PRODUCTION AND MANAGEMENT OF MAJOR VEGETABLE CROPS IN ETHIOPIA

VOLUME I

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Cover Pictures: Cabbage, carrot, shallot, tomato and garlic from Holetta, Melkasa and Debre Zeit agricultural research centres respectively.
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Foreword

In Ethiopia, the technique of growing vegetables has undergone a marked change since the inception of the national agricultural research system in the 1960s. In fact, it is worth mentioning that applied research on wide arrays of vegetable crops were given top priority and put in observation trials initially at DebreZeit Agricultural Research Center (DZARC) on a better status than the commodities such as cereals and pulses over six decades back. However, the efforts made since then did not make significant achievements as compared with other crops of national and global interest.

The increased population of the country has led to a new awareness of the importance of vegetable crops as source of food accompanied by the realization that many of them can supply essential nutritional and medicinal materials, which may not be readily available from other sources. In spite of the great advancement in ways and means of growing vegetable crops and for knowledge available, the most important factor is the growers themselves. In order to improve their livelihoods the growers must have first a thorough and all-rounded knowledge and practical experience on production and management of horticultural crops in general.

This book provides a comprehensive account of the principles and practices currently in use in the production and management of vegetable crops. Hence, it is unequivocal that development agents throughout the country can use the publication as practical guide to perform their core responsibilities effectively and efficiently.

Further private and commercial growers can appreciate the potential that exist for increasing the production of vegetables in the country. The availability of this book is significant at this particular time when the government is preparing to launch the Second Growth and Transformation Plan and where the horticulture sub-sector is recognized as playing vital role in intensification, diversification, and expansion of vegetable crops production. It also is commensurate with EIAR’s spearheading the national research undertakings to enhance the growth and development of the sub-sector and to promote effectively sustainable competitiveness in the global markets.
Finally, I would like to express my heartfelt appreciation and gratitude to KOPIA, Korean horticultural research scientist group for the initiation, preparation and sponsoring of the printing of the book and to all contributors as well. Without their concerted efforts, the production of this publication would have not been possible. EIAR is encouraging and supporting national and international research staff to do more of this kind of undertakings and related duties with enthusiasm, courage, and professionalism.

Fentahun Mengistu (PhD)
Director General, EIAR
Preamble

The Korean Project on International Agriculture (KOPIA) Ethiopia-Center is sponsored by Rural Development Administration (RDA) in Korea. Because of the already strong bilateral relation between the Federal Democratic Republic of Ethiopia and the Republic of Korea and because of the existing political stability in Ethiopia, the Government of Korea has considered Ethiopia potential country in establishing sound collaborative development program in the horticulture sector. Ethiopia with its very high agricultural potential only requires financial resources. KOPIA gave its consent for the project to under way and affirmed its willingness to avail experienced research personnel to participate in the adaptation process of Korean new technologies.

With that background, the KOPIA Ethiopia Center was established in April 2011 with its Head Quarters at the premises of Ethiopian Institute of Agricultural Research in Addis Ababa. The Project has specific activities that are duly approved and recognized by the Government of Ethiopia with EIAR as the coordinating office. Currently, the KOPIA Project activities are being undertaken at some federal research centers that include DebreZeit, Holetta, Melkassa, Kulumsa, and Wendogenet. More centers will be considered in the near future.

The primary objectives of KOPIA - Ethiopia Center are briefly mentioned. These are:

- To provide training, production management and development of technologies on various vegetable crops that include high value tomato varieties, hot pepper, onion, garlic, shallot, carrot, and cabbages;
- To establish farm-research to create strong organic linkage through network between research, development and extension activities;
- To introduce and develop Korean vegetable varieties for adaptation at different agro-ecologies;
- To provide training to EIAR researchers on vegetable cultivation, breeding and to farmers, the basics in vegetable production and management technologies;
- To improve and diversify high quality vegetable crops production in Ethiopia by sharing the Korean knowledge and experiences as depiction of the stated slogan i.e. “We love to share what we have ex-
experience". Indeed, the publication of this book, in such very short time, would justify it true, and in due course would help to develop strong aspiration for continuous efforts in this regard:

- To enhance adaptation, optimization and evaluation of Korean food recipes; and
- To organize field visit for researchers, administrators, and policy makers to demonstrate the progress made and thereby enhance and strengthen the growth and development plan of the horticulture sector.

I believe it is worth mentioning that this project will justify the intent for strong commitment of the government of Korea for its strong participation in the efforts of the Second Growth and Transformation Plan of Ethiopia. Hence, in an effort to strengthen the research endeavor of EIAR, KOPIA will focus more on introducing seeds of elite varieties of vegetable crops for adaptation trials at different centers or agro-ecologies. The result observed so far is very much encouraging. KOPIA has taken this as incentives to strengthen its activities. KOPIA is also interested to assist in food recipes through field demonstration so that the adaption of more Korean vegetable foods as supplement to the cereal based local staple food, which is low in nutritious values. So far, several demonstrations have been done with organoleptic panelists in food tasting and quality assessment of it. We noticed that the people we are acquainted with or participants are always eager to learn new styles of food preparation with vegetable crops. This kind of training will continue.

Included in this book are technologies developed by EIAR researchers, which are designed to help vegetable farmers improve their cultural and improved management practices of vegetable production towards developing sustainably improved livelihood of farmers. I am very grateful for their contribution. It is with utmost pride and deep satisfaction that the names and addresses of all contributors are included in the last page of the book. The support of EIAR’s management is also highly appreciated and duly acknowledged.

Finally, I would like to extend my sincere gratitude and heartfelt appreciation to the Rural Development Administration, South Korea for the financial support that made the publication of this book possible.

SeongSook Han (PhD)
Director, KOPIA Ethiopia Center
1. Introduction

Tomato (*Lycopersicon esculentum*) belongs to the *Solanaceae* family. The Central and South America are the origin and diversity of the crop. It became distributed to Europe and Asia in the early and mid-1960s. The crop spread via traders to Egypt, Sudan, South Africa, West Africa and to the rest. The different varieties of tomato vary in shape, size, and color. It varies from small cherry like, fresh market and processing types. Tomato is served raw, baked, stewed, fried, and processed to pickles, sauce, juice and concentrated pastes. It is an excellent source of vitamin C, biotin, molybdenum, vitamin K, vitamin A (in the form of beta-carotene), vitamin B₆, vitamin E, foliate, niacin. It is also a good source of protein, chromium, pantothenic acid, molybdenum, choline, zinc, and iron.

Tomato is grown on more than 5 million ha in the world with a production of about 129 million tons (FAO 2000). China is the world's top tomato growing country, accounting for more than 25% of the world's tomato acreage. Egypt and India together account for more than 20% of the world total; Turkey and Nigeria are the other major tomato producing countries. Asia and Africa account for about 79% of the global tomato production area, with about 65% of the world output (FAO 2008). The crop is an important cash-generating crop to small-scale farmers and provides employment opportunity to many individuals in the production and processing industries.

In Ethiopia, according to the Central Statistics Authority the total area under rain-fed tomato was estimated to be 7237.35 million hectares with 555,142.79 tons of fruits (CSA 2013/14). However, farmers have started producing tomatoes under irrigation and reported better yield.

Tomato covers only 3% of the total vegetable production area. However, the overall productivity of the crops is very low compared to the results obtained at the research centers and experiences of other countries.

Because of its multiple harvesting opportunities and high nutritious values, the demand for tomatoes is very high. Hence, the information in-
cluded in this book would be very helpful since it has a thorough coverage about the production of healthy seedlings, proper types of fertilizers, time and rate of application, use of recommended chemicals to control diseases and pests.

2. Climate and Soil

Tomato requires warm, clear, dry conditions and altitudes ranging between 700 and 2000 meter above sea level. The optimum temperature for seed germination ranges between 18 and 24°C and the maximum 30°C and minimum 8-11°C. However, if temperature increases up to 35°C, germination percentage will decrease. After transplanting, it needs optimum day temperature of 25-28°C and 15°C optimum night temperature. At temperature over 30°C, fruit enlargement and color development are affected markedly. Poor fruit set and poor quality seed occur if the maximum day temperatures exceed 38°C for 5-10 days before anthesis and 1-3 days following anthesis. At 10°C or below it is highly likely that large percentage of flowers will abort.

Light intensity has also direct effect on the carotene content of the fruit. Hence, plants growing under strong light intensity have high carotene content as compared to plants growing under shade or weak light intensity.

Tomatoes can be grown on well-drained soils. Loams, sandy loams and silty loams are preferred to light soils under long growing season for high production. Sandy soils are preferable if early harvest is desired. The favorable pH level ranges between 5.5 and 7.0. At higher or lower pH levels phosphorous and certain micronutrients (Fe) become less available for plant uptake.

3. The Crop

Based on its growth habits, Tomato can be classified into three major groups. These are recognized by the arrangement of the leaves and the inflorescence on the stem as:
Indeterminate growth
This is a continuous type of growth habit of the main and side stems. The number of leaves between inflorescence is more or less constant, starting from a specific flowering set. Varieties of indeterminate growth are usually grown as greenhouse or staked tomatoes.

Determinate growth
This is another type of growth habit of the tomato plants where the main and side stems stop growth after a specific number of inflorescences that varies with the specific variety.

Semi-determinate growth
Plants in this category show branches that stop growth with an inflorescence; but this usually occurs at an advanced growth stage. Varieties in this group are usually grown as out-door and non-staked tomatoes.

The flowers of the tomato plant are generally borne in clusters of 4 to 8 but small-fruited types may have 30 to 50 flowers per cluster. The flowers are mainly self-pollinated by the wind. The fruits have 2 to 18 locules (chambers or sections).

3.1. Varieties
Through the years of research, undertakings fourteen varieties have been released and disseminated to farmers. Four of these varieties are processing types while ten are for fresh market (four determinate and six indeterminate) types. They are open pollinated varieties that fit to the different production systems. Most of these varieties are popular among the farming communities especially in the Central Rift Valley (Table 1). Furthermore, twelve hybrid tomato varieties are imported through different companies. They are registered and recommended for production (Table 2). Some of these hybrids have become very popular and widely under production.
4. Nursery and Field Management

The general management of tomato production consists of nursery management and field management. These are discussed as follows.

4.1. Nursery management

4.1.1. Seed source and rate

In the production system of any crop, it is advisable to use certified seeds. However, certified seeds are mostly not readily available in many cases. Thus, farmer’s particularly vegetable growers either obtain seeds from local market or extract their own seeds from categorically rejected fruits in the previous harvest. Seeds purchased from the local market and traditionally extracted seeds are not reliable. They are attacked by seed-borne pathogens and are the primary cause of the disease in the nursery. It is therefore, advisable to purchase seeds from known source. The seeds should be treated with recommended chemicals prior to sowing in order to protect the seeds both from seed and from soil borne pathogens.

Depending on the size of the production field, it is essential that enough seedbeds or cell trays or containers are prepared. About 250-300 g seeds with over 90% germination potential is required for one hectare depending on the method one chooses to raise the seedlings. Seedlings raised on cell trays saves seeds than raising it on seedbeds. Seeds are sown to 1-2 cm depth with 15 cm between rows. However, growers commonly use high seed rate per seedbed to secure maximum seedlings that can be used for gaping in case transplanted seedlings failed to establish in the fields. Using high seed rate has the following drawbacks:

a) Creates overcrowding of seedlings and restricts aeration;

b) Crowded seedlings create competition;

c) Seedlings become weak, lack stem strength and develop poor root system;

d) Create favorable conditions for growth and development of the pathogens. Crowded seedlings easily transmit diseases;

e) Infected seedlings die either in the seedbed or after transplanted; and become potential source for diseases transmission.

Thus, using recommended seed rate per unit area of land and sowing same in rows is an important management practice.
4.1.2. Methods of raising seedlings

Planting seeds directly in the field is not the common method in the production of tomato. Such method cannot ensure full plant stand as 100% germination is highly unlikely to happen in the field and become impractical to apply gaping. Further, germinating seedlings are very tender and cannot withstand the high temperature in the open field and hence become very difficult to provide full protection to the young plantlets in the field. The high cost of seed, time and means required to protect the young plants in the entire field and the frequently low germination rate make the procedure impractical. Therefore, the production of seedlings in seedbed or in a controlled environment for subsequent transplanting into the field is most recommended procedure that is normally used. The different methods of seedling production are described in brief.

Raised seedbeds
They are normally 15-20 cm high. More applicable during rainy seasons in order to avoid flooding and facilitate drainage and in areas with poorly drained soils (clay soil).

Sunken seedbeds
Have about 15-20 cm. depth; applicable in dry seasons and well-drained light soils.

Flat seedbed:
Used where the land is level with adequate drainage system.

4.1.2.1. Seedbeds

It is prepared as follows:-

a) Prepare seedbeds with recommended dimensions (1 m x 5 m or 1 m x 10 m);
b) Sterilize the bed using heat (burning straw on beds) or the recommended chemicals to kill weed-seeds, insect and pathogen (damping-off), cover beds with black plastic sheet for a week;
c) Incorporate well-decomposed compost or farmyard manure and add fertilizer as per the recommendation;
d) Make furrows at recommended spacing and depth;
e) Sow the seeds evenly on the seedbeds; cover the seeds lightly with fine soil;
f) Spread a thin layer of straw-mulch on the seedbed; and
g) When the seedlings emerge, remove the mulch.

**Thinning:** Provide a 5 cm spacing between plants within the row. Thin out the excessive plants. This is usually done within two to three days after the first true leaves have appeared.

4.1.2.2. **Tray method**

The method involves raising seedlings in trays in a shelter place, especially during unfavorable conditions. It provides convenience to transport the young seedlings to the fields located at distant place. The method is prepared as follows.

a) Use 10 to 12 cm deep plastic or wooden boxes;
b) Prepare the growing medium using a mixture of soil, forest soil, sand and compost with 5:3:1:1 ratio, respectively, for most vegetable crops use well-decomposed and sieved compost to facilitate the emergence of seedlings;
c) Sterilize the growing media-mixture by heat or chemical as mentioned in the seed-bed method;
d) Fill the tray with the mixed media;
e) Sow seeds in 0.5 to 1 centimeter deep furrows;
f) Mulch with fine straw or other materials; and
g) Inspect seedlings daily and apply recommended control measures against serious disease and insects.

4.1.2.3. **Container method**

This method involves raising seedlings in separate pots or containers to provide adequate nutrients and growing medium for healthy root development and seedling growth.

The pot-grown seedlings would have a 100% establishment rate in the field since they are transplanted with the medium-root block. This pre-
vents injury to the roots and the seedlings do not suffer from transplanting shock.

Containers made of biodegradable material such as rolled banana leaves, or other locally available leaves or thin plastic pots 5 to 6 cm wide are generally used. All containers or pots must have a hole at the bottom/base for drainage purposes.

In this method, sterilized growing medium used in the flat or tray method can be used. The procedure is as follows.

a) Sterilize the medium;
b) Sow two to three seeds per pot;
c) Cover the seeds and irrigate gently with watering can;
d) Mulch with proper material;
e) As one to two true leaves appear, thin-out excess seedlings, keeping only one seedling per pot; and
f) Prick out the excess seedlings.

4.1.3. Fertilizer

Incorporating well-decomposed manure is essential for good seedling production. The amount of fertilizer to be applied on seedbed depends on the fertility of the soil. About 100 g Urea is applied at thinning (at first true leaf stage) time to enhance growth. The fertilizer is worked under to facilitate absorption.

4.1.4. Irrigation

Water is applied frequently with a watering can. Application could be changed to flooding when seedlings reach 5 to 8 cm high. It should be watered with a fine spray of a sprinkling can or with garden hose. Water dashed on seedbed through a hose with large size washout the seeds. The seeds bed neither should be allowed to dry out, nor should be kept soaked; but sufficient water should be applied only to keep the soil wet enough. It is important to keep the soils moist until the plants are well established. Keeping the surface wet or over watering is favorable for damping off diseases. Watering is preferred in the morning or late in the afternoon, but not encouraged in strong sun.
4.1.5. Seedling protection

Damping off (*Pythium* spp, *Phytophthora* spp.) is the most common seedbed disease in the tomato. These soil-borne fungi are common in tomato fields. At pre-emergence, the disease decays germinating seed before it pushes through the soil, and causes poor seedling stand even with seeds of high germination capacity. Whereas, at post-emergence, the fungi affect seedlings to shrivel and wipeout the entire plant unless control measures are practiced. Excess amount of moisture, dense seedlings, excess amount of nitrogen, carelessly handling of plants and the presence of weeds favor damping off disease. The use of seed protective chemical treatments, burning straws on seedbed and solarization of seedbed for about a month are believed very effective in reducing the incidence.

4.1.6. Hardening seedlings

It is important that seedlings should be hardened before transplanting to the field in order to enable them withstand the hot (harsh) field conditions. This should be done by reducing the frequency of watering and allowing the soil to low moisture status when it is ready for field planting. Withholding irrigation water for two to three days before uprooting the seedlings from seedbed facilitates the removal of transplants.

4.2. Field Management

4.2.1. Site selection

The field site for the production of tomatoes should be carefully selected. Sites with slight to moderate slope are ideal for tomato production. Such sites facilitate and avoid poorly drained fields. Therefore, draining excess water out of the field is unequivocal.

The location of the tomato field should be far away from related plants such as the tobacco, potato, pepper, and eggplants because they have common disease and pest problems. Moreover, it is important that the site selected should not have been used for the production of these crops in the previous season.
4.2.2. Field preparation

Plough the land thoroughly to a depth of 25 cm for at least three times. The first plough should be done immediately after harvesting. This helps to incorporate weeds and other stubbles into the soil. The second plough should be done a month after the first. This is done to break clods and to level the field. A third time plough is essential to ensure a smooth-level-field for transplanting. Manures and fertilizers are applied and covered with the last ploughing. Ridges and furrows should be formed now at the recommended spacing.

4.2.3. Seedling transplanting

Tomato seedlings would be ready for transplanting in the field when they are 12 to 15 cm tall (pencil size) or at three to four true leaves stage, which is roughly 28 to 35 days in the nursery beds.

If seedlings are to be transplanted under hot and dry weather conditions, it is important to harden them by stopping irrigation three to four days before transplanting. This would help to minimize or reduce seedling mortality in the field. However, care should be taken not to over harden seedlings since it slows down plant growth in the field. Hardening by root pruning is suggested for over-aged seedlings to minimize transplanting shock.

Transplanting seedlings is done by pulling them carefully from the seedbed using shovel or fork or other convenient tools. This method ensures that all the roots remain intact. It is not advised to pull up plants by hand. This can easily damage the root system, particularly the adventitious roots. Cover the uprooted seedling with wet materials, preferably sacks to keep the roots moist and put them in a cool place under shade until ready for transplanting. If hot weather condition persists, wet only the roots. Transplanting is done by choosing healthy seedlings.

Once the seedlings are removed from nursery, they should be transplanted immediately. If the roots are long and extensive, shorten them with a sharp knife and trim off some of the leaves. Long roots do not fit well in the transplanting holes and with too many leaves; transpiration might be higher when the plant is short of water supply. A day before transplanting, depending on the spacing requirement of the crop, prepare the holes in the field and irrigate. Great care should be taken to position the roots
properly while placing the plants into the holes. Bending the roots upward should be absolutely avoided.

In hot area transplanting should be done late in the afternoon. This would give the seedlings the cool night hours that will help the roots to recover and allow them to take up enough soil moisture for the following hot day. In cooler areas and cloudy days transplanting can be done at any time of the day. Watering adequately is a requirement after transplanting.

The soil should be well pressed after transplanting. Irrigation should be applied immediately to establish good root-soil contact. Proper planting of seedlings increase yield greatly as compared to the traditional way of planting with bending the root systems which affects or delays the normal growth of plants and reduce yield.

4.2.4. Spacing and plant population

Plant population and spacing are important management practices that greatly influence yield and quality of tomato fruits. The distance between plants and between rows depends on the methods and purpose of production, soil fertility, plant structure, vine types and farm equipment. Transplanting tomatoes at the recommended spacing between rows and between plants is 100 cm and 30 cm, respectively.

4.2.5. Irrigation

The tomato plants have high water requirement throughout the growing period until fruiting occurs. Water is often required during dry season. The plants are resistant to moderate drought. However, proper management is essential to assure high yield and quality. About 70% of the root system is in the upper 20 cm of the soil profile. Therefore, a drip irrigation system equipped with a fustigation device is advisable. Water requirements will differ at various growth stages. The requirement increases from transplanting until beginning of fruit setting; reaching a peak during fruit development and then decreasing during ripening.

The tomato fruit contains 90-96% water. Insufficient water during flowering and fruit development leads to flower and fruit drops, blossom end rot, physiological disorder and subsequently low fruit yield and quality. On the other hand, excessive irrigation will create anaerobic soil conditions and consequently cause root death, delayed flowering, and fruit dis-
orders. Therefore, proper irrigation water management at different developmental stages (seedling, vegetative growth, flowering and fruiting) is the most important practice to be considered for high quality fruit production. Furrow irrigation system is the most common practice used by farmers in the country; but it is poorly managed due to lack of experiences/skills.

Fields should be irrigated if there are signs of wilting at midday, when stressed plants are likely to make a slow recovery after drought injury. Irrigation should be done to maintain uniform soil moisture to promote uniform growth and fruit setting. Furrow irrigation is recommended to be applied early in the day so that the field is dry before nightfall. Irrigating late in the afternoon and over irrigation creates favorable conditions for disease infection especially ‘root rot’ diseases. Drip irrigation system is becoming important for efficient use of water and for the production of high quality fruit yields.

4.2.6. Fertilizer

Plants do require adequate amount of nutrients in order to produce high yield of good quality. Addition of cattle manure/compost just after harvest during the first plough helps to increase soil organic matter content and maintain soil fertility.

The demands for nitrogen, phosphorous and potassium are high, and fertilizer containing these nutrients should be applied before planting, with the amount of nitrogen less than that of either phosphorous or potassium. However, soils known to be high in residual nitrogen should also be avoided to prevent the crop from producing excessive foliage at the expense of fruit.

In Ethiopia, the easily available inorganic fertilizers were phosphors in the form of di-ammonium phosphate (DAP) and urea. DAP at the rate of 200 kg/ha was recommended to be applied after the field has been levelled and should be mixed well with the soil. According to the research recommendation, application of 100 kg urea per hectare provided good results applied in two splits as side dressing. The first half applied in the early growth stage of the plant at 15 – 20 days after transplanting. The second half applied later at the second cultivation. However, the actual amount of fertilizer to apply depends on soil fertility, fertilizer recovery rate, soil organic matter, soil mineralization of N and leaching of N ferti-
lizer. Ideally, it is wise to conduct soil fertilizer trials to determine the optimum fertilizer rate for a given area.

4.2.7. Cultivation and weeding

Weeding is an unavoidable task in tomato production. Hand hoeing and cultivation is needed to control weeds. Cultivation of vegetable fields 2-3 times during plant growth period is highly advantageous. It avoids weed competition with the crop for nutrients and sunlight. It has been found that cultivation provides effective aeration in the root zone and enhances plant growth and fruit development.

4.2.8. Staking and pruning

Plant support (staking) is an important practice for tomato production. The short set processing types that are hard skinned could be produced without support. However, all fresh market types should be provided with support or mulch to produce clean and healthy fruits for the fresh market. Staking is done with a pole placed about every one meter along the row and supported with horizontal trellises of two to three wires at 20 cm above the ground and between the wires. The plants are tied to the wires with fine ropes. This is commonly used in tomato production by small-scale farmers using different local materials such as bamboo and eucalyptus.

4.2.9. Mulching

In addition to staking practices, mulching un-staked tomato plants with grass straw is also a common practice by the farmers. Mulching can reduce fruit losses by protecting the fruits from direct contact with the soil. It also suppresses weed growth; helps soil and water conservation and improves the root environment for better growth of tomatoes.

5. Major diseases

The tomato is subject to attack by wide range of diseases that affect roots, leaves, stem, and fruits. The most important diseases are fusarium wilt, bacterial wilt, bacterial canker, early blight, late blight, septoria leaf spot and root knot nematode.
5.1. Damping off

Damping off is a major problem at the early stage of vegetable seedlings on the seedbed. The disease can be caused by a complex of fungal pathogens (Phytophthora sp., Fusarium sp., Pythium sp. and Rhizoctonia sp.). All these pathogens are soil borne and stay for longer time in the soil. The disease can cause post and pre emergence seedling mortality.

Symptoms
Germinating seedlings may be killed by the pathogen before or soon after they emerge from the soil. Affected seedlings show water soaked lesion around the soil level. Later, seedlings show wilting symptom and die within short time (Fig. 1). If infected seedlings are transplanted to the field, the disease can be transferred to the main production field and cause severe crop damage.

![Figure 1. Symptoms of damping off on pepper](image)

Control measures
The disease can be controlled through effective prevention and chemical methods that include the following;

a) Use of raised seedbed (This practice will not allow excess water to remain on the seedbed);

b) Use of disease free or certified seeds;
c) Soil solarization using polythene sheets;

d) Burning of fire wood or stalks of sorghum/maize on the seedbed;

e) Seed treatment using seed dressing fungicides (Apron star, Thiram); and

f) Fungicide spray.

5.2. Tomato late blight

Late blight caused by *Phytophthorainfestans* is a major production constraint wherever tomato and potato are grown. The disease is more severe during high rainfall and humidity. Yield loss due to late blight can reach up to 50-70% during favorable weather conditions for growth and development of the pathogen.

**Symptoms**

Late blight of tomato can appear at any stage of the crop starting from seedling to fruit maturity stage. Under field conditions, infected plants showed blight symptom at the edge of the leaves. On the underside of the leaves, often white fungal growth (mycelium) can be observed especially in the morning (Fig. 2). During favorable weather conditions and severe infection, total crop loss is quite common.

![Figure 2. Damage symptoms of late blight (*Phytophthorainfestans*) on tomato](image)

**Control measures**

The control measures for late blight are presented as follows;

a) Transplanting of healthy seedlings;
b) Crop rotation with none related crops or none Solanaceous crops;
c) Avoidance of alternative hosts such as Solanaceous weeds;
d) Use of resistant/tolerant varieties; and
e) Application of registered fungicides.

5.3. Powdery mildew (*Leveillulataurica*)

Powdery mildew is a common disease of tomato and pepper in warm arid and semi-arid regions of the country. Yield reduction of tomato due to powdery mildew infestation ranges between 10 and 90%. The devastating nature of this disease is heavy leaf defoliation followed by exposing the fruits to sunlight, which causes sun scorching effect. Scorched tomato fruits do not have market demand.

**Symptoms**
The most common symptoms are bright yellow lesion on the upper side of the leaf. Necrotic spots with concentric rings may develop in the center. A light white powdery covering will be observed on the lower surface of the leaf (Fig. 3). During favorable weather condition for the pathogen, leaves may defoliate and fruits exposed to sunlight and become sun scorched.

![Figure 3. Symptom of powdery mildew on tomato](image)

**Control measures**

All commercial varieties of tomato are susceptible to powdery mildew. This disease is more problematic during the off-season on irrigated toma-
toes. Application of locally registered fungicide is recommended. Bayleton is one of the locally registered and widely used fungicides against powdery mildews.

Prevention
a) Crop rotation using none Solanaceous crop species;
b) Use of tolerant/resistant varieties;
c) Use of pathogen free seed;
d) Seed treatment using seed dressing fungicides.

5.4. Viruses
A number of viruses are attacking tomato in many parts of the world. Different viruses are also recorded as major production constraints of tomato in Ethiopia. Among these the tomato mosaic virus (ToMV), tobacco mosaic virus (TMV), tomato yellow leaf curl virus (TYLCV) are the most important ones. Depending on the kind of virus and severity of infection, they can cause complete crop failure on tomato and pepper.

Symptoms
Since a complex of viruses is associated with the tomato plant, symptoms also varied accordingly. Viruses can attack tomato at all developmental stages. Early infection (before flowering) can cause total crop loss. The major visible symptoms due to virus infection on tomato include:

a) Stunting or dwarfing of plants;
b) Yellowing of leaves;
c) Curling or rolling of leaves;
d) Malformed/deformed leaves (Fig. 4)

Figure 4. Symptoms of tomato yellow leaf curl virus
Control measures

There is no recommended chemical treatment available for the control of plant viruses. However, the following are preventive methods that can reduce the level of virus infection.

a) Use of healthy seedlings;

b) Discourage tobacco smokers during seedling raising and cultivation;

c) Rouging of virus infected plants;

d) Crop rotation;

e) Avoidance of volunteer Solanaceous crops and weeds;

f) Application of insecticide against insect vectors (virus transmitters).

6. Major insect pests

The major insect and mite pests of tomato include African bollworm (*Helicoverpa armigera*), potato tuber moth (*Phthorimaea operculella*) and tomato leaf miner/fruit borer (*Tuta absoluta*), whiteflies and spider mites. *Tuta absoluta* and *Phthorimaea operculella* are closely related and their damage symptoms and management options are similar. Hence, only the descriptions for *T. absoluta* are presented herein.

6.1. African bollworm (*Helicoverpa armigera*)

Larvae of the African bollworm feed on leaves, flowers, and fruit of tomato. Caterpillars prefer green fruit and seldom enter ripe fruits. They usually bore from the stem end, causing extensive fruit damage and promoting decay caused by secondary infections (Fig. 5). The adult is a stout moth, about 6-18 mm long with a wingspan of 16-18 mm. The color varies from dull yellow to brown, with little distinctive marking on the wing. Eggs are tiny, round, and yellowish, which darken before the larvae hatches. Female moths are attracted to tomato plants at the flowering and fruiting stages. Eggs are normally laid near or on flowers or small fruits. The fully-grown larvae are 40 mm long. They vary in color from almost black, brown, green to pale yellow, or pink. They are characterized by lengthwise alternating light and dark stripes, with a typical light stripe along each side of their bodies. The fully-grown larvae drop from the plant and burrow into the soil to pupate. The pupa is light brown. Adults emerge in 1-2 weeks, mate and begin laying eggs at 48 hours after emergence.
Control measures

Prevention

The prevention of ABW includes the following:

a) Tilling and plowing old tomato fields to expose pupae to the sun and by natural enemies;

b) Using maize and sorghum traps to divert ABW elsewhere;

c) Destruction of weeds that may harbor developing larvae; and

d) Use ABW resistant varieties such as Melka Shola.

Direct Control

The measure includes

a) Early detection of the eggs or the caterpillars before they bore into the fruit set;

b) Hand picking and destruction of eggs;

c) Use of aqueous extracts of neem seed (30 kg/ha) at flowering and fruiting periods; and

d) Use of microbial insecticide \(\textit{Bacillus thuringiensis}\) at 1 kg/ha applied at flowering and fruiting periods.

Chemical Control

Applications of insecticides to control African bollworm on the tomato should be made at flowering and fruiting stages. The registered chemicals for the control of ABW on other plants are listed below.
Agro-Lambacin Super 315 EC (Profenofos 30% + Lambda cyhalothrin 1.5% EC); Dimethoate 40% EC (Agro-Thoate 40% EC); Highway 50 EC (Lambda-cyhalothrin) and check for other registered insecticides from the list of registered pesticides in Ethiopia (available from Plant Health Regulatory Directorate of the Ministry of Agriculture)

6.2. Tomato leaf miner/fruit borer, *Tutaabsoluta*

*Tutaabsoluta* is a new and serious pest of tomato to Ethiopia. It affects tomato from emergence up to fruit maturity. Damage is caused by all larval instars throughout the whole plant. The larvae feed inside leaves forming irregular leaf mines which may later become necrotic (Fig. 6). Larvae can form extensive galleries in the stems which alter the normal growth of the plants. The larvae burrow into the fruit, forming galleries which represent open areas for entry of invasion by secondary pathogens, leading to fruit rot. The extent of the damage can reach up to 100%. Females lay individual, small (0.35 mm long) cylindrical creamy yellow eggs. Very young larvae are light yellow or green and only 0.5 mm in length. As they mature, larvae develop a darker green color. Pupation may take place in the soil, on the leaf surface or within mines.

![Figure 6: Tomato leaf and fruit infested by *T. absoluta*](image)

**Control measures**

To control the pest the recommended management practices are the following.
Prevention
The damages caused by the pest can be prevented as presented below.

a) Use pest free seedlings;
b) Cultivate the soil and cover with plastic mulch or perform solarization between planting cycles; this prevents the insect pupae from transforming to adult and hence reduce egg number or new infestation;
c) Use clean tomato transportation boxes;
d) Rotate tomato with non-related crops or species;
e) Destroy cultivated hosts such as pepper and eggplant and wild hosts;
f) Use double door for greenhouse entrance room and cover with a black polyethylene sheet to reduce the influx of the moth to the greenhouse;
g) Plow the field immediately after the last harvest to kill the pupae in the soil; Apply field sanitation at all time and all adjacent farms; and
h) Grow bottle gourd around the tomato fields to increase the natural enemy population.

Direct Control
The measure includes

a) Selective removal and destruction of infested plant material;
b) Remove and destruct of infested fruits. Dispose them using polythene bags;
c) Use pheromone trap for mass trapping of adults; and

d) Use neem seed preparations (30 kg/ha)

Chemical Control
The following insecticides are recommended.

a) Coragen 200 SC (Chlorantraniliprole 200 g/L); apply at 250 ml per ha 2 to 3 times per crop growing season;
b) Tracer 480 SC (Spinosad); apply at 150 ml per ha 2 to 3 times per crop growing season;
c) Ampligo 150 ZC (Chlorantraniliprole 100 g/L + \(\lambda\)-cyhalothrin 50 g/L). Apply at 300 ml per ha 2 to 3 times per crop growing season; and
d) Radiant 120 SC (Spinetoram); apply at 130 ml per ha 2 to 3 times per crop growing season.
Check for other insecticides registered for use against *Tuta absoluta* in Ethiopia (List is available from the Plant Health Regulatory Directorate of the Ministry of Agriculture)

### 6.3. Red spider mites (*Tetranychus spp.*)

Spider mite infested leaves first show a white to yellow speckling and then turn pale or bronzed, as the infestation becomes heavy. They prefer the lower surface of the leaves, but in severe infestations will occur on both leaf surfaces as well as on the stems and fruits (Figs. 7 & 8). Under heavy infestation the plant can become completely covered with webbing. High spider mite infestations cause defoliation, which leads to production of smaller and lighter fruits. Spider mite attack may also cause speckling of the fruits. Spider mites are normally active within a temperature range of 16-37 °C. A new generation will develop every 10-13 days in a temperature range of 24 to 26 °C. The lifespan of a spider mite is 13-32 days. It includes five stages: egg, larva (first instar), and two nymphal stages (second and third instars), and adult. A female may lay over 100 eggs during its lifespan on leaves, stems or fruits.

![Figure 7. Leaf damage (left), plant damage (center) and webbing due to heavy infestation (right) of SM](image)

![Figure 8. Spider mites damage on tomato fruit (left) and adults (right)](image)
Control Measures

Effective management practices to control spider mites are discussed.

Direct Control

a) Keep the field free of weeds;
b) Remove and burn or compost crop residues immediately after harvest; avoid planting adjacent to an infested field;
c) Irrigate crops regularly; and
d) Predatory mites are capable of reducing infestation, provided they are not disturbed by broad spectrum insecticides.

Chemical Control

Chemicals registered for spider mites on other plants are also recommended.
Dynamec 1.8 EC (Abamectin 18 gm/L); Secure 36% SC (Chlorfenapyr); other miticides effective elsewhere include Apollo (common name Clofentezine) and Nissorun (Hexythiiazox).

6.4. Whiteflies

Whiteflies are leaf-sucking pests that remove plant nutrients and weaken the plants. It is an efficient vector of the Tomato Yellow Leaf Curl Virus (TYLCV). Even small numbers of whiteflies may need to be controlled in areas where TYLCV is common. The adults resemble very small moths. They have a coating of white, powdery wax on the body and wings (Fig. 9). Eggs are elliptical, about 0.2-0.3 mm long, attached vertically to the leaf surface by a short stalk, which is inserted into the leaf tissue. They are normally laid in an arc or circle comprising 20-40 eggs on the underside of young leaves. The first juvenile stage crawls on the leaf surface for some time before settling and fixes itself on the lower surface 1-2 days after hatching. It then starts sucking and excretes tiny wax filaments from the edge of its body. During the period of larval development, the tomato plant continues to grow and thus the juvenile stages are found on the lower leaves. The 'puparium' (scale-like final juvenile stage) is flat and whitish to yellowish in color. The life cycle in warm weather takes 3-4 weeks to complete.
Control measures

To control the pests the recommended management practices are the following:

Prevention

Whitefly can be prevented with application of the following recommendations.

a) Proper time of sowing seeds and transplanting can be an effective cultural approach for pest management. Avoid the season when whiteflies are more likely to occur; and

b) Weeds play an important role in harboring whiteflies between crop plantings. They also often harbor whitefly-transmitted viruses. Therefore, attention should be paid to removing weeds in advance of planting tomatoes. Tomato fields should also be kept weed-free.

Direct control

Use of aqueous extracts of neem seed (30 kg per ha) at flowering and fruiting periods

Chemical control

Most of the chemicals listed here are registered for other plants as well. Actara 25 WG (Thiamethoxam 250 g/kg); Confidor SL 200 (Imidacloprid 200 g/L); Cybold 2.5 ULV (Flucythrinate 2.5% ULV; Fastac 100 g/L EC (Alphacypermethrin); Effective insecticides elsewhere amitraz, burpofezin, imidacloprid and pymetrozine.
7. Physiological Disorders

A number of physiological disorders affect tomato fruit quality. These occur due to nutrition deficiencies, extreme temperatures, moisture stress, and varietal characteristics. The most common ones currently observed in the main production areas are blossom end rot, blotchy ripening, cat faces, cracking, puffiness, and sunscald. Proper management practices can reduce and avoid the incidences.

8. Harvest and post-harvest handling

It is a well-established fact that vegetable crops are highly perishable in nature. They require careful attention in harvesting and post-harvest operations in order to reduce losses and export market standard produces that would ensure high price for producers, distributors, processors, and traders. The losses are high due to low moisture stress, over ripening, mechanical injury, rough handling, and packaging and transporting.

8.1. Harvesting Stages

The stage of maturity at which the tomato fruits depend on are mentioned:

a) The purpose for which tomatoes are grown (fresh or processing);
b) The distance between the production site to the market place (retailer or consumers); and
c) Availability of storage facilities.

The fruits could be harvested at different ripening stages in creates or plastic boxes. The different harvesting stages are:

a) Mature green: The fruits are fully green, the seed cavity filled with jelly substance, and the seeds are well developed;
b) Turning/breaker: The surface of the fruit, at the blossom end, turns to pink;
c) Pink: Most of the surface of the fruit turned to pink;
d) Red/hard ripe: The fruit is fully colored, but firm flesh; and
e) Over ripe: The fruits are fully colored, but soft.
Fresh market tomatoes could better be harvested at turning stage, i.e., when fruits can be easily transported for distant market or stored for long period. Depending on cultivars, fruits could be ready for harvest at about 75 to 90 days after transplanting. The fruits could be carefully removed from the plant and put in the crate or plastic boxes. The duration of harvest for fresh market is about 5-7 times (30-40 days).

8.2. Sorting and grading

Once fruits are harvested, they must be sorted as marketable and unmarketable types especially those that are of poor quality due to physiological disorder or pathological and mechanical damages. It is important to select fruits that are firm, not over ripe, fairly well formed, smooth, clean and well-developed, good color, texture, and flavor, free from blemishes and defects like sunscald, injury, puffiness, cat-faces and good appearance. Losses are high if fruits are not properly handled and disposed immediately. Well-organized tomato market channels is needed in order to assist and encourage those involved in the development of fresh market tomato industry.

8.3. Storage

It is important to distribute the produce to the market before the quality is lost. Fresh market tomatoes harvested at turning stage can be held for about a week at 10-12°C and long storage for 1-2 weeks. However, red ripened tomatoes will not stay edible for more than 7 days. Fruits could be stored in ventilated ambient conditions or cold storage. Harvesting at breaker stages has the advantage of keeping fruit for longer period. Storage in breaker and turning stages has about five days storability advantages over fully red ripen fruits.

9. Seed Extraction and Production of Seedlings

Tomato fruits for seed production have same season of production, nursery management, fertilizer application, weeding, spacing, disease control practices as in market tomato fruit production.
9.1. Isolation, rotation and rouging

Self-pollination is high in the tomato plants. Minimum distance between different varieties is enough to prevent mechanical admixtures at harvesting time. It is very crucial to rotate tomato with non-related crop species for 2-3 years. Rouging can be done on plants with undesirable characteristics such as disease, growth habit, yield characters, fruit shape, color, and size.

9.2. Fruit harvesting and seed extraction

Good fruits selected from healthy and true to type plants should be collected for seed extraction. The fruits should be free from diseases. Any physical damage must be typical to the variety in color, size, and shape (Fig. 10). Seeds are extracted from ripe fruits by hand. The tomato seeds are embodied in jelly like substance and hence seed extraction requires special care. Different extraction methods can be used depending on availability of facility, technology, and amount of seed to be extracted. Under small scale, mass of ripe fruits are cut with knife and seeds with the gelatinous material surrounding them are squeezed into containers. During this process the main fruit walls, pulp, and other debris are excluded.

The seeds then are separated by fermentation, in sodium carbonate and hydrochloric acid. At Melkassa Research Center, separation of seeds by fermentation is the most practical one.
9.3. Fermentation, washing and drying

Seeds and gelatinous material are left to ferment for up to three days at 24-27°C (Fig. 11). The mixture should be stirred several times (three times) a day to maintain uniform rate of fermentation in the container avoiding discoloration of seeds and fungus development. The fermentation time must not be extended beyond that required for breaking down the mucilage or else seed quality will be affected by premature germination.

Fermentation and temperature affect the success in seed extraction. When cottony growth covering the pulp is observed, fermentation is completed and needs to be thoroughly washed i.e. 2-3 times. Seed will sink to the bottom of the container and clean seed should be collected after the pulp is drained off. The seed should be dried immediately after washing is completed. In warm dry weather the seeds can be sun dried in appropriate material such as tray/nylon net/cloth bags for about two days or so until 7 to 9% of moisture content is attained.
9.4. Seed yield

Seed yield in tomato depends on cultivar and other production factors. The number of seeds per fruit ranges from 150 to 300 or more. On the average seed yield of 90-125 kg/ha is obtained in Ethiopia. The weight of 1000 seeds with above 90% germination is about 2.3 - 2.7 g.

9.5. Seed storage

Seed can be stored in paper bags, cloth bags, or other non-airtight containers. Porous materials are not recommended for storing seed for longer term unless the surrounding air remains cool and dry. Seed can retain full viability for about 3 to 4 years if stored at room temperature or at low moisture (7 to 9%) level and relative humidity up to 70%.
Table 1. Hybrid tomato cultivars registered by different companies

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<td>Determinate</td>
<td>100-120</td>
<td>Cylindrical</td>
<td>80-70</td>
<td>430</td>
<td>1998</td>
<td>Processing and fresh market</td>
</tr>
<tr>
<td>Melkasalsa</td>
<td>Determinate</td>
<td>100-110</td>
<td>Pear</td>
<td>40-50</td>
<td>450</td>
<td>1998</td>
<td>&quot;</td>
</tr>
<tr>
<td>Chali</td>
<td>Determinate</td>
<td>85-100</td>
<td>Square</td>
<td>80-90</td>
<td>430</td>
<td>2007</td>
<td>&quot;</td>
</tr>
<tr>
<td>Cochoro</td>
<td>Determinate</td>
<td>85-90</td>
<td>Square</td>
<td>70-80</td>
<td>463</td>
<td>2007</td>
<td>&quot;</td>
</tr>
<tr>
<td>Eshet</td>
<td>Indeterminate</td>
<td>75-80</td>
<td>Slightly flatten</td>
<td>130-140</td>
<td>394</td>
<td>2005</td>
<td>Fresh market</td>
</tr>
<tr>
<td>Metadel</td>
<td>Indeterminate</td>
<td>75-90</td>
<td>Slightly flatten</td>
<td>90-140</td>
<td>345</td>
<td>2005</td>
<td>&quot;</td>
</tr>
<tr>
<td>Fetan</td>
<td>Determinate</td>
<td>75-80</td>
<td>Cylindrical</td>
<td>110-120</td>
<td>454</td>
<td>2005</td>
<td>&quot;</td>
</tr>
<tr>
<td>Bishola</td>
<td>Determinate</td>
<td>85-90</td>
<td>Slightly cylindrical</td>
<td>140-150</td>
<td>340</td>
<td>2005</td>
<td>&quot;</td>
</tr>
<tr>
<td>Miya</td>
<td>Semi-determ</td>
<td>90-100</td>
<td>Plum</td>
<td>75-80</td>
<td>471</td>
<td>2007</td>
<td>&quot;</td>
</tr>
<tr>
<td>Woyeno</td>
<td>Determinate</td>
<td>85-90</td>
<td>Oval</td>
<td>40-50</td>
<td>249</td>
<td>2006</td>
<td>&quot;</td>
</tr>
<tr>
<td>Sirenka-1</td>
<td>Indeterminate</td>
<td>95-100</td>
<td>Highly round</td>
<td>60-70</td>
<td>382</td>
<td>2006</td>
<td>&quot;</td>
</tr>
<tr>
<td>Mersa</td>
<td>Indeterminate</td>
<td>100-120</td>
<td>Oblong</td>
<td>42-50</td>
<td>276</td>
<td>2006</td>
<td>&quot;</td>
</tr>
<tr>
<td>Lekku</td>
<td>Indeterminate</td>
<td>75-80</td>
<td>Cylindrical</td>
<td>55-60</td>
<td>337</td>
<td>2006</td>
<td>&quot;</td>
</tr>
<tr>
<td>ARP Tomato d2</td>
<td>Determinate</td>
<td>75-80</td>
<td>Cylindrical</td>
<td>395</td>
<td>2012</td>
<td>&quot;</td>
<td></td>
</tr>
</tbody>
</table>

*Source: MoA Variety Registry Book (1998-2012)*
10. References
CHAPTER II: Hotpepper

1. Introduction

Pepper (Capsicum annum) belongs to the Solanaceae family. Central and South America are its centers of origin and diversity. It spread into the new world from Mexico and Peru before its subsequent introduction into Asia and Africa.

Capsicum is one of the most economically important vegetable crops worldwide. It ranks third in economic importance after peas and tomatoes (Ali, 2006) and second after tomatoes (Yoon et al. 1989). The world average area coverage of Capsicum for dry and green is estimated at 1,989,664 and 1,914,685 hectares in 2012 with a total production of 3,352,163 and 31,171,567 tones, respectively. The world’s average yield of capsicum is 16.85 quintals/ha for dry pod and 162.8 quintals/ha for green pod (FAOSTAT 2012). The top five leading capsicum-producing countries in the world are India, China, Peru, Bangladesh, and Pakistan. Ethiopia ranks 8th in pepper production.

Pungency and oleoresin are the most important attributes of pepper used in food products, as spice and in pharmaceutical applications (Rajish k. et al. 2011). It is the most produced type as spice flavoring and color to food while providing essential vitamins and minerals. In addition to its value as a spice for food consumption, it has many nutritional and medicinal values and provides euphoria as ornamental plants (Pérez-Gálvez et al., 2003). Hot pepper is used to treat many diseases and ailments. According to Norman (1992), the approximate nutrient value per 100 g fresh edible portion of pepper is energy (46 cal), protein (2.0 g), fat (2.0 g), total sugar (55 g), phosphorus (45 mg), potassium (240 mg), calcium (18 mg), magnesium (27 mg), sodium (2 mg).

In Ethiopia Capsicum is the leading crop among vegetables grown in terms of area coverage (CSA, 2012/13). It is grown in many parts of the country. It is an important ingredient in the local dishes and as coloring agents in the processing industries and export in the form of oleoresin (red pigment). Different types of peppers such as bell (sweet) pepper, which is not pungent, chili (mitimita) and hot pepper (berbere), which are the pungent type, are produced in the country.
2. Climate and Soil

The climate and soil requirement of pepper are similar to those for tomatoes. However climatic conditions at the time of flowering and fruit setting have significant effect on yield of pepper. The crop is a warm season crop requiring an optimum day and night temperatures of 20-30°C and 15-20°C, respectively. It is very sensitive to low and high temperatures. Night temperature below 15°C and day temperature above 32°C for extended periods retard growth and development, inhibits fruit setting and finally decreases yield. Moreover, high temperature associated with low relative humidity at the time of flowering increases transpiration resulting in abscission of buds, flowers, and resulting in small fruits.

Hot pepper can be grown on well-drained soil types including black soils. However, the ideal soil type for capsicum production is loam or sandy loam soil with good water-holding capacity. The crop can be grown successfully on soil with pH of 6-7.

It is grown as a rain fed crop in areas with 850 – 1200 mm annual rainfall. Heavy rainfall leads to poor fruit set and rotting of fruits and dry spell results in substantial reduction of yield.

3. The Crop

Capsicum varieties vary in fruit characteristics such as pungency, color, shape, flavor, size, skin thickness, number of fruits per plant and number of seeds per fruit. They are also differentiated by their inflorescence (number of flowers per axils, flower position, corolla color), intended use (fresh market, processing), and growth habit, height, plant canopy, leaf width, leaf color, leaf shape, maturity. Capsicum plants are bushy, reaches 60–80 cm in height and are semi-perennials but grown as annuals in cultivation. The average growing season of the crop is about 110-130 days after transplanting though it varies with cultivar, climate, and season. The pungency of hot pepper is due to the presence of capsaicin (C\(_{12}\) H\(_{27}\) O\(_3\) N) that is present in the placenta.

Capsicum is self-pollinating species; albeit a considerable amount of cross-pollination (40-65%) occurs mainly by insects and to lesser extent by wind. Among capsicum cultivars, there is noticeable heterostylity where flowers differ in the stigma position in relation to anthers.
long-styled flowers in which the stigma extends beyond the stamens favor cross-pollination whereas a high degree of self-pollination is expected from the short-styled ones. In some cultivars protogene, which is a condition where the stigma is receptive before pollen shading is also common?

Based on fruit shape and size, more than 20 market types of hot and sweet peppers are known in the world. These can be grouped into five broad market categories:

a) Fresh market (green, red, multi-color whole fruits);
b) Fresh processing (sauce, paste, canning, pickling);
c) Dried spice (whole fruits and powder);
d) Industrial extracts (paprika/ oleoresin, capsaicinoids and carotenoids); and
e) Ornamental (plants and/or fruits) (Poulos, 1994). Further to the market types conventional nutritional food uses, Poulos mentioned a number of other alternatives for examples paprika oleoresin, medicines and non-food for examples defense, spiritual, and ethno-botanical) uses.

In Ethiopia, the pepper types are grouped as chili (mitmita), green pepper (Karia), hot pepper (Red-ripen pods (berbere) types. The hot pungent type is used in powdered form in local stew “Wot” making, for preparing sauce used to eat raw meat with or eaten with injera (local bread). The sweet type is used in mixed vegetable salad. The sweet non-pungent paprika cultivars have also a very high industrial usesfor its oleoresin content.
Table 3. Released open pollinating capsicum varieties

<table>
<thead>
<tr>
<th>Variety</th>
<th>Year of release</th>
<th>Maturity (days)</th>
<th>Yield (q/ha)</th>
<th>Area of adaptation</th>
<th>Unique characters/</th>
</tr>
</thead>
<tbody>
<tr>
<td>MarekoFana</td>
<td>1984</td>
<td>110-130</td>
<td>15-20</td>
<td>Altitude: 1400-1900m a.s.l, Temperature: 25°C-28°C (day) and 15°C-20°C (night)</td>
<td>High acceptance for local use for its brown pod color</td>
</tr>
<tr>
<td>MelkaAwaze</td>
<td>2007</td>
<td>100-110</td>
<td>25-28</td>
<td>Altitude: 1000-2200m a.s.l, RF: 900-1300mm, Temperature: 25°C-28°C (day) and 15°C-20°C (night)</td>
<td>Tolerant to soil born diseases, early matur­ing</td>
</tr>
<tr>
<td>MelkaShote</td>
<td>2007</td>
<td>110-120</td>
<td>20-30</td>
<td>Altitude: 1400-1900m a.s.l, Temperature: 25°C-28°C (day) and 15°C-20°C (night)</td>
<td>Tolerant to soil born diseases</td>
</tr>
<tr>
<td>MelkaZala</td>
<td>2004</td>
<td>130-150</td>
<td>15-25</td>
<td>Altitude: 1400-1900m a.s.l, Temperature: 25°C-28°C (day) and 15°C-20°C (night)</td>
<td>Tolerant to soil born diseases</td>
</tr>
<tr>
<td>MelkaDima</td>
<td>2004</td>
<td>120-140</td>
<td>13-20</td>
<td>Altitude: 1400-1900m a.s.l, Temperature: 25°C-28°C (day) and 15°C-20°C (night)</td>
<td>Processing type, high oleo resin content</td>
</tr>
<tr>
<td>MelkaEshet</td>
<td>2004</td>
<td>100-120</td>
<td>15-20</td>
<td>Altitude: 1400-2200m a.s.l, Temperature: 13-23°C</td>
<td>Processing type, high oleo resin content</td>
</tr>
<tr>
<td>OdaHaro</td>
<td>2005</td>
<td>139</td>
<td>11-12.5</td>
<td>Altitude: 1400-2200m a.s.l, Temperature: 13-23°C</td>
<td>Resistance to bacterial leaf spot, fungal leaf disease, Phytophtora (root dis), virus</td>
</tr>
</tbody>
</table>

Table 4. Registered hybrid hot pepper

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Yield (t/ha)</th>
<th>Year of registration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serenade</td>
<td>1.5-2.0</td>
<td>2011</td>
</tr>
<tr>
<td>Sahem</td>
<td>-</td>
<td>2013</td>
</tr>
<tr>
<td>Saidah</td>
<td>52.9</td>
<td>2013</td>
</tr>
<tr>
<td>Capsi</td>
<td>6-6.5</td>
<td>2011</td>
</tr>
<tr>
<td>Spicy</td>
<td>5-5.5</td>
<td>2011</td>
</tr>
<tr>
<td>SCH 925</td>
<td>6-6.5</td>
<td>2011</td>
</tr>
<tr>
<td>SCH 942</td>
<td>6-6.5</td>
<td>2011</td>
</tr>
</tbody>
</table>

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4. Nursery and Field Management

4.1. Nursery management

Production under field condition follows different operations. Capsicum may be directly seeded or transplanted using seedlings raised in seedbed/tray. Transplanting has the advantage of economic use of seeds, suitable to select superior seedlings and easiness for field establishment. However, direct sowing requires high amount of seed 10 times more (4000 g) than transplants (300 -350g) albeit seedlings thinned out from the direct seeded field could be used as transplants to establish a different plot. Intensive field management is also important for successful seedling establishment. Nonetheless, transplants could be produced either in the field in seedbed or controlled greenhouse or lath house using trays. Seedbed is most common used by farmers in Ethiopia. Currently, with the introduction of hybrid vegetable cultivars in the central Rift Valley corresponding high seed cost, there is a tendency, among farmers, of using tray for seedling production.

4.1.1. Nursery sites

In vegetable crop proper seedling production, practices influence the health and vigor of seedlings. Hence, close attention must be given to the selection of proper nursery site for producing vigorous and healthy seedlings.

a) Seedbeds site should be easily accessible to carryout frequent visits/supervision can be carried out;
b) Site should be away from any obstructions that affect the availability of light;
c) Preference should be given to well-drained sandy loam soils;
d) The soil should be in loose and friable condition;
e) The seedbeds should be at a new sites that is well protected from strong winds; and
f) The area be kept free from weeds and other plants which are hosts of insect pests, virus and/or other diseases.
Seed source
Proper identification of the required varieties is crucial. In Ethiopia, vegetable growers either obtain seeds from local market or extract their own seeds from the previous harvest fruit that are categorically rejected and unmarketable. Purchased seeds from the local market and/or traditionally extracted seeds are unreliable and more likely are attacked by seed borne pathogens and become the cause to transmit the disease in the nursery. In order to avoid such problems, treating the seeds with chemicals prior to sowing is advisable. Treating vegetable seeds with Apron star can also help to control disease-causing organisms during seed germination and seedling emergence.

4.1.2. Seedbed preparation

Before seedbed preparation, it is important that the seed rate, number, type, and size of seedbeds required should be considered. Till the nursery bed properly; prepare the bed carefully. Remove roots, stones and clods; the seedbeds should be easy for cultivation, irrigation and hardening-off operations. A suitable basic design for a seedbed should be one-meter width with 5 or 10 m length and 40-50 cm between beds to allow working half the seedbed from each side. Three kinds of seedbeds are commonly used in producing capsicum seedlings, depending on the soil and climatic conditions. These are

a) **Flat seedbed**: Used where the land is level with adequate drainage system;

b) **Elevated or raised seedbed**: This type is constructed to avoid excess water on seedbed. Used in rainy season or when water logged soil condition is expected; and

c) **Sunken seedbed**: Used in areas with a prolonged dry season and it can help to conserve and economize water.

Seed sowing:
About 700-750 g/ha seed with over 90%, germination potential is required for one hectare; and 20-25 g of seed for 1x5 m seedbed size (Fig. 12). Seed is sown in the row at 15 cm row apart at the depth of 0.5-1 cm, covered with pulverized/fine soil, and lightly firmed. The whole bed is mulched with grass or straw to protect seeds from washing away during watering, and from strong hot-sun. Apply water using watering can. The seedlings are then thinned at 1-2 cm spacing at the first true leaf stage and proper management practices are followed to produce healthy and vigorous seedl-
ings. No further shade is necessary then after to avoid the development of long and spindly (etiolated) seedlings, which is a common problem in farmer’s field. Raising large number of seedlings helps to select vigorous, strong and healthy transplants. It is important to examine the nursery bed daily.

Figure 12: Seedbed ready for seed sowing

4.1.3. Fertilizer application

Organic manure or compost and inorganic fertilizers provide nutrients for producing healthy and vigorous seedlings. It is advisable to incorporate well decomposed manure for good seedling production. However, the amount of fertilizer applied on seedbed depends on the fertility of the soil. Use recommended rate of both DAP and Urea. A blanket applications of DAP (200 g/per seedbed) and Urea (100 g/seedbed) are required at planting and thinning time at first true leaf stage, respectively, to enhance growth and development.

4.1.4. Irrigation

Water application on seedbed uniformly with correct amount is an important task in nursery management. At initial stages, water is applied frequently with a fine spray/watering can. Seedbeds should never be allowed to dry out nor should be kept soaked. Sufficient water should be applied to until the plants are well established. Watering is preferred in the morning or late in the afternoon, but not encouraged in strong sun. Keep the surface wet or avoid over watering to control damping off diseases.
4.1.5. Hardening seedlings

Seedlings need to be hardened before transplanting to the field to enable them withstand the field conditions. This should be done by reducing the frequency of watering and allowing the soil to low moisture status when it is ready for field planting. Avoiding irrigation water for two to three days before uprooting the seedlings from seedbed facilitates the removal of transplants.

4.2. Field management

4.2.1. Site selection

The site where capsicum is to be grown should be carefully selected. Sites with slight to moderate slope are ideal for pepper cultivation, as they promote drainage. When the soil is kept too wet for long time, there will be limited air circulation, which causes serious injury to plants. Thus, draining excess water out of the field is important. Crop rotations following tobacco, tomato, potato and eggplants should also be avoided, as they are susceptible to many of the common diseases with pepper. The site selected should not have been cropped to the above crops during the last two to three cropping.

4.2.2. Field preparation

Tilling the land thoroughly for a minimum of three times to a depth of 25 cm is crucial. The first plough should be done immediately after harvest to incorporate weeds and other remains into the soil. The second plough is done after a month of the first plough to break clods and level the field. To ensure a smooth level field for transplanting, tilling the field for the third time is important. Ridges and furrows are formed at recommended spacing.

4.2.3. Transplanting seedlings

Pepper seedlings are ready to be transplanted when seedlings are 12 to 15cm tall and produce 3-4 true leaves. Hardening the plants to prevent transplant shock in the main field is essential. During transplanting seedlings should be carefully pulled out from the nursery bed with soil around the roots using shovels, rakes, forks, and pickaxes. Care should be taken not to damage the root systems particularly the adventitious roots. Cover seedlings with wet materials, preferably sacks during transportation to
keep the roots moist and put them in a cool place under shade until ready to be transplanted. It is crucial to transplant only vigorous and disease free seedlings.

**Planting time**

Seedlings are usually transplanted in late afternoon or on a cloudy day to minimize transplant shock. Planting holes are prepared in rows using pegs or any other materials. The following care should be taken during planting:

a) Place seedlings at the upper edge of the ridge especially in rain fed production;

b) Place seedlings properly into the hole to the level of the cotyledons or first true leaves; do not damage or bend the main root; and

c) Press the soil around the plant well firmed and apply water immediately to establish good root system.

**4.2.4. Spacing**

Planting pepper in-rows is not a popular practice among Ethiopian farmers. They traditionally plant pepper randomly without considering standard spacing. Transplanting pepper in rows with spacing of 60 x 40 cm for rain fed plantation and 70 x 30 cm for irrigation increase productivity (Fig. 13). It uniformly provides the available nutrients; avoids plant competition, allows root growth and development, enhances plant growth and lateral branch production and thereby increases flowering. Furthermore, it facilitates field operation like cultivation, weeding, hoeing, fertilizer application, proper draining of fields and better crop protection. Conversely, if planted randomly as it was observed in farmers’ field, plants fail to develop the proper size required to produce good crops and to provide good foliage cover to protect the fruits from sunscald that reduces total yield.
4.2.5. Water management

Capsicum is mainly grown under rain-fed conditions, but it can be grown under irrigation as well. The plants are shallow-rooted and have low tolerance to drought or flooding. When peppers are grown under rain fed conditions, heavy rain can cause flooding and plants cannot tolerate excess water. They tend to wilt and possibly die if they stand in water for a long time. *Phytophthora* blight and bacterial wilt can occur where soil remains wet for long periods and may cause total crop loss. Thus, fields should be drained quickly after heavy rain.

Capsicum planted under irrigated condition, cannot withstand long dry periods. Under such condition, the plants may shade flowers and drop fruits. In Ethiopia the depth under which water is optimum volume has not yet been established. Irrigation at an interval of every other day for the first three weeks and at 5-7 days then after depending on soil and growing conditions can provide good yield. Fields should be irrigated if there are signs of wilting at midday. Stressed plants are likely to make a slow recovery after drought injury. Irrigation should be done to maintain uniform soil moisture to promote uniform growth and fruit setting. Applying furrow irrigation is recommended early in the day so that the field is dry before nightfall (Fig. 14). Avoid irrigating late in the afternoon and over-irrigating in order to control root-rot diseases. While irrigating the pepper field, the field should be divided in every 5 to 6 m blocks to enable excess water draining from the field.
4.2.6. Cultivation

Peppers have shallow roots and are attacked easily by weeds. Weeding around the plants should be done as deemed essential. Hand hoeing and cultivation is needed to control weeds. Research results indicated that cultivation of pepper fields 2-3 times during its growth period is highly advantageous as it effectively avoids competition between the crops and weeds allows aeration in the root zone and enhances plant growth.

4.2.7. Fertilizer application

Addition of manure/compost just after harvest during the first plough helps to improve the soil organic matter content and maintain soil fertility. Ideally, there should be specific fertilizer and rate recommendations for a specific area. Apparently, areas vary with soil fertility, fertilizer recovery rate, soil organic matter content, soil mineralization, and leaching of N fertilizer. Application of fertilizer based on the level of the soil fertility is necessary. If manure is not available, application of diammonium phosphate (DAP) and urea is recommended. According to the research recommendation at Melkassa condition, apply DAP at the rate of 200 kg/ha after the field has been leveled and thoroughly mixed with the soil. Application of Urea at 100 kg/ha provides good results and it may be applied in two splits. The first half can be applied at an early stage of plant growth at about 20 days after transplanting and the second half during the second cultivation.
5. **Major Diseases**

All major diseases of tomato indicated in chapter 1 (Damping off, Late blight and Powdery mildew) do attack pepper. Therefore, the type of symptoms they cause and all management practices mentioned on tomato apply for hot pepper.

6. **Major Insect Pests**

6.1. *African bollworm (ABW), Helicoveraarmigera-Hubner*

**Damages:** A small-darkened partially healed hole at the base of the fruit pedicle is the damage caused by the warm. Inside of the infested fruit a cavity containing insect refuse and decay can be observed. Damaged fruits ripen early, but usually are not marketable. At the base of the fruit pedicle if a darkened hole is found, remove the fruit and cut it open to see tunneling caused by the insect. This cavity may contain insect refuse and decay. Often caterpillar is present. Caterpillars move from one fruit to the next destroying only small portion of each fruit (Fig. 15). Pupation occurs in soil near the base of the plant. For the pest biology, refer to the section under tomato.
Control measures

Prevention

Prevention of the pest is of primary concern in the control of ABW

a) Removal of crop residues and plowing fields after harvesting to eliminate resting sites for the pest;
b) Deep plowing immediately after the last harvest in off-season to expose pupae for sun light or post-harvest cultivation to reduce diapausing population in the dry season;
c) Use trap crops like lupine, pigeon pea, bean, and sunflower that attract and divert significantly high ABW; and use pest free seedlings; and

d) Destroy cultivated hosts and wild hosts.

**Direct Control**

This type of controlling method includes removal of all infested plant materials and destroying unmarketable fruit from and around the farm.

**Chemical**

Application of recommended chemicals is most effective means of controlling the ABW. Some are listed as follows;

Thionex 25 % ULV, Thionex 35 % ULV, Thionex 25 % EC/ULV endosulfan) Apply at 1-2 lit h⁻¹, Helerat 5%EC (Lambda Cythlothrin). Apply at 1-2 lit h⁻¹, and Highway 50% EC (Lambda Cythlothrin). Apply at 1-2 lit ha⁻¹

**6.2. Termites**

**Damage**

In Ethiopia, several species of termite attack different crop species including pepper. They are particularly important in Wellega area of western Ethiopia.

Pepper plant is either cut by termites just below or above the soil surface with access from soil-covered galleries on the base of the plant. Severe infestation lowers plant population. The stem can be excavated and packed with soil. Uprooting of damaged plants reveal foraging termites and roots destroyed or severely reduced due to termite penetration and feeding activity.
Control measures

Prevention

Prevention of termites is one of the primary concerns of their controlling practices

a) Breaking up of termite galleries by deep plowing and regular cultivation around the plants;

b) Hoe weeding or ridging soon after rain to destroy the foraging galleries that run near soil surface and disturbing termites that are foraging;

c) Apply good management practices (plowing, cultivation, weeding, appropriate fertilization, quality seed, avoiding mechanical damage to plants);

d) Inter cropping with other crop species;

e) Flooding, hoeing, organic amendments, use of fully decomposed farm yard manure etc. are also used to control termites; and

f) Mulching with maize stover, grass and haricot bean residue.

Direct control

a) Termites can be preyed upon by a wide variety of predators such as birds, lizards, frogs, spiders, bats, other mammals and ants;

b) Wood ash helps to repel termites; can be applied around the base of the plant; and

c) Use of entomopathogens such as *Beauveriabassiana* and *Metharizium anisopilae*.

Chemical control

Chemical control of termites has been one of the effective methods. The following chemicals are recommended to that effect.

a) Diazinon 60% EC at 2 / ha. Applied as soil treatment (soil surface or side dressing by making a 5 cm deep furrow); and

b) Chloropyrifos 48% EC at 2.5 / ha. Applied same as above.
6.3. Aphids

Damage

They are small pear shaped insects. They vary in color from green to black. Leaves that are beginning to curl under or have signs of black sooty mold on the upper surface reveal the insect. Leaves are distorted, stunted, and often curled under (Fig. 16). The upper leaf surface is sticky and has a black moldy growth. Infested plants have fewer fruits than usual. Some wilting may also be evident.

Figure 16. Aphid (left), distortion and curling of leaves (middle) and sooty mold on leaves (right)

Control measures

Prevention

Prevention of aphid includes destruction and removal of crop residues immediately after harvesting in order to minimize the spread of aphids to adjacent crops. Intercropping hot pepper with other crops such as beans also helps to prevent aphids.

Direct control

This method can control aphids if properly used. Hence, Neem seed extracts (15 to 30 kg /ha) have given effective control of the aphid but with minimal effect. Aphids are naturally controlled by parasitic wasps such as
the braconid *Diaeretiella rapae*; and predators such as ladybird beetles, hoverflies and lacewings.

**Chemical control**

The following chemicals have been recommended to control aphids.

a) Ethiodemethrin 2.5% EC (Deltamethrin 25 g/L);

b) In Ethiopia other insecticides are registered for the control of aphids on other crop plants. Prevention of termites is one of the primary concerns of their control practices. These include Agrothoate 40% EC (Dimethoate), Gain 20 SL (Imidacloprid), Profit 72% EC (Profenofos), Closer 240 SC (Sulfoxoflor); and

c) Check for the availability of other registered pesticides for the control of aphids.

### 7. Harvest and Postharvest Management

Pepper harvesting may be done at either green or dried stages, depending on the preferences/purpose of production. For fresh consumption, peppers are harvested at the green stage. After harvest, fruits should be stored in a cool, shaded, dry place until they are sold. The dried or powdered use, harvest the fruits at leathery stage with low moisture content. Fruits take approximately 50-55 days after flowering to ripen depending on temperature, soil fertility, and variety. However, warmer temperatures will hasten ripening, while cooler temperatures will delay it.

Harvesting can be done on a weekly basis as fruits ripen. Pepper is commonly dried after harvest and sold as dried fruits or ground into powder. The most important consideration in the dried pepper is to preserve the red color of the mature fruits. Pepper is well adapted to drying under the sun. Spread the crop in thin layer on wooden beds that allow ventilation, hard dry surface, and sheets made from jutes, or black plastic sheets. It should be regularly stirred to ensure uniform drying and to reduce discoloration and fungal growth. Correctly dried peppers should be bagged in jute bags and should be stored under cool storage,
8. **Seed Production**

Pepper for seed production can grow under warm and humid conditions, but requires dry weather condition at maturity. It gives best fruit yield and better seed set at 20 to 30°C and 15 to 20°C day and night temperatures, respectively. Flowering is induced only in short days; flower anthesis earlier at relatively high light temperature than at low temperature. Pepper fruits produce few seeds when night temperature is very low. Seed production management practices are almost the same as in pepper fruit production.

**Pollination**
Capsicum is a self-pollinating crop but cross-pollination up to 68% can occur between and within varieties. The single style is usually longer than the stamens. Flowers remain open for 2-3 days and anthers normally dehisce an hour after the flowers open. The stigma become receptive up to 2 days after anthesis. Pollination is usually favored by insects such as bees, ants, and thrips. Therefore, to prevent cross-pollination between two cross compatible varieties, a distance of 200-400 m is recommended. This is to prevent seed contamination through cross-pollination as well as mechanical mixing of the seed during harvest. If a number of varieties are needed to be maintained in small area, the seed can be obtained by enclosing a group of plants in insect proof nets.

**Rotation**
Pepper is susceptible to soil borne diseases; therefore, 2 to 3 years is recommended between successive pepper crop and other related crop production.

**Rouging**
It is important that rouging in pepper should be done three times, i.e. before flowering, early flowering and at maturity. However, rouging before flowering is more beneficial. Plants should be rouged based on the plant and fruit characters as a whole rather than the individual character. Off-types should be removed as soon as they are observed. When the fruits begin showing the final red color, plants with off-color fruits have to be removed. In addition to off-types, diseased plants should also be removed.
9. Harvesting, Drying and Seed Extraction

Red-ripe fruit at leathery stage is handpicked (Fig. 17). The dry and wet methods of pepper seed extraction are common in pepper. It is not possible to dry completely the large fleshy-fruited sweet peppers; they are therefore wet extracted without drying. The small-fruited pungent types can be successfully dried before seed is extracted in the sun for 10 – 15 days depending on weather condition. The dried fruits are hand flailed to extract seeds. Further, separation is done by winnowing. Seeds are cleaned to free pulp and skins and dried below 8% moisture in partial sunlight before storage.

![Pepper pod harvesting stage, seed extraction and drying](image)

Figure 17. Pepper pod harvesting stage, seed extraction and drying

**Seed yield**
Seed yield depends on variety and growing conditions.

**Seed storage**
Under small scale condition seed can be stored in bags in vapor proof containers (Fig. 18).
Figure 18. Pepper seed storage facilities
10. References


CHAPTER III: Onion

1. Introduction

Onion (Allium cepa) also known as the bulb onion or common onion, is the most widely cultivated species of the genus Allium in the world. The crop has been used as food since time immemorial. It is believed that Allium cepa had been domesticated independently in several places and occupied vast areas in west Asia. Most of the botanists believed that it has its origin in areas including Iran, Pakistan, and the mountainous countries in the north (Ram, 2005).

Onion production in Ethiopia is an important farming enterprise among small and large-scale farmers mainly in the Awash Valley and Lake Regions where the bulk of dry bulbs and seeds are produced. This crop plays an important role in creating jobs and source of income for small-scale farmers (Lemma and Shimelis, 2003). However, the productivity of onion in Ethiopia is lower than the Africa average and that of the world. China, Russian Federation, and Turkey are the leading producing countries of onion and show 26, 2.31, and 2.22% share, respectively from the global production. Average onion production of the World is 19% while the shares of Europe, Asia, American, Africa and Ethiopia are 35, 18, 32, 15 and 10 t/ha, respectively. The total land area under onion production is 21,865.37 hectares and 789,912.0 households owning the land under onion production with total production of 2.2 million tons of dry bulbs. In Ethiopia, even though the yield of onion is low compared to other countries, the dry bulb and seed production technologies have significantly changed the livelihood of many farmers, especially in the Rift Valley areas (Lemma et al, 2008).

Ethiopia has a great potential to produce onion throughout the year both for local consumption and for export. Relatively onion is a newly introduced bulb crop in Ethiopia but because of its several advantages, it has easily become popular among producers. Its relatively high yield potential, availability of desirable cultivars for various uses, ease of propagation (seed), high domestic (bulb and seed) and export (bulb and cut flowers) markets in fresh and processed form make the onion economically a very significant crop. Onion is one of the few vegetable crops that can be kept for longer periods and withstand the hazards of rough handling in-
cluding long distance transport. Hence, onion dry bulb can be stored for long time and can be marketed at a time when the prices are in favor for the grower. Therefore, there is a lesser risk of over-production of onion than most other perishable vegetable crops, which have to be marketed immediately after harvest.

Onion is a widely used crop for different purposes. Immature and mature bulbs are eaten raw as a salad. They are cooked in a variety of ways such as fried, boiled, and roasted. Onion are extensively used for flavoring soups, ketchups, canned meat products, sausages, sauces, stews, curries, fried fish and meat and a great variety of other savory dishes. The main edible portion of onion is the bulb, which is constituted by the fleshy sheath on stem plate. Onion bulb is rich source of phosphorous, calcium, carbohydrates, protein, and vitamin C (Ali et al. 2007). Its most important character is its flavor, which increases the taste of food.

2. Climate and Soil

In Ethiopia onion grows between 500 and 2400 meter above sea level (masl) albeit the best growing altitude is between 700 and 1800 masl (Lemma and Shimeles, 2003). Onion can be grown under a wide range of climatic conditions. It grows well under mild weather condition without extreme heat or cold or excessive rainfall. The plant is hardy and in the young stage can withstand freezing temperatures. The main environmental factors, which affect onion production, are temperature and photoperiod.

The crop requires cool condition during the early part of its development and warm condition during bulbing, bulb maturity, harvesting and curing stages. Onion bulbs have specific temperature requirement for seed and bulb production. In Ethiopia, onion can be grown at 700-2000 masl. Day temperatures of 20°C - 26°C and 11 - 15°C night temperature are ideal for bulb production. In cooler areas where temperature falls to 4-10°C or at an altitude of greater than 2000 masl bolting and disease resistant or tolerant cultivars like Red Creole can be used. High temperature favors bulbing and accelerates maturity that could result in small, splitted, double bulb and low yield and poor quality bulbs. Lower temperature delays bulbing and maturity at least by 2-3 week and reduce yield. However, low temperature is required for flower stalk development, while warm and dry conditions are conducive for seed maturity and harvest. It is important to
identify locations with optimum climatic conditions favorable to attain high yield and quality of dry bulb and seed production.

Onions start bulb formation when the day length is of the normal duration. Different Cultivars of onions require different day lengths to initiate bulbing. Before bulbing can occur, a certain amount of vegetative growth is required for the plant to respond to day length. At a specific threshold, past the “juvenile” stage of leaf growth, the plant becomes sensitive to the bulbing stimulus that is triggered if the days are long enough. If the requirement for day length is not met i.e., the days is not long enough when the onion plant is physiologically mature leaf production continues without bulb formation. The effect of photoperiod is clearly interrelated with that of temperature and light spectral quality; the higher the temperature, the more bulbing is promoted a given photoperiod.

Onion can grow in all types of soils from sandy loam to heavy clay. Highest yield can be obtained from well-drained loam soil with pH of 6-6.8. To avoid build-up of soil borne diseases, it should be rotated with unrelated crops such as beans, and cereals. Onion could be planted on same field/land at least ones every 3-4 years. Onion yields are very severely reduced by soil salinity, and they are among the most sensitive crops in this respect. Therefore, saline soils should be avoided in the production of onion.

3. The Crop

The onion bulb consists of the swollen bases (sheaths) of bladed leaves surrounding swollen bladeless leaves. Each leaf consists of a blade and sheath; the blade may or may not be distinctive. The sheath develops to encircle the growing point and forms a tube that encloses younger leaves and the shoot apex. Collectively, the grouping of these sheaths comprises the pseudostem. Leaves arise from the short, compressed, disc like stem, which continues to increase in diameter with maturation and resembles an inverted cone. The onionskin is formed from the dry paper like outermost leaf scales that lose their freshness during bulbing. Major bulb features are uniformity of shape, size and skin color, pungency and dry matter.

The shape covers a wide range from globose to bottle like and to flattened-disc form. The color of the membranous skins may be white, silver, buff, yellowish, bronze, rose red, purple or violate. The color of the fleshy
scales may vary from white to bluish red. There is also much variation in flavor. The onion root system is fibrous, spreading just beneath the soil surface to a distance of 30 to 46 cm. There are few laterals, and total root growth is sparse and not especially aggressive.

Bulb onions are classified into short, intermediate, and long day. Short-day cultivars bulb when day length is 10 to 11 hour-lengths. Intermediate cultivar requires 12 to 13 hour-day lengths to initiate bulbing and long day cultivars require 14 to 16 hour-day lengths. Within day length groupings, there are early and late maturing cultivars. Short day cultivars are adapted to Ethiopian conditions.

In Ethiopia, the onion has been considered an important vegetable crop used as spice in flavoring a great variety of savoring dishes. It has been one of the research priority crops among others. A number of introduced varieties had been under research investigation for adaptation trials for subsequent economic values. Thus, the characteristics of some recommended varieties and hybrids that have been introduced by different companies are presented in Tables 5 and 6, respectively.
Table 5. Characteristics of released/recommended onion cultivars

<table>
<thead>
<tr>
<th>Character/ cultivar</th>
<th>Adama Red</th>
<th>Melkam</th>
<th>Red Creole</th>
<th>Bombay Red</th>
<th>Nasik Red</th>
<th>Nafis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf color</td>
<td>Medium-green</td>
<td>Dark-green</td>
<td>Light-green</td>
<td>Dark-green</td>
<td>Deep-green</td>
<td>Deep-green</td>
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<tr>
<td>Leaf arrangement</td>
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<td>Erect</td>
<td>Medium</td>
<td>Medium</td>
<td>Erect</td>
<td>Erect</td>
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<tr>
<td>Bulb size (g)</td>
<td>60-80</td>
<td>70-90</td>
<td>80-100</td>
<td>85-100</td>
<td>85-100</td>
<td>100-130</td>
</tr>
<tr>
<td>Bulb shape</td>
<td>Flat-globe</td>
<td>High-globe</td>
<td>Thick-flat</td>
<td>Flat-globe</td>
<td>Globe</td>
<td>Globe</td>
</tr>
<tr>
<td>Bulb skin color</td>
<td>Dark-red</td>
<td>Medium-Red</td>
<td>Medium-red</td>
<td>Light-red</td>
<td>Medium-red</td>
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<tr>
<td>Bulb flesh color</td>
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<td>Reddish-white</td>
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<td>Maturity (days)</td>
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<td>110-130</td>
<td>130-145</td>
<td>&lt;120</td>
<td>90-110</td>
<td>90-100</td>
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<td>TSS (%)</td>
<td>10-13</td>
<td>10-12</td>
<td>11-14</td>
<td>9-11</td>
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<td>Medium</td>
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<td>2009</td>
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<td>2011</td>
<td>Greenlife</td>
<td></td>
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<tr>
<td>Red king</td>
<td>2011</td>
<td>Markos Plc</td>
<td></td>
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<td>Jambar</td>
<td>2011</td>
<td>Makubo</td>
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<td>Vibha Seed</td>
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</table>

Source: Ministry of Agriculture 2013

4. Nursery and Field Management

4.1. Nursery management

4.1.1. Site selection

Site selection is an important part to be considered in venturing on horticultural crops production at all levels. It is also important to appreciate the specific needs of the various horticultural crops. The climate and soils requirement should be considered before one venture into horticultural production.

4.1.2. Seedling preparation

Onion bulbs are produced either by seed directly sown to the field or transplanting seedlings or from dry sets depending on the growing conditions of specific region. Seedlings can be produced in one of the three possible methods i.e., producing seedlings on seedbeds (Fig. 19), direct sowing to the field and/or use of dry sets.

Transplanting has the advantage over direct sowing on economic use of seed and for selecting superior (healthy and vigorous) seedlings. It is easy to weed and water during the early period of onion growth. It enables the farmer to attend closely to the seedlings in seedbeds.

Direct sowing in the field requires high amount of seed of three times (12 kg) more than using transplants (3-4 kg). It also requires proper land le-
velling, weeding, and thinning. Seedling thinned out from direct seeded fields requires being transplanted to the field or wasted otherwise.

Unlike seedlings or seeds, onion sets can be used as well. Sets are small dry bulblets usually less than 2.5 cm in diameter. It can adapt to short growing seasons and are tolerant to harsh environment it is earlier and produce heavy crops than either seeds or seedlings. Therefore, it is important to select the planting methods appropriate to specific growing conditions.

![Image of onion planting](image)

Figure 19. Long strips of seedbeds for onion (preparation, left; sown beds covered with straw, right)

### 4.2. Field management

The field management and operation like irrigation, fertilizer application, plant population, weeding and insect and disease protection measures affect onion production and productivity.

#### 4.2.1. Field preparation

A planting site should be clean, free from weeds, flat and has dependable water supply. The field/land must be well ploughed and harrowed to a fine tilth, leveled, and should be fairly firm and free from clods before either seeding or transplanting seedlings.

#### 4.2.2. Plant spacing

Plant spacing is an important practice influencing dry bulb yield and quality of onion production. Onion is planted in flat ridges to facilitate cultivation, weeding, and irrigation. Spacing of 40 x 20 x 5-7 cm (40 cm between double rows on a ridge, 20 cm between rows on the bed and 5-7 cm between plants) is suitable for small-scale hand operated production sys-
tern. The spacing could be adjusted depending on the availability of facilities especially for tractor operated large-scale production.

4.2.3. Transplanting seedlings

Depending on the weather soil condition and cultivar, seedlings will be ready for transplanting 45-55 days after seeding. Healthy and vigorous seedlings of 12-15 cm height or 3-4 true leaf stages are carefully uprooted from the seedbed. Prior to planting pre irrigation is also carried out to settle the soil around the transplants and facilitate the planting operation. Following the recommended plant spacing, holes are dug/made with pegs that are large enough to accommodate the roots. Then seedlings are placed in a hole and the soil is pressed around the root by hand or on foot to avoid formation of air pocket near the root and to protect the seedlings from dry up. Water must be applied immediately after transplanting. Similar to other transplanted vegetables, withholding irrigation water for two to three days before uprooting the seedlings facilitates the uprooting and subsequent good field establishment of seedlings. Light root pruning plant parts is practiced to facilitate the transplanting operation.

4.2.4. Fertilizer

The addition of manure, compost and/or inorganic fertilizers improves onion production and hence benefits the producers. The first two are locally available and are important in supplying the necessary nutrients, improves soil texture and water holding capacity of the soil. The amount to be applied depends on the type and fertility status of the soil. The rate for a particular locality or soil types has to be determined before application. Soil incorporation of 200 kg/ha DAP before transplanting and side dressing of 100 kg/ha Urea at 45 days after planting is sufficient.

4.2.5. Water requirement

The crop has shallow root system and needs frequent irrigation after short interval. Irrigation should be provided at regular intervals for good crop yield. Critical periods for irrigation are during stand establishment and the period of bulb development through maturity. Onions at the bulbing stage utilize substantial amounts of water, although excessive moisture must be avoided during the growing season. Though onions need lots of water, the soil should not be soggy all the time. Watering when onions are bulbing keeps some soils from hardening around the bulbs and allows bulb expan-
sion. Cut back/reduce on watering when the tops start dying back to prevent the bulbs from rotting. Stopping irrigation too soon will reduce yield, irrigating too late, or applying too much water late in the season, can cause splitting, delay maturity, and increase the incidence of decay. The study conducted at Melkassa showed that higher yield was obtained at an irrigation interval of three and six days. The result further revealed that onion dry bulb yield decline from 20.4 t ha\(^{-1}\) to 1.1 t ha\(^{-1}\) as an irrigation interval increased from 3 to 12 days. Furrow irrigation is most common practice in onion production in Ethiopia. Irrigation should be terminated as the onion bulb begins to mature and the tops begin to fall that is 15-25 days before harvest.

4.2.6. Cultivation and weeding

Three to four cultivations are needed for the control of weeds fertilizer dressing, and for reconstructing the ridges. Cultivation should be shallow to avoid root damage.

5. Major Diseases

5.1. Botrytis leaf blight

Botrytis leaf Blight (BLB) or neck rot is the cause of leaf spots in foliage and sometimes in the outer scales of the bulb (Fig.20). It is a cool, wet-weather disease. Optimum temperature range of 15°C to 20°C. This disease may be caused by one or more of the following pathogens *Botrytis allii* or *B. aclada*, *B. squamosa*, and *B. cinerea*. It is one of the major foliar diseases of onion in cool climate areas worldwide. The severity of epidemics depends on local weather conditions. Botrytis Leaf Blight is an economically important disease only on common onion. Severely affected bulbs may not dry down enough for proper storage.

Neck rot is primarily a storage disease, although infection originates in the field as leaves and necks mature and become infected by spores blown from infested onion debris and improperly disposed cull piles.

**Symptoms**

The first symptoms to develop are discrete, circular to elliptical lesions. These are grayish white, about 1 by 3 mm, and later become brownish-white and desiccated. A characteristic silvery-white "halo" with uneven margins usually develops around newly formed lesions as a result of en-
zyme activity, which separates the leaf epidermis from the underlying tissue. The gray mold fungus, *B. cinerea*, may also infect onion leaves, but the resulting lesions are smaller, do not penetrate the inside of the leaf nor do they develop halos. *B. allii* (or *B. aclada*, the causal agent of Neck Rot) can cause limited foliar spotting, but it usually remains in a latent state until the bulb is mature or the leaf has senesced.

Under favorable weather conditions, the number of lesions on a leaf increases, the lesions expand and merge and the leaves begin to die back. Dieback begins at the leaf tip and may extend down the entire leaf. The lower, older leaves are more susceptible to infection and are the first to die. Sporulation occurs on necrotic leaf tips and occasionally on large lesions. Several species of *Botrytis* are associated with neck rot symptoms; the one caused by *B. squamosa* is known as Small Sclerotial.

![Figure 20. Greyish white and circular to elliptical lesion symptoms of Botrytis leaf blight on Onion leaf (A) and on bulb (B).](image)

**Biology**

*Botrytis squamosa* is a polycyclic pathogen with the potential to cause rapid disease development under favorable environmental conditions. Sclerotia overwinter in the soil, on onion debris, and on bulbs in cull piles. In the spring, the sclerotia produce conidia at temperatures between 3 and 27°C, with maximum production at 9°C. Conidia are the most important initial inoculum. Sclerotia may survive at least 21 months in organic soil, but conidia usually survive for less than three months. The conidia of *B. squamosa* are released during the daytime between 0900 and 1200 hours. A smaller peak may occur in the evening and large releases of spores are
associated with rain showers. The conidia are dry and are dispersed in turbulent air. The optimum conditions for infection are 12 hours of leaf wetness at 15 to 18°C. Infection is reduced above 27°C.

Control measures

Prevention

Three- to four-year crop rotation plays an important part in reducing the incidence of infested onion debris and of Botrytis. Proper sanitation is also one of the effective prevention methods. Incorporating onion debris into the soil immediately after harvest is important. No exposed culls should be present anywhere in the growing region. The use of clean seed and transplants that are free of contamination are other important aspects of prevention of the pathogens.

Chemical

Late season applications of labelled fungicides such as Chlorothalonil, Mancozeb, Metalaxyl, Acrobat, Switch, Endura, Quadris, Pristine, Cabrio, or Rovral may provide some foliage protection and reduce neck contamination. Good control has been achieved through tank mixes of a broad-spectrum fungicide and a single mode of action fungicide, especially if it has systemic activity.

5.2. Fusarium basal rot (*Fusarium oxysporum*)

Biology

The disease is also known as basal rot and caused by *Fusarium oxysporum*. Basal rot occurs in most onion and garlic growing areas of the world and is most prevalent under high-temperature conditions. The fungus attacks cloves and seedlings, causing pre- and post-emergence damping-off, root rot of older plants, and steam plate discoloration and basal rot of bulbs in the field and in storage. Yield losses by Basal rot can be more than 50%. *F. oxysporum* produces chlamydospores, microconidia and macroconidia, on the host and in culture. Isolations from onion bulbs and soil indicate that the pathogen exists in soil primarily as a sporodochial type. The many *formae speciales* of *F. oxysporum* are differentiated by the ability of the specific pathogen to infect a host.
Fusarium species are soil inhabitants, and infection is usually believed to follow injury, as such caused by maggots, cultivation, or pink root. Most yield losses result from disease development in the field, but Basal rot can also progress in storage. The pathogen attacks only members of the genus Allium; onion, garlic, shallot, Chives and leek are also susceptible, but the disease is economically important only in onion and garlic.

Symptoms
Progressive yellowing and dieback occur from the tips of leaves. Fusarium basal rot enters the bulb through small wounds in the surface of the onion bulb (Fig. 21). Affected roots are dark brown to dark pink. When an infected bulb is cut vertically, a brown discoloration of the stem plate tissue is apparent. Later, the stem plate tissue becomes pitted and shows a dry rot. Under dry conditions, the stem plate and dry outer scales crack open. Basal rot can continue in storage.

Garlic can be infected at any stage of growth but symptoms are not always diagnostic. Cloves may decay before emergence. Seedling infection of the basal plate causes chlorosis and necrosis of the leaves. The bulbs of actively growing plants may develop a firm dry rot characterized by a reddish fringe on the lesions. In other cases, there may be no symptoms of infection, and discoloration on the bulb is not necessarily diagnostic.

Figure 21. Fusarium Basal rot on onion (A) and garlic (B)

Biology
The pathogen (*F. oxysporum*) produces chlamydospores, macroconidia and microconidia. Chlamydospores are rounding thick-walled, and are formed abundantly in soil. Macroconidia are short to medium in length, falcate, thin-walled, slightly tapered at the end, and usually 3-4 sep-
tate. Microcondia are usually non-septate, oval to reniform in shape, and abundant in culture. The fungus survives indefinitely in soil. Infection occurs through wounds or root scars at the base of the bulb. Optimum temperatures being 26°C to 28°C. More prevalent in transplanted onions/shallots than in direct-seeded.

There are many unknowns in the epidemiology and development of this disease. Seed with a high incidence of infection may produce a crop with no symptoms for one or more generations, and then in another season disease will develop in the field. It is not known what environmental or other conditions result in disease expression. The fungus does survive in the soil. Initial infection may occur at the stem plate from soil-borne inoculum, and remain localized for varying periods of time, which may explain the lack of symptoms.

**Control Measures**

**Prevention**

The pathogen could be managed with effective cultural practices primarily with prevention. Avoid fields with a history of Basal rot problems and rotate 3 to 4 years out of onions, garlic, and leeks. Control soil insects and foliage diseases. Cure onions properly before storage. Store at cool, dry place since infection is favored by warm conditions. Destroy all infected onion plants and bulbs. Do not replant any plants susceptible to *Fusarium* species fungi in same area for the following planting season.

**Chemical control**

There has not been a recommendation of chemical control for *Fusarium* basal rot to date. The only way to remove *Fusarium* from the soil is through extensive fumigation techniques that are expensive. Fungicide treatment of seed garlic cloves is the most effective method of disease management. Benomyl applied in hot water, as recommended for the control of *Penicillium* clove rot, is a very effective seed treatment and controls both seed borne and soil borne diseases.
6. Major Insect Pests
6.1. Thrips (Thripstabaci)

Biology: Thrips are very small, just barely visible to the naked eye. They are about the size of a flea. The immature thrips are either yellow or white. Adult individuals are yellowish-brown and move quickly. They feed by rasping the epidermis of the leaves and sucking the sap that exude (Fig. 22). They often congregate along the leaf veins. Thrips damaged onion leaves are silvery or have tiny brownish marks or spots. They may be wilted or distorted. Outer leaves are brown at the tips. In cases of severe injury, leaves drop and bulbs are small and misshapen. Yield loss can be more than 50% if control measures are not taken. Eggs are inserted within leaf tissues. They are white, and take 4-10 days to hatch. Nymphs molt twice in about five days; they are white or yellow. Pupation occurs in the soil and takes 4-7 days. One generation can take place in about three weeks.

![Immature thrips in the leaf sheath (left) and silvery leaf spots (right)](image)

**Control Measures**

**Prevention**

Destruction of crop residues and plowing fields after harvesting to eliminate resting sites for the pest; avoid planting onion crops in succession; prepare the soil well before transplanting onion; intercrop onion with carrot or cabbage; removal of weeds that may harbor thrips.
Direct control

Mulching with straw may provide shelter for thrips predators, thereby reducing thrips populations; if possible use sprinkler irrigation to reduce thrips population; use yellow sticky traps; use neem seed preparations (30 kg/ha).

Chemical control

Nimbicidine (Neem); apply at one ml/ L of water; radiant (Tracer); apply at 130 ml/ ha; check for other insecticides registered for use against Tutaabsoluta in Ethiopia (List is available from the Plant Health Regulatory Directorate of the Ministry of Agriculture).

7. Harvesting and Post-Harvest Handling

Onion bulb should be harvested at the right stage. Depending on variety and season of the year, it takes 55-65 days to develop visible bulbing from the time of transplanting and then 60-70 days bulbing to maturity. Thus, it takes 110 - 130 days from transplanting to bulb maturity. Bulbs are better harvested when all the leaves are dry or fall over. However, harvesting is possible when 25-50% of the tops are down. Farmers are used to harvest even earlier depending on availability of good market price.

7.1. Bulb grading

After bulbs are harvested, curing is done to prevent disease infection and improve its storage life. The bulbs are left for 3-5 days until leaves are completely dried and the neck gets soft. This could be accomplished in either the field or open shade or ventilated store. Such curing practice improves yield and quality in terms of skin color and its retention. Once cured root and leaves are properly trimmed and graded it can be transported to markets or kept in storage.

7.2. Post-harvest handling

All the necessary precaution measures have to be taken to keep the bulb healthy and in good conditions till reach consumers. Careful handling
during harvesting, transporting, and loading is necessary to avoid physical damages. Sort out dry bulbs to marketable quality that fit for normal consumption. Eliminate defected, sprouted thick necked and splitted bulbs. Select standard quality and save. Categorizes marketable bulbs based on to the market standards. Grade dried onion bulbs sufficiently for distinct shape, color, and size free from any damage and free from foreign smell.

7.3. Dry storage

Types of cultivars, quality of bulbs, field management, and handling practices are important conditions influencing storability. Cultivars with soft neck and high dry matter store well compared to the thick necked and low solid content. Similarly, cultivars with high dry matter stores well.

Develop less costly ventilated storage facilities applicable to small farmers. Store onion under natural ambient ventilation or forced ventilation. Under cold storage dry bulbs could be stored either 0-5°C at 65-75 % or 25-30°C at 65-75% RH. Simple ventilated storage constructed from poles, wire meshes and sheets of grass roofing are found effective in extending the shelf life of onion in the Rift Valley. Such simple ventilated shade could be constructed from any locally available materials such as bamboo, grasses, small poles and be effectively used for small and bulk storage. Ventilated structure also minimize losses and maximize storage period which could be achieved by orienting the store to the prevailing wind and sometimes by hanging bunches and stacking the bulbs on wooden/mesh shelves with sufficient air space. The bulbs could be stored 2-4 months.

8. Seed Production

Onion is a biennial crop that takes two seasons to produce seeds. In the first year bulbs are formed and in the second year stalks develop and seed are produced. The number of stalks per plant may vary from 1 to 20 or more depending on the variety, size of mother bulb and time of planting. The number of flowers per umbel varies considerably from 50 to over 2000. Opening of flowers usually continues for a period of two weeks or more and onion plant may be in bloom for over 30 days (Fig. 23).
During flowering, seed development and maturity excessive rainfall and very cool condition are undesirable as they lead to disease development and poor seed setting. Good sunshine at the time of full blooming stage will facilitate the activity of beneficial insects for higher rate of cross-pollination and seed set. The relative humidity should be lower at the time of seed development.

**Pollination:** Onion is a cross pollinating crop. Efficient pollination depends largely on presence of insects such as honeybee, flies in the area and their activity at flowering time (Fig. 24). It is essential to ensure that there is a sufficient pollinating insect including honeybees to achieve the full potential of onion seed and consequent higher seed yield production.

**8.1. Isolation**

Onion is a cross pollinating plant. A minimum isolation distance of 1000 m between different cultivars is required. Shorter distance may be used if the cultivars have the same bulb color.
8.2. Method of seed production

There are two distinct methods of onion seed production. These are bulb-to-seed method and seed-to-seed method. The most commonly used method is the bulb-to-seed. This method has the advantage of maintaining seed quality. It allows selection of bulbs of appropriate size, uniform, typical color, shape, free from decay, diseases and physical damages. It also produces several stalks per bulb and hence gives higher seed yield. This method takes 10-12 months to produce seed. Typical mother bulbs can be selected and stored for one to two months until ready for planting in the cooler seasons (early September to October).

The seed-to-seed method lacks the merits of bulb-to-seed method mentioned above. It also produces less flower stalk per bulb and takes 7-8 months to produce seed.

8.3. Harvesting and curing of bulbs

It is important that bulbs become fully matured before harvesting. After harvesting, the bulbs should be trampled leaving 1.25 cm long necks. Curing of bulbs should be done before storing. The time required for curing depends largely on weather conditions and may take from 3 to 4 weeks.

8.4. Bulb selection and storage of bulbs

Rouging out can be made before bulb maturity and during sorting of bulbs for replanting. Removing plants with off-type foliage, bulb color, early bolting, late maturing, non-typical bulb shape, color, size, early bolters, bull neck, bottle-shaped, splitted, damaged and diseased ones should be removed.

Bulbs, which are damaged, twins/splitted and very large, doubles and long thick-necked bulbs should be discarded, too.

Bulbs with typical color, shape of the cultivar and medium sized (5-6 cm) are selected and stored until planting. In general, only true-to-type bulbs are selected. The seed yield is affected by the size of the bulb, the bigger the bulb size, the higher is the seed yield.
The place where bulbs are to be stored should have ventilation. Before storage, bulbs need to be well dried and cured. The storage temperature influences seed yield; an optimum temperature of about 12°C is best for storage of mother bulbs. Plants from such bulbs produce early and heavy yield than those grown from the bulbs, which have been stored at higher or lower temperature.

8.5. Mother bulb planting

The optimum time for mother bulb planting is between August and October. Planting from August to October can give high number of flower stalks and seed yield. Double row planting of 50x30x20 cm with 125,000 bulb per hectare (80 to 90 q/ha of mother bulb) should be used for Melkassa climatic condition (Fig. 25). Onion can also be planted in single row in ridge with a similar spacing (50 cm between rows and 20 cm between plants) for ease of weeding and pesticides applications, but there is yield reduction. Bulbs are planted 2 to 3 cm deep.

Light irrigation is applied immediately after planting. Subsequent irrigation may be given at 7-10 days interval. Irrigation should be stopped when the seeds reached maturity. If the soil is not fertile apply 200-250 kg DAP at planting and 100-150 kg Urea in two splits; half at planting time and the rest half a month after emergence. Weeding frequency for seed production is similar to the practice for bulb production. However, care should be taken during flowering as weeding at this stage can damage flower stalk. Hence, field should be free from weeds just before flowering.
8.6. Seed harvesting and threshing

The seed is harvested when the seed-head/umbel opens and exposes the black seeds. A field is considered ready to harvest when 10 percent of the heads with black seeds are exposed. However, it is better to harvest mature umbels when 50% black seeds are exposed on an umbel. At this stage, practically all the seed is well matured to give a good germination. Two to three pickings may be necessary to harvest the heads. The seed heads with a small portion of the stalk attached are cut with a sharp knife. When cutting the umbels are supported in the palm of the hand and held between fingers to avoid seed loss.

The seed heads/umbels after harvest are thoroughly dried on canvas under shade or in morning or late afternoon sun for few days. Seeds can be threshed by mowing or rubbing of dried umbels carefully and then clean the seeds by winnowing (Fig. 26).

The seeds are put in a bucket and soaked with clean water carefully for 3-5 minutes. The pure seeds are separated from light seeds and other trashes based on their weight after 3-5 minutes of soaking; heavy seeds sink and poor quality seeds and chaffs float (Fig. 27).

Figure 26. Onion umbel drying, threshing, and separating seed from chaffs
8.7. Seed yield and storage

Cultivar and growing conditions affect seed yield. On the average 8-12 q/ha is obtained under Melkassa condition.

Seed should be stored in porous materials such as cloth or paper bags or similar materials in dry and well-aerated conditions at 7-9 % moisture. The seed moisture could significantly affect seed quality. If seed’s moisture content is high, it normally loses its viability at faster rate.
9. References


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CHAPTER IV. Garlic

1. Introduction

Garlic (*Allium sativum*) originated in the northwestern Tien-Shan Mountains in Central Asia, the region that borders China, Kazakhstan and Kyrgyzstan. The Mediterranean and the Caucasus regions are considered as secondary centers (Etoh and Simon, 2002 cited Kazakova, 1971 and Etoh, 1986). It is the second most widely used crop of the cultivated *Alliums* worldwide probably after the onion (Brewster, 1994). According to FAOSAT, 2014, the total world production of garlic in 2012 was over 24.84 million tons. The major onion producing countries are China, India, South Korea, and USA. Egypt and Ethiopia are the major producers in Africa. In Ethiopia 128,441 tons of garlic was produced on 10,690 ha in 2010/2011 rainy season (CSA, 2010/11).

Garlic has been used as condiment and medicine for over 5000 years (Bondnaret et al., 1997). As a condiment, it has been used for flavoring soups, stews, pickles, and salads. Dehydrated, powdered granulated garlic or ‘garlic wine’ is used for industrial and home purposes. Garlic in the form of ‘garlic wine’ and granules has been processed at industrial level in South Korea. Garlic is also regarded as a powerful antidote against all kinds of poisons. Allicin, the volatile compound released when a clove is crashed, lowers blood sugar level, cholesterol and lipoproteins; has antibacterial, anti-helminthic, anti-carcinogenic, insecticidal and larvaecidal properties (Koch, 1996). It is used to alleviate common cold and to repel mosquitoes in Ethiopia, China, and India.

Garlic is a good source of minerals and vitamins. A 100 g of garlic contains 181 mg calcium, 153 mg phosphorus, 14.2 μg Selenium, 1.672 mg manganese, 25 mg Magnesium, 1.7 mg Iron, 1.16 mg Zinc, 31.2 mg vitamins C, 1.235 mg, and vitamin B-6 (USDA, 2009). Moreover, it has considerable antioxidant strength, and has low levels of sodium, cholesterol, and unsaturated fats. Owing to its considerable culinary and medicinal values, garlic will continue to be an important commodity for local and export markets both as fresh and processed products. Therefore, production of high quality and quantity garlic can benefit growers, consumers and the nation at large through reduced expenses on health care and generating foreign currency.
Garlic has two strains: "hard-neck" or "soft-neck", depending on whether they bolt or not. 'Hard-neck' strains produce a solid small flowering-stalk called the scape (Fig. 1.). The scape produces small vegetative bulbils (top sets) but not true seeds. The bulbils can be used as propagules. The bulbils can be grown for two seasons to get marketable bulbs. Soft-neck strains of garlic do not produce a scape and bulbils have larger number of cloves. These are the strains of garlic widely grown in Ethiopia.

2. Climatic and Soil

Garlic is extremely hardy and survives long periods at temperatures below 0°C (Brewster 1994). It withstands moderate frost. In the temperate zone, garlic cloves are planted in autumn and overwinter either as dormant bulb or as seedling 3-4 leaf stage as a means of initiating vigorous bulbing. In Ethiopia, garlic is adapted to cool climate as high as 3000 masl and large sized bulbs are produced in cool highlands of North Shewa, Arsi, North Gonder, Bale and Sidama. Thus, garlic is one of the few alternative crops that thrives best in these areas. Many strains of garlic require a cold period to initiate bulbing. Rainfall of about 600 to 700 mm and optimum temperature of 12 to 24 °C are required during the growing period.

Garlic is photoperiod (duration of daily light) sensitive. It is adapted to the temperate zone and it is growing during 14-16 hour long photoperiod. On the other hand, those adapted to tropical zone can bulb at 12 hours of
photoperiod. Variety adaptation trials in Ethiopia showed that garlic introduced from temperate countries such as China and Italy failed to produce bulbs or produced puffy bulbs that are not divided into cloves after about seven months of growth at DebreZeit and Kulumsa (Fig. 29). Similarly, in 2012 farmers who purchased and planted introduced garlic bulbs in Gojam and Arsi areas suffered total loss of crops due to failure of bulbing.

Figure 29. Garlic varieties introduced from different temperate zone countries and grown for more than seven months at DebreZeitAgriculturalResearchCenter: a) and b) failed to bulb, and c) produced puffy - a bulb with no division into cloves.

Garlic thrives best on fertile and well-drained soils. Heavy soils hinder bulb expansion, especially if allowed to dry-out resulting in rough and irregular shaped bulbs. Garlic grown on Vertisols under well regulated irrigation give better yield than those grown on Alfisol. Soils with high organic matter content are preferred due to their increased moisture and nutrient holding capacity, and less prone to crusting and compaction. Soils with very high un-decomposed organic matter produced multiple shoots. Suitable soil pH ranges from 6.0 - 7.5.

3. The Crop

Garlic genotypes in Ethiopia have many (up to 20) small sized cloves per bulb which are difficult to peel. Internationally known cultivars often have six to ten large cloves which can be peeled easily. Garlic bulbs have either white skin color or white with purple tinges. Three garlic cultivars: ‘Tsedey’ and ‘BishaftuNetch’ (1999/2000) and ‘Kuriftu’ (2006) (Fig 30) were released from DebreZeitAgriculturalResearchCenter (DZARC). They yield is about 75 q/ha⁻¹ under optimum management with plant population of 333 thousand. Garlic attains maturity within 120 days.
Garlic has a long dormancy period compared to other *Alliums* such as onion and shallot. Research results conducted at DZARC showed that local cultivars of garlic required about 120 days to sprout uniformity in the field. On the other hand, cloves planted shortly after harvesting sprouted and matured erratically for about one month posing great difficulty in managing and harvesting the crop. A clove that broke dormancy has a growing central shoot that can be seen by naked eye.

4. Establishment/Management

4.1. Preparation of planting material

Garlic cloves for planting should be in plump with intact roots. Plump cloves can be achieved by harvesting well matured bulbs and storing them as whole bulbs but not as separated cloves. Bulbs without roots could be due to white rot and should be avoided. If split cloves are stored, they lose weight and deteriorate fast. Medium sized (1.5 - 5 g) and uniform cloves are preferred for planting; avoid small cloves (Fig.31). Small cloves produce weak plants while non-uniform cloves produce plants of various vigor.
4.2. Land preparation and planting

Land on which to plant garlic should be ploughed to fine tilth during dry period and weeds should be exposed to the sun and removed. Planting can be done on a flat land during rainy season or under drip irrigation. It can also be done either on top or side of a furrow under ridge to facilitate furrow irrigation, depending on the moisture level of the soil. Cloves should be planted in upright position but never on their sides or upside-down.

Cloves are spaced 40 cm between double rows on a ridge, 20 cm between rows and 10 cm between cloves or plants (Fig. 32). Further improvement in yield could be obtained by narrowing the spacing (increasing plant population) but it should be investigated in relation to its impact on bulb size.

In most parts of Ethiopia, planting starts at the beginning of the long rainy season, from early-May to mid-June, depending on agro-ecology. Garlic can also be planted from late August to early March under irrigation provided maturity and harvest is planned not to coincide with the rainy period.
Figure 32. Double row spacing of garlic on ridge and furrow planting: (a) 40 cm and 20 cm between double rows and single rows, and (b) 10 cm between plants
4.3. Cultivation

Garlic has short roots and sparse canopy that it cannot compete with weeds especially at early stage of growth. Good land preparation prior to planting considerably reduces the need for cultivation. Grass weeds are difficult to control after planting and should be harrowed and exposed to the sunlight during dry period. Hand weeding is preferred during early stage of growth to avoid uprooting and trampling on young plants. Shallow cultivation is then required every three to four weeks depending on weed’s severity.

4.4. Fertilization

Garlic is a heavy feeder of nutrients. It has high uptake of nitrogen, phosphorus and potassium at early stage of its development. The amount of fertilizer required depends on the fertility of the soil and should be based on the results of soil analysis. However, the general recommendation used nationally is 200 kg DAP and 150 kg Urea ha⁻¹. Band application of N, P and K fertilizers below or 5 cm to the side of a clove is recommended at planting. Application of nitrogen should be completed four to six weeks prior to harvest. Excess nitrogen such as in backyards increases the percentage of plants with secondary growth.

4.5. Irrigation

Garlic has a rather sparse and shallow root system (top 60 cm). It is sensitive to water-stress throughout the growing season especially during bulb ing. The amount of irrigation varies depending on the soil type and weather conditions. However, in most soils, 2.5 cm of water per week is required during the growing season; whereas in sandy soils during hot and dry weather about 5 cm, water is required. Salinity of irrigation water should not be greater than 3.0 dS m⁻¹. Irrigate twice a week from planting until more than 80% of planted cloves sprout in order to obtain uniform and rapid sprouting. Then after, the frequency can be reduced to once a week. Fluctuation of soil moisture between dry and wet conditions may result in irregular growth and development of misshapen bulbs. Irrigation should be stopped three weeks before harvest or at physiological maturity when leaves start senescing or turning yellow and necks become soft. For fresh market crops, irrigation should cease three weeks before harvest. Late irrigation may result in rotting of the base plate, peeling-off, and dis-
coloration of the outer skin and finally splitting apart of cloves from a bulb.

5. **Harvesting**

Increase in bulb size (dry matter) of garlic continues until the leaves of the plants begin to dry, turning tan brown from the tips toward the base of the leaves. Thus bulbs should be harvested when leaves turn yellow, necks soften and/or bend over. Such bulbs have distinct and well-formed cloves which can store well (Figs. 33 a and b). Harvesting is done by hand pulling of plants after loosening the soil with spading fork or hoe. Early harvesting results in bulbs, which are immature and tend to shrivel when cured (Figs.33c and d). Late harvesting may lead to stained bulbs, decayed wrapper leaves, and loss of roots leading to splitting of cloves due to attack by black mold and *Sclerotium* rot.

![Figure 33. Maturity stage of garlic bulb: a) mature bulb, b) cross section of mature bulb, c) immature bulb, and d) cross section of immature bulb](image-url)
6. Curing, Trimming and Grading

Curing is a process of “drying” bulbs after harvest so that the leaves and roots loose water. Curing can be done under shed or in a diffused light store for about two weeks. The top of a cured bulb is topped at about 2.5 cm above the bulb and roots are trimmed to ease bulk storage and transport. On the other hand, topping at longer height or bunching untopped bulbs are practiced for storage under ceiling of houses. Garlic bulbs can be graded into different categories based on bulb diameter. Internationally recognized grades are: colossal (7.5 cm and larger), super jumbo (6.25-7.5 cm), extra jumbo (5.625-6.25cm) and extra flower (less than 5cm).

7. Storage

Garlic bulbs for consumption can be stored at room temperature for several months. Storage at 5°C and 25°C encourages sprouting and weight loss, respectively. Thus bulbs for prolonged storage should be stored at 0°C and 60% relative humidity. In Ethiopia, bulbs are transported and stored in 25, 50, 120 kg bags in dry stores. Hanging garlic bunches under ceilings of houses is also done to maintain planting material until next season. Storage life under appropriate conditions could be 5-8 months depending upon the cultivar. Adequate air circulation and proper storage containers are important to remove transpired heat and moisture. Otherwise, higher relative humidity provides suitable conditions for development of penicillin mold and root growth.

8. Major Diseases of Garlic

8.1. White-rot

Biology

White-rot caused by the fungus Sclerotium cepivorum occurs in all places wherever Allium species is grown. S. cepivorum is a soil borne fungus. The fungus produces sclerotia that are the major means of survival and the principal means of dissemination. Sclerotia of S. cepivorum consist of a narrow rind; with thick-pigmented walls, surrounding a medulla of closely interwoven, moderately thick-walled hyphae approximately 300 μm in diameter with interhyphal spaces filled with medullary tissue.
Sclerotia from an initially high population may survive 20 to 30 years or more in soil without the presence of an *Allium* host. Only *Allium* spp. such as onion, leek, and shallot are attacked. Sclerotia can infect plants from 30 cm below the surface. One sclerotium can infect a group of 20 to 30 adjacent plants. Fungal activity is favored by cool soils and is restricted above 25°C. Once the disease is in the field, it is very difficult to grow *Allium* spp. successfully.

**Symptoms**

Leaves decay at the base, turn yellow, wilt, and topple over. Older leaves collapse first. Roots are rotted, and the top of the plant can be pulled out of the ground easily (Fig.6B). Fluffy white mycelium may be on remaining roots and bulb (Fig.34A). The affected bulb may become watery, and the outer scales crack as it dries and shrinks. Small (0.02 inch) sclerotia form in affected bulb parts and on the surface, often around the neck. Sclerotia are smaller and rounder than those of the neck rot disease. Symptoms of Allium white-rot on onion showing small black sclerotia that form in the mycelium is indicated in Fig.34C.

Figure 34 White rot infection on garlic bulb (A), stem (B) and Shallot bulb (C).
Biology

Sclerotia are the primary inoculums of the disease. The pathogen can persist as dormant sclerotia in the soil for many years in the absence of *Allium* hosts. Viable sclerotia have been observed after 18 years in the field in the absence of host plants. They are subject to exogenous dormancy, which is imposed by the fungistatic influences of the soil microflora, but they germinate readily in sterile soil. The period of dormancy lasts for 1-3 months, and during this time sclerotia rarely germinate even in the presence of host plants. Sclerotia are difficult to eliminate from soil because they are adapted to survival under severe environmental conditions. They germinate any time after onions or other *allium* hosts have been seeded and after sclerotia overcome dormancy. Mycelium grows upwards (Fig. 35A) and produces sclerotia. Sclerotium germinates in response to organic sulphur compounds formed on roots. Sclerotia (Fig 35B) survive for more than 20 years in soil and disease severity depends on sclerotia level. Sclerotia are uniformly round structures with a black rind surrounding a thick walled mycelium. Reproductive structure for white rot is sclerotia, which can lie dormant on a decayed host plant for weeks to months after its formation. Germination occurs as a plug of mycelium stimulated by organic sulphur compounds formed on roots of a growing garlic or onion plant.
The mycelium invades the roots then stem plate or bulb within days to weeks. The bulb rots and dies. An infestation can affect from several plants to large areas of a field. In Ethiopia garlic, onion and shallot are infected by the disease especially in the highlands. However, severe damage is observed on garlic. White rot severity depends on pathogen population, weather and soil temperature. One sclerotium/10 kg of soil initiates disease while 10-20 sclerotia/kg will infect all plants. Cool moist soil conditions favor disease development. Infection could start when soil temperature is 10 - 23.9°C and the optimum is 16-18°C while growth is inhibited at temperature higher than 25.5°C. Dispersal is through infected soil, planting material, farm equipment, and irrigation. The disease is not found in the Rift Valley area of Ethiopia.

Control measures

In order to manage white rot one has to consider the entire pathosystem i.e. the host, (planting material) Pathogen and the environment (soil). There are several methods that can contribute to the effective management of *Allium* White Rot. Most researchers advocate an integrated approach to the management of this disease.

**Prevention:** These include

a. **Reduce the initial inoculum including the following**
Avoid use of irrigation; use resistant cultivars; remove disease causing structure sclerotium through careful field selection; control alternative hosts and good stubble management; exclude unclean seeds; apply restriction measure not to introduce white rot infested *Alliums* from endemic areas; do not plant *Alliums* in fields with a history of white rot; apply proper eradication measures and keep storage facilities clean; the use of resistant/tolerant cultivars is recommended to reduce initial inoculums

b. **Reduce the apparent infection rate**
Avoid using fields with previous history of white rot and use clean planting materials; provide proper and sustainable sanitation measure to keep fields clean; remove infected materials from the field.

c. **Reduction of the duration of the epidemic is equally important as A & B above**
This can be done by planting early maturing *Allium* cultivars and applying strict quarantine measures in the introduction of inoculum free planting
materials from outside the country. Protect the soil from soil born pathogens by fumigation with methyl bromide; dressing cloves with registered materials; and apply hot water treatment at 45°C for about 15 minutes. This has been practiced and showed promising results in Ethiopia. The use of resistant/tolerant varieties is recommended.

8.2. Garlic rust (*Pucciniaastriformis*)

Garlic rust is widespread especially where it can probably be more serious locally than in the lowlands. Economic damage due to the disease is frequently localized and sporadic, but serious losses have been reported from Brazil, Israel, and South Africa.

Garlic rust is caused by various *Puccinia* spp. Physiologic specialization appears to exist, but there has been no adequate study on this. High nitrogen application may increase disease incidence.

**Symptoms**

The initial symptoms in all the Alliums appear as small (less than 2 mm), white flecks on both sides of leaves. The small white spots expand somewhat over time (1 to 3 mm) into oblong lesions that rupture (Fig.36). The pustules usually occur between leaf veins. Teliospores develop on the leaves and urediospore pustules are visible, resulting in black pustules that remain covered by leaf epidermis until maturity. Severely infected leaves and fields will turn prematurely yellow and then dry up to a brown color. Usually, garlic plants infected with rust have small cloves (Fig.37).

![Figure 36. Severe infections of garlic with rust and a disappointed farmer in North Wello/Ethiopia](image-url)
Biology
The urediospores and teliospores both overwinter and therefore, both serve as primary inoculums in the spring on the emerging garlic crop. Urediospores are more important in rust survival. Urediospores and teliospores may travel by wind over long distances. Urediospores need at least four hours of 97% relative humidity to germinate and infect but do not survive when immersed in water. Optimum temperatures for infection are between 10°C and 15°C. Temperatures above 24°C and below 10°C inhibit infection. The cyclical production of urediospores during the growing season serves as a continuous inoculums source throughout the life cycle of the crop. When plants are physiologically stressed the disease tends to be more severe.

Control Measures

Prevention

Good management strategy includes use of pathogen free planting material; weed control; planting Alliums in rotation with unrelated crops; applying proper fungicides at the proper rate, time and frequency.
9. References


CHAPTER V: Shallot

1. Introduction

Shallot is a close relative of the onions. However, as opposed to onion, which has a single bulb, shallot, produces multiple shoots and cluster of small bulbs that are attached to the base plate. It is often multiplied vegetative by bulb splits. However, recently seed propagated shallot cultivars have been developed in other countries as well as in Ethiopia. Shallot is preferred to bulb onions for its strong pungency and delicate flavor; ability to grow and mature within short period of time (3-4 months); and tolerance to foliage pathogens (Pernospora destructor and Alternaria porri) mainly due to fast regeneration of leaves soon after attack. Thus, shallots can be grown more successfully in the humid tropics than bulb onion (Currah and Proctor, 1990). It also gives better ground cover to protect the soil and suppress weeds.

In Ethiopia, it is mainly used for flavoring the local dish 'Wat'. The bulbs, sheaths, and green leaves are used along with pepper and other spices in the preparation of a blended spice called “Berbere.”

2. Climate and Soil

Shallot adapts well to a wide range of climatic and soil conditions. In Ethiopia, it is mainly produced in the mid- and high-altitude areas ranging from the highlands of Arsi and Bale (2400 meter above sea levels; masl) to the lowlands of Kesem and Shenkora (1600 masl). The major production areas include: Fedis in Hararghe; Huruta, Sire, Shirka, Bokoji and Arsi Negelle in Arsi; Sinana in Bale; Ambo, Welisso, Godino, Kesem and Majete in Shewa; Bure, Adet, Debre Work and the vicinities of Debre Markos in Gojam and Wora Ilu and Wora Babo in Wello sub-regions (Getachew and Asfaw, 2000).

3. The Crop

Three vegetatively propagated varieties of shallot namely Huruta, Negelle and Minjar have been released from Debre Zeit Agricultural Research Center since 1999. A fourth cultivar named Yeras was introduced from Thailand through the Melkassa Agricultural Research Centre.

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Huruta:-
It is adapted to mid to highland areas, has red color and big sized bulbs. It is a late and vigorous cultivar and matures within 120 days.

Negelle:-
It is adapted to mid to highlands. It has bigger but fewer bulbs than Huruta. Most of its features are similar to Huruta.

Minjar:-
It is adapted to a wide range of agro-ecologies from lowlands to highlands. It has dark red and medium sized bulbs with up to 20 bulblets per plant (Fig.38). Of the three cultivars, Minjar is most tolerant to leaf diseases. It matures earlier (110 days) than Huruta and Negelle. Each of these cultivars gives yield up to 25 t ha\(^{-1}\) under good management practices.

Figure 38. Shallot cultivar Minjar

Yeras:-
It is seed propagated cultivar originated in Thailand. It was introduced and recommended by Melkassa Agricultural Research Centre for low to mid-altitudes. It has light red bulbs and can yield higher than those vegetative propagated cultivars.

4. Establishment/Management

The establishment of shallot under commercial production has been limited because it is propagated vegetatively; requires more planting materials; preparing the materials takes time and it is costly. However, with the new introduced cultivar (Yeras) and other cultivars in the pipeline,
there is a bright future for the development of more new shallot cultivars.

4.1. Vegetative propagation

Shallot is propagated vegetatively, which requires large quantity of mother bulbs (1.2 t ha⁻¹) as planting material, which is often very expensive during planting time. It is bulky to transport and difficult to store. The bulbs carry fungal diseases and latent viruses from one generation to the next. Bulbs have a short shelf life of about three to four months. Therefore, planting material is obtained through exchange between irrigated lowland and rain-fed highland areas.

Bulbs for planting should break its dormancy, which takes about a month after harvesting. Bulbs are split before planting and rotten or shriveled bulbs are discarded while small and very large sized bulbs can be saved for home consumption. Medium (>25 mm) sized bulbs are preferred for planting.

In Ethiopia the lower 3/4 part (occasionally treated with wood ash) of the topped bulbs is used for planting. The top 1/3 of the bulbs are used for consumption. There was no significant difference in bulb yield was obtained between the split and whole bulb planting methods. This practice, however, may not be advised in areas where bulb transmitted diseases are common.

Bulbs are spaced 40 cm between double rows and 20 cm between rows and plants. However, in the seed propagated cultivars, spacing between plants can be reduced to 10 cm.

In most parts of Ethiopia, shallot is planted at the beginning the main rainy season from May to July. In areas where “belg” rain is available, planting is done in March. In irrigable areas, planting can be done at any time between mid-august to end of March. However, planting should be planned so that the crops mature and become ready for harvest in the dry period.

Planting is done by placing the bulbs gently on the side of the ridges in an up-right position and covering with fine soil.
4.2. Production through botanical seeds

Nursery management of shallots propagated through botanical seeds is quite similar to that of onion. Other cultural practices are similar to the description given above under vegetative propagation. Although the intrarow spacing is not determined for seed propagated shallots, it is expected to be wider than the 5 cm set for onions and narrower than 10 cm set for vegetatively propagated shallots.

4.3. Weeding/Cultivating

In the production of shallot weed control should be planned so that the weed population is reduced after planting. Intensive land preparation and harrowing during the dry periods would enable to reduce the weed population. Moreover, depending on the weed population, light cultivation every three to four weeks is necessary. Care should be taken not to damage/injure bulbs during cultivation.

4.4. Fertilization

The blanket fertilizer recommendation for shallots is 200 kg DAP and 150 kg Urea ha⁻¹ at planting time. Half of the Urea (75 kg) is applied one to two weeks after 50% sprouting and the remaining half one month later.

5. Harvesting, Curing and Storage

Shallot takes about 110 to 120 days to mature depending on the cultivar and the agro-ecology of the area. Mature plants show softening of the neck and bending of leaves. Harvesting can be done from physiological maturity until leaves dry completely. Field storage for up to two weeks is often practiced to escape low market price during gluts if no risk of rain is anticipated. The bulbs can be cured well during field storage; albeit loss of the outer skin and weight can be encountered. Harvested shallots are cured under shed or diffused light store for a week or two. Trimming and topping is done in the same way as described above for garlic.

Shallot bulbs do not have good storage quality. Most of the harvest is sold soon after harvest while the remaining is stored for propagation. It has been noted that the price of shallots during planting time is almost three
folds higher than the price during pick harvest. Therefore, effective means of storage of bulbs can help to generate good revenue and considerably reduce production cost, as the demand for planting materials is high at planting time.

In the *Shenkora* area, farmers store shallot bulbs by alternately piling bulbs and wheat straw in the ratio of 2:1 (v/v). Finally, a wooden conical shaped roof is constructed over the pile and is covered with straw to prevent the entry of rain. Hanging shallot bunches under roofs is also a common practice of storage in Ethiopia (Fig. 2). Farmers in some shallot and onion producing countries use stores made of bamboos or other wooden walls and racks where bulbs are spread into thin layer on the rack.

Wholesalers pack shallot in 100 kg sacks and transport to the store where piles are stacked one on top of the other. The practice often leads to more sprouting and rotting due to impaired ventilation and physical damage caused due to weight. To minimize the losses, the sacks are frequently emptied; damaged and rotten bulbs are removed; and the bulbs are recured.

Shallot bulbs stored at 0°C will have less rooting, sprouting and weight loss (Fig. 39). However, those stored at 4 or 10 °C could have high rooting and sprouting whereas those stored at 20°C had high weight loss. Bulbs planted after storage at 4 or 10°C bolted more than those stored at 0 or 10°C.

![Figure 39. Shallot bulbs stored under the roof/ceiling of farmer's house](image)

6. **Seed Production**

Shallot is a biennial plant that takes two seasons for seed production.
However, the crop is usually grown as an annual for bulb production. During the first season bulbs are formed. In the next season, flower-stalks and seeds are developed. The change from vegetative to reproductive phases needs exposure of mother bulbs to low temperature (8-12°C) for eight weeks when the plants are one to two months old. This temperature naturally occurs between October and November in the mid-and-high-altitude areas of Ethiopia. Therefore, planting mother bulbs at the end of August or at the beginning of September can pre-dispose the plants of the right stage to the required temperature for flower-stalk initiation and bolting. Later plantings may disfavor development of inflorescence initials leading to reversion to vegetative (bulb) development due to higher temperature.

Alike in the onions, seeds of shallot can be produced either through bulb-to-seed or seed-to-seed methods as described below.

6.1. Bulb to seed
The bulb to seed production is described as follows.

a) Sow seeds and produce bulbs in the first season (Table 7). Schedule bulb production so that harvesting is done in mid-June;
b) Select bulbs based on color, shape, size (medium), etc of the cultivar’s characteristic and discard misshapen, split, rotten, sprouted, injured and diseased bulbs;
c) Store the selected bulbs for one month to break dormancy;
d) Plant the bulbs to produce seeds in the second season. Ridge and furrow planting is often used with spacing between double rows (40 cm), rows (20 cm) and plants (10 cm); and
e) Rouge off-type plants with different height, leaf and sheath colors, susceptibility to diseases, etc.

The method has the advantage of improving or maintaining varietal purity/quality due to selection of good quality bulbs. It takes 15 to 16 months to produce seeds.
Table 7. Crop calendar for shallot bulb and seed production

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<td>bolting /flowering/</td>
<td>seed set</td>
<td>seed</td>
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* indicate the X\textsuperscript{th} week of the month
6.2. Seed to seed

This can be done as follows. Sow seeds and allow them grow; produce flower-stalks and seeds in the same season. Rouge off-type plants with different height, leaf and sheath colors, and susceptible to diseases.

As opposed to the bulb-to-seed method, this method doesn’t give the possibility of selecting for good quality bulbs. It may also lead to developing unnecessary plants that tend to flower in the first season. It takes 7 to 8 months to produce seeds.

6.3. Pollination

a) Shallots are highly cross pollinated (up to 90%); the male flower weathers before the female matures;

b) Bees and flies pollinate shallot flowers. Placing bee hives near the farm at flowering increases seed set. Pesticide sprays during this period should be avoided; and

c) Isolation distance of at least 400 m between similar cultivars and 5 km between different colors onions. Rain during flowering inhibits pollination.

6.4. Agronomic practices

Most of the agronomic practices are the same as the above for bulb production. Some of the particulars are:

a) Spacing for shallot seed production is under investigation. Until then, spacing for onion seed production (50 cm, 30 cm, 20 cm, between double rows, rows and plants, respectively) is adopted; and

b) Flower stalks may fall and need support in some cases

6.5. Seed maturity and harvest

Inflorescences of a shallot plant bolt for an extended period of up to three weeks or longer. Florets on each umbel mature at different times (Fig. 3). Consequently, seeds mature and become ready for harvest after about five
months from planting, between March and April. At maturity, early set capsules crack open and black seeds become visible while most others capsules turn from green to light yellow.

Harvesting should be done when 5-10% of the capsules mature though a few late capsules may still be green. Late harvesting leads to shattering of seeds of open capsules while early harvesting results in more immature seeds. Immature seeds do not fill well, may fail to germinate or produce weak seedlings, therefore, should be discarded during cleaning. Warm and dry weather is required during seed setting and harvesting. Harvesting and processing of seeds can be done as follows:

a) Cut mature umbels with a shear and dry them on canvas;
b) Thresh the seeds by rubbing against the canvas or lightly pounding with stick. Remove chaffs; very fine chaffs and light seeds can be removed by immersing the seeds in a bucket of water for about three minutes;
c) Dry the seeds to moisture content of 7 to 9%. Pack them in airtight containers (plastic or aluminum bags). Lower the humidity 20 to 25% and the seed moisture content 6 to 8%. Low storage temperatures can result in long storage life.
d) Store the seeds in cool dry place but not more than a year;
e) Seed yields may range from 500 to 2000 kg/ha as in onions; and
f) The weight of 1000 shallot seeds ranges from 3.4g.
7. Major Diseases

Several diseases are known to attack shallot however, only the most economically important diseases in Ethiopia are discussed in this chapter. Most diseases of shallot and onion, in most cases, can be caused by the same pathogens.

7.1. Downy mildew (*Peronospora destructor*)

Downy mildew is caused by a fungus-like microorganism known as *Peronospora destructor* that overwinters on infected plants or debris. There are no resistant cultivars. Many *Allium* spp. are affected including onion, chives, garlic, leek, and shallot. This disease is favored by cool (less than
-5.5°C) and humid weather. Spores (conidia) can be wind-blown long distances and are produced at 6.1°C to 26.6°C (optimum is 11.1°C to 12.8°C). A pathogen cycle from infection to sporulation can be completed in about 2 weeks. Necks on bulbs of diseased plants can remain succulent and being infected by secondary pathogens after harvest.

**Symptoms**

Pale–green, yellowish to brownish areas of irregular size and shape on infected leaves or seed stalks are usually noticed. Symptom can be seen within defined regions in a field and produces fruiting bodies and spores called sporangia on the surface of the leaves and seed stalks. Leaves become girdled in the region where mildew develops and the leaves collapse (Fig.41). The disease is favored by humid weather conditions and can infect garlic.

Downy mildew symptoms appear on older leaves as elongated patches that vary in size and are slightly paler than the rest of the foliage. Diseased parts, such as leaf tips, fold over and collapse. Lesions on seed stems are circular and elongated and often affect only one side of the leaf. Weakening of one side of the leaf frequently causes it to break over (Anonymous, 2014).

![Figure 41. Shallot infected with downy mildew at DebreZeit/Ethiopia](image)

**Biology**

The downy mildew pathogen survives in living plants, including onion bulbs in the field or cull piles and in perennial shallots. The pathogen can also persist as oospores in shallot tissue or the soil. Studies indicate that
mycelium surviving in overwintering shallots is the most important source of inoculum. Onion leaves can be infected at any stage.

Sporangia form on leaves or seed stalks of infected plants and are dispersed in air currents. Downy mildew develops rapidly under cool, humid conditions. Sporulation takes place at night; between midnight and sunrise at high RH (95%) with an optimum of 12-13°C and daytime temperatures over 24°C inhibit sporulation. Sporangia are released as the relative humidity in the airdrops during the morning. Sporangia are short-lived, but can survive for 2 to 3 days in the field, especially under low light conditions. Infection of a susceptible leaf require a minimum of 3 to 6 hours of leaf wetness at temperatures between 6 and 27°C, with an optimum of 10-12°C.

Disease management

Prevention

Plant when the weather is dry and temperatures are over 25°C. Avoid planting in the same area because old crops may serve as inoculum for the pathogen in the new plantings. Avoid farms located in the mountains or cool valleys. Do not use overhead irrigation as downy mildew sporulates at night when the leaves are wet. Use disease free seeds. Bulbs should be heat treated to control infection, if they are to be used to establish seedlings. Keep fields distant apart from old plantings and use soil that have good drainage properties. Use Nitrogen fertilizer sparingly. Avoid dense planting or planting near weeds. Remove unharvested plant parts, destroy volunteer shallots, and crop debris as soon as the crops are harvested. Use sound rotation practices so that shallots or its relatives should not be planted within 2 to 4 yearson same field.

Chemical

Use fungicides that are recommended, apply protecting fungicides if early symptoms of the disease are detected; rotate these fungicides using 7-10 day intervals; fungicides should be applied after an irrigation cycle and after a heavy rainfall.
7.2. Purple blotch (*Alternariaporri*)

Purple blotch (PB) occurs throughout the world and yield losses could reach 50%. The disease is caused by *Alternariaporri*. It is a common disease of shallot, onion, and garlic (Fig.42). It can be destructive alone or as a secondary pathogen. *Alternariaporri* can also infect several other *Allium* species (Ellis, and Holliday, 1970). In Ethiopia purple blotch had not been known to affect garlic however, it was first recorded on garlic at Chefe-Donsa in 2002 (Fig.42B).

**Symptoms**

Symptoms are of two types. Initially, flecks similar to those induced by the botrytis leaf blight fungus may occur. Oval to football-shaped lesions appear containing alternating, concentric zones of dark and lighter tissue. With increasing severity of the disease, leaves become generally yellow to brown and lose erectness.

![Purple blotch symptoms on shallot (A) and garlic (B).](image)

**Biology**

The mycelium and conidia overwinter on infested onion residues. Conidia are produced in the spring and disperse by wind or splashing water to onion leaves. Germinate in 45 to 60 minutes at 28-36°C. Penetrate leaf tissue through uninjured epidermis, stomata. Lesions may appear shortly and conidia are produced thereafter. Almost no infection occurs at or below 13°C. The optimum temperature for sporulation is 25°C at 90% relative humidity. Spore release is promoted by irrigation, wind, and rain. Temperatures below 13°C are not conducive; above 13°C contribute to the development of the disease. Long periods of leaf wetness and relative humidity above 90 percent generate higher probabilities for infection and
disease occurrence. Nine to eleven hours of leaf wetness periods are ade­quately to promote spore production and infection. Emerging leaves be­come increasingly more susceptible to the disease as the bulbs approach maturity.

Control Measure

Prevention

Rotate crops with non-susceptible crops; use healthy transplant; harvest during dry weather when the bulbs are fully mature and the tops are dry; bulbs should be stored at 0°C and 65 to 75% relative humidity; applying broad-spectrum protective fungicides prior to spore deposition will provide effective control of Purple blotch; hot water seed treatments reduced inoculum but it also reduced seed germination and vigor.

Chemicals

Before using any pesticide, please make sure that the pesticide has been registered by the Ministry of Agriculture for use in Ethiopia. Spraying with recommended and registered fungicides is often necessary. Spray treatments should be initiated when symptoms first appear and leaf wetness periods exceed 11 hours. Thoroughly covering shallot leaves with the spray is essential to achieve success.

8. Major Insect Pests

8.1. Onion thrips

Onion thrips, *Thripstabaci* attacks many cultivated and wild plant species. Shallot and garlic are among the cultivated hosts of onion thrips in Ethiopia (Fig. 43). Although high onion thrips population damages leaf of shallot and garlic, this leaf damage occasionally leads to bulb yield losses. For instance, under DebreZeit condition bulb yield losses varied between less than zero and 25% in shallot and 21% in garlic. A negative bulb yield loss means the bulb yield from insecticide untreated shallot or garlic was greater than insecticide sprayed counterparts.

Onion thrips also infests shallot bulbs if there is high population at the time of harvest and continues to breed if the bulbs are kept for curing or
stored for the next planting. Bulb infestation in garlic is less because the scales of garlic bulbs are too tight to allow entrance of onion thrips to the bulbs. Other than the direct damage done by onion thrips on shallot and garlic, the injury that left after feeding eases the penetration for *Alternaria tala*porri, the causal agent of purple blotch of shallot and garlic.

![Figure 43. Onion thrips on shallot](image)

**Description**

Adult onion thrips are tiny cigar-shaped insect. The females are 1.0 - 1.3 mm in length and males are ~0.7 mm in length. The color of adult onion thrips is pale yellow if it develops under high temperature or dark brown when it develops under lower temperature condition. Adult onion thrips have seven-segmented antennae and a gray or yellowish gray ocellar pigment. These gray ocellar crescents are used to distinguish onion thrips from most species in Thripidae, which have orange to red ocellar crescents. It also has four fringed wings. Eggs are kidney shaped and are inserted either in the upper or lower surface of a leaf very close to the surface. The nymphs are tiny wingless and almost white in color. The prepupa and pupa of onion thrips differ from the larvae by the presence of wing sheaths.

**Life cycle**

Onion thrips undergoes incomplete metamorphosis. Thus, its lifecycle consists of an egg, larval instars, pre-pupa, pupa, and adult stages. Onion thrips reproduces sexually by laying eggs and asexually through parthenogenesis. The onion thrips lay eggs in younger leaf or bulb tissues, but they lay more eggs and develop faster on leaves than on bulbs. It lays
more eggs during the first 10 days of oviposition, which allows a rapid establishment of large populations.

The eggs hatch in few days in to larva/ nymph. The nymph feeds and molts four times before it develops to adult. Pupation takes place in the soil. Under warm climatic condition onionthrips requires about two weeks to develop from egg stage to adult stage. Consequently, it has several overlapping generations in a season.

**Symptom**

The nymphs and adults of onion thrips rasps the leaf tissue leaving the epidermis intact and suck the sap that exuded from the injured tissue. This injury causes tiny white spots and when the spots coalesce, the leaf becomes sliver colored. This injury reduces the photosynthetic ability of the leaf, interferes with transportation of nutrients to the bulb, and predisposes the plant for fungal attack. Onion thrips feeds between leaf bases of the plant where it is difficult to reach them with insecticides.

**Seasonal distribution**

The ecology of onion thrips is not well studied under Ethiopian conditions. However, because of the warm climate, onion thrips activity is believed to be continuous during the dry and the wet seasons. The available literatures on the seasonal distribution of onion thrips indicate that the density of onion thrips in the main rain season -from July to September- is low because of the low temperature and lethal action of the heavy rain. Onion thrips population density is also low during the cooler months- October to January. However, it is high from February to May during which the temperature is hot and the rain is nearly absent. These weather conditions increase onion thrips population growth and the severity of injury.

**Scouting**

Scouting is a process of counting / estimating the pests on a sufficiently representative number of plants in the crop. The information generated is used for decision-making on whether or not to apply pesticides. During scouting, it is necessary to count both the pests and their natural enemies. Therefore, the scout should not only be knowledgeable in scouting and monitoring techniques but also able to identify correctly all pests and associated natural enemies in the crop.
Scouting continues until the crop matures and this continuous monitoring helps to detect pest activity that was not detected during the previous scouting, to check whether the pest population is increasing or decreasing, to know if the natural enemy density is sufficient enough to suppress the pest population below a level that does not cause economic damage, or to know the effectiveness of control measures. If predators are numerous, pesticide application may not be required or it may be necessary to apply more selective pesticide.

Onion thrips can only be found by careful searching of leaves, especially at the leaf base. Then the number of adults and nymphs present on the plant are visually counted in situ. The use of magnifying lens eases the counting. Other sampling methods such as beating and shaking a plant onto counting board/sheet or washing the plants with water also gives satisfactory results.

Management of onion thrips

Cultural control

Water stress predisposes shallot and other alliums to onion thrips attack. Therefore, irrigating shallot fields with water will make the crop less attractive to onion thrips. In some areas of northwest Ethiopia farmers spray shallot with water or mulch their field with faba bean/field pea straw. Water spraying can dislodge thrips or they may drown and die because of suffocation. Mulching affects the number of onion thrips nymphs that undergo pupation in the soil. Maintaining weed free shallot fields also reduces onion thrips infestation.

Host-plant resistance

Although the resistance of shallot or garlic to onion thrips has not been assessed, in onion (Allium cepa) the leaf structure of different varieties affects the numbers of onion thrips they support. In susceptible varieties, the young blades generally have one flat side, which is closely pressed to the flat surface of the opposite leaf, thus providing many crevices into which the larvae can creep for protection. In contrast, other varieties have leaves almost circular in cross-section with a wide angle between the two youngest leaves, thereby reducing the number of crevices suitable as larval shelter.
Unlike onion and garlic, shallot produces new shoots and leaves once the central/main shoot terminates growth. The advantage or disadvantage of such growth habit in relation to onion thrips has not been studied.

**Natural enemies of onion thrips**

Ladybird beetles such as *Adonia variegata* and the pirate bug (*Orius* spp. (Hemiptera: Anthocoridae) are predators on onion thrips in the Rift Valley section of Ethiopia.

**Insecticides**

The onion thrips inserts eggs in leaf or bulb tissue, feeds in between leaf bases, and pupates in the soil. This behavior helps the insect to escape contact with insecticides. Consequently, onion thrips population surges usually two weeks after insecticide application. Re-infestation by immigrant onion thrips form the surrounding crop fields may contribute to the rapid buildup of onion thrips population. This in turn requires either frequent application of insecticides or the application of persistent insecticides. However, the use of persistent insecticides has undesirable effect on the environment. In Ethiopia, currently there are no insecticides specifically labeled for use on shallot and garlic for the control of onion thrips. Consequently, farmers use insecticides registered for use on cotton, flowers, tomato and other crops.

**Integrated Pest Management**

Integration of the cultural and insecticidal control of onion thrips and creating favorable condition for natural enemy multiplication will provide economical control of this thrips in shallot.

**8.2. Cutworms**

Cutworm, *Agrostis sp.* and the armyworm, *Spodoptera* sp. occasionally attack shallot particularly at the early stage. The cutworm severs young seedlings at or slightly below the soil surface, while the armyworm climbs up on the above ground part and sometimes feeds within the tube leaf of shallot and onions. Neither cutworm management method nor its ecology has been studied under Ethiopian conditions.
Description

The cutworm passes through six instar stages and has variable body color. The older instars have greasy appearance. The adult moth has dark gray forewings marked with darker or lighter spots and narrow bands. The hind wing is uniformly lighter in color.

Life cycle

The female moth lays several hundreds of eggs either singly or in small clutch on warm dry soil or dry plant residue in sparsely populated vegetation. The eggs hatch in few days and the early instars feed on the foliage of weeds. The medium and older instars usually feed on roots and stems. Pupation takes place in the soil.

Symptom

It is believed that because of the toxins present in shallot/onion early instars of cutworms do not feed on them. Therefore, it is only the older instars that are capable of feeding on these plant species. The older instars cut the plant near or slightly below the soil surface, and when the soil is dug few centimeters deep near the cut plant the larva will be found. The percentage of cut plants is also an indicator of the level of population in the field.

Control

In many cases, feeding on shallot/onion by cutworms or armyworm does not cause economic damage. Prior to planting shallot/onion, the larvae of cutworms spent most of their lifetime on weeds available in the field. When these older larvae survived the injurious action of plowing and other farm operations, they attack the sprouting shallot. Therefore, controlling weeds and other plants at least three weeks ahead of shallot planting will greatly reduce available food for the growing larvae and ultimately the number of larvae that survive starvation. The cutworm does not attack shallot, as the plants get older.

Low temperature, high soil moisture, and rainy condition are natural mortality factors that reduce considerably the population of cutworm larvae. When the moisture content of the soil is high, larvae often feed on the foliage of shallot. This feeding habit exposes the larvae to predators.
9. References
CHAPTER VI: Carrot

1. Introduction

Carrot (*Daucus carota*) is one of the important vegetable crops grown worldwide. It is originated in Central Asia, Afghanistan and spread to west and east through traders. Currently, western carrots of orange roots are common in Europe and North America. Eastern carrots are growing mainly in Asia with distinct yellow and purple color. In Ethiopia, orange colored carrots are the most common type. It is well adapted to mid-and-high-altitude areas and produced under rainfed and irrigation conditions.

Carrot is among the top-ten most economically important vegetable crops in the world, in terms of production area coverage and market value.

It is one of the widely produced and consumed root vegetables in Ethiopia. It is taken raw as well as in cooked form. Its consumption is mainly concentrated in urban areas of the country. In Ethiopia, over 51046 tons of carrots were produced on an area of 1,132.94 hectares in 2013. The production per unit area is about 45 q/ha.

Carrots contain 88% water, 4.7% sugar, 2.6% protein, 1% ash, and 0.2% fat. It also contains carotenoids, flavonoids, vitamins, and minerals thus making the crop a rich source of nutrition that is essential for good health. Carotenoids and anthocyanins are also the major antioxidant pigments found in carrots. Carotenoids are the yellow, orange, or red colored phytochemicals found in most yellow and orange-fleshed cultivars. The widely used orange carrot is high in α- and β-carotenes and is a rich source of vitamin A. The yellow-fleshed carrot is due to lutein, which plays an important role in prevention of muscular degeneration. Carrots also contain flavonoids like kaempferol, quercetin and luteolin. According to Silva Dias, among the 39 fruits and vegetables, carrots have been ranked 10th in nutritional value. Carrot is a good source of dietary fibre and other minerals like molybdenum, which is rarely found in many vegetables, magnesium, manganese and potassium.

Recently, due to improved awareness of consumers, about the health contributing attribute of vegetables resulted in increased demand for same. Hence, a continuing increase in health consciousness would favor sus-
tainable consumption of vegetables including carrots. Moreover, there exists higher level of malnutrition in the country of which vitamin A deficiency is the most prominent one (Demisseiet al. 2010). Therefore, an increase in carrot production and promoting its consumption is a kind of nutrition sensitive intervention that would reduce undernourishment and in part contributing for an improved family livelihood.

2. Climate and Soil

The carrot is a cool-season vegetable crop with some tropical types that can tolerate quite high temperatures. It requires 15 to 20°C temperature for its optimum growth. Temperatures below 10°C cause longer, more slender and paler roots. Conversely, higher temperature and extended periods of hot weather can cause shorter, thicker and coarse roots with strong flavor. Well drained soils which have good reserve of organic matter and essential elements are suitable for carrot production. Poorly drained soil encourages the spread of bacterial disease. Heavy soil encourages the production of malformed roots of poor quality. The ideal soil is deep, loose and well-drained, sandy or loamy sand with a pH of 6.0 to 6.5. Soils that are heavy and capped resulted in deformed root growth and poor seed germination.

3. The Crop

The most common types of carrots that are grown in Ethiopia are temperate or European types. These are:

**Nantes**

Almost a cylindrical root system terminating abruptly in small, thin, tail, 12–15 cm long, fine textured; orange fleshed with self-colored core, mature in 90–110 days.

**Chantenay**

Roots are conical to near conical and are thick, attractive orange, smooth, thick at the shoulder with tapering towards the distinct stumpy end. Core indistinct, fleshy tender, sweet and fine textured. It is an excellent variety for canning and storage.
4. **Land Preparation**

4.1. **Site selection**

Suitable site selection is an important part in the carrot root/seed production endeavors. The site should have well drained soil and well protected from wind. It should be a new site that had not been planted with crops of related species and weeds that can host common diseases. It should be easily accessible to inputs including water sources.

4.1.1. **Field preparation**

The field should be worked deep to a depth of, at least, 30 cm. If the soil is not thoroughly prepared and contains clods, seed germination will be hampered and quality roots cannot be produced. Root deformity usually occurs in fields which are not properly prepared. In areas with poor drainage and longer rainy season raised beds with 20 cm height can be prepared. Land surface should be as smooth as possible before sowing (Fig. 44).

![Figure. 44. Well prepared carrot field](image-url)
4.2. Sowing

Carrots are grown directly from seed and about 4 to 5 kg/ha of carrot seed is required for planting one hectare. The seed is sown/drilled on shallow seedbeds in rows that are 25 cm apart. Seedlings are thinned out when reached about 10 cm heights at about 5 cm spacing between plants. In Ethiopia carrot can be sown in March for the Belg production and from June to July for the main rainy season (Meher) production. Carrot germination is slow and requires about 10–20 days to sprout. It is essential that at the time of sowing the soil should have sufficient moisture or light irrigation should be applied immediately after sowing.

4.3. Fertilization

The crop has high potassium and relatively low nitrogen need. However, fertilizer should be applied based on the results of soil analyses. The Amhara Regional Agricultural Research Institute (ARARI, 2005) recommends 175 kg DAP per hectare as blanket recommendation for carrot. In less fertile soil areas like Tigray Regional State, farmers use 40-50 q/ha of well-decomposed manure, 100 kg/ha DAP before planting and 50 kg/ha urea before planting, at planting and after first cultivation, respectively. However, in some reports the application of compost or organic manure does not seem acceptable, since they cause unattractive and hairy roots, with a coarser texture.

4.4. Cultivation

Carrot seedlings grow slowly at first. The field should be free of weeds especially for the first three to six weeks after sowing. Earthling up should be practiced to allow proper aeration and root development. During cultivation, care should be taken to protect the crown of the roots from exposure to sunlight in order to protect greening that seriously lowers the quality of the roots.

5. Major Diseases

Numerous fungal, bacterial, nematode as well as insect pests cause recurrent yield reduction in carrot. To alleviate the challenges related with these diseases and pests’ relevant pest diagnosis together with manage-
ment approaches has to be applied. The major diseases of carrot are discussed in brief.

5.1. *Alternaria* Leaf blight

**Epidemiology**

The fungus (*Alternaria dauci*) sporulates profusely on dead and dying plant tissue, especially during moderate to warm weather (16 to 25°C or 60 to 77°F) with prolonged periods (8 to 12 hours) of leaf wetness. Wind and splashing water readily disseminates spores into and among adjacent fields. The pathogen can also move from field to field on contaminated equipment. *A. daucisurvives* between carrot crops as a pathogen of wild and volunteer carrot, in infected crop debris, in the soil for up to one year, and in/on and on contaminated seed.

**Symptoms**

Symptoms first appear as greenish brown, water-soaked lesions. Lesions quickly become dark brown to black with or without yellow halos. Under disease-conducive conditions, lesions coalesce and cause entire leaves to become yellow, collapse, and die. Older leaves are most susceptible to infection and often the first to develop symptoms (Fig. 45), but all leaves can be infected. Petiole lesions appear similar to leaf lesions, but are more elongated; petiole lesions quickly kill entire leaves.

![Figure 45. Alternaria leaf blight of carrot](image)
Control measures

Cultural and chemical method

The disease can be controlled effectively by using high quality seeds free from the pathogen. Other treatment includes: treating seeds with hot water to reduce seed contamination, selecting cultivars resistant or tolerant to *Alternaria* leaf blight, apply a three-year or longer crop rotation scheme with small grains, bury crop debris deeply after harvest and controlling wild and volunteer carrot. Further, high planting density has to be avoided and orientation of the rows must be parallel to the prevailing wind direction. In addition, fungicides like chlorothalonil, copper (Kocide) and Ridomil Gold are effective against the pathogen.

5.2. Powdery mildew

Epidemiology

Spores of the fungus (*Erysipheheraclei*) can be carried long distances by wind from other carrot fields, volunteer carrots, or other related host plants. Unlike other fungi, the spores do not require a film of water to cause infection. It only requires periods of high humidity and moderate temperatures of 10-32°C for infection. Powdery mildew is most likely to occur in regions with warm dry climates. Infections of carrot begin on older plant parts, and carrot fields become more susceptible as they age.

Symptoms

Initially, patches of white, powdery growth appear on older leaves and petioles. The powdery growth can be very dense and noticeable. All above ground plant parts are susceptible to infection, including flower stalks and bracts. As the infection progresses, it moves onto younger plant tissue (Fig.46), where it cause chlorotic lesions. Although plants can survive heavy infections, if left unchecked, it can cause premature senescence.
Control measures

Cultural and chemical method

The most effective way of controlling powdery mildew on carrot is avoiding water stress, crop rotation, incorporation of infested soil after harvest, maintaining plant vigor (without over fertilization) and use of resistant cultivars can help to prevent powdery mildew. Chemicals like sulfur powder can be used to control the pathogen.

5.3. Root knot nematode

Epidemiology

Root knot nematodes (*Meloidogyne spp.*) survive between crops on alternate hosts and in egg masses in the soil. When conditions are suitable, the eggs hatch and juvenile nematodes penetrate root tips. Female nematodes mature within the roots and a gall develops around them. The females lay eggs into a gelatinous matrix on the root surface. The eggs either hatch immediately or become dormant until active growth commences. Nematodes spread mainly by surface water drainage, wind blowing soil and farm equipment.

Symptoms

Larvae feed on root tips and rootlets, affecting foliage growth and weight and length of roots. The pathogen causes malformation of the edible root,
including forking, galling and hairiness (Fig. 47) Severe infections may result in decomposition by secondary pathogens. A loss in stand will occur if seedlings are attacked. Older, infected plants appear stunted and chlorotic and have a tendency to wilt. Damage levels can be high even when nematode populations are low.

Figure 47. Carrot infested by root-knot nematode

Control measures

Cultural method

Several cultural practices, such as crop rotation, fallow soil, soil solarization, and certain soil amendments, are helpful in reducing root-knot nematode losses.

Chemical and biological Method

Root knot nematode can be controlled effectively by soil fumigation with nematicides and Bio-agents like Pasteuriapenetrans, Trichodermaharzianum, DactylellaoviparasiticaandVAM fungi.

6. Major Insect Pests

6.1. Cut worm

Biology

Cutworms (Fig. 48), overwinter as eggs, larvae, pupae or adult moths depending upon the species. They have 1 to 4 generations per year depending upon the species and location. Moths lay eggs on the soil and the larvae hatch to feed on plants. Weedy areas, fields of grasses or pasture are ideal sites for cutworms to overwinter. It is often in these areas and along field borders where problems arise. If weeds are permitted to grow after
crop harvest, large numbers of cutworms may survive to attack carrot in the following season.

**Damage**

The cutworm feeds at or below the soil surface at night. It is an active feeder of young foliage and stems tissue and can cut off many young seedlings.

![Figure 48. Cutworms of carrot](image)

**Control measure**

**Chemical**

Effective chemicals used for control include permethrin, chlorpyrifos and cypermethrin.

**Cultural**

Crop rotation should be used, avoiding susceptible crops. Planting should not be done in wet, grassy areas. Grassy weeds should be kept under control.

**Biological**

There are a number of braconid parasites and predaceous ground beetles that can reduce the damages caused by cutworm infestation.

**Physiological disorders**

One of the major physiological disorders that are seen in carrot field is splitting or cracking of roots. The splitting correlates with the amount of
nitrogen in the soil, high N in the soil increases splitting while it tends to reduce the physiological disorder. Larger roots are more prone to splitting than smaller ones and there is greater splitting in carrot grown under wider spacing. Irrigation and herbicides do not significantly affect the amount of splitting of carrot roots.

7. Harvesting and Postharvest Management

7.1. Maturity and harvesting

Carrots are harvested when they reach a diameter of 20 mm and more, or 90 to 120 days after sowing. Delay in harvesting can result in feathery and unfit roots for consumption. Mostly, when the carrots have reached the mature stage, the base tips appear on the soil surface (Fig.496). They are normally dug out, with a spade when the soil is sufficiently moist.

![Carrot harvesting](image)

Figure 49. Carrot harvesting

7.2. Post-harvest handling

Cleaning and trimming, sorting and grading

Careful handling of carrots during and after harvest prevents bruising, shatter-cracks, and tip breaks and prolongs storage life. Generally carrot roots are trimmed and washed before sending them to market. Carrots can be sorted by hand for removing damaged and decayed roots (Figs 50&51). They are usually graded based on their size, i.e. diameter meas-
ured at widest point or root length. They should have uniform shape and color for the cultivar with smooth and tender texture.

Figure 50. Cleaning and removing soils

Figure 51. A good-sized quality carrot.

7.3. Packaging and storage of carrot

Packaging materials like baskets, net bags, and cartons can be used for packing carrots. They should be packed properly and could neither be over packed nor under packed. Temperature is the most important factor affecting the storage of carrots. Carrots can be stored for 3-4 days at ambient conditions. Matured carrots can be stored for 4-5 months at temperatures of 0°C and 95% relative humidity. During storage, carrots should be kept away from ethylene-producing vegetables or fruits like ripe tomatoes or banana as this will make the carrot to taste bitter (Maike, et al. 2012).
8. Carrot Seed Production

Carrots can be put into two categories based on their growth cycle. Cultivars originated in Asia are annuals. They do not have vernalization requirement. They can bolt and produce seeds during the first season. On the other hand, cultivars originated in the temperate regions of Europe and North America produce roots and rosette of leaves at the end of the first season. They receive cold (vernalizing) temperature and then bolt, flower, and produce seeds in the second season. Plants that bolt early during the first year are discarded or rouged out because they produce poor quality roots.

8.1. Climatic requirement (seed production)

Carrots are moderately hardy and tolerate high temperature, but seedlings are more sensitive to both temperature extremes. Production of carrot roots (stecklings) need similar climate as that of root production for consumption. Field transplanted stecklings, which have developed sufficient foliage need cold temperature of about 10°C for 4 to 8 weeks to initiate inflorescences. Warmer temperature is required for inflorescence elongation, flowering, and seed development. The seed maturity and harvesting needs dry weather (Navazio, et. al., 2010). Therefore, transplanting of stecklings between the first and second weeks of September enables the plants to be exposed to low temperature between November and December and to warm temperatures between February and April in the high and mid-altitudes of Ethiopia. Irrigation must be supplemented during the dry period for proper growth and development.

8.2. Methods of seed production

Carrot seeds are produced under two different methods, namely “seed-to-seed” or “root-to-seed.”

8.2.1. Seed-to-seed

In the seed-to-seed method carrot seeds are directly sown in the field in June and are left in the same field to produce roots. The mature roots are left in the same field to produce inflorescence, flowers and seeds. In this method carrots can be sown as densely as for root production and are later thinned out to 50 cm intra-row and 100 cm inter-row. During harvest in September; the thinned out roots can be sold or consumed. The roots
retained in the field get mild cold (vernalizing) temperature between October and December and then bolt, flower and produce seeds until April (Table 1). The seed-to-seed method relies on very good quality initial seed and satisfactory isolation because roots cannot be inspected and selected. Instead, the foliage can be inspected for any differences in characters from that of the cultivar.

8.2.2. Root-to-seed
Carrot seeds are sown at the rate of 6-8 kg ha\(^{-1}\) in the first year to produce roots ('stecklings') on a smaller land than the field on which seed is to be produced. The root-to-seed method enables selection of the best roots that are characteristics of the cultivar. The method also allows planting the stecklings in a smaller nursery plot during the first season of growth. The mature roots are lifted and stored under cool conditions. Biannual varieties should be stored at 1-3°C and 90-95% humidity for 8 to 10 weeks (Navazio et al., 2010). Selected stecklings are then transplanted into a permanent field between the last weeks of August and first week of September. The stecklings should be watered frequently to enhance good establishment. However, stecklings of annual carrot varieties may not need cold storage and can be transplanted immediately or a few days after lifting. Stecklings raised on 1 m\(^2\) can be enough for an area of 5-10 m\(^2\) of seed crop depending on the extent of rouging.

8.3. Preparation and establishment of steckling

Establishment of steckling should be done as follows.

a) Rouge plants with undesirable root or foliage characters;
b) Lift roots carefully and avoid damage that may expose them to bacterial and fungal infections and rotting;
c) Remove the tops carefully before or after lifting; but do not damage the root crowns. Leave about 5 cm of the leaf on the roots (Fig. 52);
d) Discard diseased, misshapen or mechanically damaged roots;
e) Transplant on well drained soils to avoid the development of bacterial soft rot that may rot the roots and reduces plant population. Space stecklings 75 and 100 cm between rows and 30 and 50 cm between plants depending on the cultivar;
f) The crown of the root must be at, or just below, the surface of the firmed soil;
g) Mulch the stickling after transplanting to protect them from desiccation or frost in frost prone areas;
h) Irrigate frequently until most roots regenerate to avoid desiccation that adversely affects establishment and subsequent seed yield. But care should be taken not to soak and rot the roots;
i) When re-establishing, the plant earthen up with about 10 cm of soil; and
j) Apply DAP (175 kg/ha).

![Carrot roots (stecklings) prepared for transplanting](image)

**8.4. Rouging**

Remove plants that display atypical foliage, bolt in the seed-to-root phase or early during root-to-seed phase. Discard roots that show poor color, split or fanged roots or those with rough (hairy) surface. Trueness to type is based on root shape, color, size, etc. (Fig 8).

**8.5. Pollination**

The crop is either cross- or self-pollinated. The difference is discussed. Honeybees are efficient pollinators of carrots and placing beehives closer to seed production fields can enhance seed yield and quality.

a. Cross-pollination - individual carrot flowers are normally protandrous (the pollen matures before the ovary becomes receptive) and much cross-pollination occurs between plants in a seed crop.
b. Self-pollination - occurs because of the extended flowering period, resulting from several successive umbels per plant and the succession of flowers on individual umbels

8.6. Isolation

To avoid self-pollination between related species a minimum isolation distance is essential. According to George (2009) the recommended isolation distance for the various seed types is given below:

a. Basic seed – isolation distance should be at least 1600 m

b. Commercial seed crops - because of the high possibility of cross-pollination, isolation distances should be 1000 m.

8.7. Harvesting seeds

Carrots have a distinct order of flowering and maturity, which relates to umbel position (Figs. 53&54). The king or primary umbel is the first to flower and ripen. Under DebreZeit conditions (1900 masl) the king umbel of AUA-108 flowered, seeds matured and harvested in 110, 128 145 days after planting the stecklings, respectively. Secondary and tertiary umbels flowered and matured 1-2 and 3-4 weeks after the king umbel, respectively. At maturity, seeds turn from dark green to brown and also begin to detach from the umbel, but remain on the umbel surface because of the racemes (little hooks that cover the seed). Much of this seed can still be lost due to shattering. The recommendations on harvesting are mentioned.

a) Harvest early in the morning avoid periods of high wind and rain to reduce shattering of seeds;

b) Under small-scale or high-value seed production and where labour is cheap, the umbels can be cut by hand as they ripen;

c) Dry the harvested umbels in windrows on a canvas; and

d) Spines or ‘beards’ on the seed must be removed to improve seed flow and reduce the volume of the seed lot.
8.8. Seed yield

Good quality seed is generally plump and heavy. Good seed will remain intact while poor seed crushes and breaks apart when a pressure is applied. According to George (2009) seed yield of open-pollinated varieties is about 600 kg/ha in temperate zone. However, in tropical regions, the European varieties yield about 300 kg/ha. Asian varieties produce only
about 250 kg/ha. The 1000 grain weight of sound carrot seeds is about 0.8 g. It was found that seeds harvested 50 days after anthesis, dried at 15-35 °C gave the highest and most rapid germination and seedling emergence. Seedlings from primary umbel seeds are more vigorous than those from secondary umbels. Cropping calendar for carrot production is given in Table 8.

Table 8. Crop calendar of carrot root and seed production.

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<thead>
<tr>
<th>Activity</th>
<th>Jun</th>
<th>July</th>
<th>Aug</th>
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<th>Oct</th>
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Method Seed-to-root Root-to-seed

<table>
<thead>
<tr>
<th>Stage</th>
<th>Seed - vegetative plant - roots</th>
<th>Roots - vegetative plant</th>
<th>Inflorescence initiation</th>
<th>Inflorescence elongation, flowering, seed set</th>
<th>Seed maturity and harvest</th>
</tr>
</thead>
</table>

* the x th week of the month
9. References


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CHAPTER VII: Cabbage

1. Introduction

Cabbage (Brassica oleracea var. Capitata L.) belongs to the Brassicaceae family. It is closely related to the broccoli, cauliflower and Brussels sprouts. The majority of cabbage cultivars are of the green (white) type, while there are cultivars that have red or purple leaves and others, such as the Savoy types that have wrinkled leaves. Cabbage is one of the most important vegetable crops under cultivation. Wild populations of B. oleracea are distributed along the Atlantic coasts of Spain, France, and Great Britain, where they usually grow in steep parts of maritime cliffs consisting of limestone or chalk (Gustafsson and Lanner-Herrera, 1997).

Cabbage is economically an important vegetable throughout the world. It is one of the widely consumed vegetable crops in Ethiopia especially in the urban areas. According to CSA (2013) reports cabbage occupied 3,961.84 ha of land with a production of 27,018.83 tones. The productivity is low (6.8 t/ha) compared to other regions of the world. According to recent FAO statistics, there are more than two million hectares of cabbage and other Brassicas in production globally, with an average yield of 29 t ha\(^{-1}\) (FAO 2011).

Consumption of vegetables and fruits is extremely sub-optimal in Ethiopia. It is important that efforts should be made to promote production and consumption of fruits and vegetables. The main constituents of green cabbage are carbohydrates, comprising nearly 90% of the dry weight. Freshly harvested cabbage contains on average 90.6–92.5% water, 1.2% protein, 0.12–0.18% lipids, 5.4% carbohydrates, and 1.6–6.2% fiber. Total sugar content varies depending on the cabbage cultivar from about 3–9%. Glucose (1.40–2.06%) is the most important sugar, followed by fructose (1.06–1.74%) and sucrose (0.02–0.05%) (USDA, 2006). Cabbage also has an important role in a healthy dietary approach by contributing to human health as it contains significant amounts of glutamine, an amino acid which has anti-inflammatory properties, dietary glucosinolates and their hydrolytic products that act as anti-cancer agents.

Cabbage is used mainly in raw salads, fresh food item cooked with other foods. It is suitable for processing by freezing, canning, and dehydration.
It is also used in preparation of dried soup mixture with different combination of other vegetables such as carrots, celery, corn, onions. Industrial products like sauerkraut and hydrolyzed cabbages are also used for flavorings compounds.

The rapid transformation of the vegetable market has forced producers of brassicas to increase the quality of their products. Nowadays, consumers are aware of the need for a constant supply of photo-chemicals contained in plants to get optimal health benefits and there is a growing tendency to demand quality products with a higher added value. In this aspect, cabbage and kale crops are becoming more popular because of their nutritional value and anti-cancer properties.

2. Climate and Soil

Cabbage is a cool season, annual vegetable crop growing in areas with adequate and well distributed rains for best productivity. The optimum temperature is 10 to 25°C, while temperature above 27°C may affect growth. Mature plants can tolerate a temperature of -3°C, but prolonged low temperatures in the range -1 to -4°C will induce bolting in most varieties resulting in seed production. In the tropics, the production of cabbage is typically limited to highland areas. It can also flourish under irrigation in the lower altitudes. When grown in the warm condition of lowland tropics, the crop is more susceptible to diseases and insect infestation and may fail to form heads. In such regions it is highly recommended to use heat-tolerant lines. Cabbage is grown on all types of soils from sands to heavy soils with a pH of 5.5 – 6.5. Sandy or sandy-loam soils are considered best for very early crop. Crop clay loams and silty soils are preferred for late crops.

3. The Crop

The cultivated cabbage is grown as biennial albeit grown as an annual crop. There is a great variation among the cultivated types of cabbages. They differ in size, shape, and color of leaves, and in size, shape, color, and texture of the head.
4. Nursery and Field Management

4.1. Nursery management

4.1.1. Site selection
Vegetable crops have specific demands for conducive environment from nursery site to field conditions. Conducive environment refers to the climate of the area, soil, rainfall, proximity to market, labor, and freedom from pernicious weeds, pests and diseases. Therefore, it is important that the site should be selected taking into consideration the points mentioned here.

4.1.2. Seedbed preparation
Once the proper site is selected, seedbed preparation will continue. The size of the seedbed is of prime importance so that proper amount of seedlings is grown to cover the planned area. Seeds can be broadcasted or sown by hand aiming at a stand of 450 plants m². A seed rate of 500 g/ha is a normal or recommended for cabbage. Seeds are planted on 5 beds of 10 m x 1 m each for 1 ha. Prepare seedbeds that are approximately 15 cm high with the seed rows spaced 6 cm apart and 0.5 cm planting depth should be followed. The soil should be fumigated with recommended chemicals two weeks before planting time, to control soil borne diseases and pests (nematodes). The seedbeds should be fertile and well drained. AVRDC fertilized recommendation at 40 g/m² ammonium sulfate, 50 g/m² superphosphate, 30 g/m² potassium chloride, and 2 kg/m² compost.

Although raising seedlings in plug or containers is another means of raising transplants this is not a common practice among individual growers in Ethiopia. However, it has become much practiced in high tech companies in the country. Considering the importance of this method and its potential contribution for the growth and development of the sub-sector, the method is given due attention and further description is included. Although, cost effectiveness of the method should be considered, this method is advantageous as it allows field planting without disturbing the root system. Plug trays or containers filled with a disease free sowing medium having a proper water-holding capacity are ideal. Two to three seed are placed in a plug with optimum temperature for germination at 20–25°C. Under such conditions, the seed takes 3–5 days to emerge.
Then, the seedlings will be thinned out to one vigorous seedling per plug, when plants reached a two to three true leaves stage. After thinning, water-soluble fertilizer will be applied. Plug seedlings will be ready to be transplanted in the field three weeks after sowing. The seedlings should be covered with a fine-mesh nylon netting to protect them from heavy rain, hot sun, and virus transmitting insects. About five days before transplanting to the field, reduce water supply to the seedlings and expose them to strong sunlight to harden them. This will decrease transplanting shock. If transplanting must be delayed for some reason, a more intensive hardening will be needed.

Nitrogen at 90 mg/plant proved to be ideal for raising good quality cabbage transplants, which can be easily pulled out of the seedling trays and has the largest dry root mass.

4.2. Field management

4.2.1. Field preparation
Field preparation should be carried out well in advance of planting. Deep plowing followed by incorporating bulky organic matter, if possible, should be done. The soil for cabbage production should be well drained and high in organic matter. The optimum pH is 5.5 to 6.1. Lime application should be considered at pH below 5.5. Cabbage can grow on black cotton soils as well but only if considerable drainage practices are followed. Land clearing and deep ploughing should be practiced several weeks before planting to mitigate the build-up of disease and pests. The plot is then pulverized with a disk harrow or other suitable implements immediately before planting to give a fine tilth.

4.2.2. Field layout
Field-layout will be based on the field plan prepared earlier taking into account the topography of the production field and other essential production factors.

4.2.3. Spacing
In most vegetable crops, proper density ensures high yield, good quality and low production cost. For late and large headed cabbage cultivars, crop population of approximately 35 000 plants/ha is recommended. Copenhagen Market cultivar grown on sandy loam soil produced larger and heavier heads with a crop population of approximately 40 000 plants/ha and 50
x 50 cm spacing. A reduction of intra-row spacing to 40 cm showed no significant differences in head diameter, head height, and mass. In Ethiopia, 40cm X 60cm spacing is practiced in most cabbage growing areas.

4.2.4. Planting/transplanting
Cabbage may be planted by direct-seeding although it is not widely practiced by growers. For direct seeding about 2 kg/ha may be required. The use of vigorous transplants at planting is necessary to ensure successful cabbage production. Seedlings should be transplanted as soon as they reach the desired size, which is after 3 to 5 weeks. The ideal transplant is well hardened, with 5 to 6 leaves, vigorous and free from diseases. Transplanting is recommended in the late afternoon to reduce heat shock caused by sunlight.

Transplanting is done on moist soil. The soil around the roots should be firm. Seedlings are transplanted in double rows on raised beds or ridges to reduce waterlogging and stem or root rot diseases. Insecticides, such as diazinon, may be applied to prevent root damage caused by root maggots and cutworms. Irrigate the field after planting so that the root system will adhere to the soil immediately after transplanting. If transplanting and field irrigation is to be done in late afternoon, furrow irrigation can be postponed until the next morning.

4.2.5. Fertilization
Fertilizer and improved seeds use are limited in Ethiopia despite government efforts to encourage the adoption of modern agricultural practices. Cabbage growers in the country use blanket fertilizer recommendation with variable rates and time of application of Urea and DAP. Integrated Soil Fertility Management (ISFM) approach, which combines various existing soil fertility management techniques, is becoming a necessity. This does not only reduce the production cost due to reduced fertilizer use but also improves the soil quality leading to sustainability.

Cabbage is high a demanding vegetable crop for major plant nutrients like N, P, K and judicious fertilizer application practices should be followed as on many intensively cropped vegetable farms. Applying complete fertilizers over many years has raised the soil P level beyond the critical range needed for good crop growth.

A research report at DebreZeit Research Centre the use of N (92 kg/ha), P (46 kg/ha), fertilizers supplemented with 2 t/haFYM resulted in a signifi-
cant yield increase over the recommended rates. Reducing the recommended fertilizers by 1/3 did not significantly reduce yield, if supplemented by 2 t/ha FYM. In Pakistan, application of N, P\textsubscript{2}O\textsubscript{5}, and K\textsubscript{2}O at ratio of 160:90:60 along with 15 to 20 t/ha FYM gave a desirable result in terms of growth and marketable yield of cabbage.

Cabbage needs micronutrients for proper growth and development. The crop has a high requirement of calcium and deficiencies can be corrected with foliar sprays of calcium nitrate. Magnesium may be deficient on acid soils, very light soils or on soils that are very high in potassium. Spraying the plants with 5 kg magnesium per hectare can rectify the problem.

Cabbage is very susceptible to molybdenum deficiency. Sodium or ammonium molybdate can be used as a foliar spray as deficiency symptoms are noticed.

4.2.6. Irrigation
Cabbage is moderately sensitive to water stress. Development of efficient and economically viable irrigation management for effective use of limited water resources is needed. Cabbage fields can be irrigated by furrow or drip irrigation can combine with fertigation system. Cabbage is also moderately sensitive to salinity with 10% yield reduction recorded for 2.8 ECe value. Leafy vegetables like cabbage appear less adapted to irrigation deficit than fruit tree crops. Studies suggest irrigation deficit of 50% evapo-transpiration (ETc) have decreased plant growth and yield, while a 75% of ETc had little influence on plant growth, but it still reduced both marketable and total yield.

Cabbage should be irrigated immediately after sowing or transplanting. Young plants should receive enough water for vegetative growth before forming heads. Excess moisture when the heads have formed may cause cracking. In the rainy season, excellent drainage is essential for plant survival and growth. Raised beds, cleanly weeded furrows, and clean, large drainage canals help to drain quickly off excessive water after heavy rain.

4.2.7. Mulching
Mulching is recommended for all seasons as it provides partial weed control. Moreover, in the dry season, it conserves and stabilizes soil moisture conditions while, during the rainy season, it hastens the establishment of transplants by promoting root development in the upper stratum of soil.
Mulch is also good for preserving the structure of the plant bed during heavy rain season. Cabbage fields mulched with white plastic or sawdust (7.5 cm thick) significantly increase plant growth and yield, weed infestation and moisture conservation on a loamy soil.

4.2.8. Cultivation
Weeds compete with cabbage for essential nutrients and seriously limit its yield. They may also serve as refuge for insect pests and diseases. Cabbage fields left un-weeded at early stages of growth will face severe economic yield loss. Weeds are controlled mechanically or by hand as well as chemically through the application of registered herbicides. The weed seed reservoir in the soil can be reduced by crop rotation, summer fallow, and stale seedbed technique. Weed management in cole crops begins with some form of tillage before seeding or transplanting to destroy emerged weeds. Mechanical cultivation between rows is a valuable option in cabbage, but cultivation should not extend any deeper than 5 cm into the soil, as it is a shallow rooted crop. On small areas, using organic or plastic mulch will help suppress many weeds. Any chemical products for weed control must be used according to the direction on the label and applied with the proper equipment calibrated to apply correct rates.

5. Harvesting and Post-harvest Management

5.1. Harvesting

Harvesting is done when the cabbage is fully developed so that it feels firm and solid to the touch. Harvest heads when they are firm and compact. Prematurely harvested heads lack development of young, tender leaves and are light while over-matured heads may burst in the field.

Cabbage is harvested by hand by bending the head to one side and cutting flat close to the head with a sharp knife or small machete, leaving several wrapper leaves to cushion during handling. The head should not be removed by snapping or twisting to avoid damaging the head. Broken stems are also more susceptible to decay. Damaged, or diseased wrapper leaves should be avoided. Heads with insect damage and other defects should be discarded.

The harvested cabbages should be pre-cooled as soon as possible to reduce wilting. Hydro-cooling or forced-air cooling can be used to remove
field heat before any further postharvest activity is preceded. In resource poor environments the harvest can also be kept in cool shaded places constructed from local materials. Cabbage put in non-ventilated field sacks will heat up due to tissue respiration and start to wilt. It is recommended that harvesting should be done during the coolest time of the day, preferably in the morning when the head is most turgid.

It is essential that heads not harvested be left undamaged because fields may be harvested as many as three times for maximum yield. The major signs of loss of quality are yellowing of the outer leaves, core elongation, internal yellowing in the apex region, leaf abscission, and sometimes rootlet development at the core-end.

5.1.1. Cleaning
A simple field packing station can be constructed from wooden poles and a sheet of polyethylene. Thatch roofed structure can provide shade and keep the station cool. The structure should be oriented so that the roof overhang keeps out the sun’s rays. The first step in preparing cabbage for market is to remove the torn and loose outer wrapper leaves so that the head has a clean, compact, and fresh appearance. Only 3 to 6 tight wrapper leaves should be left on the head. Loose leaves interfere with ventilation between heads, which is important whether the cabbage is packed for market or put into storage. The stem end should be trimmed close to the base of the head so it does not protrude out more than 2 cm.

5.1.2. Sorting
Cabbage should be sorted out according to size, shape, and compactness of the head. Cabbage heads can be classified on size categories as small, medium and large based on the weight of the head. Small sized heads weigh 0.8 kg or less, medium sized heads weigh between 0.9 kg and 1.4 kg, and large sized cabbage heads weigh 1.5 kg or more. Only the cabbage with crisp and turgid leaves should be packed for market. The heads should be firm, heavy for the size and free of insect, decay, seed stalk development and other defects.

5.2. Post-harvest management

5.2.1. Packing
Heading-type cabbages are packed in fiberboard cartons, wooden or wire-bound crates, or mesh bags that hold 23 kg. Uniformity of head size and the proper count per carton are important. Normally 18 to 22 heads are
packed in a 23 kg container. Wooden crates are easier to stack, load, and provide considerably more protection to the produce.

5.2.2. Storage and temperature control
The maximum storage life and retention of cabbage quality varies greatly depending on the cabbage type, cultivar, and storage conditions. A temperature of 0°C with a 98–100% relative humidity is recommended for long-term storage of cabbage in order to reduce moisture loss and yellowing. Deterioration of cabbage is accelerated under non-refrigerated temperatures and is associated with discoloration of the stem end, leaf wilting, loss of fresh green color, and postharvest decay. Storing cabbage at ambient temperature will require extensive trimming of the leaves to maintain a marketable head. Kramchotee et al. (2012) reported that cabbage can be stored successfully at 4°C for 18 days and 12 days at 10°C. At ambient temperature, cabbage deteriorated rapidly and lasted for only 4 days. Moreover, total soluble solids and ascorbic acid contents are higher in cabbages kept at 4 and 10°C than those stored at 28°C. Low temperature storage reduced the losses in soluble solids and ascorbic acid contents thereby preserving the nutritional value of cabbage.

Low Quality Market Polythenes (LQMP) are also used at normal temperature and the produce remained good up to 6 days of storage (Jany et al. 2008). Citric acid (1%) treatment combined with low temperature storage (0°C) are used to prolonged the shelf life of minimally processed cabbage for 22 days, time sufficient for acceptable marketing of the product with much of the physical quality properties retained.

5.2.3. Value addition
Fresh cut cabbage is used raw in salads such as coleslaw and as cooked vegetable (added to soups or stews). Cabbage is also dehydrated (dried, flaked or powder) for use as a flavoring agent in soups and as an ingredient in other dehydrated foods. Cabbage can also be canned, prickled, frozen and cabbage juice can be extracted to make ink.

6. Seed Production
Seed production is an important activity in the horticulture sub-sector. Ethiopia has conducive environment for the production of seeds for almost all kinds of crops. Unfortunately, the country has been depending on imported seeds of various vegetable crops and even planting materials for some perennial horticultural crops for a long time. However, production
of seeds particularly for vegetable crops has been given priority by the research centers, and the results have become successful. Therefore, basic requirement for the production of cabbage seeds is described.

Environmental factors are important in the production of cabbage seed. The same climatic factors, which influence the cultivation of a market cabbage, also apply on cabbage seed production. Low atmospheric humidity, minimal rainfall, adequate irrigation, and optimal temperature are needed. Furthermore, for seed production suitable day length, good soil and adequate fertilization and optimum sowing or planting time is essential. The N:P:K ratio of nutrients applied during preparation varies widely between different seed production areas, but the general recommendation is 1:2:2. To produce disease-free and high quality cabbage seed it is desirable to select a dry climate or at least a season with low air humidity, especially during the seed ripening and harvesting stages. When humidity is high, as in a humid tropical climate, special arrangements have to be made for artificial drying and seed storage.

6.1. Photoperiod and vernalization

Photoperiod is very important for seed production of cabbage. Cabbage is a long day plant and does not normally flower in the low land tropics because the photoperiod in the tropics is minimal. However, it has been proven that low temperature can replace the photoperiodic requirement of cabbage to some extent and thus cabbage can bolt and set seed when cultivated at high elevations of the tropics, where the temperature is cool (Opena et al. 1988). Cabbage normally requires a cold period below 5 to 12°C from few days to several weeks, for flower induction and development. Some tropical cabbage cultivars, on the other hand, can produce seed without requiring very low temperatures. The vernalization requirement of these tropical varieties can be fulfilled at rather high temperature, i.e., near to below 20°C for a period of time, which higher altitudes in the tropics can usually satisfy.

6.2. Special seed production techniques

Sowing dates depend on the local environment, custom and experience with specific cultivars. Sowing should be timed so that the variety receives sufficient vernalization and that the plants flower and seed under suitable climatic condition. Young plants from the seed flats are transplanted when they have reached the 5 to 7 leaf stage. If seed is to be pro-
duced from hearted cabbage, it is usually necessary to incise the mature heads after checking for trueness to type. There are several ways of achieving this but all have the objective of allowing the flower stalk to emerge unhindered by the mechanical barrier of the tightly folded leaves that encase it. A quick method is to cut the top of the head in the form of a cross, but the growing point must not be damaged.

6.3. Rouging

Continuous rouging has to be practiced to discard off-types for vegetative and reproductive traits. Plants with aberrant bolting or flowering dates should be discarded. It is advisable to remove extremely vigorous or week plants. Very vigorous plants are often products of out crossing. At the bolting stage prior to flowering, a thorough inspection of the seed production site is necessary in order to remove all possible sources of contaminating pollen. Obvious off-types in foliage characters, blind plants, can be rouged at early stage. The mature head is checked for characters such as shapes, relative size, firmness, and maturity according to the standard characteristics of the variety. Discard plants that are either too early or too late for the cultivar.

6.4. Pollination and isolation

Most cole crops are predominantly cross-pollinated, although some self-pollination can occur. Bees and *Diptera* species are the main pollinating agents of *Brassica* species (George, 2009). The self-incompatibility mechanism is not operative at bud stage and thus selfed seeds can be produced if pollinated two to three days before blooming (Opena et al. 1988). Although by far the most commonly used method to overcome incompatibility, it is always laborious and expensive. Seed producers must keep in mind that cultivars of the same species will cross-pollinate with other cultivars of the same species. That means that broccoli, brussels sprouts, kohlrabi, collards, cauliflower and kale can all cross-pollinate each other as they are all *B. oleracea*.

Most authorities consider it important to have a greater recommended distance (up to 1500 m) between different types of *B. oleracea*, e.g. cabbages and kohlrabi, than between different cultivars of the same type, e.g. two cabbage cultivars (up to 1000 m).
6.5. Removing weeds and other contaminants

Some of the common weeds of Cruciferae are alternative hosts to important seed-borne pathogens such as Alternaria brassicola and Phoma lingam. Therefore, care must be taken to avoid sites where these may cause problems. Other problems of weed seed contamination in the harvested seed lot can be created by the presence of some weed species if they are allowed to go to seed within the scheduled seed crop, these include Galium aparine (cleavers) and Chenopodium album (fat-hen) (Raymond and George 2009).

6.6. Open-pollinated seed production

In seed production of open-pollinated cultivars care should be taken to maintain two essential, but contradictory, features. These are identity and integral heterozygosity of the cultivar. In order to maintain the identity of a cultivar, a strict selection of elite, true-to-type plant is employed in breeder seed production. The number of selected plants used as parents, especially of breeder seeds should be large enough to curtail any undesirable genetic drift. In general 50 to 100 plants are believed to be sufficient, although there is no definite information on the critical number (Opema et al. 1988).

6.6.1. Hybrid seed production

In the case of F1 hybrid seed production, both parental lines should be self-incompatible but cross compatible. The ratio of female-to-male parent is usually 1:1 or 2:1 depending on the pollination potential of the inbred lines. The reproducibility of hybrids depends absolutely on the presence of parental inbred that can be multiplied easily and economically. As the parental inbred lines are self-compatible, their maintenance is achieved mainly through the exploitation of the phenomenon of ‘juvenile compatibility’. In crucifers, the self-incompatibility mechanism is not operative at bud stage and thus selfed seeds can be produced if pollinated 2 to 3 days before blooming (Opema et al. 1988). Bud pollination, although by far the most commonly used method to overcome incompatibility. It is always laborious and expensive. Other methods like isolation cage technique with pollinating agent like bee can also be practiced.
6.6.2. Harvesting and storage

The cabbage siliques ripen in more or less the same sequence in which the flower opens. As the seed ripens, the siliques start to dry out which have a strong tendency to shatter. When a noticeable proportion of the siliques have turned orange brown, at which time the seed crop should be at an appropriate stage for harvesting. Many seed producers prefer to cut the ripening stalks and continue to dry them in a sunny place. When 80% of the siliques have turned orange-brown, the plants can be severed at the bottom and may be grouped in bundles and then hanged on a pole for several days under the sun after drying. When all of the siliques are completely dried, the siliques are then threshed on top of the plastic sheet placed on level ground.

The moisture content of fully dried seeds is about 12%. Properly dried and cool-stored seeds can retain good viability for 3 to 4 years since seed aging, under these conditions, advances very slowly. The main requirement of seed storage in a hot humid climate is to prevent the well-dried seed from regaining moisture from the atmosphere. Bagged seed in the refrigeration unit should be adequate to counteract the storage problems.

7. Major Diseases

7.1. Alternaria leaf spot

Biology
Crop residues are commonly the primary source of inoculum. Cruciferous weeds may also harbor these fungi (Alternaria spp.). The pathogens may also be seed borne. Conidia of Alternaria spp. are disseminated by wind and water. Disease development is favored by free moisture on plant surfaces and temperatures between 20-27°C (68-81°F).

Symptoms
Alternaria species cause leaf spots that appear on older tissue and often begin as small, circular lesions. These lesions expand and develop concentric rings with chlorotic haloes (Fig. 55). Lesions centers may break apart, with a shot hole appearance on the leaf, if conditions are favorable, become covered with a sooty black mass of spores.
Control measure
Use high-quality seed free of Alternaria species. Incorporate cruciferous residues, practice crop rotation, and apply foliar fungicides to help control of the disease.

7.2. Black leg (*Phoma lingam*)

Biology
Crop debris, soil, seed, and crucifer weeds harbor the causal agent (*Phoma lingam*). Seedlings develop symptoms in 2 to 3 weeks. Spores of the fungus dispersed by irrigation water to surrounding healthy seedlings. Secondary infection may also occur when the young plants are dipped in water prior to transplant. The disease may also spread by splashing rain, workers, and equipment.

Symptoms
Symptoms manifest as oval, sunken, light-brown cankers with purple-to-black margins near the base of stems. Cankers enlarge and girdle stems, causing plant collapse. Leaf spots gradually enlarge, becoming circular with gray centers. Under favorable conditions, small black fruiting structures (pycnidia) develop into stem cankers and leaf spots. Severely infected plants are stunted and wilted (Fig. 56). The leaves remain attached and the plant turns a dull blue-red color. The root system may be destroyed, although new roots may form above the stem cankers, allowing the plant to remain alive.
Control measure

Use seed free from the pathogen, remove cruciferous weeds, eradicate or deep plow plant debris and apply a three-to-four year rotation to non-host plants or weeds.

8. Major Insect Pests

8.1. Diamond black moth (DBM)

Damage

Newly hatched larvae mine tunnels in the leaves. As they grow older, the larvae feed on the undersides of leaves but do not eat the veins, leaving the surfaces untouched, resulting in the 'window effect'. Larvae make irregular holes, tunnel into the cabbage heads preventing further development.

Biology

Eggs are usually laid on the upper leaf surface. Each female lays between 50 and 400 eggs. The eggs hatch in 2 to 7 days and the small caterpillars crawl to the lower leaf surfaces and feed as leaf miners inside the leaves for a few days. After the first molt, the caterpillars emerge from the leaves and feed on the lower surfaces (Fig. 57). The total larval period varies from 14 to 28 days. The pupal stage last for about 5 - 10 days. DBM are not good fliers and cannot fly for long distances. However, they are often carried over long distances by wind and by infested plant parts by people.
Figure 57. Larva and adult DBM feeding on cabbage leaf

Control measure

Cultural
Planting mustard as trap crop every 15 rows of cabbage reduces attack. However, monitor trap crops frequently so as to control DBM before it can transfer to the main crop.

Biological
Spraying cabbage with *Bacillus thuringiensis* (BT) suspension when larvae are less than 5 mm long controls the effect of DBM.

Chemical
Broad-spectrum insecticides like Deltamethrin, Carbaryl, Dimethoate, and Endosulfan can be applied for the management.

8.2. Flea beetles

Damage
Flea beetles feed on seedlings. They usually feed on the undersides of leaves leaving numerous small round or irregularly shaped holes, although not generally all the way through the leaf. Because the beetle is small and active, it usually does not feed much in one spot. The larvae are root feeders. They trim the root hairs and make circular pits in taproots. The adults feed on the leaves and stems of emerging seedlings. They chew small holes or pits, usually less than 3 mm in diameter giving the leaves a characteristic of "shot hole" appearance.
**Biology**

The adults can overwinter in sheltered sites on leaf litter and plant debris. They become active with temperatures rising above 20°C. Adults disperse, frequently in large numbers, on prevailing winds. They can travel long distances. When they locate a suitable host crop, they settle and start to feed, often on seedling tissues below ground (Fig. 58). After mating, the beetles lay their eggs in the soil near host plants. After living in the soil for 4 to 5 weeks, the fully-grown larvae are about 5-6 mm long. They pupate in the soil. The duration of the pupal stage depends mainly on temperature and it may take up to 4 weeks.

![Flea beetle of cabbage](image)

**Figure 58. Flea beetle of cabbage**

**Control measures**

**Cultural**

Radish and Chinese mustard are good trap crops. Adult flea beetles are attracted to the tallest and earliest crop available. Additionally effective farm hygiene has to be practiced.

**Biological**

Predators known to feed on flea beetles include lacewing larvae (*Chrysopacarnea*), big-eyed bugs (*Geocorisbullatus*) and two-lined clops(*Collopsvittatus*) coupled with cultural practices be employed.

**Chemical**

Insecticides like Lambda-cyhalothrin, Deltamethrin and Cypermethrin used for the control of the insect.
8.3. Cabbage Aphid

Damage

Both the nymphs and the adults pierce the plant tissues/leaves to feed on plant sap. The infected leaves become severely distorted when the saliva of aphids are injected into them. Heavily infested ones will turn yellow and eventually wilt because of excessive sap removal. The aphids’ feeding on cabbage causes crinkling and cupping of leaves, defoliation, and stunted growth (Fig. 5). Aphids produce large amounts of a sugary liquid waste called honeydew. The appearance of a sooty mold on plants is an indication of an aphid infestation. A fungus, called sooty mold, grows on honeydew deposits that is accumulated on leaves and turns branches. Finally, leaves and branches turn black.

Biology

The cabbage aphid overwinters as small, shiny black-colored eggs laid particularly around the leaf scars of plants. When the temperature rises, the aphids hatch and colonize the new emerging flowering stems or harvested vegetable crops that have not been ploughed in. Then, winged aphids fly away to colonize new host plants. They produce wingless aphids. These aphids produce more young aphids that form new colonies. They feed on the tender, actively growing shoots and leaves, often on the underside of leaves where they are protected from the sun and rain (Fig. 59). When aphid numbers outrun food supply, winged forms reappear and migrate to nearby plants to renew the growth cycle. This happens regularly during the growing season. Warm, dry weather favors a rapid build-up of aphid colonies.

Figure 59. Aphid infested cabbage leaf
Control measure

Biological
Lady beetles, syrphid fly and the parasitic wasp are important natural enemies of aphids.

Cultural
Destroy crop remnants immediately after harvest and remove or control alternate hosts, including mustards and related weeds, around field borders. Rouging of infested plants from the field can be effective early in the crop cycle.

Chemical
Diazinon, Dimethoate, and Endosulfan can be used for the control of the insect (recommendation).
9. References


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