increasing fruit production.

Adequate moisture is required during vegetative growth and for optimum flowering and fruit development. Almost complete post set drop is observed during drought (Singh, 2007). In dry tropics, flowering is greatly influenced of water availability (Subey et al., 2002). To promote the
development of the fruiting twigs, irrigating at an interval of every 10 to 15 days in summer and about 25 days in winter is recommended (Singh, 2007). During the rainy season, plants hardly require any irrigation.

Crop husbandry

Guava can be propagated both sexually (seed) and by various asexual methods. Sexually propagated trees of guava exhibit a lot of variations in the quality of the fruit, therefore, it is necessary to propagate guava, especially varieties of desirable characters. Common vegetative propagation methods include air layering, patch budding, side grafting, approach grafting, softwood cutting, and root cutting/stooling. One of the difficulties of budded and grafted guavas is the production of water shoots and suckers from the rootstocks.

The guava by nature is a bush-like tree. However, good framework can be made by training and removing extraneous growth as soon as it appears near the base of the trunk. Initial training is necessary for development of a strong framework for which the first 60 to 90 cm from the base of the trunk should be cleaned followed by 4 to 5 scaffold branches at an interval of 20-25 cm. When the plants attain a height of about 1.5 to 1.8 m, it is then headed back to make the center open. Commonly, a framework of four strong branches, individually located in four quarters of the tree, is established. The crotch angle between the branches and the main stem should be wide enough to facilitate adequate penetration of light and provide physical strength to support fruit load at maturity. Well-shaped trees should be maintained through regular but light pruning of vertical shoots. Most of the guava trees, whether propagated from seed or as grafted trees, produce an abundance of suckers that should be removed to keep the stem free and clean at least up to 50 cm above the ground. All dead, diseased, crowded growth and suckers coming up from the base and sides of the framework should be pruned back annually. Due to the natural habit of guava plants to bear fruit on new and emerging vegetative growth from mature wood, it is very important to keep a good balance between the amount of vegetative growth and mature wood to ensure the next season’s production and, thus maintain
fructing regularity for steady income (Yadava, 1996). Unproductive and old
trees are headed back (stumped to the ground level) as a result of which new
shoots are formed; they can be easily utilized for propagation (e.g.,
air-layering) and also grow up (rejuvenate) to give fruit again.

Guava trees grow rapidly, and seedling trees require 4-5 years to
come into bearing, while vegetatively propagated often start fructing at the age
of 2-3 years; they are in full bearing at 8 years and cropping may continue
for 30 years or more. There are two main flowering seasons, one during
March to May, the fruits of which are harvested in rainy season and the
other in July/August with the fruits harvested during winter. Among two
flowering seasons, maximum fructing occurs in rainy season (Singh, 2007).
However, in mild tropical or cool subtropical climate, guava can flower and
fruit continuously throughout the year if water and temperature do not become
limiting factors. According to Singh (2007), fruits maturing (harvested) during
rainy season are poor in quality, rough, insipid, watery and less nutritive.

Depending on cultivars or type and growing condition, guava fruit
takes approximately 100 to 150 days from bloom to harvest (Rathore, 1976).
Since healthy guava trees fruit abundantly, there is always a chance that
fruit-bearing branches will break. Thinning in the early stages of fruit growth
and development may help the remaining fruits attain proper size, and may
not only reduce breakage of branches, but also promote bearing regularity and
uniformity in the areas with multiple flowering seasons (Biswas et al., 1989).
Hand-thinning is the common procedure, and chemical fruit thinning has not
been popular so far.

The guava is one of the most common and widely grown fruit crops
in Ethiopia. The seeds can be carried by birds and trees grown from sporadic
seedlings are wide spread in the country. It is successfully grown in a wide
range of environmental and edaphic conditions because of its tolerance to
drought and salinity as compared to most of the warm climate fruit plants.
Therefore, it is very suitable for homestead planting (where inputs are in short
supply). Despite its nutritive value in Ethiopia, the market demand for fresh
fruit is not appreciable. Hence, the principal outlet for the fruit is processing
(canning, preparation of soft drinks, jellies, marmalade, pastes and similar
products).

Guava plants are spaced 6 x 6 m or 5 x 5 m in square system of planting. In some orchards a rectangular planting system at spacing of 6 x 5 m is followed. In guava, bearing is on current season’s growth and flowers appear on axils of new leaves. Therefore, the guava is highly suitable for high density plantation, where pruning is applied. Guava can also be planted in a hedgerow system at spacing of 6 x 3 m or 6 x 2 m (Mitra and Bose, 1999). According to Mitra and Bose (1999), in hedgerow planting, the trees are confined to a hedge shape of 2 m inter-row width and 2 m height for which regular pruning is necessary.

In Ethiopia, so far no research attention has been given to improve its yield and quality (Asmare Dagnew, personal communication, 2013). However, small observational plots have been established from local and introduced materials at Melkassa and Jimma Agricultural Research Centers. Three of these guava cultivars, namely ‘Beaumont’, ‘Waiakea’ and ‘Kahua Kula’ are processing type with high acid content, and desirable pale pink color; while the remaining five guava cultivars including ‘Nura Era’, ‘Hirna’, ‘Sodere-1’, ‘70-512’ and ‘70-513’ were collected locally and are considered suitable for fresh consumption (dessert) because of their low acid content. It was observed that guava fruits are prone to damage by birds and false codling moth.

Various diseases attack guava; some of the important ones are the following:

1. **Anthracnose** - The disease is caused by *Gloesporium psidii* (*Glomerella psidii*). The disease attacks all parts of the plant except roots. The growing tip of affected plants turns dark brown and the black necrotic areas extend backward causing the dieback of plants. The disease can be controlled by spraying the trees with copper oxychloride, cuprous oxide or Difolatan (Bose et al., 1999).

2. **Cercospora leaf spot** - The disease is caused by *Cercospora savaeulae*, and the affected leaves show brown water-soaked patches on their under surface.
The infection can be reduced by spraying copper oxychloride at 0.3 per cent. Several insects attack guavas, though most of them are not serious. Guava fruit flies (Anastrepha suspensa Shiner, and Ceratitis capitata Wiedemann) are the most important pests (Yadav, 1996). They lay eggs in the fruit and may cause serious losses. Infestations are sometimes so heavy that the fruit may be virtually crawling with larvae. The larvae feed on the pulp and the infestations cause the fruit to rot. Control measures (Singh, 1992): (1) collect all affected fruits and burn properly, (2) take the soil around tree during summer months, this helps in checking the pest population as the pupae and hibernating larvae are destroyed by natural enemies, (3) spray with malathion 0.05 per cent.

Mealy bugs suck sap from young leaves, twigs and flower. Particularly mealy bugs are found in clusters on the under surface of the leaves. The affected parts dry up and yield is considerably affected. Aphids feed on new growth (shoots) but can be controlled by spraying malathion or other insecticides.

Harvest and postharvest handling

Harvesting of guava fruits is usually determined on the basis of visual fruit color observations (Singh, 2007). Harvesting should be carried out at the turning stage when the fruit is fully developed and has started turning color from green to yellowish. Fruits harvested at this stage will be ripening off the plant, and thus develop full color, nutritional quality, and typical guava flavor associated with good eating enjoyment. Fruits allowed to remain longer on the plant (overripe) may drop and bruise when they strike the ground. The skin of the guava is very delicate so fruits must be handled with care.

During the peak period of season, harvest interval cannot be more than 2 to 3 days otherwise losses of over-ripe fruits become a problem. When only fully ripe fruits are harvested on a 3-day cycle, losses between 35 and 40 per cent can occur, as fruits ripen so rapidly and abscise (Singh, 2007). It is desirable to harvest the fruits with the stalk along with one or two leaves. It delays ripening and the fruits are attractive in appearance. The fruit is soft
and requires considerable care in picking and handling. The fruit is picked selectively by hand. Once picked, the fruit deteriorates rapidly, if left standing in the hot sun in the fields. Hence, while in the field, they should be stored in a cool location under trees or in a centralized shed, protected from the scorching sun. Over-ripe fruits and those severely infected with fruit flies and diseases should be destroyed rather than left to fall and rot in the field, as these fruits become the source of continuous field infection. If the fruit is to be shipped to distant market it should be mature, full sized and of firm texture, but without an obvious color break on the surface. Fruits for local market can be harvested in a more advanced stage of maturity. Guavas can be stored for three to four weeks at 7-10°C and 85-90 per cent relative humidity. For processing, fruits should be transported to the cannery as rapidly as possible.

References


The passion fruit is a member of the Passifloraceae family. It is a vine of potential importance as a vitamin source and for export (as juice, pulp and syrup for flavoring).

**Botany**

Four species are known to be cultivated: The purple passion fruit (*Passiflora edulis*), the golden passion fruit (*P. edulis v. flavicarpa*), the giant passion fruit (*P. quadrangularis*), and the sweet passion fruit (*P. ligularis*). The purple and golden (yellow) passion fruit are recognized forms of edible passion fruit. The purple passion fruit is originally native of Tropical America, whereas yellow passion fruit is being considered as a mutation of the purple variety or as a natural hybrid between purple and another related species of passion fruit (Akamine and Girolami, 1959). These varieties are of commercial importance in many parts of the world, including Ethiopia.

The plants have a weak taproot and extensive ivory-colored lateral roots. The stem is usually solitary, up to 7 cm in basal diameter, extends 5 to 10 m or more into the crowns of trees, and is covered by a thin, flaky, light brown bark. The stem-wood is light and brittle. The twigs are yellow-green, turning brown, and support themselves on vegetation by means of tendrils that arise at the leaf axils. The leaves are alternate, green to yellow-green, three-lobed (on mature plants) with serrate edges. The petioles are 3 to 6 cm long and the blades are 5 to 11 cm long by 4 to 10 cm broad. Solitary flowers arise at the leaf axils. The flowers measure 5 to 7 cm across with five greenish-white sepals and five white petals topped with a
fringe-like corona of straight purple and white rays. There are five stamens with large anthers and a triple-branched style. The fruit is globose or ovoid, purple or yellow and 4 to 7 cm in diameter. Inside a thick rind are many dark-brown to black seeds enveloped in small sacs filled with aromatic yellow or orange juice. The fruits of the purple passion fruit are smaller but more aromatic than those of the yellow form (Cevedo-Rodriguez, 1985; Morton, 1987).

Ecological requirements

The species is shallow-rooted but withstands drought by defoliating. Passionfruit tolerates a wide variety of soils and grows best on well-drained sandy loams with pH of 6.5 to 7.5 (Morton, 1987). Passionfruit is moderately intolerant of shade, requires trees, brush, or fences for support, and benefits from but does not require soil disturbance for reproduction.

Until very recent time, commercial scale production of passion fruit was unknown in Ethiopia (Jackson et al., 1985). To this date, large-scale production is limited to the Upper Awash Valley. The fruits are used for domestic consumption (as a dessert or juice) and also for export. Two forms are recognized:

**Purple passion fruit,** *Passiflora edulis* var. *edulis,* is the normal form, and has round or egg-shaped fruits, 4-5 cm in diameter, deep purple when ripe. It thrives in the subtropics and in tropical highlands; e.g., in Ethiopia the crop is grown from 800 to 2,400 m a.s.l.

Principal characteristics of the purple type (GIP, 2011):

- Purple rind and smaller fruit.
- Sweet less acidic pulp richer in aroma and flavor and has a higher proportion of juice (35-38%).
- Can self pollinate but pollination is best under humid conditions.
- Less vigorous vine.
• If crossing yellow and purple types, it is necessary to use the purple parent as the seed parent because the flowers of the yellow are not receptive to the pollen of the purple, and an early blooming yellow must be flavored in order to have a sufficient overlapping period for pollen transfer. These crosses have some ability to withstand ‘woodiness’ virus.

• Black seeds.

Yellow passion fruit, *Passiflora edulis*, var. *flavicarpa*, the flowers of the yellow passion fruit are perfect but self-sterile and self-incompatible which lead to poor fruit set (Bruckner *et al.*, 1995). Principal characteristics of the yellow type include (PIP, 2011):

• Yellow rind and larger fruit (5-6 cm in diameter, as big as a tennis ball).
• More acid flavor.
• Flowers are self-sterile – wind is ineffective because of the heaviness and stickiness of the pollen. They must be pollinated, and bees are efficient pollinators.
• More vigorous vine.
• Less tolerant to frost.
• Resistant to nematodes and Fusarium wilt.
• Brown seeds.

It produces very aromatic and rather acid juice and is better adapted to the tropical lowlands. It should not be picked, but left on the vine until it falls for full development of the flavor. The fallen fruit must be gathered every morning. Because of this no cover crop can be grown between the rows.

The passion fruit can be grown on a variety of soils, but very heavy, poorly drained soils should be avoided.
Crop husbandry

Passion fruit can be propagated by seed or by cuttings, but where commercial plantings are carried out; seeding is the most common method. If cuttings must be taken, however, neither the very young nor the older parts of the vine should be used. Two internodes suffice for a cutting, and rooting may be encouraged by the use of a hormone such as indoleacetic acid. Propagation by seed is a relatively simple operation. Seed is extracted from the fruit during processing and is readily available. Seeds germinate best if allowed to ferment for a few days in the fruit pulp before cleaning and are lightly scarified by clipping or sandpapering (Morton, 1987). Seeds are sown rather thickly on a well prepared seed bed, lightly covered with soil and well watered. Light grass mulch may be placed on the soil to prevent rapid drying out of the soil surface and to prevent wide fluctuations in soil temperature. It is also a common practice to put a shade over the nursery beds.

According to Morton (1987), passion fruit can also be started from cuttings, layers, and grafts. Commonly stem cuttings of 2-3 inter-nodes taken from reasonably matured wood of pencil thickness are used. The purple passion fruit is also sometimes grafted onto other rootstocks to provide resistance to *fusarium wilt* disease. Vines are planted 3-7 m apart, although the purple variety is less vigorous and can be planted 3 m apart. In Ethiopia the recommended spacing is 3 m between plants and 2 m between rows (3 x 2 m). The vines are trained on one- or two- wire trellises similar to those used for grapes (Fig. 15-1). On one- wire trellise only one stem is permitted to develop and is trained in one direction on the trellis. Side branches will grow and hang downward. If a two-wire trellis is used, two stems from a single plant are allowed to develop and both stems are trained to grow in the same direction with one on each wire. Fruit is borne on the side branches about a year after establishment.
Pruning consists mainly of cutting back the side branches that develop to the ground from the main stem, and dead and diseased parts (Morley-Bunker, 1999). The passion fruit is cross-pollinated by insects and some clones are self sterile. Periods of wet weather (rainy periods) during flowering cause pollen grains to swell and rupture rendering them unviable, in addition bees and other insect pollinators are not active during wet weather. This results in
a subsequent crop of empty or poorly filled fruit (Rigden, 2013).

The flowers of purple passionfruit can self-pollinate (Morton, 1987). Plants continue to give economic yields from five to six years. Passion fruit are borne on current season shoots so pruning is essential to maintain adequate production. Some pruning is also necessary to control disease and to prevent mechanical damage to the fruit. Pruning is usually done in the second season, and the pruning should be made by cutting each lateral back to a new shoot as close to the main arms as possible or 10 to 15 cm from the main arm if mechanically pruning (McCarty, 2005). Because fruit bearing takes place on new wood, light pruning does not reduce yield. Plants live from 3 to 8 years and do not re-sprout (Morton, 1987). Commercial stands are managed in vineyards, somewhat like grapes.

Passion fruits respond well to fertilizer applications, especially nitrogen.

Three diseases are serious on passion fruit (Rice et al., 1994): fusarium wilt, leaf spot and woodiness.

The fungal fusarium wilt is soil-borne and causes a complete collapse of the plant within 48 hours of the appearance of the first symptoms. The disease may be prevented by grafting onto resistant rootstocks.

Leaf spot is serious during very wet weather. The following cultural practices are suggested to manage the disease (PIP, 2011):

- Effective vineyard sanitation;
- planting on mounds or ridges is recommended for better drainage;
- Pruning and leaf thinning to increase air flow and allow more light to reach the canopy.

Woodiness is caused by a group of viruses transmitted by vegetative propagation or aphids. The disease causes starting leaf discoloration and most seriously thick-walled and misshapen fruit, which may shrivel and dry before ripening. All infected plants should be destroyed (e.g., burning them down).
Usage of virus free seedlings of new plantings, eradication of old and abandoned orchards before starting new crops, care during trimming operations to eliminate mechanical transmission of viruses, avoiding leguminous plants which may harbor the virus near the orchard and rouging of diseased plants by means of systematic inspections during the first five months after transplanting can aid in checking the incidence and spread of potyvirus infection in passion fruit vineyards (Gloria et al., 2002).

Harvest and postharvest handling

Passion fruit requires a period of 8-12 months of growth until the first harvest. The length of the growing period depends mainly on soil fertility and climatic factors. The fruit can be stored for 3-5 weeks without losing its quality if kept in the cool (7°C).

Passion fruit is climacteric, and the climacteric rise occurs while the fruit is still attached to the plant (Biale, 1975). Fruit picked from the vine have an unripened flavor (Knight and Sauls, 1983). According to Biale (1975) the storage life of passion fruit may be extended considerably if mature-green fruit could be harvested before the climacteric rise and induced ripened in storage at low temperatures.

References


The strawberry, a member of the Rosaceae family, is a perennial plant characterized by an evolutionary morphology (vegetative growth, formation of runners, fructification).

**Botany**

Strawberry cultivars can be divided into two groups according to the type of photoperiod inducing flower initiation: short day and day-neutral cultivars.

Short day (SD) cultivars are the most widely produced in temperate climates. For these plants floral induction occurs when the length of the day is shorter than the critical photoperiod of 14 hrs and the temperatures are cooler. Temperature is important for floral induction: under short days the optimum temperatures is between 15°C and 18°C, while below 10°C and above 25°C floral induction is rather ineffective (Sonsteby and Heide, 2006). In short day conditions, axillary buds differentiate to rosette-like structures called “branch crowns”, whereas in long-day conditions (LD) they form runners, branches with 2 long internodes followed by a daughter plant (leaf rosette). The number of crown branches determines the yield of the plant, since inflorescences are formed from the apical meristems of the crown.

Day-neutral varieties have been developed as strawberry production expanded in further regions in the world. They produce crowns and flower buds approximately three months after planting regardless of the day length. The optimal conditions for flower induction are between 15°C and 21°C, however temperatures higher than 27°C have an inhibitory effect on flowering.
In tropics strawberry fruit produces well at altitudes above 1,000 m. The plant is a low-growing herb and reproduces naturally by runners or stolons. The production of flowers and stolons is controlled by the length of the day. Flowers are produced in short days and stolons in long days. Since days are uniformly short in the equatorial tropics many cultivars produce fruit over a long period but produce fewer runners than when grown in temperate regions. Storing plants at 0°C for three weeks prior to planting and exposure to long days through artificial lighting will often increase runner production when it is desirable for propagation purposes (Rice et al., 1994).

In every leaf axillary of the strawberry plant a bud is located, which can create, depending on the development phase of the plant, either runners, or a new shoot axis or an inflorescence (Hancock, 1999). The strawberry inflorescence is as such a modified stem and is terminated with the primary blossom. Following the primary blossom there are typically two secondary and four tertiary blossoms decreasing in size. Flowering and fruiting time is slightly delayed.

The flowers of most strawberry cultivars are hermaphroditic and self pollinating. The resulting seeds are the achenes and form the true fruits, while the fruit receptacle constitutes the strawberry flesh. The receptacle is composed of an epidermal layer, a cortex and a pith. The latter two layers are separated by vascular bundles that supply nutrients to the developing embryos (Hancock, 1999).

Ecological requisirments

Light to medium textured and well-drained soils are more suitable than heavy soils. The water holding capacity of the soil should be good. Strawberries while they can grow on a wide range of soil due to their shallow root system grow best on loam or sandy loam soils. These soils provide good drainage but also can supply adequate water and nutrients. Sandy soils or heavy clay soils may be modified by the addition of organic matter to improve drainage and the water holding capacity of the respective soil type.
Another alternative to planting on soils with poor drainage is to use raised beds. Strawberries also may be easily grown in containers. Strawberries will generally grow best at a pH of 6.2 but can grow in a range of pH from 5.5 to 7.0. Below pH of 5.5, Al toxicity is a problem while above 7.0, micronutrients may become deficient.

Many strawberry cultivars (cultivated varieties) are susceptible to *Verticillium* wilt (Barney, 1999). This fungal disease can persist in the soil for many years, even in the absence of susceptible hosts. *Verticillium* is common on potatoes and tomatoes. If possible, avoid planting strawberries where these crops have been grown within the past five years, and select strawberry cultivars that are resistant to *Verticillium* wilt.

The climatic conditions (temperature) at an altitude of 1,600 to 1,900 m are very suitable for strawberry production in Ethiopia. In cooler (above 1,900 m) and warmer (below 1,600 m) climates, results are less favorable. Owing to the highly perishable nature of the fruit it is important that production should be located within reasonable transport range of the market outlet.

**Crop husbandry**

Strawberries are propagated vegetatively from runners (Fig. 16-1). A single runner may give rise to several plants. About 30 plants can develop from a runner maintained in a nursery (growth medium). Identified and certified plants are recommended for multiplication purposes.
Propagation by splitting up the crowns of old fruiting plants is also possible, but not recommendable as the results are generally unsatisfactory. The spacing used for strawberries are: 80 x 60 cm (for multiplication of planting material) and 90 x 60 x 30 cm (for fruit production in double row planting system). Strawberries must be planted carefully so that the crowns are leveled with the soil surface because deep or shallow planting is harmful to the plants. Roots should be spread out and not bent. After planting, irrigation must be frequent since the root system is adventitious and shallow rooted.

After the plants are established they can either be grown in the **matted row system** where all runners are allowed to remain and a solid cover of the bed is obtained, or the **hillock or mother plant system** where runners are removed and large single plants are formed. The **matted row system** has the advantage of smothering weeds but yield may be reduced if the plants become too crowded. The **mother plant system**, which is generally preferred in warm climates, is high yielding and allows for better air penetration, which in turn reduces the chance of an outbreak of disease. Plants should be mulched with straw or plastic sheeting or other materials.
In Ethiopia the crop has been grown for many years. Strawberry cultivars, namely ‘Cambridge Favorite’, ‘Cambridge Vigor’, ‘Red Gauntlet’, ‘Hummi Triscana’ and ‘Gorilla’ performed well at Jimma and Melkassa Agricultural Research Centers (Asmare Dagnew, personal communication, 2013). Spacing of 60 cm between rows on the bed and 30 cm between plants in the row were suggested.

Under local conditions, strawberries are always in the flowering phases and will start to produce flowers a few days after planting. It is necessary to remove all flowers by hand. In the case of plant multiplication blocks, the deflowering is continued so that assimilates are used for runner production. In the case of fruit production crops, deflowering is continued only until the plants have grown to a full size to adequately support fruit growth. The period of deflowering may last for about four months and deflowering should be carried out once weekly.

The economic life cycle of strawberry will be determined by a drop in yield and decrease in fruit size. Production usually declines during the second and third years of fruiting; therefore a new planting should be established after strawberry plants produce fruits for more than 3 to 4 years for maximum production. They generally are productive for 3 to 4 years after that fruit quality and yields often decline (http://ohioline.osu.edu).

Weed control is essential for good production. The weeds can effectively compete for water and nutrients with the shallow rooted strawberries. The weeds should be hand pulled but must be taken care not to damage the shallow roots of the strawberry plant. Mulches may be used to help prevent weeds from growing around strawberries. Black plastic is commonly used, since it prevents the sun’s rays from penetrating, the beds remain cool, resulting in slower initial growth of the plants and reduced irrigation frequency compared to clear plastic mulch (Guerena and Born, 2007).

The strawberry is susceptible to many diseases and nematodes. Nematode problems are prevented either by growing plants in soil which has not previously grown fruits or vegetables that are sensitive to host nematode (Noling, 2012). Plants used for propagation should also be free from nematodes. Only obtaining plants from nurseries producing virus-free plants
can prevent virus diseases. In many instances, this is nearly impossible. So the best option is to use only those plants, which are free of obvious virus symptoms. Thus planting with discolored, crinkled or misshapen leaves should be avoided. Also, avoid planting strawberry plants in areas where potatoes, tomatoes, or sod were grown recently. Insect and disease problems may result in serious plant damage in such areas.

Leaf spot and grey mould are the most serious fungal diseases. Leaf spot forms small black spots on the leaves in the rainy season. The pathogens are spread by splashing water and are harboured by dead leaves and other plant debris (Guerena and Born, 2007). Sanitation, as well as spraying of appropriate fungicides (captan or copper oxychloride) and can control the disease.

Grey mould, caused by the fungus Botrytis cinerea, is one of the most common and serious fruit rot diseases. The fungus grows best in cool damp weather, and grey mould can be devastating if rainy weather coincides with harvest, when strawberry fruit is at its ripest and most susceptible stage (Guerena and Born, 2007). Pickers handling infected berries can spread the infection to healthy berries. Control of grey mould is aided by removing infected debris from the field and by providing good drainage. Clean mulch, which keeps fruit off the ground, is also highly recommended. Removing leaves from the field as soon as the harvest season ends can significantly reduce the incidence of grey mould on fruit in the following year (Sutton et al., 1988). Adequate plant spacing could also reduce the incidence of the disease as it allows air circulation. Where necessary, periodic sprays with captan carbendazim dicloran or vinclozolin could also help in managing the disease.

Leaf spot is caused by fungus that overwinters on old, infected leaves. Dark red or purplish spots form on leaves, gradually becoming grayish or almost white. Fully developed spots are with whitish centers and reddish margins. The spots are scattered widely over the leaf surfaces and interfere with leaf functions. Infections occur during moist weather. Following cultural practices described for gray mold can help in managing the disease.

Powdery mildew is a fungal disease that affects strawberry foliage,
flowers, and fruit. Powdery mildew causes the edges of infected leaves to curl upward (Barney, 1999). Leaves are coated with a grayish-white powdery mold and may turn purplish or red. In irrigated fields, the fungus may also attack the fruit. Follow the cultural practices described for gray mold.

*Verticillium wilt* is a fungal pathogen. In strawberries, symptoms include wilting of individual plants, often in patches throughout a planting. Older leaves wilt and tend to curl up along the mid-vein. Infected plants become stunted, dry, and flattened with small, yellowish leaves. Brownish streaks occur in the vascular tissue of crown roots or at the base of the petioles. To manage *Verticillium wilt*, Barney (1999) recommended the following:

- Avoid planting strawberries where tomatoes, potatoes, peppers and eggplants, have been grown within the past five years.
- Select resistant cultivars and plant high-quality, nursery-grown stock.
- Remove infected plants together with adjacent plants.
- Do not replant in spots where infections occurred.
- Keep your planting weed-free.
- Use soil fumigants before planting in large commercial fields.

Several nematodes damage strawberries, including root knot nematodes. Besides damaging the roots by feeding, some nematodes carry virus diseases that infect strawberries. According to Barney (1999) to control nematodes and the viruses they transmit, start with virus-free nursery stock. Rotate strawberry beds to a new site every three to four years. Plant rotation crops, such as vegetables or green manures, but do not use potatoes, tomatoes, or eggplants as rotation crops. Potatoes, tomatoes and eggplants can carry *Verticillium wilt*.

*Botrytis*, also known as gray mold, is a fungus that infects ripe and nearly ripe strawberry fruits. Berries infected with *Botrytis* soften and begin to rot, eventually becoming covered with gray mold (Barney, 1999). The disease is greatly aggravated by wet conditions. Avoiding sprinkler irrigation, if possible, or watering early in the day can reduce the disease problem. Picking fruits at least every other day and storing them in refrigerator quickly can
help in reducing the disease. It is also advisable to remove rotted fruits from the strawberry rows. Spreading of clean straw under the plants can also reduce infections.

Ripe strawberries are highly attractive to birds, which can cause serious damage to commercial and home crops. Scare devices sometimes are used to frighten birds away. Birds are highly adaptive, however, and are seldom deterred for long. The most effective method of bird control is to cover the strawberries with bird netting. Anchoring of the edges of the net is necessary to prevent the birds from walking under it.

Harvest and postharvest handling

Once harvesting is started, it is likely to continue for a period of 10-12 months. The fruit must not be in contact with the soil, which can be achieved by mulching. The fruit is harvested when it is still firm but almost fully colored. Fruit is picked from the plant by nipping the stalk between thumb and finger. Strawberry fruit is highly perishable and so should be picked carefully with the stem being attached and then placed directly into the containers in which the fruits will be sold. To ensure high fruit quality, berries need to be harvested in early morning after the dew is off the ground. Strawberries are picked by pinching off the stems with thumb and forefinger, leaving the stem and cap attached to the berry. This method reduces damage to the fruit and increases shelf life.

Proper postharvest handling of strawberries is essential. Cooling the berries will remove field heat and increase shelf life. Harvesting early in the day while temperatures are cool and then pre-cooling the fruit before shipping will extend the shelf life significantly (Guerena and Born, 2007). It is vital that the fruit be cooled as soon as possible. The more the delay between harvesting and cooling exceeds one hour, the greater the losses to deterioration (Kader, 1992). A storage life of 7-14 days may be expected if the fruit is stored at 0°C as quickly as possible at a relative humidity of 95%.
References


http://edis.ifas.ufl.edu


Many of the deciduous fruits are native to temperate regions where they drop their leaves when winter comes and resume growth when temperatures rise in the spring. The most important deciduous tree fruits grown in Ethiopia are the pome fruits (apples and pears) and the stone fruits (including peaches, nectarine and plums). These fruits are adapted to the cool climate conditions (or to high altitude areas) and are potentially important as export crops, and for processing as jams and juices. Temperate fruits contribute to the horticulture industry by providing an alternative to the tropical and subtropical fruits normally grown in Ethiopia, which do well only in lower-elevation, warm ecologies.

Chilling requirements

The apple (*M. domestica*) is a fruit tree in the general category of temperate plants, which are characterized as requiring an annual cold period to satisfy their ‘chilling requirement’. If the chilling requirement is not satisfied, the buds will not open; if the chilling requirement is partially met, the buds will open sporadically and both the bloom and harvest periods will be abnormally extended. According to Labuschagne *et al.* (2002), the chilling requirement of most varieties varies from 200 to 4,100 hours, and can be higher in other apple cultivars and influenced by genetic variation. Some cultivars may require between 1,200 and 1,500 hours of chilling in the range of 4-7°C (Linden *et al.*, 1996).

Chilling is achieved, between roughly November 1st and February 15th in northern latitudes, with the most benefit derived from chilling hours
occurring in December and January. These hours are cumulative and need not be continuous. Temperatures below 0°C or above about 10°C do not provide chilling and may actually negate previously accumulated chilling hours. The number of chilling hours required for each fruit variety is different to some extent (Gardea et al., 2000; Regnold et al., 2001).

Deciduous fruits have evolved a biological cycle involving a minimum yearly “rest” period (a period of minimal metabolism) before they will begin active growth. Generally 7°C is regarded as the highest temperature at which chilling can occur and the rest requirement of a specific fruit is the number of hours of temperature below 7°C which must pass before bud dormancy can be broken.

Lack of effective winter chilling is one of the major problems in tropical areas when growing temperate fruits (Webster, 2005). When dormancy release is unsuccessful, abnormal growth characteristics such as reduced break of vegetative and reproducing buds, prolonged flowering periods, lower fruit set and uneven fruit size occur (Richardson et al., 1974; Mauget and Rageau, 1988). Warm winters result in prolonged dormancy leading to poor flowering, very strong apical dominance, unsynchronized growth patterns and, consequently, low yields (Jacobs et al., 1981; Cook and Jacobs, 2000).

In the subtropical type of climate, buds of temperate fruits go into winter rest, requiring chilling to resume growth. Some chilling occurs, but often not enough, so that chemical or cultural treatments are needed for bud break and a new cycle.

In the tropics, where no chilling occurs and where both temperature and day length are relatively uniform, successful culture of temperate fruits depends on artificial induction of a new growth cycle after floral initiation is assumed but before endodormancy becomes dominant.

Generally, in the tropics, where chilling condition is lacking, the trees will suffer from a physiological disorder called delayed foliation. This can be recognized by the failure of trees to produce leaves properly in the spring. When the temperatures are not cold enough, trees will flower over an abnormally long period, leaf production will be sporadic, and usually the terminal buds will die. The result of this is a poor yield and possibly the
death of the tree.

The problem of insufficient chilling in low latitudes (tropics and subtropics) is overcome by the combination of techniques including (Edwards, 1990; Alum and Magherini, 1995): (a) cultivar selection; (b) careful site selection; (c) the use of rest breaking treatments; or (d) rest avoidance.

**Cultivar selection** - The selection of appropriate cultivars is the most important factor in preventing problems arising from insufficient rest period. The selection or breeding of species with low chilling requirements has taken place in many countries including Ethiopia during the last few decades and the use of adapted selections has resulted in a considerable increase in temperate fruit production in low latitudes. Only by selecting cultivars with low chilling requirements, deciduous fruits can be raised successfully in the tropics unless special rest-breaking treatments are applied.

Apple cultivars differ in their chilling requirements, for example, it was estimated previously that Anna needs approximately 200-300 chill units to break bud dormancy, Dorsett Golden needs some 800-900 chill units and ‘Golden Delicious’ needs 1,050-1,100 chill units (Hauagge and Cummins, 1991). Palmer (2003) on the other hand reported that apple cultivar ‘Golden Delicious’, requires much more chilling (1,000-1,600 hrs).

Dormancy development in axillary buds is gradual. It starts with paradormancy (initial stage of dormancy development); mostly due to apical dominance that prevents laterals from breaking. The level of apical dominance is species-related, with stronger polarity or acrotony in pome fruits than in peaches, plums and apricots (Erez, 2000). However, within each species, polarity is cultivar-dependent. In the case of apples, four groups were defined (Lespinasse and Delort, 1986 cited in Erez, 2000) as to their pattern of growth from upright growth of spur types to wider open pattern of cultivars like ‘Granny Smith’. According to Erez (2000), this characteristic is becoming of special importance when management practices are used in warm climates. As to lateral buds: as they are formed successively on the growing branch, they enter endodormancy consecutively. The first to form are the basal buds and their entrance into endodormancy is therefore, earliest. Late forming buds
may remain paradormant (temporarily dormant) side by side with endodormant basal buds.

The terminal bud reacts differently, it may continue to grow much later in the season and is thus more affected by environmental conditions that retard its entering into dormancy. Typically, under warm climates with otherwise non-limiting conditions, longer terminal growth occurs which may accentuate paradormancy of the lateral buds and affect their chilling requirement (Erez, 2000). According to the author, flower buds of low chill cultivars will not enter endodormancy or will enter it very slowly when autumn temperatures remain high. Vegetative buds, on the other hand, will respond to short days in spite of high temperatures (Lerner, 1990 cited in Erez, 2000). This may lead to autumn bloom, sometime very abundant, under warm conditions when bud break is stimulated by loss of leaves, irrigation after a long period of drought or dormancy-breaking chemical sprays (Erez, 1987).

Response to chilling varies with type of bud. Generally the terminal bud has a lower chilling requirement, which may be interpreted as having a shallower dormancy. This is especially evident under conditions where chilling is marginal. Under such conditions, the terminal bud breaks first; with little competition from other buds, growth may be vigorous.

_Careful site selection_ - In general, high altitudes have colder temperatures. Therefore sites should be chosen where the altitude is high enough for sufficiently cold temperatures to occur over sufficiently long periods to meet the chilling requirement of a given fruit plant. Alum and Magherini (1995) reported suitability of high-altitude areas, above 2,000 m, of Ethiopia for apple production, where temperatures are similar to those of subtropical regions, with resulting satisfaction of chilling requirements, especially for cultivars with low chilling requirements.

_The use of rest breaking treatments_ - In areas of inadequate chilling, where low-chilling varieties may not have been planted, temperate fruit culture has depended on chemical sprays to stimulate bud burst and thus compensate for incomplete chilling. That is, where temperatures are too warm and insufficient
rest occurs, the chilling requirement can be partially overcome through the use of rest-breaking chemicals. The chemicals most often used are (Erez, 2000; Tromp, 2005): mineral oils, dinitro compounds, KNO₃, thiourea, Dormex (hydrogen cyanamide, CH₂N₂), and mixtures of cytokinin and gibberellins. In general, the effect of the chemical is both dose- and time-dependent. Therefore care should be taken not to damage the most sensitive organs like flower buds when any of the above listed chemicals are to be used.

The combination of oil and dinitro-orthocresol (DNOC) is widely used spray. It contains 4-6% dormant oil plus 0.1-0.2% DNOC. The oil enhances the effect of DNOC. Studies conducted by Ashebir et al. (2010), in Ethiopia (Tigray), showed that apple trees treated with Dormex and winter oil, separately or in combination, showed significantly early bud break and then blooming than control and trees which received single defoliation per year. According to Ashebir et al. (2010), the growth pattern (from bud break to fruit set) of cultivars tested was nearly synchronized and similar in both the Dormex- and winter-oil-treated trees.

Rest avoidance - Horticultural practices induce repeated cycles of growth, flowering, and fruiting to avoid endodormancy and thus avoid the chilling requirement. Low level of budburst and pronounced apical dominance in apples under tropical conditions favors the formation of a few vigorously elongating shoots rather than many spurs (Edwards, 1990). Tying shoots down to a near horizontal position stimulates lateral budburst, increases the number of spurs and promotes terminal bud formation. Bud break occurs much more readily in horizontally oriented branches than in upright ones (Erez, 2000). According to the author, this effect definitely results from the change in balance of hormones in the buds and from the reduced vigor if bending is done during the growing period. It also reflects a reduction of apical dominance that tends to prevent bud break on most of the laterals on a vertical branch, leading to the proper bud break syndrome.

Apical dominance is a major concern in warm-winter climates. With upright branches, earlier break of the terminals, which have lower chilling requirements, will induce a strong correlative inhibition thereby further
reducing the level of lateral bud break. Thus branch bending techniques are used in many warm countries (Erez, 2000).

Fig. 17-1 below shows a well distributed scaffold branches with a wide crotch angle.

![Figure 17-1](image)

**Figure 17-1.** Growth habit of ‘Golden Delicious’. Note the well-defined central leader, wide-angled crotches, and moderate extension growth.

Source: Forshey and Elfving (1976)

In equatorial tropics, temperatures are not low enough to induce natural leaf drop (Fischer, 2000). To ensure the continuous cropping system in tropical growing condition, the core event is the removal of mature foliage after harvest at the end of each growth cycle (Edwards, 1990). This practice prevents the onset of dormancy and permits the next cycle to commence (Tromp, 2005). Timing in relation to terminal bud formation in apples, and lateral flower bud formation in peaches, is critical. Premature defoliation prevents flower initiation, whereas delayed defoliation reduces budburst. According to Erez (2000), early defoliation leads to reduced chilling requirement and vice versa. A possible cause for this lies in the movement of chemicals (that control the depth of dormancy) from the leaves into the buds. Buds formed on vegetative growth late in the season will require more chilling to support their growth than those formed on early spring growth.
The bud break of apples in the tropics, due to defoliation, is preceded by a large increase in accumulation of gibberellins in the apex tissue of closed buds (Taylor et al., 1984; Edwards, 1985) and a decline in abscisic acid concentration (Edwards, 1985) in the bud. If the timing of defoliation is correct, bud burst follows within one to four weeks (Edwards, 1990).

In the tropics, it has been found in practice that defoliation will induce bud break if applied at the right time in the growing cycle, prior to endodormancy (Erez, 2000). In Tigray (north Ethiopia), Ashebir et al. (2010) evaluated the response of different apple cultivars (‘Golden Delicious’, ‘Gala’, ‘Fuji’, ‘Granny Smith’ and ‘Jonagold’) grown on M9 rootstock with different dormancy-management practices, and found that the defoliation treatment alone was not sufficient to break dormancy for the cultivars ‘Golden Delicious’, ‘Granny Smith’ or ‘Gala’, but showed promising results with dormancy breaking on cultivar ‘Jonagold’.

Success is dependent on inducing a continuous succession of growth cycles throughout the year thereby avoiding dormancy and the associated chilling requirement (Edwards, 1990). Resumption of vegetative growth to ensure flower initiation, defoliation to prevent the onset of dormancy, and stimulation of adequate and uniform budburst are essential for success.

Ethiopia has tremendous potential for the production of temperate zone fruit crops, subject to the availability of appropriate cultivars and cultural practices. The major limitation to realization of this potential has been the lack of sufficient low-chilling cultivars adapted to the different parts (commonly upland areas) of the country. Cultural treatments that adapt temperate crops to the tropics, such as defoliation, pruning, withholding water, and various chemical sprays, must be timed properly to initiate each new cropping cycle.

17. 1. Apple (*Malus domestica*)

Apples, unlike pears, are fairly well adapted to upland areas in the tropics although there are even some cultivars of pear, which can succeed in the colder areas. Several apple cultivars are known to have low chilling
requirements to successfully grow in the tropics.

Apples are adapted to altitudes above 1,300 m in many tropical regions. Nevertheless, the low-chilling requiring cultivars often are not as good quality as many cultivars requiring colder weather. Trees are propagated by grafting or budding onto either seedling or vegetatively reproduced rootstocks.

Most apples are partially self-fertile. Although the flowers are complete and pollen is generally fertile, good crops depend upon pollen from other cultivars (Christopher, 2001). The author describes good pollinating cultivars (pollinizers) as those which (1) adapt to the agro-climate of the area, (2) are compatible to the main cultivar, (3) bloom and bear at the same time or at the same age as the main cultivar, (4) have pollen of high viability, (5) bloom every year, and (6) yield fruit of commercial value.

Honeybees are the principal agent for accomplishing pollen transfer in apple orchards. Some other bees and flies are also effective. Bringing about the desired cross-pollination varies with bee activity (hive strength). That is, the larger the colony, the larger percentage of the bees visit blossoms. Climatic condition during blossom also has significant influence on pollination. Periods of low temperature as well as high winds or rain may prevent pollination even when satisfactory pollen supplies are available.

Pollination and fertilization usually have to take place for apple trees to set fruit. As a result of these processes, seeds begin to form and produce hormones necessary for fruit development. The number of seeds per fruit is a measure of successful pollination and fertilization. The higher the seed count, the better the final fruit set and, usually, the better the yield, because increased number of seeds results in higher sink strength in the fruit (Keulemans et al., 1996). An apple that contains only a few seeds is more likely to drop before reaching maturity, especially if water, nutrients or carbohydrates are in short supply (Blažek and Drobková, 1976; Dennis, 1986; Green, 1989).

Besides affecting fruit set, seed count affects several fruit quality parameters, especially fruit size and weight (Miller and Kaiser, 1994; Volz et al., 1995; Keulemans et al., 1996). A low seed count has often been found to correlate with ribbed or malformed fruits (Brault and de Oliviera, 1995;
Brookfield et al., 1996; Buccheri and Vato, 2004). A high seed count has also been associated with increased calcium content, reduced fruit length-to-width ratio, increased firmness, and increased acidity (Broom et al., 1998; Tomala, 1999; Buccheri and Vato, 2004).

Apples succeed best in regions where the trees experience uninterrupted winter rest, since the trees require certain minimum chilling period for growth and fruiting. Kronenbourg (1979) suggested a chilling requirement of 1,000 hours at below 7°C. However, some cultivars have low (250 hours) chilling requirement. It is therefore, important to experimentally identify cultivars (with low chilling requirement) that may produce fruits of acceptable yield and quality.

Considering Kenyan experience, Greensbach (2007) reported that the apple trees in warmer climates have a tendency to grow more upright with strong, branchless shoots. Here in Ethiopia as well apple trees have more or less similar growth behaivior as reported in Kenya.

Proper training and pruning are essential for development of structurally strong, productive apple and pear trees (Forshey and Elfving, 1976; Lord, 2010). Limb positioning is important because it determines whether the branch will produce primarily fruit or vegetation. When branches grow straight up, they mostly show vegetative growth and very little fruit. By contrast, branches that grow straight out from the tree (i.e., horizontally oriented) are very fruitful, but produce little new vegetative growth (Roper, 2005). According to the author, the ideal limb position is about 30 degrees above horizontal creating a 60 degrees crotch angle (Fig. 17-2). This allows maximum fruit production, while still promoting growth of new wood for future fruiting.

Lord (2010) also reported that branches are most productive at an angle 60 to 75 degrees from the vertical leader or trunk (not quite, but nearly flat). The branches on well-feathered nursery trees will naturally develop wide, strong crotches. Few branches that are too upright-growing can easily be tied down or spread to a wider angle.
The use of a tree-training stake is a key first step to properly train young apple and pear trees. Dwarf trees frequently require some sort of support, in part because they bear fruit so young in life.

Staked trees are easy to train; the trunk (often called the leader) is simply tied to the stake using soft twine, chain ties or other suitable material. Lateral limbs that need spreading can be pulled down into position with soft twine tied to the stake or tied to anchors made from plastic jugs (of appropriate size) filled with water or sand. Staked trees will bear fruit earlier in life (Lord, 2010).

When pruning trees, growers need to make cut flush with the branch collar that forms where the shoot meets the branch or trunk. Where larger branches meet the main trunk, it’s important to undercut the branch a few centimeters away from the trunk, then finish the cut from above. The stub has to be removed by cutting close to the branch collar as this helps to prevent damaging the bark on the trunk.

Thinning cuts (removing branches at their base) are usually better than heading cuts (removing the ends of branches). Here, branches from two adjacent trees are crowding each other. Numerous heading-back cuts stimulate
undesirable vegetative growth in the vicinity of the cuts and result in loss of fruitfulness farther back on the branches. Removing the large branch, eliminates crowding without stimulating undesirable vegetative growth.

Griesbach (2007) described two systems (‘open center’ and ‘pyramid shape’) in which the young trees are pruned to establish their future structure and shape. The ‘open center’, also called the ‘vase shape’ tree consists of a relatively short trunk which has been created by pruning the young single-stemmed young tree at a height of approximately 60-70 cm from soil level. This stimulates side branching below the point of cutting. Usually 3 or 4 shoots, well distributed around the trunk and of roughly equal vigor will be selected. These will form the future scaffold’s main branches. Wide angles and strong unions are preferred. It is also advisable to remove the topmost shoots (which will tend to be too upright) so as to obtain a well shaped vase tree. Any suckers arising from the rootstock should also be removed.

According to Griesbach (2007), during the next season the selected scaffold branches are pruned back by upto half of their length, to induce the development of side branches (laterals). The side branches should be spaced 40-50 cm apart on both sides of the scaffold branches. Vigorous competing shoots should be removed, while retaining as many short shoots and spurs as possible. However, short shoots and spurs should be thinned out only when overcrowded.

When fruiting starts, the growth of the tree will be slowed down, and pruning will change to judicious thinning of shoots and spurs, heading back of branches that are too long and whippy, and spacing of new shoots to obtain optimum light, stimulating growth (where necessary), and keeping the size of the tree within the optimum planting distance.

The ‘pyramid shape’ (Fig. 17-3) tree consists of a single vertical trunk with main branches spread evenly up and around it and becoming less vigorous towards the top of the tree (Griesbach, 2007). The trunk ends in a single vertical shoot. The height and spread of trees will depend on the rootstock, cultivar, soil, and spacing, but the height is normally limited to 2.5-3.0 m.

The goal of pruning of the trees is to create a central leader tree
with several whorls of scaffold branches growing from the trunk in tiers. To achieve this, after planting, head the whip (single-stemmed young tree) back to about 90 cm above soil level. If the tree has already produced side branches prune the leader approx. 25-30 cm above the side branches. The buds below the heading are the ones to grow, and once these side shoots are about 25 cm long, tie them into a horizontal position the same way as was previously done with the existing ones. During the following year, again head back the leader 25 cm above the first tier of branches, and develop the second tier the same way as was done a year before. Any shoot which might compete with the trunk and alter the shape of the pyramid should be removed.

Manipulation of the height of trees is done by heading back the vertical elongation to a lower side shoot, when the tree reaches a height of approximately 3 m. Main branches that become too long or whippy should be headed back to suitable side shoots. Growth in the upper part of trees must not be allowed to become too strong; judicious pruning of such shoots should therefore be done annually together with fruit thinning to obtain regular crops of good quality fruit. Vigorous, upright growing shoot is selected to be the new central leader. This shoot should be near the top of the tree. Below the new leader, four to six shoots are selected to become the lowest set of scaffold branches. The best shoots for scaffold branches will come from the trunk at a wide angle rather than a sharp (narrow) angle. These shoots should be equally spaced vertically (up and down the trunk) and horizontally (around the trunk). Scaffold branches rising at a sharp angle from the trunk will break off of the trunk more easily than those at a flatter angle. When proper pruning is done, the lower branches will be longer and stronger than the branches higher on the trunk.
Popular apple cultivars in East Africa include ‘Anna’, ‘Golden Dorsett’ and ‘Winter Banana’ (Hailemariam et al., 2005). According to these authors, ‘Anna’ and ‘Princesa’ are commonly grown in the central highlands of Ethiopia, while ‘Granny Smith’ and an apple type (locally known as ‘BR’) are well known at ‘Chencha’, southern Ethiopia. ‘Ein Shemer’ is another apple cultivar which has shown promising performance in uplands of Ethiopia. It is a pollen donor for self-sterile cultivars like ‘Anna’.

Table 17-1 below shows crop calendar of apple at the central highland of Ethiopia (North Shoa, Degem woreda) as reported by Hailemariam et al. (2005).
Table 17-1. Crop calendar of apple.

<table>
<thead>
<tr>
<th>Activity (Plant response)</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of dormancy (vegetative rest)</td>
<td>June – August</td>
</tr>
<tr>
<td>Dormancy break</td>
<td>End of August</td>
</tr>
<tr>
<td>Flowering</td>
<td>End of August</td>
</tr>
<tr>
<td>Fruit setting</td>
<td>September – October</td>
</tr>
<tr>
<td>Tree management</td>
<td>End of August – May</td>
</tr>
<tr>
<td>Winter pruning and training</td>
<td>End of August – Mid-September</td>
</tr>
<tr>
<td>Summer pruning and training</td>
<td>December – January</td>
</tr>
<tr>
<td>Fruit harvesting</td>
<td>End of January – March</td>
</tr>
</tbody>
</table>

Controlling early fruiting - It is advisable to overcome fruiting at least during the first two years after planting as it will have a negative impact on future production (Hailemariam et al., 2005). During the early stage, apple trees need to be encouraged to develop strong leader and scaffold branches.

Fruit or flower thinning is commercially practiced in order to maximize crop value by optimizing marketable fruit sizes, yields, fruit color, shape and quality, as well as to promote return bloom and tree growth and maintain tree structure (Byers, 2003). Trees with heavy fruit set must have a portion of the fruit removed to produce fruit of adequate size and quality. Excessive fruit loads can break limbs. Experience in growing fruits for the fresh market shows that in most seasons a reduction in the number of fruits per tree (fruit thinning) is necessary in order to produce fruit which satisfies consumer requirements. Therefore, fruit thinning is well recognized as one of the most important orchard operations. It results in improved fruit size and uniformity, reduces competition between the fruit and other growing parts of plants such as shoots and roots, promotes regular bearing, reduces limb breakage, permits culling of undesirable fruits, assists in maintaining general tree vigor, and decreases the labour requirements of crop picking (Griesbach, 2007). Too much fruit on a tree will cause small fruit, broken branches, and a reduced crop the following year.

Fruits are normally thinned as early as practical, but generally only
after the first fruit-drop (usually due to lack of pollination) has taken place. Thinning is commonly done manually and fruits are retained more-or-less in proportion to the final fruit size desired (between 5 cm and 20 cm from fruit to fruit). Excess fruits are removed by twisting, pulling or pinching them off.

Harvest and postharvest handling

Apple is a climacteric fruit which does not fully ripe while attached to mother plant. In a climacteric fruit such as the apple, ethylene advances the timing of the climacteric, autocatalytic production continues after removal of ethylene and, in contrast to a non-climacteric fruit, the magnitude of the respiratory rise is independent of the concentration of applied ethylene. Thus timing of the climacteric and ripening of apple fruit is advanced by exposure to ethylene.

Some of the important indicators of ripening are softening, the change of background or ground color from green to yellow, loss of acidity, conversion of starch to sugars, formation of cuticular waxes and synthesis of aromatic compounds. The harvest date within the maturation and ripening period has a profound effect on the storage quality of fruit. As quality factors such as flavor and aroma of the fruit increase, the storage potential of the fruit decreases and therefore harvest decisions are a compromise between the quality and storability of fruit (Griesbach, 2007). The increases in fruit quality are typically associated with the climacteric. The length of storage of apples can usually be increased by harvesting fruits before they are fully mature, but quality characteristics such as color and varietal flavor develop less in these fruits, and they can be more susceptible to physiological disorders, such as bitter pit and superficial scald. Fruit harvested over-mature tend to be softer and more easily damaged and may have water-core and be more susceptible to diseases and physiological disorders, such as senescent breakdown.

Harvest decisions have to be based not only on physiological maturity, but also on market requirements, which include factors such as blush, background color and usually the absence of water-core.
17. 2. Apple rootstocks

Choice of suitable rootstocks (especially the use of dwarfing rootstocks) to counter excessive vigor shown under tropical conditions (Edwards, 1990) is very important. Distinguishing characteristics of some apple rootstocks are given below:

**Seedling rootstock** - Used for non-irrigated sites, low vigor sites, and weaker varieties. Seedling rootstocks are usually very vigorous, produce large, full-sized trees that come into bearing late (7-10 yr.).

**Malling-Merton 111 (MM.111)** - Produces trees 80 to 90% of standard that are moderately slow bearing with medium productivity. More drought tolerant, somewhat better anchored, and slightly more productive than other rootstocks. However, its large tree size is too large for most plantings.

**Malling-Merton 106 (MM.106)** - Size 70 to 80% of standard, it is consistently a highly productive rootstock. Much better anchored and substantially more productive than trees on M.7. It is early bearing with few suckers.

**Malling 7 (M.7)** - This rootstock produces a semidwarf tree that is freestanding in deep well drained soils. In shallow soils, it tends to lean, hence high budding and deeper planting may help remedy this problem. The rootstock may sucker profusely.

**Malling 7a (M.7a)** - a clone of the original M.7, semi-dwarf rootstock. Usually produces a tree about 60% the size of the same tree on seedling rootstock. Tends to sucker profusely.

**Malling 26 (M.26)** - Semi-dwarf to dwarfing rootstock (a more vigorous rootstock than M.9). Usually produces a tree 30-50% the size of the same tree on seedling rootstock. It can be used to produce either a dwarf or a semidwarf tree, depending on scion variety, production system and soil type.
Malling 27 (M.27) - A very dwarfing rootstock. Unless the central leader is supported, the tree will be very small. In commercial nurseries (elsewhere) it is commonly used as an intermediate stock on MM.106 or MM.111.

Malling 9 (M.9) - Dwarfing rootstock. Usually produces a very small tree less than 30% the size of the same tree on similar rootstock. Commercially, the most frequently planted rootstock worldwide. However, a poor performer if not adequately managed. Poorly anchored, has brittle root system. Provision of trellising is therefore necessary.

Mark - Dwarfing, relatively new rootstock. Originated as MAC-9 (Michigan Apple Clone) from Michigan State University (released for commercial use in 1985). Tree size is slightly less than M.26 and it can grow freestanding. It has a tendency to crop heavily on young trees and may cause stunting if fruit are not adequately thinned. It is very precocious.

17.3. Pear (Pyrus communis)

The pear has a higher chilling requirement than the apple and can be expected to succeed only in the coolest areas. Like the apple, low-chilling pear cultivars often have poorer flavor and texture than temperate climate selections. Pear is propagated by grafting. Most pears are self-sterile so another cultivar should be planted close by for pollination.

Pears take longer than apples to begin fruiting, usually 3 to 5 years after planting (Griesbach, 2007). Many cultivars tend to set heavy crops of fruit which the tree is unable to develop to a good marketable size. Removing excess fruit ensures satisfactory development of color, shape, and size of the pears remaining on the tree. Over-cropped trees are also prone to serious limb breakage problems.

The earlier thinning is completed, the more effective it is at achieving the desired results. According to Griesbach (2007), leaving one pear per cluster and spacing these about 10-15 cm apart can give better result. If fruit set on a tree is not excessive, 2-3 fruits per cluster will reach satisfactory size
without thinning.

All pear fruits, whether intended for the market or for use at home, should be hand-picked with care. The fruit is considered ready for harvesting when there is a perceptible change in the skin color, when the seeds begin to turn brown or when the stalk separates readily from the branch when the fruit is lifted lightly. These tests are an indication of picking maturity only; most pears will need to be store-ripened before they are ready to eat.

The two most serious diseases of pome fruits are *scab* and *powdery mildew*.

*Scab* is a fungus, which causes brown spots on fruits and leaves. Symptoms first appear on the undersides of leaves, the side exposed as buds open. Later, symptoms are found on both sides of leaves. The spores germinate only when leaf and fruit surfaces are moist for 12 or more hours (depending on the temperature). Severe infection can cause leaves to abscise, resulting in defoliated trees (Grove *et al.*, 2003). Scab is controlled primarily with fungicides applied in predetermined schedules, beginning at green tip. Thus when conditions are favorable for spore germination, fungicidal sprays are recommended.

*Powdery mildew* is a fungus, which is recognizable by the greyish-white mycelia, which appear on the leaves. Leaves, flowers and fruit are susceptible to infection by the powdery mildew fungus. The foliage of new terminal growth is extremely susceptible to infection (Grove *et al.*, 2003). The initial signs of powdery mildew consist of white to grey felt-like patches on the lower leaf surface. These patches are comprised of masses of fungal mycelia and spores (conidia). As disease progresses, mildew signs may also appear on the upper leaf surface and eventually cover the entire leaf. Powdery-mildew epidemics are favored by high humidity; therefore problems with mildew can often be avoided or reduced with cultural practices that promote air movement and light penetration. On susceptible cultivars, effective disease management usually depends on a fungicide-spray programme. Applying fungicidal sprays beginning at bud break.
Aphids - These colony dwellers suck on leaves, flowers and young shoots, causing them to curl and become blighted. Aphids may also transmit viral diseases and the honeydew they produce develops into sooty mould.

References


18. 1. Peach and Nectarine (*Prunus persica* L. Batsch)

Peaches (*Prunus persica* L. Batsch) and nectarines (*P. persica* L. Batsch, var. *nectarine*) belong to the Rosaceae family and are thought to have originated in China (Salunkhe and Desai, 1984). The nectarine is considered a sport (mutated form) of the peach differing primarily in that the skin of the fruit is smooth (Christopher, 2001).

*P. persica* L. Batsch is a diploid species (*2n* = 16) with a medium tree height (up to 8 m); the leaves are lanceolate, glabrous and serrate, broadest near the middle, with a glandular petiole; the flowers are generally pink, but also white or red; the fruit is pubescent or glabrous, fleshy and the mesocarp does not split; the stony endocarp is very deeply pitted, furrowed and very hard (Bassi and Monet, 2008).

Like other stone fruits, peaches and nectarines, both closely related (Brady, 1993), have a characteristic, lignified endocarp (pit or stone) that encloses the seed, a fleshy mesocarp and a thin exocarp. However, nectarine cells have smaller intercellular spaces than peaches and are, therefore, denser. In addition, they lack pubescence on the skin, which is controlled by a single gene (Lill *et al.*, 1989). The absence of fuzz on the nectarine is fundamentally the only difference between nectarine and the peach. Nectarine fruits may be a little smaller in size, firmer fleshed and may possess stronger flavor and aroma. On the basis of the separation of the stone from the flesh, peaches and nectarines can be divided into two groups (Christopher, 2001; Bal, 2002): (1) *free stone* - the flesh (mesocarp) of the peach may separate
from the stone at maturity, and (2) clingstone - flesh firmly attached to the pit (stone or endocarp). In both types there are yellow-fleshed and white-fleshed cultivars.

Clingstones generally appear better canned than freestones. This is because clingstons‘ flesh is firm enough to retain its shape during canning. Freestone peaches are used to some extent for canning, but they are mainly eaten fresh.

The peel of both peach and nectarine may be highly colored due to the accumulation of anthocyanin. Peaches and nectarines with low, medium or high acid concentrations are also available (Genard et al., 1999). Peach fruit is rich in ascorbic acid (vitamin C), carotenoids (provitamin A), and phenolic compounds that are good sources of antioxidants (Byrne, 2002).

Despite lack of sufficient winter chilling temperature, which is necessary for breaking dormancy, peaches have shown a good adaptation in Ethiopia. Upland areas like Holetta are suitable for successful peach production. Cultivars Ventura peach and Penamint nectarin are found to be promising as tested at Holetta (National Deciduous Fruits Research Center) (Sam-Aggrey and Bereke-Tsehaye, 1987). Generally, in Ethiopia, commercial production of peaches may be possible over a wider climatic range than with either apple or pear. This has been suggested because peaches require less cold (chilling temperature) to break the rest period in tropical climate compared to that of apples and pears.

For best tree growth and production of peaches and nectarines, a deep, reasonably fertile, well-drained sandy loam soil is preferred. Heavy and poorly drained soils should be avoided.

Peach is usually propagated by budding (T-budding) scion onto desirable peach seedling rootstocks. Seeds for rootstock propagation, extracted from fully mature fruits, germinate faster and more uniformly if the stone has been cracked (Griesbach, 2007). These freshly obtained seeds should be planted as soon as possible in order to avoid seed dormancy. Seeds that are not removed from the stone must be stratified for about 3-4 months at a temperature of 3-5°C before they are ready to germinate. According to Griesbach (2007), dry seeds should be soaked in water for 12-24 hours, then
drained and mixed with a moisture retaining medium like peat moss, vermiculate or well washed sand. A fungicide may be added as a seed protectant. Polyethylene bags make excellent containers; they provide aeration and prevent drying. Under local conditions seed must be stratified in refrigerators and should be examined periodically; if the seed is dry the medium is re-moistened. At the end of the stratification period some of the seeds may begin to germinate in storage. This will be the proper time to transfer the seeds into well prepared seedbeds for their further development.

Young peach trees are generally pruned to an open-center or vase-shaped form, keeping the pruning to a minimum to avoid growth retardation and a delay in the onset of bearing. Peaches and nectarines bear fruits laterally on shoots that have been grown in the previous summer. Thus, relatively heavy pruning of mature trees is necessary to ensure a continuing supply of vigorous shoots.

Peach and nectarine trees must be pruned annually to enhance tree growth, reduce fruit thinning costs and adjust crop load for the following season. During the first two to three years after planting young trees are trained to develop a branching system or tree canopy that will later support a well distributed crop. After three growing seasons, a well-trained peach tree should have 3 to 5 scaffold branches with wide angles, evenly distributed around the tree (Marini, 2009). The most common method involves selecting 3 primary branches with wide crotch angles and that are spaced evenly around the trunk. Young fruiting trees usually grow fairly vigorously and moderate corrective pruning is needed to keep their centers open and maintain the desired tree sizes. A spreading growth habit will be encouraged by the weight of fruit on the limbs and heavy pruning should not be necessary.

Mature, producing trees from about three to ten years of age are usually pruned when dormant and during the late spring and summer (Ferguson, 2007). Although each tree will grow differently with few trees being perfectly symmetrical, the overall goal for peaches and nectarines is to develop an open center or vase-shaped tree (Fig. 18-1) with a spreading but upright growth habit. The system allows for adequate light penetration into the center of the tree, minimizing shading problems especially in higher vigor trees.
Figure 18-1. Open center or vase-shaped tree.

Pruning the bearing tree involves a continuing process of replacing the bearing wood in a desired location and of ensuring necessary vigor by sufficiently severe pruning. In order to keep bearing shoots close to the trunk, heavy heading back to lateral branches must be practiced occasionally. A balance between fruit production and vegetative growth must be achieved. If growth is less vigorous, increased fertility and heavier pruning may be used to improve it. If stronger vegetative growth takes place, less severe pruning should be done (Christopher, 2001).

Leaders should be headed to outward growing buds or shoots similar or greater in angle to those being removed to ensure the open center is maintained. Thus, the terminal and lateral shoots which have developed over the outer surface of the tree are the most important for fruit production. The best and most fruits are produced in the upper third of the tree. To bring overgrown, old trees back to fruiting, it will be necessary to carry out some heavy rejuvenative pruning (Griesbach, 2007). Additional objectives of dormant pruning are to remove dead or diseased shoots, rootstock suckers, and vegetative water sprouts from the center of the tree.

Horizontal limbs on young trees should be avoided as they will bend downward with the weight of a crop and will eventually need to be removed to allow equipment to move under the tree. Watersprouts (upright shoots...
developing along the upper side of a branch) will also arise along the top of a horizontal limb. An angle of 40 to 50 degrees from the vertical is most desirable (Marini, 2009). Root suckers, downward growing shoots, and strong vertical shoots that shade the tree center should be removed. The tree should be kept balanced by shortening the strongest branch.

The major objective of pruning older trees is to encourage the production of good fruiting shoots. Old trees can be invigorated by cutting back into wood that is 3 or more years old (Marini, 2009). Cut is made to good outward-growing side limbs. Pruning to invigorate old trees will reduce the following season's crop because much bearing surface is lost, but it is the only way to renew the tree. Increasing the nitrogen fertilizer by 10 to 20% may also help encourage new growth.

Trees, that are moderately to heavily pruned, make excellent growth of new wood during the two seasons following treatment. Such severe pruning to renew old trees is profitable only in blocks where most of the trees are still present and are in reasonably good vigor. Where more than 20% of the trees are missing or are weak, renewal pruning may not be profitable. It is best to remove the old trees and replant the entire block (Marini, 2009).

The flowers in peach are perfect, solitary, and pink in color. The flowers develop on shoots produced the previous season. While some shoots may be short and spur like, most production is on relatively long terminals. The flower bud opens before the leaf bud. Peaches are pollinated through insects, and its pollen is highly viable. Commercial peach varieties are self-fruitful (Bassi and Monet, 2008) and set good crops without cross-pollination.

There are two types of buds on a peach tree (Marini, 2009). The terminal bud at the end of a shoot is always vegetative and produces a leafy shoot. Axillary buds develop during the summer at the bases of leaves on current season's shoots and can be either leaf or flower buds. Peach flower buds are termed "pure" or "simple" because they contain only flower tissue. A peach flower bud produces a single flower that can set one fruit.

Each node (the point on the shoot where a leaf is attached) on a vegetative shoot may have from zero to 3 buds. Nodes at the terminal end of
a shoot usually have single buds. The small pointed buds are vegetative and the larger, rounder, and more hairy buds are flower buds. Many of the nodes on the lower two-thirds of a shoot have 2 or 3 buds arranged side by side. There can be any combination of flower (F) and leaf (L) buds (FL, FF, FLF, FFF), but most often a leaf bud is flanked by flower buds (FLF) (Marini, 2009).

Diseases and pests of peach and nectarines include the following:

**Peach leaf curl** (Leaf curl), caused by *Taphrina deformans* (Berk.) Tul., is a cosmopolitan disease and occurs wherever peaches and nectarines are grown (Adaskaveg *et al*., 2008). Leaves first develop discolored areas that thicken and then become wrinkled and puckered, causing the leaves to curl. Infected leaves can have a range of colors from light green to yellow, red and purple. They may be covered with a subtle white layer of sexually produced spore sacs (asci containing ascospores) and then turn brown and generally abscise. Defoliated trees will leaf out again but fruit set will be sparse in the current year and the following season. The peach leaf curl pathogen also infects young, green twigs and shoots. Affected shoots become thickened, stunted, distorted, and often die (UC, 2008). Fruit infections are less common (Adaskaveg *et al*., 2008). They are characterized by irregular, raised green (initially) or reddish lesions. Later in the season these infected areas of fruit become corky and tend to crack. If leaf curl infection builds up and is left uncontrolled for several years, the tree may decline and need to be removed (UC, 2008).

The fungus over-winters in the asexual, yeast-like bud-conidia stage, which contaminates twigs and buds of the tree (Adaskaveg *et al*., 2008). Emerging leaves are infected when the fungus changes to a mycelial parasitic phase. Naked asci are then produced on the leaf surface and the sexual ascospores are forcibly discharged. These spores germinate and form more bud-conidia that contaminate twig tissues. Infections occur at temperatures of 10-21°C, but ascospores and bud-conidia can survive hot, dry conditions for several months. Periods of cool, wet weather during early bud development
favor leaf curl disease. When temperatures at early leaf development are high, infections rarely become established.

Peach leaf curl can be managed with one well-timed preventive fungicide application either in late autumn after 90% of the leaves have fallen or in spring before bud swell (Adaskaveg et al., 2008; UC, 2008). Treatments after infection or symptom development are ineffective. Sanitation and cultural practices do not provide control against this disease. Vigor of infected trees should be maintained by irrigation and N fertilization management, as well as reducing stress from crop load by extra thinning.

**Rust** - Peach rust, caused by *Tranzschelia discolor* Tranz. & Lit., occurs wherever stone fruits are grown (Adaskaveg et al., 2008). Incidence of the disease in different years and different peach production regions is highly variable and epidemics occur in years with excessive wetness during the growing season.

On peach, in addition to leaves and fruit, the fungus can infect stem tissues. Leaf infections develop as angular, yellow lesions with rusty-brown urediniospore-producing pustules (uredinia) on the lower leaf surfaces. Heavy leaf infection can result in premature defoliation of the tree. Symptoms on immature fruits are green, circular lesions. On mature fruit, lesions are sunken with yellow halos and the mesocarp below the lesion is discolored. The fungi over-winter as mycelium in twigs, but may also survive as urediniospores on twigs or as uredinia on non-abscised leaves (Adaskaveg et al., 2008). For management of peach rust, preventive applications of fungicides are done before rains.

**Powdery mildew** - Powdery mildew of peach and nectarine occurs worldwide, but is most damaging in semiarid growing areas. Leaves, buds, green shoots and fruits are commonly attacked, but flower infections are rare (Adaskaveg et al., 2008). On twigs, mildews are white and felt-like. Peach and nectarine fruits are susceptible from the early stages of development until pit hardening. Infections usually result in some deformation of the fruit surface with depressed or slightly raised areas. Infections on peach fruit become necrotic
after pit hardening, whereas on nectarine and occasionally also on peach the tissue remains green.

Infected young leaves may drop or fail to elongate and unfold normally, while those of new shoots become narrow, strap-like, and distorted. Infected leaves may become completely coated with the thick, white, powdery mycelium and spores of the fungus, or the infected areas may appear as whitish patches. Mature leaves are more resistant to the fungus. This white, powdery appearance is the result of large masses of conidia that are produced on the leaf surface. This whitish growth often can be seen on infected fruit as well. Affected current year's twigs are stunted in growth and the lateral buds which differentiate into blossom buds may be destroyed.

On developing fruit, the disease first appears as white, round spots. These spots increase in size until a large portion of the fruit is covered. About the time of pit-hardening, the skin of the fruit under the spot turns pinkish and eventually becomes a dark brown, at which time the fungus and its spores disappear. The fruit surface becomes leathery and hard and may crack. As the fruit matures, it becomes more resistant to the fungus (Thomson and Ockey, 1999; Adaskaveg et al., 2008).

The fungus over-winters as mycelium inside the bud-scales, primary infection occurs as leaves emerge from these infected buds (Thomson and Ockey, 1999). Secondary infections occur when conidia produced by primary and subsequent secondary infections are blown or splashed by rain onto susceptible tissues. Fruit (before pit hardening) and succulent terminal growth are susceptible to infection.

Wherever possible, those conditions which favor the fungus should be avoided. Attention should be given to trees planted near one another, and to those with dense foliage. A good circulation of air and plenty of sunlight is essential in this connection.

The disease is effectively managed by avoiding peach cultivars susceptible to powdery mildew. With susceptible cultivars, spray treatments may be needed. Begin fungicide sprays at initial fall and continue at 10- to 14-day intervals until the pit hardening stage is reached (Thomson and Ockey, 1999). Fruit of susceptible cultivars become resistant at this stage.
Under severe conditions, additional sprays may be needed to prevent infections of leaves and shoots.

**Scab**, caused by the fungus *Venturia carpophila*, is an important fungal disease of peaches, nectarines and other *Prunus* species in warm areas with high rainfall, or when orchards are irrigated by overhead sprinkler (Adaskaveg *et al.*, 2008). Infections can occur on twigs, leaves and fruit, but symptoms are most noticeable on fruit. On twigs, where the fungus over-winters, superficial circular to oval lesions that are slightly raised develop on new succulent growth. Management of scab is mainly accomplished with the use of fungicidal sprays. Pruning trees to allow adequate sunlight penetration and unimpeded air movement may improve scab management by facilitating rapid drying and good fungicide coverage.

**Bacterial spot**, also known as bacteriosis, bacterial leaf spot and bacterial shot hole, infects most *Prunus* species but causes significant economic losses on peaches, nectarines and plums (Ritchie *et al.*, 2008). Bacterial spot affects leaves, fruits and twigs. Leaf lesions and chlorosis are usually the first and most obvious symptoms observed. Lesions start as greyish, angular areas, centers of the spots become purple and necrotic and, if centers abscise, leaves develop a shot-hole, tattered appearance. Leaves may become chlorotic and abscise. Fruit symptoms are first visible as small, angular, water-soaked lesions 3-5 weeks after petal fall. These early infections can develop into deep, cavernous appearing lesions (Ritchie *et al.*, 2008).

Bacterial spot lesions on fruit may be confused with peach scab lesions, which are darker in color, circular and usually more restricted to the surface of the peach skin. Also, no bacterial streaming should be detected from peach scab.

The pathogen over-winters on peach trees in association with buds, in protected areas on the woody tree surface, and in leaf scars that become infected during defoliation the previous season (Shepard and Zehr, 1994). Moisture such as splashing or wind-blown rain or dripping of dew is essential for bacterial dissemination to newly emerging leaves and fruit. Bacterial spot
is more severe where peaches are grown in sandy than in heavier soils. Once bacterial spot is established in an orchard, disease control can be very difficult (Ritchie, 1999).

Insect pests of stone fruits include three species of scale: *pernicious scale*, *red scale*, and *grey scale*. Control is primarily through the use of chemical sprays during the dormant period.

Dense populations of sucking aphids can attack the leaf surface and young shoots. Damage includes poor fruit set, curled, distorted leaves, and dieback of tender young shoots.

Some peach cultivars may be badly infested with codling moth larvae. Eggs are deposited on ripening fruits and the hatching caterpillars penetrate into the pulp. Infested fruit will drop prematurely.

Fruit flies are widespread and peaches are a favorite host. Small, white, legless maggots can be found in the rotting pulp of ripening fruits which usually drop and cause a great financial loss to the farmer.

Harvest and postharvest handling

Peach fruits are mature and ready to pick when the skin background color becomes creamy yellow. They continue to ripen and soften after picking but the highest-quality fruits are those allowed to become fully ripe on the tree. Although the fruits are not adapted to long storage, they can be stored for two to four weeks, depending upon the cultivar and harvest maturity, if stored at about 0°C and 90% relative humidity.

Peaches and nectarines ripen and deteriorate quickly at ambient temperature. Therefore, cold storage is used to slow these processes and decay development. However, chilling injury limits the storage life of peaches and nectarines under low temperature.

18. 2. Plums (*Prunus* spp.)

There are many species of plums. Most of the plums grown commercially are either the hexaploid, *Prunus domestica* L. (European) or the diploid, *P.
18. DRUPE FRUITS (*Prunus* spp.)

*Prunus salicina* Lindl (Japanese or Oriental or Asian plum) (Kishore *et al*., 1991; Okie and Hancock, 2008). European plums (primarily *Prunus domestica*) are generally better adapted to cooler regions than Japanese types.

The Japanese plum is likely to succeed in the tropics, but it is essential to choose appropriate cultivars that suit best to a given agro-ecological zone. Plums, because of their wide variability between different species, exhibit considerable varietal differences in their climatic requirements. European plums require 800 to 1,000 hours below 7.2°C of winter chilling for satisfactory bud break in the spring. The cultivars of the Japanese plum require comparatively less of winter chilling (Kishore *et al*., 1991).

Plums are generally propagated through hard-wood cuttings. In case rootstocks are to be used, budding and grafting method are employed for its propagation. In most cases a planting distance of 6 x 5 m is used. A spacing of 5 x 4 m is also known to be sufficient if crop trees are regularly pruned. Pruning is recommended to keep the balance between vegetative growth and fruiting. Most oriental cultivars are self-sterile and require other cultivars for pollination. At present plums are grown in and around Addis Ababa. The potential for further expansion to areas with similar agroecological conditions (probably altitudes ranging from 1,700-2,600 m) in the country seems high.

Since many plum cultivars are self-unfruitful (self-incompatible) and many are poor pollen producers, compatibility with other cultivars can strongly influence productivity (Okie and Hancock, 2008). According to these authors, European plums are often self-fertile in contrast to Japanese plums, which usually require ample bees to cross-pollinate the flowers. In practice bees are helpful to increase fruit set in European plums as well, as the pistil often extends above the stamens, and the pollen is little moved by the wind. Possible causes of poor pollination in most plums include self-sterility, cross incompatibility and different periods of flowering (Kishore *et al*., 1991). Therefore to achieve good fruit set, especially in Japanese plums, it is necessary to plant different cultivars (compatible pollinating cultivar flowering during the same period). Because of the existence of variability among cultivars/varieties and species, it may be said, that a plum should be identified both as to variety and species before one can make the best cultural
recommendations (Mitov et al., 1990; Christopher, 2001). Therefore, when making commercial (large scale) plantings of plums, pollination should be thoroughly investigated on the basis of local practice and recommendations.

In plums the preferred tree shape is ‘open center’ with good light distribution even for larger tree sizes. Most of the young plum trees obtained from the nursery will be in the shape of a straight whip without lateral branches. Thus, pruning at planting usually consists of cutting this whip back to 50-60 cm from the ground. This stimulates side branching below the point of cutting. Pruning during the tree’s formative years is light: interior branches and water sprouts are controlled by pruning or bending, and growing laterals (scaffolds) are headed to induce branching. At maturity, vigorous upright shoots are removed since fruiting occurs mostly on spurs. To maintain fruit size, renewal of fruiting wood is necessary since spurs live for only about 5-8 years (Griesbach, 2007). To avoid problems associated with heavy crops, it is necessary to thin the fruits. This should be done after natural drop and before seed hardens.

Depending on cultivar, plums are ready to be picked 80-120 days after flowering. Fruits may be picked before they are completely ripe since they will finish ripening off the tree. Fruit maturity first begins at the top of trees and later at the bottom, which usually necessitates more than one picking stretched over a period of 7-10 days. Plums are highly perishable and must be picked and handled with care.

References


CHAPTER 19
UNDERUTILIZED FRUITS IN ETHIOPIA

19. 1. Loquat (*Eriobotrya japonica* Lindl.)

Loquat, a member of the Rosaceae family, is a dense evergreen shrub or small tree, which grows to about 8 m, rarely exceeding 10 m in height. It is native to eastern central China (Pathak, 1999). Because of its ornamental appearance and ease of cultivation, it is a popular backyard tree and is often found in gardens and parks as well.

In Ethiopia the crop is mainly grown in urban areas between 1,500 m and 2,400 m. It grows well in moist and wet “Weyna Dega” agroclimatic zones, and requires moderate to heavy rainfall; is drought tolerant once established. Loquat thrives well in a wide range of soils, but well-drained, deep sandy loam soil rich in organic matter is well suited for its cultivation. It cannot tolerate waterlogged condition. A milder subtropical climate with average rainfall of 600 to 1,000 mm, well distributed, is best suited for normal growth and fruiting of loquat.

The fruits are 3-8 cm long and have a tough skin covering a soft flesh with large seeds in the center (Tous and Ferguson, 1996). The fruits are egg shaped, yellow and borne in loose clusters (Fig. 19.1-1). The flesh is juicy and is firm in some cultivars, while soft in others; its color ranges from almost white to deep orange, with sub acid flavor. The seeds are as many as 10, since there are five cells (compartments) in the ovary and two ovules in each cell. Several ovules are aborted and not more than three to five seeds develop (Bal, 2002).

Loquat is propagated by seed, air layering, T-budding and side grafting.
Seeds should be immediately sown after their extraction from the fruits. Since seedling trees may produce poor-quality fruit, vegetative propagation is preferable, and thus seedling plants should only be used for rootstock purposes (Tous and Ferguson, 1996). Trees are planted 4-5 m apart and will grow fairly rapidly once established. Some thinning operation (formative pruning) is desirable when trees are still young. The vegetatively propagated trees commonly start bearing fruits after four years of planting. Seedling trees take 6-8 years because of relatively long juvenile period (Pathak, 1999). Flowering usually occurs during the cool season of the year and thinning of fruits is often necessary to produce large, good quality fruits.

Loquat bears flowers on current season growth. Most of the loquat cultivars are self-unfruitful because of self-incompatibility problem, though they produce perfect flowers (Pathak, 1999; Baj, 2002). Fruiting will be poor if only single variety is planted in orchard. Effective fruiting is therefore possible when they are interplanted with compatible cultivar.

Fruits are harvested when they turn yellow to orange and begin to soften. Harvesting of immature loquat fruits should be avoided; as such fruits will not ripen to eating quality of the tree (Tous and Ferguson, 1996). All fruits in a cluster mature uniformly and, therefore, the entire cluster may be cut carefully.

The yield in loquat increases as the tree grows older and commercial bearing starts after 15 years of field planting. The average yield of fruit is about 16 to 20 kg/tree. A healthy and well-managed tree may yield 40 to 50 kg fruits (Pathak, 1999). In many loquat-growing countries, scab (black spot) disease is common. Symptoms appear as round dead spots on the leaves and fruits, and may cause leaf fall and death of young fruits. In Ethiopia, this disease has not been reported so far.

19. 2. Casimiroa (White Sapote) (*Casimiroa edulis*)

The Casimiroa (‘Kasmir’ or ‘Abolker’) is native to the tropical highlands of Central and South America. Although a popular common name of the fruit is white sapote because of its white flesh, casimiroa is not in the sapote family.
The *Casimiroa edulis* is not a Sapotacea, rather, it belongs to the Rutaceae family (Samson, 1986).

Casimiroa edulis is medium-sized, an evergreen tree to 18 m tall, with spreading, often drooping branches and a broad leafy crown (Orwa et al., 2009). It is much-branched tree with a short trunk often hidden by the hanging branches and foliage of old trees.

The plant grows from tropical highlands to subtropics. The tree is slow growing but drought-resistant. Fruits resemble green tomato or an apple (Fig. 19.2-1), and are fleshy with a soft peel, sweet whitish flesh, and stony seeds. Casimiroa is very sweet (27% sugars), highly nutritious, and rich in vitamins, including A and C (http://florawww.eeb.uconn.edu). The pulp is smooth and has no noticeable fibre. However, some varieties are bitter near the paper thin skin. To avoid the bitter pulp, the fruit may be thickly peeled, or soft fruit may be halved and scooped out, avoiding the pulp near the skin. The creamy or yellowish flesh is melting and juicy and had a distinctive sweet flavor. Each fruit has 1 to 5 large ovoid or ellipsoid seeds imbedded in the flesh. Fruit size, seed to flesh ratio, taste and other characteristics vary greatly between varieties.

In Ethiopia casimiroa is cultivated in home gardens and backyards between 1,700 m and 2,400 m. So far, its cultivation is confined to the cities and towns mainly grown for home use and for its aesthetic value. It is propagated by seed and grafting. Seedlings are easily raised from seeds. The fruit contains a varying percentage of sterile seeds that are markedly smaller than fertile seeds. Fertile seeds will usually germinate in a month. Seedlings take 7 or 8 years to come into bearing, and their fruit is generally of inferior quality. *C. edulis* is hermaphroditic, occasionally unisexual due to aborted stigmas (Orwa et al., 2009).

The fruit is picked when fully mature but while still firm; the fruit softens to edible condition in 2 to 3 days (http://www.desert-tropicals.com). When the fruit becomes ripe, the stem falls off (Crane and Balerdi, 2013). The fruits must be handled with care even when unripe as they bruise so easily and any bruised skin will blacken and the flesh beneath turns bitter. Mature fruits must be clipped from the branches leaving a short piece of stem
attached. This stub will fall off naturally when the fruits become eating-ripe. Overripe fruit becomes slightly bitter (CRBC, 1996). If plucked by hand, the fruits will separate from the stem if given a slight twist but they will soon show a soft bruised spot at the stem end which quickly spreads over much of the fruit, becoming watery and decayed. If picked just a few days before fully ripe and ready to fall, the fruits turn soft quickly but they can be picked several weeks in advance of the falling stage and most will develop full flavor.

Fully tree-ripened White sapote fruits is attacked by insects. Harvested fruit should be ripened at room temperature (26-28°C) (Crane and Balerdi, 2013). Ripe fruit is quite perishable but it may be refrigerated. Once ripe, fruit may be stored for 7 to 10 days in the refrigerator. However, it is best to use fruit as soon as possible.

19.3. Annonaceous fruits

The Annonaceous fruits, indigenous to tropical America, are widely grown in tropical and subtropical parts of the world. The annonas are shrubs or small trees, whose height varies from 5 to 11 m depending on several factors, such as species, climate, soil and crop management (Pinto et al., 2005). About 50 species of shrubs and trees belong to the genus Annona bearing aggregate fleshy fruit but only six species produce fruits of commercial importance (Bal, 2002; Pinto et al., 2005).

Annonaceous fruit-trees have a considerable diversity and degree of adaptation to different environments (Pinto et al., 2005). The high nutritional value of the fruit, its very distinct flavors and aromas and its attractive shapes and colors justify the importance of these fruits. Its food value varies considerably, but most forms have an abundance of carbohydrates, proteins, calcium, phosphorus, iron, thiamine, niacin and riboflavin, while some are rich in magnesium, ascorbic acid and carotene.

The Annonaceae contains species which are mostly tropical and subtropical, although some species can be grown in temperate climates (Pinto et al., 2005). The annonas grow at a range of altitudes, and those with the widest adaptation to altitude are also those with the widest adaptation to
latitudes (Nakasone and Paull, 1998; Pinto et al., 2005).

Rainfall influences the efficiency of pollination (Nakasone and Paull, 1998), generally reducing it significantly when rains occur during peak flowering periods. According to Nakasone and Paull (1998), wind is a factor that affects annona cultivation, often severely, as it can reduce humidity around the stigma and reduce pollination. Wind can also break branches, especially if laden with fruit, and fruits are sensitive to dry winds.

In Ethiopia, sporadic plantings of *Annona reticulata* (Bullock’s heart), *Annona muricata* (Soursop), *Annona cherimola* (Cherimoya) and *Annona squamosa* (Custard apple, or sugar apple, or sweetsop) are grown in various parts at homestead level.

**Bullock’s Heart (Annona reticulata L.)** - Bullock’s heart (also called Custard apple) belongs to the Annonaceae family. It is a deciduous tree (shrubby tree up to 6-8 m tall) with an open, irregular crown and slender, glabrous leaves which in some varieties are long and narrow, straight and pointed at the apex; and in other varieties wrinkled (Morton, 1987; Orwa et al., 2009). The flowers are generally in groups of three or four, with three long outer petals and three very small inner ones. The fruit is heart-shaped or spherical (Fig. 19.3-1) and 8 to 15 cm in diameter; according to the cultivar, the flesh varies from juicy and very aromatic to hard with a repulsive taste. There is a wide variability in the presence of groups of hard cells that are similar to grains of sand (Pinto et al., 2005). Both the outside and inside color varies according to the cultivar. The sweet fleshy pulp is edible. There are numerous dark/orange or brown seeds in the flesh. Trees bear about 20-40 fruits per year each about 300 g in weight. The most attractive aspects of this species are: (i) its pleasant-tasting fruit, which is generally sweet and creamy; (ii) the relatively small volume taken up by the skin and seed; and (iii) the plant’s modest soil requirements.

Bullock’s heart is widely grown in the tropics on a great range of soils with good drainage and at an elevation of 1,000 m (Nakasone and Paull, 1998). A warm humid climate is required. In Ethiopia the crop is grown in home gardens, in the moist and wet “Kolla” agro climatic zones, between 500
m and 1,600 m a.s.l.

Propagation is usually by seed but it can be easily grafted (Orwa et al., 2009). Trees are spaced 5 m apart, and start bearing 3-5 years from planting. Bullock’s heart production is limited may be because of reproduction by seed, which results in many trees producing much smaller fruit; and the attack of the seed weevil which lays its eggs in the young fruit. When the adult insect develops, it bores tunnels through the flesh, causing mycotic infections and a consequent deterioration of the fruit.

Soursop (Annona muricata) - It is a semi-evergreen upright/slender tree, 5 to 7 m in height. The leaves are short, obovate-oblong to elliptic and shining above. In drought conditions, the tree may lose its leaves (Pinto et al., 2005). Fruit of soursop is heart-shaped, extra large with many soft spines pointing towards apex (Fig. 19.3-2). The white, juicy pulp has acidic mango like flavor. Cross-pollination is required as the pistil is ripe before the pollen (protogynous nature) (Nakasone and Pauli, 1998). Hand-pollination is expensive but sometimes necessary to assure a good fruit set. Soursop grows well on different soil types provided they are not waterlogged. Soursop is flourishing in tropical climate (preferably in the humid tropics).

In Ethiopia the soursop is grown (on limited scale) in dry and moist “Kolla” agroclimatic zones. It is potentially a desirable tree in home gardens as the delicious fruits can earn good cash and can be used for juice and other similar purposes. Soursop trees remain small and can best be planted 4 to 5 m apart. It can be propagated by seed, budding, grafting or cuttings.

Cherimoya (Annona cherimola) - It is a deciduous, small spreading tree with grayish pubescent shoots (Orwa et al., 2009). The lower surface of leaf is velvety tomentum (furry, soft). The flowers are usually solitary with narrow outer petals. The stamens and pistils of cherimoya often mature at different times, and therefore hand pollination is necessary. This practice (artificial/hand pollination) is known to result in much better fruit set and larger fruit. Cherimoya is one of the finest subtropical fruits and the best annonaceous fruit because of its acidic-sweet flavor, buttery consistency of pulp and low
seed content. The fruits are 8 to 15 cm in diameter, green in color and round to heartshaped (Fig. 19.3-3). Cherimoya, unlike bullock's heart and soursop, prefers subtropical type climate (i.e., it is less suitable for typical tropical climate). It is not adapted to high humidity regimes and it is reported that the dry season favors fruiting (Pinto et al., 2005).

Figure 19.3-1. Annona reticulata  
Figure 19.3-3. Annona cherimola

19. 4. Cactus pear, ‘Beles’ (Opuntia ficus-indica)

Cactus pear ('Beles'), a member of the Cactaceae family, is a succulent, usually small tree or dense bush, attaining a height of 5 m. The stem and branches are formed of large, elliptic to obovate flattened ear-like joints (cladodes), which are up to 40 cm long. Cladodes have the appearance and function of a leaf. The fruit is generally fleshy, pear-shaped and has a number of small spines, with a soft juicy pulp that contains numerous small black seeds (Tous and Ferguson, 1996).

In addition to its food value, cactus pear is used as a fodder, bee forage, live-fence and for soil conservation. The cladodes are commonly used as feed for domestic animals and are browsed by wild animals as well.

In Ethiopia, the possibility to develop cactus pear plant as formal fruit crop (i.e., cultivated at commercial and/or homestead levels) is enormous, mainly because of its wider ecological adaptation, and easy establishment and maintenance.

‘Beles’ can grow in arid, semi-arid and humid zones. It grows on a
variety of soils but thrives best on well-drained deep red limestone soils. It does not perform well on black vertisol and shallow cristaline soils. Water logged conditions should be avoided. This plant is better adapted to an altitudinal range varying from 1,300-2,600 m a.s.l. It is popular in eastern and southern Tigray, eastern; northern; and southern Wollo, eastern Shewa; eastern Hararge; and some parts of Arsi and Bale administrative regions (Zenebe, 1993).

Cactus pear is a plant easy to propagate. It can be propagated from seeds or from cuttings. Seed propagation is not used commercially, but is used in the breeding programs to develop new varieties. Cuttings should be collected only from healthy branches with large clean cladodes. The choice of using single cladodes or branches will depend on the availability and distance to the new orchard. When using individual cladodes it is preferable to use complete/full pads. However, if the planting material is scarce, it is possible to use cladode fractions. Dividing the cladode into pieces smaller than half will reduce the initial size and number of cladodes of the new plant and it will take longer to reach full size, and also take longer to reach the reproductive stage (Nefzaoui et al., 2010).

Planting material has to be collected when the plants are dormant. The best season is from December to February, when the plants reduce their activity. Some variations are possible due to the effect of microclimates (in different parts of the country). The rule of thumb is that collection must occur before bud emergence. Cladodes should be cut carefully (straight at the joints) avoiding unnecessary chopping. These planting materials should be allowed to heal and dehydrate for better conservation and establishment. A minimum of two weeks is necessary to undergo the healing and dehydration processes. It is necessary to treat the cuttings with Bordeaux mixture to protect them from rotting.

Because the shoots are highly susceptible to frost damage, and they start emerging 2 to 3 weeks after planting, planting should be done after the risk of frost is over. The planting distances for fruit production depend on the possibilities for crop management, especially weed control. Orchards intended for manual weeding can be planted using 4 to 5 m between rows. In those orchards intended for mechanized weed control the rows should be at least 5
The distance between plants for both systems is 2.5 to 3.0 m (Jacobo, 2004).

Pruning should be a regular practice in commercial orchards and household plantations of cactus pear as the plants grow vigorously if not properly managed. Naturally, the plants tend to spread, limited only by the competition from other cacti and tall trees. Selective pruning is therefore necessary to reduce the negative effects of alternate bearing, increase fruit quality and maintain productivity (Jacobo, 2004). Generally selective pruning aims to reduce the volume of plant canopy, plant height and eliminate deformed or diseased plant parts. It is performed annually. The effects of selective pruning are also enhanced by stand thinning.

Fruits (Fig. 19.4-1) are preferably collected at the breaker stage (half-ripe) because they are firmer than ripe and overripe fruits. During picking of fruits using of hooks or any rough materials should be avoided. This practice allows collection of fruits with less damage. After cleaning, it is advisable to arrange fruits in the collection bucket in layers, placing those at the breaker stage at the bottom, then the ripe, and finally the overripe at the top.

19.5. Date palm (*Phoenix dactylifera*)

The date palm is a member of the Palmae (Aracaceae) family. It is native to North Africa and is cultivated in dry areas. It’s most important product is the fruit (“temir”), which is eaten either fresh or dried. Dates, due to their high sugar content, represent the basic, fundamental food for North Africa, Arabia and Persia’s peoples, where hundreds of varieties are grown for commercial purposes (Oudejans, 1969; Morton, 1987). In Ethiopia the crop is grown in arid and semi-arid areas and serves as a dessert.

The palm is characterized by a very slender trunk, up to 30 m tall, conspicuously covered with the remains of sheaths from fallen leaves. Its leaves, clustered together (Fig. 19.5-1) in a maximum number of 20-30 and forming a loose crown shaft, are pinnate, up to 6 m long, upper leaves are ascending, basal leaves are recurved, the segments are coriaceous, linear, rigid and sharp pointed, blue-green in color. Its flowers, unisexual on dioecious
plants, are small, whitish, fragrant, clustered in axillary spadices up to 120 cm long markedly bent downwards by their fruit weight (Jaradat, 2011). These fruits, commonly known as dates, are oblong berries, dark-orange when ripe, up to 50 cm long in the cultivated varieties; their flesh is sacchariferous, and it contains one woody seed.

It is a plant sensitive to the cold; it thrives on any kinds of soil, provided that they are fertile and well drained; in mild climate regions, it is grown outdoors where it must be exposed to the sun; it is grown chiefly as an ornamental plant on account of its slender habit and foliage. In order for its fruits to come to a complete maturity, either high temperatures (40°C) and sufficient water amounts, these being sometimes provided by means of irrigation in production palms, are required (FAO, 2002).

Dates can be grown either from seeds or from offshoots (Rice et al., 1994). The best method to propagate date palm (for commercial purposes) is from offshoots (suckers), which are formed from beneath the soil line in dry areas or above the soil line in humid areas. Offshoots are removed intact from the mother plant. After removal, these propagules are planted in a nursery and grown until they are well rooted. After about two years in the nursery the plants are transplanted. At the time of field planting, the leaves are cut back retaining 15 to 30 cm length, or those are completely removed. Care should be taken that male suckers are also planted along with the female suckers at the rate of one male plant for about 30 to 40 female plants. The survival percentage after planting varies depending on variety and management practice (especially regular application of optimum irrigation water).

Seed propagation is also sometimes used. Though seeds give good germination, approximately half of the palms turn out to be male flower producing trees. The fruits borne by female seedlings are generally of variable and inferior quality. However, a few seedlings may produce fruits of good quality. When a seedling palm appears outstanding, it would be propagated by its offsets as a new variety. Palm trees meant for ornamental use are commonly propagated by seed.

Recently, tissue culture has been found to be an inexpensive way of propagating large numbers of dates, and the propagation of date plants in this
way is becoming common in major date growing countries (e.g., Middle East).

Dates are planted at a density of 6 x 6 m or 10 x 10 m depending on cultivars, environmental conditions and intensity of management (FAO, 2002). It will come into fruiting four to six years after planting, reaching peak production in eight to ten years and continuing to produce for up to 75 years.

The male and female flowers are borne on different trees (FAO, 2002; Jaradat, 2011). Pollination is by wind. Wind pollination of pistillate trees may be fairly successful if a large number staminate trees are well distributed throughout the orchard. The maintenance of such large staminate trees, however, proves uneconomical. If plants are left solely to the wind (for pollination) yields will be low. Commercially trees are hand pollinated by placing male flowers among the female inflorescence. For this, 3-4 strands from freshly opened male panicles are placed in the inverted position, between the strands of the female flower clusters as soon as flower anthesis takes place. A twine/string is tied loosely around the pollinated cluster (female flower) in a slip knot fashion, so that it loosens itself as the pollinated cluster expands the size. Pollen can also be spread in the air over the grove at rates of about 250cc of pollen per hectare. This operation needs to be repeated three times per week to maximize the chance of fertilization (Rice et al., 1994).

Pruning is usually done at pollination time and consists of cutting away dead or drying fronds. Fruit thinning is also practiced to reduce an overbearing (or biennial bearing) problem (Rice et al., 1994; FAO, 2002). Thinning could be accomplished by either of the following three ways or combination of these: (i) by cutting back the strands in their length, (ii) by removing some of the strands from the center of the cluster, and (iii) by reducing the number of fruits on each strand.

The stage of harvest varies with cultivar and intended use. Fruits to be used in a form of “temir” are harvested when they have lost their water and are fully ripe. Harvesting is accomplished by climbing the tree and cutting off the ripe bunches of dates. After picking, the bunches are spread on mats to dry. Yields vary from 20 to 100 kg/tree.

Low quality dates are channelled to the processing of syrup, juice, paste, candy, jam, marmalade and butter or fermented and distilled into
alcohol or vinegar. Date stones can be ground and pressed to yield oil useful in soap making.

19. 6. Fig (*Ficus carica* L.)

Fig belongs to the Moraceae family along with jackfruit and mulberry. It is believed to be indigenous to western Asia and to have been distributed by man throughout the Mediterranean area, where it is extensively cultivated. Fig is subtropical fruit, but does not require wintering to break dormancy. It can also be grown in tropics but does not do well in the low wet (humid) tropics. Fruits have high sugar content and are a fair source of vitamins A, B1 and B2. It is a good source of calcium and iron as well (Morton, 1987; Chundawat, 1990).

Fig is a shrub or low-spreading deciduous tree growing to a height of 6 to 8 m. The branches of fig are muscular and twisting, spreading wider than they are tall. Fig wood is weak and decays rapidly (Chundawat, 1990). The trunk often bears large nodal tumors, where branches have been shed or removed. The twigs are pithy rather than woody. The sap contains copious (profuse) milky latex that is irritating to human skin. Fig trees often grow as a multiple-branched shrub, especially where subjected to frequent frost damage. Roots are greedy, traveling far beyond the tree canopy (http://www.portkellsnurseries.com). Therefore Figs are not a fruit tree for small places. The fine roots that invade garden beds, however, may be cut without loss to the tree. Fig leaves are bright green, single, alternate and large. They are more or less deeply lobed (usually with 3-5 lobes) (Fig. 19.6-9), rough hairy on the upper surface and soft hairy on the underside.

The tiny flowers of the fig are out of sight, clustered inside the green "fruits", technically a *syconium*. This term is presumed to be derived from Greek sykon, to indicate/define a form of inflorescence in which the flowers are borne on the inner wall of a hollow receptacle. Pollinating insects gain access to the flowers through an opening at the apex of the *syconium*. In the case of the common fig the flowers are all female and need no pollination. There are three other types (Nafe, 1963; Morton, 1987; Chundawat,
1990): (i) the *caprifig* which has male and female flowers requiring visits by a tiny wasp (*Blastophaga grossorum*), which enters the immature figs, pollinates the flowers and causes the development of the fleshy fruit to edible size; (ii) the *Smyrna fig*, needing cross-pollination by *caprifig* in order to develop normally (this process of transfer of pollen is known as ‘Caprification’); and (iii) the *San Pedro fig* which is intermediate, its first crop independent like the common fig, its second crop dependent on pollination.

The common fig bears a first crop, called the breba crop, in the spring on last season’s growth. The second crop is borne in the fall on the new growth and is known as the main crop. In cold climates the breba crop is often destroyed by spring frosts. The matured “fruit” has a tough peel (pure green, green suffused with brown, brown or purple), often cracking upon ripeness, and exposing the pulp beneath. The interior is a white inner rind containing a seed mass bound with jelly-like flesh. The edible seeds are numerous and generally hollow, unless pollinated. Pollinated seeds provide the characteristic nutty taste of dried figs.

Fig grows on a variety of soils ranging from sandy loams to clay-loams and even tolerates soils high in lime content (Griesbach, 1992). The soil best suited to the fig seems to be that of medium to heavy nature, retentive of moisture but well-drained, even though good crops have been secured even on less open soils well supplied with manures and moisture. Poor, sandy soils should be avoided because under such conditions attacks of nematodes are common. Depending on the cultivar, the plant will grow from sea level up to over 2,000 m.

For commercial purposes, fig is generally propagated by using hardwood cuttings. The cuttings are taken from two or three years old shoots with 1½ to 2 cm thickness and short internodes. Propagation by air layering and side grafting is also possible; and topworking can easily be done through grafting. Planting distances vary from 3 x 3 m to 8 x 8 m, but 6 x 6 m seems appropriate (Chundawat, 1990). Roots of figs are greedy, traveling far beyond the tree canopy. The fine roots that invade garden beds, however, may be cut without loss to the tree.
In Ethiopia, the plant is grown in home gardens. Two cultivars namely; ‘White Andriatic’ and ‘Black Mission’ were introduced in 1994 and planted at Jimma Agricultural Research Center for evaluation. Their adaptation, however, was poor (unsatisfactory) may be because fig prefers low rainfall during flowering and fruiting (Asmare Dagnew, personal communication, 2013).

Fig trees are productive with or without heavy pruning. It is essential only during the initial years. Trees should be trained according to use of fruit, such as a low crown for fresh-market figs. Since the crop is borne on terminals of previous year’s wood, once the tree form is established, avoid heavy pruning, which causes loss of the following year’s crop. It is better to prune immediately after the main crop is harvested, or with late-ripening cultivars, summer prune half the branches and prune the remainder the following summer.

Regular fertilizing of figs is usually necessary only when they are grown on sandy soils. Excess nitrogen encourages rank growth at the expense of fruit production, and the fruit that is produced often ripens improperly, if at all.

Maturity of fig fruits can be judged on the basis of color development. Figs must be allowed to ripen fully on the tree before they are picked. They will not ripen if picked when immature. A ripe fruit will be slightly soft and starting to bend at the neck. Harvest the fruit gently to avoid bruising. Best quality figs are produced in regions with a dry climate, especially at the time of fruit development and maturation. High humidity (rains) coupled with low temperature during fruit development and ripening, usually can cause the fruits to split and consequently lower the quality of fruits (http://www.calusnefarms.com.br). The fig is a highly perishable fruit subject to rapid physiological breakdown. The postharvest life of the fruit is considered to range from 7 to 10 days even when stored at low temperatures (Chessa, 1997).

Because of losses in transport and short shelf life, figs are a high-value fruits of limited demand. Figs for shipping (distant market) are collected daily just before they reach the fully ripe stage, but yield to a soft pressure, usually indicated by small cracks in the skin (http://www.crgf.org).
They should be immediately refrigerated. Fig fruits can also be dried and stored for relatively long period in ambient temperature conditions without loss of quality.

19. 7. Jackfruit (*Artocarpus heterophyllus* Lam.)

Jackfruit belongs to the Moraceae family. It is native to Malaysia and the Western Ghats of India (Manner and Elevitch, 2006). Jackfruit is adapted to humid tropical and near-tropical climates. The jackfruit apart from its fruit value, the timber is valued for furniture and construction, and leaves are used as fodder, especially for goats.

In Ethiopia the jackfruit is grown in home gardens. The crop perhaps performs better in areas which are suitable for growing coffee as it enjoys plentiful moisture.

The tree commonly reaches 20 m or more in height (Manner and Elevitch, 2006). The leaves are oblong, oval, or elliptic in form, leathery, glossy, and deep green in color. Juvenile leaves are lobed. All parts of the plant contain sticky, white latex.

In jackfruit male and female flowers are borne in separate flower-heads. Male flower-heads develop from main or secondary branches (i.e., on new wood among the leaves or above the female). They are swollen, oblong, from an inch to four inches long and up to an inch wide at the widest part. They are pale green at first, and then darken. When mature the head is covered with yellow pollen that falls rapidly after flowering. The female heads appear on short, stout twigs that emerge from the trunk and large branches, or even from the soil-covered base of very old trees. They look like the male heads but without pollen, and soon begin to swell. The stalks of both male and female flower-heads are encircled by a small green ring.

Generally during early part of flowering season, only male spikes appear and female flowers follow later in the season. The male phase occurs for fairly a long period in the year, while both male and female spikes appear in one or more seasons. The male spikes drop after a fortnight of their emergence.
Jackfruit is composed of a large number of individual flowers and the fruit is therefore called a ‘multiple fruit’ (Varner and Elevitch, 2006). It is the largest tree-borne fruit (Fig. 19.11), weighing up to 50 kg but is more commonly in the range of 12-15 kg. Fruit color is green when immature and green, greenish-yellow to brownish-yellow when ripe. The inside of the fruit contains the edible, sweet, aromatic, crisp, soft, or melting pulp that surrounds each seed (Crane et al., 2013). The seed is thick and is white and crisp within. There may be 100 or up to 200 seeds in a single fruit, which are relatively short lived and may be stored up to about 30 days (Crane et al., 2013). When fully ripe, the unopened jackfruit emits a strong disagreeable odor, resembling that of decayed onions, while the pulp of the opened fruit smells of pineapple and banana (Morton, 1987).

In addition to the fruit, latex of the fruit can be used for repairing pottery (earthenware), while the yellow heartwood is used for timber. Trees are also used to shade coffee and as living trellises for black pepper (Piper nigrum) vines (Morton, 1987).

The jackfruit flourishes in rich, deep soil of medium or open texture. The tree needs the best drainage and cannot tolerate waterlogged condition. The tree will not tolerate drought and frost. In the regions where jackfruit is commonly grown, it succeeds without much care from man, the sole necessity being abundant moisture.

Propagation is usually by seeds which can be kept no longer than a month before planting. The seeds are best sown immediately after extraction from the ripe fruit (i.e., the viability of seeds drops fast). After overnight soaking in water, they should be planted as soon as possible after harvest, as they lose viability within 1-3 months (Love and Paull, 2011). Seeds germinate in 3-8 weeks. The seeds may be sown in situ or may be nursery-germinated and moved when no more than 4 leaves have appeared. Seedlings are best grown under shade. A more advanced seedling, with its long and delicate tap root, is very difficult to transplant successfully (Morton, 1987).

To propagate a desirable tree, selected cultivars can be grafted or budded onto seedling rootstocks (Varner and Elevitch, 2006). Propagation by root cuttings, stem cuttings and air layers are also possible (Love and Paull,
Trees may be set 13-15 m apart in any well-drained, fertile soil. The first fruit is born about eight years after planting. Little or no pruning is required other than to remove any dead branches from the interior of the tree, so that sufficient light is obtained for the developing fruit.

Jackfruits mature 3 to 8 months from flowering (Morton, 1987). When mature, there is usually a change of fruit color from light green to yellow-brown. Spines, closely spaced, yield to moderate pressure, and there is a dull, hollow sound when the fruit is tapped. After ripening, they turn brown and deteriorate rather quickly. Immature fruit is boiled, fried, or roasted. The seeds can also be boiled or roasted and eaten similar to chestnuts. The ripe bulbs (seeds), fermented and then distilled, produce strong liquor.

19. 8. Mulberry (Morus spp.)

Mulberry belongs to the Moraceae family. It is essentially a plant of the temperate zone, some of its species like Morus alba (i.e., the white fruited type) and Morus nigra (i.e., the black fruited type), grow well in low elevations of the tropical and subtropical areas (Morton, 1987). Because Mulberry adapts easily to different ecological conditions, and is easily hybridized, both naturally and artificially, abundant mulberry germplasm resources are available, making its genetic background rather complicated and highly heterozygous (Dandin, 1998).

*Morus alba* is an economically important plant used for sericulture in which it is principally grown for its leaves as food/forage for silkworms. For fresh fruit, *Morus nigra* is preferred, since the quality of the fruit is better (Singh, 1990). The fruit is consumed fresh or processed into jam, beverages and wines. Dried fruits ground to powder make excellent poultry food (Chundawat, 1990).

Mulberry is deciduous (but trees grown in tropical regions can be evergreen), monoecious, a medium-sized, multi-branched, spreading tree, reaching a height of 10 m or above with reddish or yellowish brown, smooth bark, marked with long, horizontal lenticels (Morton, 1987). Once established, the roots will continue to produce sprouts even if the plant is cut back every
year. Commercial mulberry production requires vigorous pruning to keep the tree to a height that can be harvested. Leaves are simple, alternate, ovate, 5 to 20 cm long, 2.5 to 8 cm wide, with tapering pointed tip, and 3-nerved, heart-shaped base, sharply toothed margins, sometimes deeply 3-lobed, hairy when young, rough when mature. Flowers are unisexual in drooping catkins. Fruit is a juicy syncarp an aggregate of druplets with pink, red or black color depending on the species. It is sweet-acid in taste. Mulberries ripen over an extended period of time unlike many other fruits which seem to come all at once. Generally *Morus alba* produces sweet, pinkish, white, or purplish berries.

The mulberry plant is hardy and it can be grown on poor soils even in rocky soils. However, clay-loam or sandy loam is better. Sandy soils are not suitable. Mulberry is very drought-resistant, heat-tolerant and easy to maintain or manage (Greisach, 1992). It grows from sea level to over 2,000 m.

Mulberry can be propagated through seeds, cuttings, grafting or tissue culture. Since cross-pollination is the rule in mulberry (Reich, 1992), propagation by seeds does not conserve true-to-typeness. The most common means of propagation is by planting hardwood cuttings. Stem cuttings are prepared from mature shoots, 20 to 25 cm long having 3 to 5 buds. The cuttings root easily. Mulberry can also be propagated by budding (commonly by shield technique). For fruit production spacing of 6 x 5 m or 6 x 6 m is followed, while for sericulture (silk worm rearing), the planting distance is reduced to 1 x 1 to 2 x 1 m.

Young plants require some support so that they may grow erect. For fruit production, pruning of shoots at a height of 1.0 to 1.5 m from the ground level is reported to invigorate tree growth and give large sized fruits (Chundawat, 1990). The pruning is done when the trees shed their leaves (usually in December or January).

Clusters of small petalless flowers are borne in a dense hanging spike. Male and female flowers are usually produced on separate plants (dioecious), but sometimes are produced on the same plant (monoeccious) (http://www.oardc.ohio-state.edu). The male flower cluster is narrow and somewhat elongated and the female flower cluster is more oval. The berry-like fruit is a tight, elongated cluster of white to pink (sometimes violet) smaller
fruits (Fig. 19.8-1).

Mature fruits are harvested on the judgment of color change, and the entire harvesting process is completed in three to four pickings. According to Suttie (http://www.fao.org) mulberry fruit can be eaten fresh, preserved, vinified or, in some semi-arid areas, dried for winter use.

Fruits are highly perishable in nature. Soon after harvesting and sorting, fruits should be sent to market or be used in the preparation of fruit products like jam. The fruits are very attractive to birds and mammals, which are probably responsible for its spread along fencerows and in fields (http://www.oardc.ohio-state.edu).

No serious diseases or pests have been reported so far in Ethiopia, but birds avidly eat the fruits.

19. 9. Tree tomato (*Cyphomandra betacea* Sendt. (*C. hartwegi Sendt.; *Solanum betaceum* Cav.)

The tree tomato belongs to the Solanaceae family and is native of Peru and Brazil. It is cultivated in many regions of the world (Heatherbell *et al*., 1975). The plant is a small, half-woody, attractive, fast-growing, brittle tree; shallow-rooted; reaching 3-5.5 m in height; rarely as much as 7.5 m. The leaves are muskily odorous, evergreen, alternate, more or less heart-shaped at the base, ovate, pointed at the apex, 10-35 cm long and 4-12 cm broad, thin, softly hairy, with conspicuous coarse veins. Borne in small, loose clusters near the branch tips, the fragrant flowers, 1.25-2.0 cm wide, have 5 pale-pink or lavender, pointed lobes, 5 prominent yellow stamens, and green-purple calyx. The long-stalked, pendent fruit, borne singly, or in clusters of 3 to 12, is smooth, egg-shaped (Fig. 19.9-1) but pointed at both ends and capped with the persistent conical calyx. In size it ranges from 5-10 cm long and 4-5 cm in width. Skin color may be solid deep-purple, blood-red, orange or yellow, or red-and-yellow, and may have faint dark, longitudinal stripes. Flesh color varies accordingly from orange-red or orange to yellow or cream-yellow. While the skin is somewhat tough and unpleasant in flavor, the outer layer of flesh is slightly firm, succulent and bland, and the pulp surrounding the seeds
in the two lengthwise compartments is soft, juicy, subacid to sweet; it is black in dark-purple and red fruits, yellow in yellow and orange fruits. The seeds are thin, nearly flat, circular, larger and harder than those of the true tomato and distinctly bitter. The fruit has a slightly resinous aroma and the flavor suggests a mild or underripe tomato with a faintly resinous aftertaste.

The tree tomato does best where the temperature remains above 10°C (Morton, 1987). The tree is easily damaged by wind and does not tolerate drought. Protection from wind is necessary as the tree is shallow-rooted and easily blown over. It is also brittle and its branches are easily broken, especially when overloaded with fruit.

The tree tomato cannot tolerate tightly compacted soil with low oxygen content. It requires fertile, light soil (Morton, 1987). Perfect drainage is necessary. Water standing for even a few days may kill the tree.

Seeds or cuttings may be used for propagation (CRFG, 1996). Seeds may be sown in a container or nursery bed. Seed propagated plants are usually a high-branched, erect tree, ideal for sheltered locations. Cuttings develop into a shorter, bushy plant with low-lying branches, suitable for exposed, windy sites (Morton, 1987). The tree does not always come true from seed, but is most likely to if one is careful to take seed from red fruits with black seed pulp or yellow fruits with yellow seed pulp.

The seedlings are set out in the field when 5-7 cm high, spaced 80 cm apart in rows 2 m apart. If the soil is very rich, 2.75 m is allowed between the rows and 5 m between the pairs. Closer planting is recommended in windy, unprotected locations 1.5-1.8 m between the plants and 2.5-3.0 m between the rows and the trees may be staked to prevent swaying and disturbing the roots (Morton, 1987). When plants reach 1 m in height, the tip should be cut out to encourage branching.

For propagating tree tomato plant vegetatively, cuttings should be of 1- to 2-year-old wood 10-25 mm thick and 45-75 cm long; the leaves are removed and the base cut square below a node. They can be planted directly in the field and, while precocious, should not be permitted to fruit in the first year. Plants respond well to nitrogen fertilizer, particularly after the first fruit has set.
Because of the shallow root system, deep cultivation is not possible, but light cultivation is desirable to eliminate weeds until there is sufficient vegetative growth to shade them out.

Seedling trees are pruned back the first year after planting to a height of 0.9-1.2 m to encourage branching. Annual pruning thereafter is advisable to eliminate branches that have already fruited and induce ample new shoots close to the main branches, inasmuch as fruit is produced on new growth. Otherwise, the tree will develop a broad top with fruits only on the outer fringe. And wide-spreading branches are subject to wind damage. Pruning facilitates harvesting and, if timed appropriately, can extend the total fruiting period (Morton, 1987; CRFG, 1996).

The tree tomato cannot tolerate prolonged drought and must have an ample water supply during extremely dry periods. Mulch is very beneficial in conserving moisture at such times.

Tree tomato flowers are normally self-pollinating. If wind is completely cut off so as not to stir the branches, this may adversely affect pollination unless there are bees to transfer the pollen. Unpollinated flowers will drop prematurely.

The tree usually begins to bear when 1.5 to 2 years old and continues to be productive for 5 or 6 years. If then adequately nourished, it may keep on fruiting for 11 to 12 years. Fruit production will begin a year from the time of planting. The crop does not ripen simultaneously and several pickings are necessary. The fruits are clipped, leaving about 1.25 cm of stem attached. The fruit can be eaten raw (after peeling), cooked or made into preserves (processed form). A well managed tree may yield 20 to 40 kg per year. It is believed that the tree tomato plant has an economic life of about ten years (Naik, 1963).

Because of its firm flesh and tough skin, the fruit can be shipped long distances without bruising. However, it deteriorates rather rapidly under ordinary storage conditions.

Aphids are the most common pests known to transmit different types of virus (Morton, 1987). Blights also affect tree tomato, particularly during the rainy season.
19. 10. Cape gooseberry (*Physalis peruviana* L.)

Cape gooseberry belongs to the Solanaceae family. It is a soft-wooded, perennial, somewhat vining plant. The purplish, spreading branches are ribbed and covered with fine hairs. Leaves are heart-shaped, nearly opposite. Flowers are bell-shaped, nodding formed in the leaf axils. They are yellow in color with dark purple-brown spots in the throat, and cupped by a purplish-green, hairy calyx. Fruit buds are produced after 12 to 13 stem internodes are formed.

The Cape gooseberry is a herbaceous plant bearing round fruit of a yellow color within a thin husk. Due to its long season of production (i.e., continuous bearing), hardiness and adaptation to very wide climatic range, this crop is very suitable for homestead planting (Jackson *et al.*, 1985). The fruit (Fig. 19.10-1) is a berry with smooth, waxy, orange-yellow skin and juicy pulp containing numerous very small yellowish seeds. As the fruits ripen, they begin to drop to the ground, but will continue to mature and change from green to the golden-yellow of the mature fruit. The unripe fruit is said to be poisonous to some people. Cape gooseberries are self-pollinated but pollination is enhanced by a gentle shaking of the flowering stems or giving the plants a light spraying with water. The berries are a good source of vitamins A and C and can be eaten fresh, stewed, as jam or in fruit salad.

The plant likes a sunny, frost-free location, sheltered from strong winds. The Cape gooseberry will grow in any well drained soil but does best on sandy to gravelly loam. Very good crops are obtained on rather poor sandy ground.

The Cape gooseberry plant is widely grown from seed. The plants can be raised in seedbeds or plastic tubes (Morton, 1987). An approximate seeding rate is 50 g/ha. Sowing should be done very carefully since the seeds are very small. However, volunteer plants are common in homestead plantings. High humidity is required for good germination. The seedlings should be transplanted when they are 8-10 cm high. The plants can also be propagated from 1 year old stem cuttings treated with a rooting hormone. Plants grown this way flower early and yield well but are less vigorous than seedlings.

The proposed planting system for irrigated crops is planting one row
on a bed 90 cm wide with furrows 60 cm wide. The distance between plants within the row should be 50 cm (i.e., 90 x 60 x 50 cm). Rainfed production is possible, even in areas of low rainfall. Provision of stakes close to the young cape gooseberries, and tying the stems loosely to each support, is common (Hessayon, 1990). In Kenya, Cape gooseberry is planted at a distance of 2 x 1 m and is known to be grown at elevations ranging from 1,500 to 2,300 m (Griesbach, 1992).

Cape gooseberry growth is continuous, and both vegetative and reproductive meristems remain active during the plant's life cycle. Floral, vegetative and fruit growth and development occur simultaneously (Ramirez et al., 2013).

Harvesting and the duration of harvest will be six months, or longer (http://www.crfg.org). Fruit should be harvested when it has turned yellow. Usually, the fruit is harvested when it falls to the ground, but not all fallen fruits may be in the same stage of maturity and must be held until they ripen. It may take some experience to tell when the calyx-enclosed fruits are fully ripe. A more even (uniform) color will develop if the fruit is stored in the husk (dry calyx) for a few days. The husk should not be removed before marketing as it considerably lengthens the storage life. Properly matured and prepared fruits will keep for several months. The ripe fruit can be eaten out of hand or used in a number of other ways (processed forms).

19. 11. Pomegranate (*Punica granatum* L.)

Pomegranate, belonging to the Punicaceae family, is a shrub or small tree. It has a strong tendency to sucker from the base (Morton, 1987). It is native to the Middle East but has spread to most tropical and subtropical areas of the world. Pomegranate behaves as deciduous in temperate but in tropical and subtropical regions it behaves as an evergreen or partially deciduous (Mir et al., 2012). The leaves are evergreen or deciduous, opposite or in whorls of 5 or 6, short-stemmed, oblong-lanceolate, 1-10 cm long, leathery. The fruit is a leathery-skinned berry (Fig. 19.11-1) with many seeds, each surrounded by a pink juicy pulp (edible part). The inner hard and stony seed coat encloses the
embryo. The pulp is removed from the fruit and the red juice extracted by pressure. It can be used for flavoring or for making juice drinks or jelly.

Pomegranate can be grown on a wide range of soils. It is not very particular about its soil requirement. The deep loamy or alluvial soils are ideal for its cultivation. It can tolerate mild alkaline conditions. The crop grows up to 1,800 m (Mir et al., 2012), but for its better yield and quality altitudes below 1,000 m are preferred. In areas of low winter temperature the tree is deciduous but under tropical and subtropical conditions, it is evergreen or partially deciduous. The plant is hardy and will tolerate cool conditions and temperatures as low as $-6^\circ$C does not harm it (Rice et al., 1994). In humid areas fruit production is poor, and fruit quality is adversely affected. Pomegranate is essentially a desert plant and survives long periods of drought, but for commercial production of high-quality fruits supplementary irrigation is required. The fruit cannot produce sweet fruits, unless the temperatures are high for a sufficiently long period. Some nitrogen fertilization is also needed. Generally the hardy nature, low maintenance cost, high yields, better keeping quality and survival without irrigation make pomegranate cultivation a paying proposition.

Pomegranate seeds germinate readily even when merely thrown onto the surface of loose soil and the seedlings spring up with vigor (Morton, 1987). However, to avoid seedling variation, selected cultivars are usually reproduced by means of hardwood cuttings. Hardwood/mature wood (commonly one year old) is cut into pieces of 22-30 cm long, and planted in the nursery in such a way that not more than one-third of the cutting is exposed. For better rooting, cuttings should be prepared when the plants shed their leaves (Rice et al., 1994). Under ideal conditions, the root formation starts within 15 days after planting and the plants are usually ready for transplanting in 9 months time. Leafy cuttings root easily in mist propagating beds. Air layering and root suckers may also be used for propagating pomegranate. Seeds germinate readily, but the seedlings are variable and do not reproduce the cultivar. Plants are established 5-7 m apart.

Pomegranate plant is bushy in nature and produces considerable number of shoots near the ground level. Retaining all the shoots at the base,
could increase crowding of tree frame. Commercially pomegranate is trained either as a single or multiple trunk tree (3-4 scaffold branches that are kept free from suckers) (Rice et al., 1994; Mir et al., 2012). This helps in maintaining good productivity as well as proper health of the plant. For home garden use, pomegranate can be allowed to grow a bush. It suckers readily; so annual pruning should include sucker removal plus light thinning out of the top to encourage the production of new fruiting spurs.

The pomegranate bears two distinct types of flowers on one and the same tree, hermaphrodite and staminate. The hermaphrodite flowers normally set fruit while staminate flowers which are smaller in size and have rudimentary pistil shed soon after opening. In tropical climate the pomegranate plants flower and provide fruits throughout the year (Mir et al., 2012).

Fruits are formed on one year old spur. Fruit production will begin between one and three years after planting and 100-200 kg of fruit may be produced per plant per year from the fully developed trees. Pomegranate being non-climacteric fruit should be picked when fully ripe. Harvesting of immature or overripe fruits reduces the quality. The fruits are ready for harvest in 5 to 6 months after the appearance of blossom (Mir et al., 2012). Fruits should be picked after they become full red (or in some varieties when the skin turns slightly yellow) and the juice attains a crimson color but before they split open. Mature fruit gives a metallic sound when tapped or pressed. Pomegranates store well and keep for about four to six months at 0°C if the humidity is maintained at about 90 per cent (Rice et al., 1994). Flavor generally improves in storage.

19. 12. Macadamia nut (*Macadamia integrifolia* Maiden and Betche)

Macadamia nut belongs to the Proteaceae family. It is a small upright, evergreen tree reaching a height of 15 m. Macadamias are best adapted to a frost-free subtropical climate with at least 1,250 mm of well-distributed rainfall per year. They grow best where temperatures do not drop below freezing point and do not exceed 38°C. The optimum mean temperature is considered to be 25°C (Rice et al., 1994). Wind is detrimental to production due to the
brittleness of the wood. Therefore, where strong wind prevails, windbreaks are necessary. Macadamias will grow on a wide variety of soils if drainage is adequate. A pH of 7.0 is considered ideal.

The xerophytic characteristics of the tree, including the sclerophyllous leaves and proteoid roots (dense clusters of rootlets formed to explore poor soils low in phosphorus) suggest adaptation to relatively harsh environments. However, the conditions required for optimum production may be quite different from those for survival. Mature *M. integrifolia* is capable of withstanding mild frosts (Orwa *et al*., 2009), but only for short periods. The brittle wood makes trees susceptible to wind damage.

Propagation is primarily by grafting scions from desirable cultivars onto selected rootstocks. Spacing of 8 x 8 m is recommended with a square layout and 10 x 10 cm with a tree in the center if the quincunx system is used.

Correct branching should be induced at an early age after which there should be no further pruning (Orwa *et al*., 2009). During the first 2 years, training (a form of corrective pruning) is done to develop a strong, well-balanced framework for future growth.

Harvesting and handling consists of collecting fallen ripe nuts from the ground. It is therefore important that the orchard floor be smooth, even and weed free (Rice *et al*., 1994). The harvest of immature nuts will result in many small and hard kernels which must be hand sorted out and reduce the value of the crop. After harvesting, nuts (Fig. 19.12-1) are dried to about 1.5 per cent moisture content before being shelled. Shelling is either by machine using rollers or by hand using hammers if the quantity is small.

At Jimma (southwest Ethiopia) madamia trees are well established and are fruiting successfully. This indicates the existence of a potential for commercialization of this nut bearing tree.
Figure 19.12-1. Macadamia nut. (http://i262.photobucket.com)

References


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CRFG (California Rare Fruit Growers). 1996. TAMARILLO. http://www.crfg.org


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19. UNDERUTILIZED FRUITS IN ETHIOPIA

Source: http://www.flowerpicturegallery.com

**Figure 19. 1-1.** Bearing loquat fruit tree.

Source: http://cdn3.pacifichorticulture.org

**Figure 19. 2-1.** Fruits of white sapote (green mature stage).

Source: http://www.kingsnake.com  
Source: http://www.getwellnatural.com  
Source: http://cdn.cactusplaza.com

**Figure 19. 3.** Some Annonaceae fruits.
Figure 19. 4-1. Cactus pear fruit.

Figure 19. 5-1. Date palm - fruit (Pistillate plant).

Figure 19. 6-1. Fig fruit.
Figure 19.7-1. Jackfruit.
Source: http://www.eol.org

Figure 19.8-1. Fruiting mulberry plant.
Source: http://commons.wikimedia.org

Figure 19.9-1. Tree tomato fruit.
Source: http://www.seedman.com

Figure 19.10-1. Gooseberry fruit.
Source: http://lastcrumb.com
(A) Flower and fruit at early stage

(B) Fruit at mature stage

Figure 19. 11-1. Pomegranate.

Figure 19. 12-1. Macadamia nut.
### GLOSSARY OF TERMS

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation</td>
<td>The process of change in structure or function of an individual or population caused by environmental changes.</td>
</tr>
<tr>
<td>Adventitious</td>
<td>Refers to structures arising from an unusual place; for example, buds at places other than shoot terminals or leaf axils, or roots growing from stems or leaves.</td>
</tr>
<tr>
<td>After-ripening</td>
<td>A term long used in horticultural literature to describe those physiological changes that occur within the seed after harvest that enable germination to take place.</td>
</tr>
<tr>
<td>Air layer</td>
<td>An undetached aerial portion of a plant on which roots are caused to develop commonly as the result of wounding or other stimulation.</td>
</tr>
<tr>
<td>Alternate</td>
<td>An arrangement of leaves or buds in which a bud or leaf grows on one side of a stem at one node and on the other side at the next node.</td>
</tr>
<tr>
<td>Angiosperm</td>
<td>One of a large group of seed-bearing plants in which the female gamete is protected within an enclosed ovary. A flowering plant.</td>
</tr>
<tr>
<td>Anther</td>
<td>In a flower the saclike structure of the stamen in which microspores (pollen grains) are produced; usually borne on a filament.</td>
</tr>
<tr>
<td>Anthesis</td>
<td>A developmental stage in flowering at which anthers rupture and pollen is shed. A state of full bloom.</td>
</tr>
</tbody>
</table>
Antipodal nuclei

The three or more nuclei at the end of the embryo sac opposite the egg nucleus (female gamete). They are produced by meiotic divisions of the megaspore and degenerate following sexual fertilization.

Apical dominance

The inhibition of lateral buds on a shoot due to auxins produced by the apical bud.

Apical meristem

A mass of undifferentiated cells capable of division at the tip of a root or shoot. These cells differentiate by division, allowing the plant to grow in depth or height.

Apomixis

The asexual (vegetative) production of seedlings in the usual sexual structures of the flower but without the mingling and segregation of chromosomes. Seedling characteristics are the same as those of the maternal parent.

Aseptic condition

A condition free from harmful pathogen.

Asexual reproduction

The production of a new plant by any vegetative means not involving meiosis and the union of gametes.

Axil

The angle on the upper side of the union of a branch and main stem or of a leaf and a stem.

Axillary bud

A bud formed in the axil of a leaf.

Bark

The tissues of a woody stem or root from

Berry

A simple fleshy fruit formed from a single ovary; the ovary wall is fleshy and includes one or more carpels and seeds. For example, fruits of the tomato and grape are botanically berries.

Botany

The science of plants, their characteristics, functions, life cycles, and habits.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bract</td>
<td>A modified leaf, from the axil of which arises a flower or an inflorescence.</td>
</tr>
<tr>
<td>Broadcast</td>
<td>Scattering seed or fertilizers uniformly over the soil surface rather than placing in rows.</td>
</tr>
<tr>
<td>Bud</td>
<td>A region of meristematic tissue with the potential for developing into leaves, shoots, flowers, or combinations; generally protected by modified scale leaves.</td>
</tr>
<tr>
<td>Budding</td>
<td>A form of grafting in which a single vegetative bud is taken from one plant and inserted into the stem tissue of another plant so that the two will grow together. The inserted bud develops into a new shoot.</td>
</tr>
<tr>
<td>Callus</td>
<td>Mass of large, thin-walled parenchyma cells, usually developing as the result of a wound.</td>
</tr>
<tr>
<td>Cambium(vascular)</td>
<td>A thin layer of longitudinally dividing cells between the xylem and phloem that gives rise to secondary growth.</td>
</tr>
<tr>
<td>Carbon-nitrogen ratio</td>
<td>The ratio of the weight of organic carbon to the weight of total nitrogen in a soil or in organic material.</td>
</tr>
<tr>
<td>Cell</td>
<td>The basic structural and physiological unit of plants.</td>
</tr>
<tr>
<td>Centre of origin</td>
<td>A geographical area in which a species is thought to have evolved through natural selection from its ancestors.</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>A complex organic molecule that traps light energy for conversion through photosynthesis into chemical energy.</td>
</tr>
<tr>
<td>Chloroplast</td>
<td>Chlorophyll containing in which a plant or a part of a plant is light green or greenish yellow because of poor chlorophyll development or the destruction of chlorophyll resulting from a disease or a mineral deficiency.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Classification</td>
<td>The systematic arrangement into categories on the basis of characteristics. Branch groupings are made on the basis of general characteristics and subdivisions on the basis of more detailed differences in specific properties.</td>
</tr>
<tr>
<td>Clone</td>
<td>The aggregate of individual organisms originating from one sexually produced individual (or from a mutation) and maintained exclusively by asexual propagation.</td>
</tr>
<tr>
<td>Complete flower</td>
<td>A flower that has pistils, stamens, petals, and sepals, all attached to a receptacle.</td>
</tr>
<tr>
<td>Compost</td>
<td>A mixture of organic residues and soil that has been piled, moistened, and allowed to decompose biologically. Mineral fertilizers are sometimes added.</td>
</tr>
<tr>
<td>Compound leaf</td>
<td>A leaf whose blade is divided into a number of distinct leaflets.</td>
</tr>
<tr>
<td>Contact herbicide</td>
<td>A chemical that kills plants on contact.</td>
</tr>
<tr>
<td>Cork</td>
<td>An external, secondary tissue impermeable to water and gases produced by certain kinds of woody plants.</td>
</tr>
<tr>
<td>Cork cambium</td>
<td>The cambium from which cork develops.</td>
</tr>
<tr>
<td>Corn</td>
<td>The swollen food-storing base of a stem, growing underground.</td>
</tr>
<tr>
<td>Cover crop</td>
<td>A close-growing crop grown primarily for the purpose of protecting or improving soil between periods of regular crop production or between trees and vines in orchards and vineyards.</td>
</tr>
<tr>
<td>Crop residue</td>
<td>Portion of crop plants remaining after harvest.</td>
</tr>
</tbody>
</table>
Crop rotation | Growing crop plants in a different location in a systematic sequence to help control insects and diseases, improve the soil structure and fertility, and decrease erosion.

Cross-pollination | The transfer of pollen from a stamen to the stigma of a flower on another plant, except for clones where the two plants must be in different clones.

Crown | In woody plants, the root-stem junction. Pineapple propagule situated on the top part of fruit.

Cultivar | (derived from “cultivated variety”) International term denoting certain cultivated plants that are clearly distinguishable from others by any characteristics and that retain their distinguishing characters when reproduced (sexually or asexually). In the United States, variety is considered synonymous with cultivar.

Cutting | A detached leaf, stem or root that is encouraged to form new roots and shoots and develops into a new plant.

Cytokinins | A group of plants’ growth hormones important in the regulation of nucleic acid and protein metabolism in cell division, organ initiation, and delaying senescence.

Deciduous | Refers to trees and shrubs that lose their leaves every fall. Distinguished from evergreens, which retain them.

Dichogamy | Maturation of male or female flowers at different times, ensuring cross-pollination.

Dioecious | Refers to individual plants having either staminate (male) or pistilate (female) flowers, but not both. Therefore, plants of both sexes must be grown near each other to provide pollen before fruits and seed can be produced.
Dormancy  Lack of growth of seeds or buds, due to unfavorable environmental conditions (external dormancy or quiescence) or to factors within the organ itself (internal dormancy or rest).

Double-fertilization  The process of sexual fertilization in the angiosperms in which one nucleus from the male gametophyte fertilizes the egg nucleus to form the zygote and a second nucleus from the male gametophyte fertilizes two polar nuclei to form endosperm tissue.

Drip Irrigation  A method of watering plants so that only soil in the plants’ immediate vicinity is moistened. Water is supplied from a thin plastic tube at a low rate of flow. Sometimes called trickle irrigation.

Drupe  A simple, fleshy fruit derived from a single carpel, usually one-seeded, in which the exocarp is thin, the mesocarp fleshy, and the endocarp hard.

Ecology  The study of life in relation to its environment.

Embryo  A miniature plant within a seed produced as a result of the union of a male and female gamete resulting in the development of a zygote.

Embryo sac  Typically, an eight-nucleate female gametophyte. The embryo sac arises from the megaspore by successive mitotic division.

Endocarp  Inner layer of the fruit wall (pericarp).

Endosperm  The 3n tissue of angiosperms seeds that develops from sexual fusion of the two polar nuclei of the embryo sac and a male sperm cell. The endosperm provides nutrition for the developing embryo. A food storage tissue.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Epigeal germination</td>
<td>A type of seed germination in dicots in which the cotyledons rise above the soil surface. This occurs in beans, for example.</td>
</tr>
<tr>
<td>Ethylene</td>
<td>A gaseous growth hormone ($\text{C}_2\text{H}_4$) regulating various aspects of vegetative growth, fruit ripening, and abscission of plant parts.</td>
</tr>
<tr>
<td>Etiolation</td>
<td>A condition involving lack of chlorophyll, increased stem elongation, and poor or absent leaf development. It occurs in plants growing under very low light intensity or complete darkness.</td>
</tr>
<tr>
<td>Evapo-transpiration</td>
<td>The total loss of water by evaporation from the soil surface and by transpiration from plants, from a given area, and during a specified period of time.</td>
</tr>
<tr>
<td>Evergreen</td>
<td>Trees or shrubs that are never entirely leafless, as in avocado or citrus.</td>
</tr>
<tr>
<td>Exocarp</td>
<td>The outermost layer of the fruit wall (pericarp).</td>
</tr>
<tr>
<td>Explant</td>
<td>Living tissue removed from its place in a body and placed in an artificial medium for tissue culture.</td>
</tr>
<tr>
<td>Family</td>
<td>In plant taxonomy, a group of genera.</td>
</tr>
<tr>
<td>Fertilization (floral)</td>
<td>The union of an egg and a sperm (gametes) to form a zygote.</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Any organic or inorganic material of natural or synthetic origin added to a soil to supply elements essential to the growth of plants.</td>
</tr>
<tr>
<td>Fleshy fruit</td>
<td>Any fruit formed from an ovary that has fleshy or pulpy (not dried) walls at maturity. Also, those fruits that</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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</tr>
<tr>
<td>Flooding</td>
<td>A method of irrigation by which water is released from field ditches and allowed to spread over the land.</td>
</tr>
<tr>
<td>Flower</td>
<td>Floral leaves grouped together on a stem that, in the angiosperms, are adapted for sexual reproduction.</td>
</tr>
<tr>
<td>Fruit</td>
<td>A mature ovary; in some plants other flower parts are commonly included as part of the fruit, e.g., the hypanthium of the apple flower surrounds the ovary.</td>
</tr>
<tr>
<td>Fumigation</td>
<td>Control of insects, disease-causing organisms, weeds, or nematodes by gases applied in an enclosed area such as greenhouse or under plastic laid on the soil.</td>
</tr>
<tr>
<td>Fungicide</td>
<td>A pesticide chemical used to control plant diseases caused by fungi.</td>
</tr>
<tr>
<td>Furrow irrigation</td>
<td>A method of irrigation by which the water is applied to row crops in ditches.</td>
</tr>
<tr>
<td>Gamete</td>
<td>An haploid-generation male sperm cell or a female egg cell capable of developing into an embryo after fusion with a germ cell of the opposite sex.</td>
</tr>
<tr>
<td>Genotype</td>
<td>The genetic makeup of a nucleus or of an individual.</td>
</tr>
<tr>
<td>Germination(seed)</td>
<td>Sequence of events in a viable seed starting with imbibition of water that leads to growth of the embryo and development of a seedling.</td>
</tr>
<tr>
<td>Graft</td>
<td>To place a detached branch (scion) in close cambial contact with a rooted stem (rootstock) in such a manner that scion and rootstock unite to form a new plant.</td>
</tr>
</tbody>
</table>
Green manure: A crop that is plowed under while still green and growing to improve the soil.

Growing medium (soil mix): Soil or soil substitutes prepared by combining materials such as peat moss, vermiculite, sand, or composted sawdust. Used for growing potted plants or germinating seed.

Growth regulator: A synthetic or natural compounds that controls growth responses in plants in low concentration.

Growth retardant: A chemical that selectively interferes with normal hormonal promotion of plant growth, but without appreciable toxic effects.

Haploid: Having only one complete set of chromosomes; referring to an individual or generation such as a single set of chromosomes per cell.

Hardening off: Adapting plants to outdoor conditions by withholding water, lowering the temperature, or nutrient supply. This conditions let the plants adapt and survive when transplanted outdoors.

Herbaceous: Refers to plants that do not develop woody tissues.

Herbicide: Any chemical used to kill plants; an herbicide may work against a narrow or a wide range of plant species.

Hermaphrodite flower: A flower having both stamens (male) and pistils (female).

Heterozygous: Having different genes of a Mendelian pair present in the same cell or organism; for instance, a tall pea plant with genes for both tallness (T) and dwarfishness (t).
**Homozygous**

Having similar genes in a Mendelian pair present in the same cell or organism. For instance, a dwarf pea plant with genes for dwarfness (tt) only.

**Hormone**

A chemical substance that is produced in one part of a plant and used in minute quantities to induce a growth response in another part. For example, auxins are one type of hormone.

**Humidity, relative**

The ratio of the partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a prescribed temperature. The relative humidity of air depends on the temperature and the pressure.

**Humus**

The more or less stable fraction of the soil organic matter remaining after the major portion of plant and animal residues have decomposed.

**Hypogean**

In dicots, a type of seed germination in which the germination cotyledons remain below the soil surface; for example, peas.

**Imbibition**

The absorption of liquids or vapors into the ultramicroscopic spaces in materials like cellulose.

**Imperfect flower**

A flower lacking either stamens or pistils.

**Impervious**

Resistant to penetration by fluids or by roots.

**Incompatibility (floral)**

Failure to obtain fertilization and seed formation after pollination, usually because of slow pollen tube growth in the stylar tissue.

**Incompatibility (graft)**

Failure of two graft components (stock and scion) to unite, and develop into a successfully growing plant.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Incomplete flower</td>
<td>A flower that is missing one or more of the following parts: sepals, petals, stamens, or pistils.</td>
</tr>
<tr>
<td>Indigenous</td>
<td>Produced or living naturally in a specific environment.</td>
</tr>
<tr>
<td>Indoleacetic acid (IAA)</td>
<td>A natural or synthetic plant growth regulator; an auxin.</td>
</tr>
<tr>
<td>Inflorescence</td>
<td>An axis bearing flowers, or a flower cluster (e.g., umbel, spike, panicle)</td>
</tr>
<tr>
<td>Inorganic compound</td>
<td>A chemical compound that generally is not derived from life processes; compounds that do not contain carbon.</td>
</tr>
<tr>
<td>Insecticide</td>
<td>Any chemical (organic or inorganic) substance that kills insects.</td>
</tr>
<tr>
<td>Integuments</td>
<td>The tissue covering or surrounding the ovule, usually consisting of an inner and outer layer; they subsequently become the seed coats of the mature ovule.</td>
</tr>
<tr>
<td>Internode</td>
<td>The region of a stem between two successive nodes.</td>
</tr>
<tr>
<td>In vitro</td>
<td>Latin for “in glass”. Living in test tubes; outside the organism or in an artificial environment.</td>
</tr>
<tr>
<td>Irrigation</td>
<td>Applying water to the soil, other than by natural rainfall.</td>
</tr>
<tr>
<td>Lateral bud</td>
<td>A bud that grows out from the leaf axil on the side of a stem.</td>
</tr>
<tr>
<td>Latex</td>
<td>A milky secretion produced by various kinds of plants.</td>
</tr>
<tr>
<td>Layering</td>
<td>A form of vegetative propagation in which an intact branch develops roots as the result of contact with the soil or another rooting medium.</td>
</tr>
</tbody>
</table>
Light soil

A coarse-textured sand; hence easy to till.

Lignin

An organic substance found in secondary cell walls that gives stems strength and hardness. Wood is composed of lignified xylem cells (about 15 to 30 percent by weight).

Male sterility

A condition in some plants in which pollen either is not formed or does not function normally, even though the stamens may appear normal.

Meiosis

Two successive nuclear divisions, in the course of which the diploid chromosome number is reduced to the haploid and genetic segregation occurs.

Meristem

Undifferentiated tissue whose cells can divide and differentiate to form specialized tissues; such as xylem or phloem.

Mesocarp

Middle layer of the fruit wall (pericarp).

Microclimate

Atmospheric environmental conditions in the immediate vicinity of the plant, including interchanges of energy, gases, and water between atmosphere and soil.

Micropropagation

The production of plants from very small plant parts, tissues, or cells grown aseptically in a test tube or other container where the environment and nutrition can be rigidly controlled.

Mist propagation

Applying water in mist form to leafy cuttings in the rooting stage to reduce transpiration.

Mitosis

A form of nuclear cell division in which chromosomes duplicate and divide to yield two nuclei that are identical with the original nucleus. Usually mitosis includes cellular division (cytokinesis).
Mixed bud: A bud containing both rudimentary flowers and vegetative shoots.

Monecious: A plant with separate male and female flowers on the same plant, such as walnuts.

Morphology: The study or science of the form, structure, and (plant) development of plants.

Mulch: Any material such as straw, sawdust, leaves, plastic film, and loose soil that is spread upon the surface of the soil to protect the soil and plant roots from the effects of rain, soil crusting, freezing, or evaporation.

Multiple fruit: A cluster of matured fused ovaries produced by separate flowers; for example, pineapple.

Nodes: Enlarged regions of stems that are generally solid where leaves are attached and buds are located. Stems have nodes but roots do not.

Nucellus: A tissue originally making up the major part of the young ovule, in which the embryo sac develops.

Nut: A dry, indehiscent, single-seeded fruit with a hard, woody pericarp (shell), such as walnut and macadamia nut.

Opposite: An arrangement of leaves or buds on a stem. They occur in pairs on opposite sides of a single node.

Ovary: The basal, generally enlarged part of the pistil in which seeds are formed. The ovary, at maturity, is a fruit. It is a characteristic organ of angiosperm plants.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovule</td>
<td>A rudimentary seed before fertilization, containing the embryo sac, including an egg cell, all being enclosed in the nucleolus and one or two integuments.</td>
</tr>
<tr>
<td>Parthenocarpy</td>
<td>Fruit development without sexual fertilization. Such fruits are seedless. Examples are the 'Navel' organ and some fig cultivars.</td>
</tr>
<tr>
<td>Peat</td>
<td>Any unconsolidated soil mass of semicarbonized vegetable tissue formed by partial decomposition in water. An example is sphagnum peat moss.</td>
</tr>
<tr>
<td>Pectin</td>
<td>Polysaccharide from the middle lamella of the plant cell wall; Jelly-forming substance found in fruit.</td>
</tr>
<tr>
<td>Pedicel</td>
<td>Individual flower stalk of an inflorescence.</td>
</tr>
<tr>
<td>Peduncle</td>
<td>Flower stalk that is borne singly; or the main stem of an inflorescence.</td>
</tr>
<tr>
<td>Perennial</td>
<td>A plant that grows more or less indefinitely from year to year and usually produces seed each year.</td>
</tr>
<tr>
<td>Perfect flower</td>
<td>Having both stamens and pistils; an hermaphroditic flower.</td>
</tr>
<tr>
<td>Pericarp</td>
<td>The fruit wall, which develops from the ovary wall.</td>
</tr>
<tr>
<td>Petiole</td>
<td>The stalk that attaches a leaf blade to a stem.</td>
</tr>
<tr>
<td>Phenotype</td>
<td>The external physical appearance of an organism.</td>
</tr>
<tr>
<td>Phloem</td>
<td>A tissue through which nutritive and other materials are translocated through the plant. The phloem consists of sieve tube cells, companion cells, phloem parenchyma, and fibers.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Pigments</td>
<td>Molecules that are colored by the light they absorb. Some plant pigments are water-soluble and are found mainly in the cell vacuole.</td>
</tr>
<tr>
<td>Pinching</td>
<td>The removal of the terminal bud or apical meristematic growth to stimulate branching.</td>
</tr>
<tr>
<td>Pistil</td>
<td>The seed-bearing organ in the flower, composed of the ovary, the style, and the stigma.</td>
</tr>
<tr>
<td>Pistillate flower</td>
<td>A female flower having pistils but no stamens.</td>
</tr>
<tr>
<td>Pith</td>
<td>A region in the center of some stems and roots consisting of loosely packed, thin-walled parenchyma cells.</td>
</tr>
<tr>
<td>Plumule</td>
<td>The first bud of an embryo or that portion of the young shoot above the cotyledons.</td>
</tr>
<tr>
<td>Polar nuclei</td>
<td>Two centrally located nuclei in the embryo sac that unite with a second sperm cell in a triple fusion. In certain seeds, the product of this fusion develops into the endosperm.</td>
</tr>
<tr>
<td>Pollen tube</td>
<td>A tube like structure developed by the tube nucleus in the microspore that helps guiding the sperm through the stigma and style of a flower to the embryo sac.</td>
</tr>
<tr>
<td>Pollination</td>
<td>The transfer of pollen from a stamen (or staminate cone) to a stigma (or ovulate cone).</td>
</tr>
<tr>
<td>Polyembryony</td>
<td>The presence of more than one embryo in a developing seed.</td>
</tr>
<tr>
<td>Polyploidy</td>
<td>A condition in which a plant has somatic (non sexual) cells with more than 2n chromosomes per nucleus.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Pome</td>
<td>A simple fleshy fruit, the outer portion of which is formed by floral parts that surround the ovary (i.e., apple and pear fruits).</td>
</tr>
<tr>
<td>Primary tissue</td>
<td>A tissue that is differentiated from a primary meristem.</td>
</tr>
<tr>
<td>Primordium</td>
<td>An organ in its earliest state of development, such as leaf primordium.</td>
</tr>
<tr>
<td>Radicle</td>
<td>The part of the embryonic axis that becomes the primary root. The first part of the embryo to start growth during seed germination.</td>
</tr>
<tr>
<td>Receptacle</td>
<td>The enlarged tip of a stem on which a flower is borne.</td>
</tr>
<tr>
<td>Reduction division</td>
<td>A nuclear division in which the chromosomes are reduced and handled so as to maintain satisfactory genetic identity and purity, and approved and certified by an official certifying agency. Registered seed is normally grown for the production of certified seed.</td>
</tr>
<tr>
<td>Replication</td>
<td>In cell physiology, the production of a second molecule of DNA exactly like the first molecule.</td>
</tr>
<tr>
<td>Reproduction, sexual</td>
<td>Development of new plants by seeds (except in apomixis).</td>
</tr>
<tr>
<td>Reproduction, vegetative</td>
<td>Reproduction by other than sexually produced seed. Includes grafting, cuttings, layering, and so forth, as well as apomixis.</td>
</tr>
<tr>
<td>Respiration</td>
<td>The oxidation of food by plants and animals to yield energy for cellular activities.</td>
</tr>
<tr>
<td>Rest period</td>
<td>An endogenous physiological condition of viable seeds, buds, or bulbs that prevents growth even in the presence of otherwise favorable environmental conditions. This is referred to by some seed physiologists as dormancy.</td>
</tr>
</tbody>
</table>
Rhizome  
An underground stem, usually horizontal and often elongated; distinguished from a root by the presence of nodes and internodes. Capable of producing new shoots.

Ripening  
Chemical and physical changes in a fruit that follow maturation.

Rooting media  
Materials such as peat, sand, perlite, or vermiculite in which the basal ends of cuttings are placed vertically during the development of roots.

Rootstock (understock)  
The trunk or root material to which buds or scions are inserted in grafting.

Scarify  
To scratch, chip, or nick the seed coverings of certain species to enhance the passage of water and gases as an aid to seed germination.

Scion  
A small shoot that is inserted by grafting into a rootstock.

Scion-stock interaction  
The effects of a rootstock on a scion (and vice versa) in which a scion on one kind of rootstock performs differently than it would on its own roots or on a different rootstock.

Secondary phloem  
Phloem cells formed by activity of the vascular cambium. Secondary phloem is found in biennials and perennials, but usually not in annuals.

Secondary xylem  
Xylem cells formed by activity of the vascular cambium. The development of the secondary xylem accounts for the so-called annual rings seen in most trees.

Seed  
The mature ovule of a flowering plant containing an embryo, an endosperm (sometimes), and a seed coat.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedbed</td>
<td>Soil that has been prepared for planting seeds or transplants.</td>
</tr>
<tr>
<td>Self-fertile</td>
<td>Capable of fertilization and producing viable seed after self-pollination.</td>
</tr>
<tr>
<td>Self-incompatibility</td>
<td>Inability to produce viable seed following self-pollination. The inability is sometimes due to a pollen-borne gene that prevents pollen tube growth on a stigma with the same gene.</td>
</tr>
<tr>
<td>Self-pollination</td>
<td>Transfer of pollen from the stamens to the stigma of either the same flower, other flowers on the same plant, or flowers on other plants of the same clone.</td>
</tr>
<tr>
<td>Self-sterility</td>
<td>Failure to complete fertilization and to obtain viable seed after self-pollination.</td>
</tr>
<tr>
<td>Semiarid</td>
<td>Climate in which evaporation exceeds precipitation, a transition zone between a true desert and a humid climate. Usually annual precipitation is between 250 and 500 mm.</td>
</tr>
<tr>
<td>Senescence</td>
<td>A physiological aging process in which tissues in an organism deteriorate and finally die.</td>
</tr>
<tr>
<td>Sexual reproduction</td>
<td>Development of new plants by the process of meiosis and fertilization in the flower to produce a viable embryo in a seed.</td>
</tr>
<tr>
<td>Side dressing</td>
<td>Applying fertilizer on a soil surface close enough to a plant. Cultivating or watering carries the fertilizer to the plant's roots.</td>
</tr>
<tr>
<td>Simple fruit</td>
<td>A fruit derived from a single pistil.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Soil management</td>
<td>The total tillage operations, cropping practices, fertilizing, liming, and other treatments conducted on or applied to a soil for the production of plants.</td>
</tr>
<tr>
<td>Soil organic matter</td>
<td>The organic fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.</td>
</tr>
<tr>
<td>Soil sterilization</td>
<td>Treating soil by gaseous fumigation, chemicals, heat (usually steam) at 100°C (212°F) to destroy all living organisms.</td>
</tr>
<tr>
<td>Soil tilth</td>
<td>The physical condition of soil related to its ease of tillage, fitness as a seed bed, and suitability for plant growth.</td>
</tr>
<tr>
<td>Species</td>
<td>A group of similar organisms capable of interbreeding and more or less distinctly different in geographic range and/or morphological characteristics from other species in the same genus.</td>
</tr>
<tr>
<td>Stamen</td>
<td>The male reproductive structure of a flower. The stamen produces pollen and is composed of a filament, which has borne an anther.</td>
</tr>
<tr>
<td>Staminate (male) flower</td>
<td>A flower having stamens but not pistils.</td>
</tr>
<tr>
<td>Starch</td>
<td>A complex polysaccharide carbohydrate. The form of food commonly stored by plants.</td>
</tr>
<tr>
<td>Stem</td>
<td>The main body of a plant, usually the ascending axis, whether above or below ground in opposition to the descending axis or root. Stems, but not roots produce nodes and buds.</td>
</tr>
</tbody>
</table>
Stigma
In a flower, the portion of the style pollen which adheres to stock (see Rootstock).

Stoma (stomate)
(plural, stomata, stemates) A small opening, bordered by guard cells, in the epidermis of leaves and stems, through which gases including water vapour pass.

Stool (horticultural)
Sprouts that arise from the base of the plant below ground and become rooted. They are used for vegetative propagation.

Stratification
The practice of exposing imbibed seeds to cool at 2°C to 10°C (35°F to 50°F) (sometimes warm) temperatures for a period of time prior to germination in order to break dormancy. This is a standard practice in germination of seeds of many grass and woody species.

Sub-soiling
Breaking of compact subsoils, without inverting them, with a special knifelike instrument (chisel) that is pulled through the soil at depths usually of 30 to 60 cm and at spacing usually of 60 to 150 cm.

Synergies
The two nuclei within the embryo sac at the upper end in the ovule of the flower, which, with the third (the egg), constitute the egg apparatus.

Systemic
A pesticide material absorbed by plants, making them toxic to feeding insects. Also, pertaining to a disease in which an infection spreads throughout the plant.

Tannin
Broad class of soluble polyphenols with a common property of condensing with protein to form a leather like substance that is insoluble in water.

Taproot
An elongated, deeply growing primary root.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxonomy</td>
<td>The science dealing with describing, naming, and classifying plants and animals.</td>
</tr>
<tr>
<td>Tendril</td>
<td>A slender coiling modified leaf or stem arising from stems and aiding in their support.</td>
</tr>
<tr>
<td>Terminal bud</td>
<td>A bud at the distal end of a stem.</td>
</tr>
<tr>
<td>Terrace</td>
<td>A level, usually narrow, plain bordering a river, lake or the sea. Terraces at different levels sometimes border rivers. It also refers to a raised, more or less level strip of land usually constructed on a contour and designed to make the land suitable for tillage and prevent erosion.</td>
</tr>
<tr>
<td>Tetraploid</td>
<td>Having four sets of chromosomes per nucleus.</td>
</tr>
<tr>
<td>Thinning</td>
<td>Removing young plants from a row to provide the remaining plants with more space to develop. Also, the removal of excess numbers of fruits from a tree which makes the remaining fruits become larger.</td>
</tr>
<tr>
<td>Tissue</td>
<td>A group of cells of similar structure that performs a special function.</td>
</tr>
<tr>
<td>Tissue culture</td>
<td>See micropropagation.</td>
</tr>
<tr>
<td>Top dressing</td>
<td>Applying materials such as fertilizer or compost to the soil surface while plants are growing.</td>
</tr>
<tr>
<td>Top working</td>
<td>To change the cultivar of a tree by grafting the main (top grafting) scaffold branches.</td>
</tr>
<tr>
<td>Translocation</td>
<td>The transfer of food materials or products of metabolism throughout the plant.</td>
</tr>
<tr>
<td>Transpiration</td>
<td>The loss of water vapour through the stomata of leaves.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vegetative</td>
<td>Referring to a sexual (stem, leaf, root) development in plants in contrast to sexual (flower, seed) development.</td>
</tr>
<tr>
<td>Virgin soil</td>
<td>A soil that has not been significantly disturbed from its natural environment.</td>
</tr>
<tr>
<td>Water table</td>
<td>The upper surface of ground water or that level below which the soil is saturated with water.</td>
</tr>
<tr>
<td>Weed</td>
<td>A plant not valued for use or beauty. Any plant growing where it is not wanted.</td>
</tr>
<tr>
<td>Windbreak</td>
<td>A planting of trees or shrubs, usually perpendicular or nearly so to the principal wind direction to protect soil, crops, homestead roads, and so on, against the effect of wind.</td>
</tr>
<tr>
<td>Wood</td>
<td>Secondary non-functioning xylem in a perennial shrub or tree.</td>
</tr>
<tr>
<td>Xylem</td>
<td>Specialized cells through which water and minerals move upward from the soil through a plant.</td>
</tr>
<tr>
<td>Zygote</td>
<td>A protoplast resulting from the fusion of gametes (either isogametes or heterogametes). The beginning of a new plant in sexual reproduction.</td>
</tr>
</tbody>
</table>
## Appendix

Representative nutritional values of some fruits consumed in tropical countries (per 100g edible portions)

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Water (%)</th>
<th>Calory (kCal)</th>
<th>Protein (g)</th>
<th>Fat (g)</th>
<th>Carbohydrate (g)</th>
<th>Fiber (g)</th>
<th>Ca (mg)</th>
<th>Iron (mg)</th>
<th>Vit. A (IU)</th>
<th>Thiamine (mg)</th>
<th>Riboflavin (mg)</th>
<th>Nicotinamide (mg)</th>
<th>Vit. C (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annona spp</td>
<td>75.0</td>
<td>93</td>
<td>1.0</td>
<td>0.1</td>
<td>22.0</td>
<td>1.0</td>
<td>25.0</td>
<td>0.5</td>
<td>0</td>
<td>0.10</td>
<td>0.88</td>
<td>0.8</td>
<td>30</td>
</tr>
<tr>
<td>Apple (malus)</td>
<td>84.0</td>
<td>61</td>
<td>0.3</td>
<td>0.4</td>
<td>14.0</td>
<td>1.0</td>
<td>4.0</td>
<td>0.3</td>
<td>20</td>
<td>0.04</td>
<td>0.02</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>Avocado</td>
<td>75.0</td>
<td>165</td>
<td>1.5</td>
<td>15.0</td>
<td>6.0</td>
<td>1.5</td>
<td>10.0</td>
<td>1.0</td>
<td>200</td>
<td>0.07</td>
<td>0.15</td>
<td>1.2</td>
<td>15</td>
</tr>
<tr>
<td>Banana</td>
<td>70.0</td>
<td>116</td>
<td>1.0</td>
<td>0.3</td>
<td>27.0</td>
<td>0.3</td>
<td>7.0</td>
<td>0.5</td>
<td>100</td>
<td>0.05</td>
<td>0.05</td>
<td>0.7</td>
<td>10</td>
</tr>
<tr>
<td>Cashew (apple)</td>
<td>85.0</td>
<td>56</td>
<td>0.7</td>
<td>0.0</td>
<td>13.0</td>
<td>0.6</td>
<td>2.0</td>
<td>0.5</td>
<td>150</td>
<td>0.02</td>
<td>0.02</td>
<td>0.5</td>
<td>250</td>
</tr>
<tr>
<td>Cashew (nut)</td>
<td>5.0</td>
<td>590</td>
<td>20.0</td>
<td>45.0</td>
<td>26.0</td>
<td>1.3</td>
<td>50.0</td>
<td>5.0</td>
<td>0</td>
<td>0.60</td>
<td>0.20</td>
<td>2.1</td>
<td>0</td>
</tr>
<tr>
<td>Date palm</td>
<td>22.5</td>
<td>274</td>
<td>2.2</td>
<td>0.5</td>
<td>72.9</td>
<td>2.3</td>
<td>59.0</td>
<td>3.0</td>
<td>50</td>
<td>0.09</td>
<td>0.10</td>
<td>2.2</td>
<td>0</td>
</tr>
<tr>
<td>Feijoa</td>
<td>84.9</td>
<td>-</td>
<td>0.8</td>
<td>0.2</td>
<td>4.2</td>
<td>-</td>
<td>36.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fig</td>
<td>85.0</td>
<td>49</td>
<td>1.3</td>
<td>0.0</td>
<td>11.0</td>
<td>2.0</td>
<td>50.0</td>
<td>1.0</td>
<td>80</td>
<td>0.05</td>
<td>0.05</td>
<td>0.4</td>
<td>2</td>
</tr>
<tr>
<td>Grape (V. vinifera)</td>
<td>80.0</td>
<td>76</td>
<td>1.0</td>
<td>0.0</td>
<td>18.0</td>
<td>0.5</td>
<td>20.0</td>
<td>0.3</td>
<td>0</td>
<td>0.04</td>
<td>0.02</td>
<td>0.3</td>
<td>5</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>90.0</td>
<td>37</td>
<td>0.5</td>
<td>0.0</td>
<td>9.0</td>
<td>0.3</td>
<td>20.0</td>
<td>0.5</td>
<td>0</td>
<td>0.04</td>
<td>0.01</td>
<td>0.2</td>
<td>40</td>
</tr>
<tr>
<td>Guava</td>
<td>80.0</td>
<td>58</td>
<td>1.0</td>
<td>0.4</td>
<td>13.0</td>
<td>5.5</td>
<td>15.0</td>
<td>1.0</td>
<td>200</td>
<td>0.05</td>
<td>0.04</td>
<td>1.0</td>
<td>200</td>
</tr>
<tr>
<td>Jack fruit</td>
<td>72.9</td>
<td>94</td>
<td>1.7</td>
<td>0.3</td>
<td>23.7</td>
<td>0.9</td>
<td>27.0</td>
<td>0.6</td>
<td>39</td>
<td>0.09</td>
<td>0.11</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>Lemon</td>
<td>90.0</td>
<td>36</td>
<td>0.7</td>
<td>0.0</td>
<td>8.0</td>
<td>0.5</td>
<td>22.0</td>
<td>0.5</td>
<td>0</td>
<td>0.05</td>
<td>0.00</td>
<td>0.2</td>
<td>40</td>
</tr>
<tr>
<td>Lime - see Lemon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loquat</td>
<td>88.6</td>
<td>40</td>
<td>0.5</td>
<td>0.2</td>
<td>10.2</td>
<td>0.5</td>
<td>18.0</td>
<td>0.2</td>
<td>1291</td>
<td>0.20</td>
<td>0.04</td>
<td>0.2</td>
<td>4</td>
</tr>
<tr>
<td>Macadamia</td>
<td>1.2</td>
<td>-</td>
<td>9.2</td>
<td>78.0</td>
<td>10.0</td>
<td>1.8</td>
<td>53.0</td>
<td>2.0</td>
<td>0</td>
<td>0.20</td>
<td>0.12</td>
<td>1.6</td>
<td>-</td>
</tr>
<tr>
<td>Mandarin</td>
<td>86.0</td>
<td>53</td>
<td>0.8</td>
<td>0.0</td>
<td>13.0</td>
<td>0.3</td>
<td>30.0</td>
<td>0.5</td>
<td>30</td>
<td>0.08</td>
<td>0.03</td>
<td>0.2</td>
<td>30</td>
</tr>
<tr>
<td>Mango</td>
<td>83.0</td>
<td>63</td>
<td>0.5</td>
<td>0.0</td>
<td>15.0</td>
<td>0.8</td>
<td>10.0</td>
<td>0.5</td>
<td>600-2000</td>
<td>0.03</td>
<td>0.04</td>
<td>0.3</td>
<td>30</td>
</tr>
<tr>
<td>Mulberry</td>
<td>85.0</td>
<td>60</td>
<td>1.5</td>
<td>0.0</td>
<td>14.0</td>
<td>0.7</td>
<td>1.5</td>
<td>3.0</td>
<td>26</td>
<td>0.04</td>
<td>0.08</td>
<td>10</td>
<td>39</td>
</tr>
</tbody>
</table>
### FRUIT PRODUCTION IN ETHIOPIA

#### Appendix... (contd.)

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Water (%)</th>
<th>Calory (kCal)</th>
<th>Protein (g)</th>
<th>Fat (g)</th>
<th>Carbohydrate (g)</th>
<th>Fiber (g)</th>
<th>Ca (mg)</th>
<th>Fe (mg)</th>
<th>Vit A (IU)</th>
<th>Thiamine (mg)</th>
<th>Riboflavin (mg)</th>
<th>Nicotinamide (mg)</th>
<th>Vit C (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange</td>
<td>86.0</td>
<td>53</td>
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Adapted from: Rice et al. (1994)
INDEX

(A)

abnormal physiological 159

ripening 210, 301

acid and sugar content 323

scarification 48

adventitious 55, 59

embryony 59

roots 61

shoot initiation 92

shoots 92

aeration 105, 146, 294, 437

aflatoxins 7, 8

after-ripening period 50

aggregate fruit 30, 43

agro-ecological conditions 23, 141

air drainage 114, 167

layering or marcottage 69

layering 227, 228, 392

alternate freezing and thawing 47

ammonium sulphate 229

ampelography 9

annual fruit crops 13, 17

plants 10

temperature 28, 29

anthracnose 296, 340, 354, 357, 367, 393

antioxidant 12, 33, 34, 436

compounds 12

enzymes 12

enzymes function 12

apical dominance 262, 316, 317, 318, 327

meristem 91, 92, 377, 405

apomictic 59, 60, 351

and sexual embryos 59

embryos 59

seedling 59, 60

(nucellar) seedlings 351

apomix 50, 59, 96, 97, 98, 264

approach grafting 79, 81, 352, 391

arborsculpture 57

arotenoids 12, 436, 208, 252

aseptic culture systems 55

asexual 40, 55, 58, 59, 93

embryogenesis 93

reproductive process 59

aspergillus flavus 8

astringency 192

auxillary branch (side shoots) 376

bud 353

shoot proliferation 92

(B)

bacteria-free nursery 160

seeds 160

bacterial diseases 160, 188

or viral diseases 160

bagging 293, 294

banana thrips 298

bare-root 109, 110, 111, 136

plants 109, 136

seedlings 111

bark grafting 80, 81, 83
basin 2, 146, 147, 148, 187, 189
Irrigation 147
method 147
bearing habit of fruit crops 175
beverage crops 4
biological control system 163, 236
mechanisms 46
weed control 159
bird damage 165, 166
biting mouth 162
branches 9, 14, 42, 57, 63, 170
break 121
dormancy 420, 460
breaker stage (half-ripe) 457
bridge grafting 80, 82, 165
broadcasting 140
bud grafting 84
budding techniques 88
bullhead 288
sections 288
burrowing nematode 249, 256, 272, 284, 297

(C)
callus tissue 75, 82, 92
cambium 73, 74, 75, 78, 79, 80
cells 75
layers 79, 80, 81
canopy management 339
spacing 315
carbohydrate 10, 63, 68, 95, 110, 171, 185, 186, 191, 301, 453, 421
carpels 26, 31, 32, 360, 362, 363
cell division process 55
cellulose 11, 296
central cavity 32
check method (modified basin) 148
method of irrigation 148

chemical dormancy 47
fruit thinning 392
measurements 195, 198
thinning 186
treatments 61
weed control method 157
phill injury 201, 203, 210, 212, 282
requirement 306, 306, 414, 416
temperature 49, 210, 435
threshold temperature 212
thresholds 212
sensitive fruits 212
chip budding 352
chlorophyll 52, 163, 196, 208, 252
degradation 252
cigar-end rot (cigar end tip rot) 295
culture 9, 261, 266
clay soils 116, 145, 150, 152, 258, 406
cleft grafting 81, 337, 352
climacteric and non-climacteric fruits 194, 203, 213

phase 32
point 193
rise 403
climatic adaptation 28, 263, 334
factors 113, 143, 314, 319, 330, 403
climatologic conditions 144
climbing 436
corn rootstocks 73, 76
seed orchards 42
clump (sucker): management 290
cluster botrytis (grey-mold) rot 321
weight 322
cold temperature 28, 226, 417
collecting scions and bud wood 89
color change 196, 208, 300, 467
commercial maturity 192
nursery 104  
orchard 41, 117, 182, 457  
compatible graft 75  
complex natural ingredients 95  
compound or serpentine layering 69  
contact herbicides 158  
  non-selective 158  
  selective 158  
contaminant elimination 94  
contamination risk 217  
  with pathogens 7  
contour planting 129, 130, 132  
control fruit production 170  
cool-temperate crops 116  
  zones 28  
cotyledons 52, 108, 223, 261, 334  
crop husbandry 227, 285, 313, 336, 351, 365  
  maintenance 6  
  protection 15, 163, 272, 275  
cross pollination 42, 56, 177, 178, 180  
  -contamination 217  
  -incompatibility 177, 178  
crown rot 232, 296  
cultivar selection 416  
cut flowers 4, 5  
  test 53  
  -back stream 151  

(D)  
delayed foliation 415  
  or abnormal ripening 301  
depth of planting 103  
design parameters of furrow irrigation 150  
desuckering 288, 290, 291  
diaphorina citri 232  
diploid zygote 182  
direct germination test 51  
  -seeding 106, 107, 365  
  -sowing method 100  
disinfection 94, 208  
diurnal temperature 28, 29  
  -temperature fluctuations 29  
dormancy breaking 312, 417, 420  
  -development 416  
  -management practices 420  
dormant embryo 50, 51  
double dormancy 46, 50  
drainage 14, 86, 99, 100, 102  
drip irrigation 154, 155  
  -irrigation system 155  
  -or trickle irrigation 154  
drought and disease tolerance 281  
drupe fruits 32, 435  
dry seasons 156, 227  
dwarf deciduous trees 130  
dwarfed trees 130  

(E)  
earthing-up 293  
egg mother 59  
  -nucleus (diploid) 59  
embryo abortion 41  
  -culture media 95  
  -dormancy 46, 49  
  -sac (female gametophyte) 59  
embryogenesis 93, 96, 97, 98
employment opportunity 13
endocarp 30, 31, 32, 50, 364, 435
endodormancy 415, 416, 420
endosperm 38, 45, 182, 184
environmental factors 44, 113, 137, 226
epicotyl (Stone grafting) 83
epidermal layer 406
epigeous germination 103
ethylene dibromide (EDB) 208
gas 208, 369
treatment 33, 252, 300
evaporative capacity 205
evergreen fruits 27, 28
exised-embryo test 51
exocarp 30, 31, 32, 435
exotic pests 156
explant establishment 94
external contamination sources 8
extraction of fruit seeds 43

(F)
faqualitative apomicts 59
false codling moth 236
fruit 29
farmyard manure (FYM) 138
female flower 177, 182, 361, 364
flower cluster 459, 466
gametes 38, 177
inflorescence 459
or pistillate flower 310
spikes appear 463
stage flowers 329, 330
fertile seeds 451
fertilization (syngamy) 182
fertilizer application methods 140
application program 137
field crops 4, 6

layout 134
management 7
width and length 152
firmness 195, 197, 206, 422
nursery beds 102
firm firmness 195, 197
fruity fruits 43, 163, 206
mesocarp 364, 435
food irrigation 146, 147, 148
flower clusters 175, 176, 308, 309, 310
bud formation 171
pollination application 140, 141, 142
spray of nutrients 141
sprays 141
food safety 206, 209, 214, 215, 216, 217, 219
forced or pressure cooling 211
free radical scavengers 12
freeze-damage 29
freezing injury 211
point 50, 211, 212, 226, 473
fresh-cut 219
fruit damage 114, 456, 460
hazard 117, 283
-free growing season 28
fruit bud 85, 175, 176, 309, 470
bud formation 76
coloration 212, 252
growing 112, 113, 118, 119
maturation 191, 192, 263, 365
maturity determination 195, 196
nurseries 17
nursery site 100
or flower thinning 427
processing industries 13, 41, 42
setting 184, 351, 354, 427
thinning 118, 185, 392, 395, 459
-bearing branches 191, 392
fungal diseases 154, 160, 170, 350, 364, 410
furrow irrigation 152, 154, 155, 490
  length 149, 152, 153

(G)
genomic groups 281
genotype 42, 56, 72, 76, 490
germination blockage 49
  capacity 42, 53
  conditions 46
  controlling mechanisms 46
  inhibiting chemicals 47
  medium 45, 46
  of seed 99, 506
  percentage 45, 51, 103
  period 103
  process 45
  rate 44, 45
  stimulating chemicals 45
gibberellins 95, 418, 420
glyphosate 158
good agricultural practices (GAPs) 217
  -quality seed 41
graft union 73, 74, 75, 79
grafting and budding of fruit plants 108
grafting techniques 80
gray-mold rot 208
green color 208, 231, 337
  manure 102, 120, 384, 411
  manure crops 138
growing rootstock 77, 259
  seedlings 102
growth and development stage 139
  media 44
  rate 141, 255, 380
  -regulator treatments 63

(H)
hand-pollination 454
  thinning 186, 188, 392
hard seed 32, 41, 49
  seed coats 46, 49, 50
  shell 32, 240, 247
hardwood cuttings 62, 461, 466, 472
harmful chemicals 7
harvest and postharvest handling 191, 298, 323, 340, 355, 369, 385
harvesting and processing of seeds 42
techniques/methods 199
heading back method 172, 174
heat summation (degree-days) 324, 325
heavy metals 8, 371
hedgerow planting 130, 132, 393
herbaceous cuttings 64
  plant 64, 94, 359, 470
herbicide treatment 158
herbicides/weedicides 158
hermaphrodite flowers 347, 361, 364, 473
  type 361, 364
hesperidium fruit 32
heterostyly 179
hexagonal or Equilateral Triangular 128
  system 128
high-pressure 43
  temperature injury 226
  temperature seasons 226
highly chilling-sensitive 210
horizontal limbs 438
  stem 89
hormones and growth regulators 95
horticultural crops 10, 22, 201
horticulture crops 4
  sector 5, 6, 191
host pests 101
hot water scarification 48
hygiene 67, 216, 217, 218, 368
hypogeous germination 103

i-budding 87
imbibition of moisture by the seed 60
immature fruit 191, 196, 200, 338
in vitro culture systems 90
incompatibility 56, 73, 75, 177, 178, 345, 450
incompatible combinations 178
indeciscent fruit 32
indoleacetic acid (IAA) 62, 400
indolebutyric acid (IBA) 62, 69
inorganic fertilizers 15
--- mineral elements 94
--- salts 95
insect and disease 137, 171, 410
insect pest management 162
insemination 183
insects with biting mouth parts 162
interaments 39, 59
interclonal (intraspecific) grafts 75
interfamilial grafts 75
intermediate elevations 116
interspecific (intrageneric) grafts 75
interstock 73, 76
intra-generic (intra-familial) grafts 75
inverted T-budding 86, 228
iodine solution 198
irrigation depth 148, 151, 152
--- potential 113, 118
--- water 114, 116, 117, 118, 142, 143

--- juvenile characteristics 56
--- period 56, 57, 450
--- phase 56, 58, 60
--- plants 58
--- seedling 56, 58

landscape and nursery industry 10
--- designing 4
--- developing 10
--- gardening 10
large seed 48, 51, 103, 333, 449
lateral flower bud formation 419
--- inflorescence 127, 329, 347
layering 352, 391, 392, 449, 461, 472
laying out the field 133
leaf axillary 406
--- bud 61, 64, 65, 85, 175, 309, 439, 440
--- cutting 61, 64, 65
--- cutting propagation 64
--- spot (Leaf streak or Sigatoka disease) 296
--- bud cuttings 61, 64, 65
light exclusion 67, 68
--- penetration 171, 251, 431, 437, 443
--- processing 208, 209
linearized endocarp (pit or stone) 435
long cane pruning 318, 319
low moisture content 44
--- chilling cultivars 420
--- lying sites 113
--- temperature stratification 49
machine-harvested fruits 205
macro- and micronutrients 94
macronutrients 142
maidens 286
main/primary bud 308
maintenance pruning 170, 339
male and female flower-heads 463
and female flowers 177, 364, 459, 461, 463, 466
and female-stage flowers 330
and hermaphrodite flowers 347
flower 177, 182, 279, 284, 331, 332, 360, 458, 459, 460
flower cluster 459, 466
gametes 38
or staminate flower 310
spikes appear 463
spikes drop 463
stage 329, 331
manure 83, 102, 120, 354
matted row system 408
maturation of fruit 191
mature green 199, 200, 403
green stage 298
or ripe fruit 199
phase 58
scion 56, 58
-green fruit 403
maturity and ripening 42
maximum storage life 213
mechanical abrasion 47
damage 191, 202, 203, 206, 298, 402
dormancy 47
injury 7, 201, 202, 203
injury stress 201
scarification 48
thinning 186
medium-sized seed 103
meristem-Tip elongation 91
mesocarp 30, 31, 32, 348, 364, 435, 441
metabolic processes 44
stress 201
meteorology 113
methods of budding 86
of fruit cooling 211
of grafting 78, 81
micro propagation 89, 90, 91, 92
microbial damage 201
hazards 215, 216, 217, 219
micronutrients 94, 95, 407
microorganism residues 214
microorganisms 47, 168, 202, 215, 218
minimally processed 215, 208
processed fruits and vegetables 215
minimum temperatures 363
mitotic cell division 55
moderately chilling-sensitive 210, 212
modification of storage atmosphere 44
moisture-conserving material 136
- holding capacity 145
monocarpellary 30
monocarpic 281, 282, 376
monoecious 367, 465, 466, 501
monoembryonic cultivar 349, 351
seedlings 349
trees 349
morphological characters 280
mother cell 55, 59
plant 39, 55, 59, 66, 70, 89
plant system 408
mound (stool) layering 70
mulching 137, 168, 169, 289, 384, 412
multi-carpellary 30
multiple (composite) fruit 30
fruit 376, 377, 392, 464
mycotoxins 7

(N)
naphthaleneacetic acid (NAA) 62
nematode or phylloxera 313
-free nursery 162, 250
-infected roots 161
non-chilling-sensitive fruits 212
non-climacteric fruit 33, 192, 194, 423
non-perishable 213
non-selective contact herbicides 158
normal intermediate temperature 212, 211
nucellar budding 59
embryo 60, 269
embryony 59, 60, 228, 264
seedlings 40, 349, 276, 351, 352
number of clusters per vine 322, 323
nursery pest management 108
production 109
trees 85, 337, 422
media 94
nutritional and medicinal values 10

(O)
obligate apomicts 59
optimal ripening stage 323
temperature 226
optimum commercial maturity 192
moisture level 43
quality 303, 341
seed density 103
storage temperature 210, 213, 356

( P )
packaging and handling methods 204
material must 209
paradormancy 416, 417
paradormant (temporarily dormant) 417
parenchyma cells 74, 75
parthenocarpy absent 278
pathogen-free water 216
pathogenic microorganism 205
organisms 160
seed discoloration 301
seeders 286, 288
perishable fruit 203, 210, 214, 462
perseperm 39
pest management in orchards 155
pests 31, 383, 389, 397, 453, 454
phloem 73
photochemical reactions 45
phyloclonitis citrella 239
physical dormancy 47, 50
    weed control method 157
physiological conditions 46, 49, 68
pigment synthesis 208
pistillate flowers 179, 310, 362
pit and superficial scald 428
planned tree density 131
plant diseases 156, 159
    diseases management 159
growth regulators 94, 319
nutrients 137, 139, 290
regeneration 91, 94
tissue culture 91, 94, 96
planning board 135
plastic mulch 168, 409, 410
    sheets 168, 169
Polarity in grafting 74
pollar nuclei 39
pollen contamination 42
    grain 39, 114, 177, 178, 401
    source 180, 181
tube 27, 38, 178, 345, 348
pollination management 177, 180, 181
polyembryonic seed 349, 351
    seed embryos 349
    species 265, 267, 269
Polyembryony 60, 228, 497
pome fruits 29, 32, 56, 186, 414, 416, 431
postharvest crop management 204
    disorder 301, 137
    environment 204, 206
    factors 201, 253
    handling operations 202
    life 210, 462
    management 6, 204, 220
    management practices 204
practices 253
quality deterioration 192
spoilage 156
technology 13, 191, 219, 413
treatments of fruits 206
post-zygotic abortion 363
potting soils 105
pre- and postharvest factors 253
pre-and-postharvest environmental factors 47
pre-climacteric life 298
pre-cooling technique 211
pressure (forced air) cooling 211
pretransplant 94
prevention of contamination 215
processing of fruits 214, 213
production of carbon dioxide 33
    technology 17, 54, 98, 304
propagation by cutting 61, 66, 313, 366
    by layering 66
    by runners 89
    structures 104
    techniques 17, 72
propagules (crowns and suckers) 377
propping (provision of support) 292
protandry 179
proteoid roots 474
protogyny 179
proximal end 66, 74
    inflorescences 347
pruning (clump management) 290
    method 317, 318
pseudo-stem 278, 299
pseudoterminal position 329
516 FRUIT PRODUCTION IN ETHIOPIA

(Q)
quality nursery management 111
of irrigation water 117
seedling production 111
tree production 111
quarantine 159, 245, 368
quincunx or diagonal planting 128
planting 128, 129, 132, 133

(R)
raised nursery beds 102
raising seedlings 102, 100, 105
rate of respiration 32, 33, 193
ratio of soluble solids/acidity (TSS/TA) 232
ratapon crop 291, 376, 382
sucker 291
raw material source 13
rearing and sterilization 164
rectangular planting system 127, 393
recurrent apomixis 59
refrigerated stratification 49
rejuvenation 67, 68, 170
pruning 170
repair grafting 82
reserve buds 308
respiration rate 192, 193, 195, 252
raises 193
rest-breaking chemicals 418
ring (girdle) branches 354
ripening of fruit 192, 194
patterns 192
temperature 213, 356
root cuttings 61, 65, 66, 464
feeders 163
suckers 439, 472
rooting medium 64, 65, 69, 493

(S)
stock cultivar 60, 78, 424
fidimentary leaves 308, 309
flower 89, 405, 406, 407, 408, 409
flower-bearing plant 89
flowers or stolons 406

(hab 340, 431, 443
harification 47, 48, 50, 249
stock-stock (shoot-root) relationships 76
cultivars/varieties selection 120
stock-stock combinations 57
sterophyllous leaves 474
second dormant period 347
seed bed 44, 106, 107, 400
coat dormancy 46, 47, 50
germination 44, 45, 47, 261
germination chamber 44
germination inhibitors 47
imbibition 45
layers 50
maturation 47
propagation 102, 259, 456, 458
storage 43, 47
viability tests 50
seedless grapes 311
seedlessness 27, 41
seedling rootstocks 73, 77, 429, 436, 464
clonal seed orchards 42
selecting fruit cultivars 119
self-fertile 180, 182, 421, 445
self-fruitful or self-pollinator 181
varieties 181, 182, 310
self-fruitfulness 177, 179
self-incompatibility 177, 178, 450
reaction 178
self-incompatible mechanism 328
stream size 148, 149, 150, 151, 152
structural or physiological conditions 46
stylar end breakdown 267
subepidermal vascular 301
subfreezing temperature 29
sub-optimal temperature 212
sub-surface drip 146
sub-terminal buds 328
subtropical fruit 29, 116, 222, 353, 390, 414
fruit crops 116, 390
regions 29, 417, 471
subtropics and tropical regions 222, 471
suckers 424, 429, 439, 458, 472, 473
sucking or rasping mouth parts 163
sugar-acid ratio 198
sunburn (Sun-Scald) 109, 167, 294, 336, 381, 385
sunken nursery beds 102
sun-Scald 385, 378
surface irrigation 107, 121, 145, 146, 150, 153
swarming 156
sword suckers 286, 287, 288
systemic non-selective 158
or translocated herbicides 158
selective 158
(T)
t-bud method 86
t-budding 86, 87, 228, 436, 449
temperate climate plant 306
climates 27, 405, 452
fruits 29, 414, 415
-zone regions 29
temperature point 44
temporary field storage 202
storage 111
terminal and lateral shoots 438
and sub-terminal buds 328
bearing habit 175
bud formation 418, 419
growing point 281
vegetative bud 328
tetraploids 281
tetrazolium tests 51
thinning out method 173, 174
tip layering 68
tongue approach graft 79
topography 113, 126, 144, 288, 315
total soluble solids content 258, 323
totipotency 55
training and pruning 125, 170, 316, 339
and pruning of fruit plants 170
transpiration and/or metabolic changes 202
transplant (pricking) method 107
transplanting to permanent location 109
trellising and training 314, 315
trench layering (etiolation method) 70, 68
triangular planting 128, 132, 134
triphenyltetrazolium chloride (TTC) solution 52
triploid 138, 182, 281
tropical fruit crops 116
fruits 28, 43, 70, 116, 209, 212, 350
regions 390
true sexual (zygotic) embryo 349
xerophytic 378
trunk and scaffold system 170
TTC test 52
turning color 251, 394
stage 394
self-infertile 180
self-pollination 180
self-sterile cultivars 426
self-sterility 445
self-unfruitful 450
or self-sterile 181
varieties 181, 182, 310
(self-incompatible) 445
semi-dwarf rootstock 429
semihardwood cuttings 62
semi-perishable 213
sepal 31, 397
sexual and vegetative embryos 59
propagation 38, 39, 40, 41
reproductive processes 59
seedlings (off types) 349
shallow furrow 150, 151
root system 406, 469
-rooted crops 146
shape and spacing of furrows 150
shelf-life 6, 204
shoot elongation 95
short cane pruning 318
day (SD) cultivars 405
postharvest life 210
-lived seeds 44
shrivelling and mechanical damage 191
grafting 79, 80, 352, 391, 449, 451
dressing 141
simple layering 69
single carpel 32
size and growth habit 76
soil culture system 157
softening 47, 48, 192, 341, 369, 428
softwood cuttings 63, 65, 391
soil and air temperatures 124
and water conservation 14, 477

characteristics 116
erosion 14, 117, 122, 149, 151, 157
medium 45
microorganism 47
moisture storage capacities 145
texture 115, 148, 149
wind erosion 123
borne diseases 108, 352
somatic cells 93
embryos 93
sperm cell 182
nucleus 39, 196
splice grafting 78, 94, 366
spliced approach graft 79
sprinkler and drip systems 146
irrigation 153, 247, 425
irrigation system 155
method 153
germination rate 317
stump pruning 317
stump softening 47, 48, 192, 341, 369, 428
soil and air temperatures 124
and water conservation 14, 477

INDEX 517

stigma interaction 178
stimulative parthenocarpy 27
stock and scion 72, 78, 79, 81, 88, 254
stolon 89, 406
storage and marketable 195
conditions 44, 203, 215, 469
life 191, 210, 213, 298, 356, 403, 412
stratification temperature 49
(U)
unfruitfulness in fruit plants 176, 177
unisexual flowers 177
plants 177

(V)
vascular bundles 406
vascular tissue 75, 158, 411
vegetative buds 84, 417
division (suckers or corm) 285
methods 55, 58
or asexual 55
parthenocarpy 27
propagation 55, 62, 89, 228, 285, 336, 402
propagation methods 227, 261, 352, 391
propagation techniques 72
vertebrates 155, 165
vigorous rootstock 78, 429
virulent pathogens 159
virus free rootstocks 42
-free nursery 411
v-shaped furrows 150

(W)
warm-temperate 28, 116
water suckers 286, 287
-core 428
watersprouts 438
wavelengths 45
weather conditions 113, 166, 233, 355, 367
wedge grafting 79, 80, 352
weed control methods 156, 157, 159
control program 156
management 156, 159, 289
whip grafting 78, 80

(Z)
zygote 38, 39, 59, 182
zygotic (sexual) seedlings 260
embryos 93, 269

wind damage 122, 283, 292, 336, 469, 474
pollination 459
windbreak trees 115, 125
windbreaks 108, 109, 120, 122, 227, 284
winter chilling 29, 49, 415, 445
chilling temperature 436
worker hygiene and sanitation 217
wound induced roots 61

(X)
xanthophylls 208
xerophytic characteristics 474
xylem 67, 73

(Z)
Production plays an important role in the livelihoods and food and nutritional security of Ethiopia. In recent years, in Ethiopia, the nutritional value of fruits is getting better recognition at large and their inclusion as part of the regular diet is increasing significantly. Fruit production requires mastery of both the art and science of this discipline. To successful and sustained production of good quality fruits, a good understanding and of appropriate knowledge, skills and management practices of various fruit crops is this end, scientific fruit production and management guides and textbooks are important. There is a considerable need for such resources in Ethiopia and this book is fill the prevailing information gap in the country.

Fruit Production in Ethiopia is organized into 19 chapters. The first chapter introduces definitions and divisions of horticulture; the importance of fruits and fruit crops; the problems of fruit production in Ethiopia; and the classification of fruits and fruit crops. The second and third chapters, cover the sexual (generative) and asexual (vegetative) propagation of fruit crops, respectively. The principles and practices to be followed in the establishment and management of nursery and orchard are addressed in chapters four and five, respectively. Chapter six deals with harvesting and post harvest handling of fruits, while chapters seventeen cover individual fruit crops: citrus, banana, grapes, avocado, mango, papaya, Java, passion fruit, strawberry, pome fruits (apple and pear) and drupe fruits (peach). Chapter 19 focuses on a brief description of some of the economically viable and yet underutilized fruit species in Ethiopia. In the end, glossary of technical terms, nutritional information, fruits and an index are included as appendices.