Field pea Improvement through Hybridization

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Technical Manual No.22
Field pea Improvement through Hybridization
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Introduction

Field pea (*Pisum sativum* L., 2n = 24) is one of the most important annual legume crops. The history of field pea cultivation dates back to the Neolithic farming villages of the Near East, early as 7000 BC. FAO (1998) stated that East Africa is the first origin of field pea. West Asia is the second in South and East Mediterranean sub regions. The species *Pisum sativum* is a dominant production system in Ethiopia though wild and primitive forms are also known to exist in the high elevations of the country, especially in the north (Hagedorn, 1984; Amare and Adamu, 1994). In Ethiopia, field pea grows in several regions, at an altitude of 1800-3000 m with annual rainfall of 700-1000mm.

According to Ethiopian Central Statistics Authority (2005), annually on average 183,374 ha of land has been allotted to field pea providing a total average production of 141,741 t, from 1997/98 to 2004/2005. This constitutes about 17% of the total area covered by pulses and 15% of the total annual national production of pulse crops. The crop plays an important role in the lives of the farmers in the highlands of Ethiopia. It serves as a source of food and feed with a valuable and cheap source of protein. It plays a significant role in soil fertility restoration as a suitable rotation crop that fixes atmospheric nitrogen. It is also a good source of income to the farmers and foreign currency to the country.

The productivity of the crop in Ethiopia is very unstable and low (0.8 t ha⁻¹ on average) as compared to the research findings (2.5 –3.5 t ha⁻¹). Production has been constrained by several yield limiting and reducing factors. Among these factors, that inherent low yielding potential of the indigenous cultivars (Asfaw et al., 1994), diseases like Ascochyta spp. (*Mycosphaerella pinodes*) and powdery mildew (*Erysiphe polygoni*) (Dereje and Tesfaye, 1994) and insect pests like pea aphids (*Acyrthosiphon pisum*), African ballworm (*Helicoverpa armigera*), pea bruchid (*Bruchus pisorum*) in the field and weevil (*Callosobruchus chinensis*) in the storage (Kemal and Tibebu, 1994), poor soil fertility, unimproved cultural practices such as poor seed bed preparation and lack of fertilizer use (Amare and Adamu, 1994).

Hybridization of field pea in Ethiopia was started in mid 1980’s at Holetta Research Center to transfer seed size, seed color and disease (ascochyta resistance character into local and adapted variety with good agronomic character. The effort was technically supported by the International Center
for Agricultural Research in the Dry Areas (ICARDA). Currently, there is a strong need to initiate hybridization of field pea at different centres. It is generally assumed that lack of technical skill in these aspects is one of the limiting factors particularly among young breeders and newly joining the program. Moreover, trainers can also hardly find suitable guide and appropriate source of reference materials.

The productivity of field pea in Ethiopia is far below the potential due to a number of factors. These includes the inherently low productivity and susceptibility to biotic and abiotic stresses of the landraces, unimproved cultural practices such as poor seed bed preparation, lack of fertilizer use, and poor soil fertility, etc.

The main objectives of field pea breeding in Ethiopia are to improve the quality and productivity of field pea and transferring desirable traits, from improved cultivars to attain high and stable yield, good quality for market, resistant in both biotic and abiotic stresses, suitable under different agro-ecologies and cropping systems of the country. Thus, the country benefits from its wealth of diversity in both field pea germplasm and agro-ecology.
Reproduction and Flower Morphology

Reproduction

Field pea is classified in the order Leguminales, family Leguminosae (Fabaceae), subfamily Papilionoideae (Faboideae) or Papilionaceae (Fabaceae), tribe Vicieae, genus Pisum Linnaeus. The genus P. Linnaeus distinguished two species, P. arvense, the field pea and P. sativum, the garden pea. Species designation has since been given to P. abyssinicum (Graun), P. aucheri (Jaubert and Spach), P. elatius (Stev), P. formosum (Alefeld), P. fulvum (Sibth and Sm.), P. humile (Boiss & Noe), P. jomardi (Schrank), and P. transcaucasicum (Gov./Stankov). Of these, P. sativum L. (Sens Ampl) is a cultivated one. Pea, both field and garden pea have 2n=14. In the present consideration P. sativum and P. arvense are taken to be conspecific since they are completely interfertile. The Pisum taxa can be crossed easily and freely exchange all genes.

Field pea is a sexually propagating crop and its mode of pollination is self-pollinating with very small amount (<5%) cross-pollination. Pollination and fertilization are followed by the start of embryo and endosperm development. The megasporocyte arose as the apical cell from a group of 6-7 archesporial cells and grows under a double nuclear layer. Meiosis occurred when the buds were 5-6 mm long together with the appearance of integuments. The third cell from the micropylar end of the resulting row of four megaspores and usually forms the embryo sac. Microsporogenesis occurred earlier than megasporogenesis, so that apparently mature pollen grains were present for some time before anthesis.

Flower morphology

The flowers of field pea are borne in axillary raceme of 1-3 flowers. It comprises of four main parts: the calyx, corolla, androecium, and gynoecium (Figure 1).
The *calyx* is a five-toothed structure made of five sepals. It forms a tube enclosing the bud. The *corolla* colorful part of the flower, irregular in shape and made up of five petals: the standard petal, two wings petals and two lower petals that are united along their outer edge to form a keel petal. The background color of the petals is purple, pink or white. The flowers have 10 stamens, one is physically free and nine are united in sheath, which enclose the ovary at the base. The single ovary has from two to nine ovules (sometimes 10) arranged along the inner upper stature. The style is almost at right angle to the ovary and bears hairs in varying amounts at its upper end just below the stigma. Pods are swollen or compressed, short stalked, straight or curved, 4-5 cm long, and 1.5-2.5 cm wide.
Sources of Genetic Materials

Genetic variation is a prerequisite for any improvement in a crop and it is the first step unless variation preexists. In the creation of genetic variation, the first very important step is identification and isolation of parent materials having desired characteristics to users; transfer genes that control important traits from one to the other thereby grow their progeny after selection. The efficiency of this activity determines the success of the breeding program. Similarly, contributors to field pea genetic variations in Ethiopia are germplasm collection, introduction of exotic materials and hybridization. In general, genetic variation is created through collection of landrace, introduction from exotic sources and hybridization of desired parents. An average of more than 1985 germplasm have been evaluated in Ethiopia at different levels between 1994 and 2002 and more than 31% of these germplasm have been from hybridization, 29% from local collection and 40% from introduction. Out of the released varieties, 50% was from hybridization, 28% from introduction and 22% from landrace collection.

Local germplasm

Landrace collections are usually obtained from the Institute of Biodiversity Conservation (IBC) of Ethiopia and the target collections of breeders with the collaboration of IBC. Out of 475 landrace accessions evaluated since 1994, 148 were from the target collections and the remaining was from IBC. The former were recently collected from different parts of the country (Gonder, Gojam, Shewa and Arsi). In general, landrace collections are reservoir of genetic variability and sources of many valuable genes, especially those for adaptation (Chahal and Gosal, 2002). They are used either for release after selection for high yield and wide or specific adaptation or crossed with exotic materials. From the landrace collections, four varieties (G22763-2C, FpExDz, Haik 95 and Holetta) have been released. Out of the released varieties landrace collection comprised 22%.

Introductions

A total of 207 germplasm have been introduced from different sources between 1994 and 2002. Out of these, 143 accessions were obtained from ICARDA; nine from Burundi and 155 from Australia. The acquired materials were first evaluated under isolated quarantine field at Holetta.
research center to check for alien diseases, insect pests and weeds. Adaptable germplasm were used for direct selection for yield, disease resistance, seed size, color, plant height, early flowering and maturity. Often they were used for hybridization with adapted materials to transfer their desirable genes that are lacking in the adapted local materials. The introductions have remarkable qualities such as large seed size and white/cream seed color that are preferred by users. There are many promising large seeded materials with 1000 seed weight of more than 200 g and good level of grain yield (2.0–4.0 t ha\(^{-1}\)). From 1979 to 2006 five varieties such as Mohanderfer, Tegegnech, Hasabe, Markos, and Megeri have been released from the introductions for their superiority of grain yield, seed size and/or color. Tegegnech was introduced from Burundi by pedigree name, 061K-2P-2/9/2; Hassabe and Markos were introduced through ICARDA by pedigree names, Ji No 116 and DMR-4, respectively, and Megeri was introduced from Canada by pedigree name, Helena. Out of the varieties released so far, introduction comprised 28%.

**Hybridization**

In the absence of desired variability from the existing materials, hybridization is the best method to create variability. In most cases, the exotic materials, with desirable characters (large seed size, white/green seed color, erect plant stature) but not adaptable will be crossed with the local adapted materials lack some useful characters. Hence, crosses are made between genotypes that differ for the traits of interest and in segregating populations favorable phenotypes that have incorporated the desired characters are selected and evaluated. Crossing of field pea can easily be done manually by trained personnel. At Holetta many crosses are made every year and the segregating generations are tested at Holetta representing high altitude area and at Denbi and Kulumsa representing mid-altitude areas. The relative contribution of hybridization as a source of field pea improved varieties in Ethiopia is significant as compared to collection and introduction. Out of the total varieties released in the country so far, hybridization comprised 50%.

From 1994 to 2006, four varieties such as Adi, Gume, Milky and Wolmera were improved through hybridizations and selections, were nationally released for wide adaptation in major field growing areas of the country. Adi is a cross between a locally released variety, G22763–2C, and an introduction from USA, 305PS210813-3; Milky is a cross between two ICARDA materials, NEP 634 and 180-1; Wolmera is a cross between a locally released variety, FpExDz, and an introduction from USA,
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305PS210822-1, and Gume is a cross between a released variety, and Tegegnech an introduction from USA, PSI210713.

Similarly, from the crosses made at Holetta and tested at different research centers (Adet, Sinana, Bako) representing major field pea growing areas of the country, five varieties (Adet-1, Sefinesh, Arjo-1, Bariso, and Woyyitu) have been regionally released for specific adaptation in Adet, Bako and Sinana areas. These varieties were crossed between the nationally released varieties (G22763-2C, Mohanderfer and FpExDz) and introductions from USA (Table 1).

Table 1. Nationally or regionally released varieties from crosses made at Holetta Research Center

<table>
<thead>
<tr>
<th>Released variety</th>
<th>Parents crossed</th>
<th>Releasing center</th>
<th>Released year</th>
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<tr>
<td>Adi</td>
<td>G22763-2C x 305PS210813-2</td>
<td>Holetta</td>
<td>1995</td>
</tr>
<tr>
<td>Milky</td>
<td>NEP634 x 180-1</td>
<td>Holetta</td>
<td>1995</td>
</tr>
<tr>
<td>Adet -1</td>
<td>G22763-2C x 305PS210736-2</td>
<td>Adet</td>
<td>1997</td>
</tr>
<tr>
<td>Sefinesh</td>
<td>Mohanderfer x 305PS210928-2</td>
<td>Adet</td>
<td>1997</td>
</tr>
<tr>
<td>Woyyitu</td>
<td>FPEXDZ x PS210852</td>
<td>Sinana</td>
<td>1999</td>
</tr>
<tr>
<td>Wolmera</td>
<td>FPExDz x 305PS210822-1</td>
<td>Holetta</td>
<td>2000</td>
</tr>
<tr>
<td>Arjo-1</td>
<td>Mohanderfer x PS210794</td>
<td>Bako</td>
<td>2005</td>
</tr>
<tr>
<td>Bariso</td>
<td>FPEXDZ x PS210908</td>
<td>Sinana</td>
<td>2005</td>
</tr>
<tr>
<td>Gume</td>
<td>Tegegnech x PSI210713</td>
<td>Holetta</td>
<td>2006</td>
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The parents used in the crossing, G22763-2C and FpExDz are released varieties from local collection; Tegegnech is introduction from Burundi; Mohanderfer from India; and the rest are from USA.
Definition and objective

Hybridization is defined as the crossing or mating of two or more lines with different genetic background. The main objective of hybridization is to create new genetic variability in such a way that the desired traits (genes) from all the parents are brought together into a single variety through further selection among the progenies. When the desired variability is lacking in the existing materials, hybridization is the best method of creating a new variability.

Field pea hybridization in Ethiopia commenced in 1986 with the main objective of incorporating seed quality, especially seed color, and disease resistance into the Ethiopian germplasm. Mostly the exotic materials, which have desirable characters, but lack adaptation, have been crossed to the local adapted materials that lack some useful characters. From the crosses, segregating populations with favorable phenotypes that have incorporated the desired characters are selected and evaluated. Crossing of field pea is easy and done manually by trained personnel. At Holetta, many crosses are made every year and the segregating generations are tested at Holetta, representing high altitude area Denbi and Kulumsa, representing mid-altitude areas. The level of success from crossing (ratio of effective pod to the number of crossed flowers) under field condition in Ethiopia ranges from 40 – 60% (53% on average), which is much better than that of faba bean (14-24%).

Types of hybridization

Based on the taxonomic relationship between the two parents, hybridization may be grouped as intraspecific and interspecific. When the parents involved in the crossing program belong to the same species, it is referred to as intraspecific or intervarietal hybridization. Contrarily, when the parents involved in the crossing program belong to the different species of a genus, it is referred to as interspecific or distant hybridization.
Intraspecific or intervarietal hybridization could be reclassified as simple or complex based on the number of parents involved. Crosses can be single, when only two parents are involved, and multiple, when more than two parents are involved. If three parents are involved, it is referred as three-way cross [e.g. (A x B) x C]. Similarly, if four parents are involved, then it is referred as a double cross [e.g. (A x B) x (D x D)], and so on. When the desirable characters are distributed among a number of parents, then to bring all the desired traits into a single genotype, multiple crossing needs to be employed. For instance, a series of crosses are required to bring desired traits distributed among eight separate parents into a single genotype (Figure 2).

![Diagram](image.png)

Figure 2. A series of crosses resulted in a complex hybrid possessing desirable traits distributed among eight parents (A, B, C, D, E, F, G and H)

**Procedures**

Like other crops, the desired genetic changes in field pea could be achieved through a series of interrelated and largely interdependent activities. These include creation of genetic variation, selection, evaluation, multiplication and distribution.
Selection of parents

Before hybridization or crossing, the breeder must know what is lacking in the crop must clearly define the type of variety to produce, and the important character to improve. Then search for suitable parents, which will contribute these characters, and use them in an appropriate hybridization program. Hybridization programs so far focused mostly on high-yield, large seed size, seed color (white, cream, and green) and Ascochyta blight (Mycosphaerella pinodes) and powdery mildew (Erysiphe polygoni) resistance. Selection of appropriate parental materials is the most crucial job of a plant breeder for effective hybridization. The success of hybridization program largely depends on the extent of genetic variation between materials intended for crossing. Parents for hybridization may need to fulfill the following:

Agronomic base

The ultimate goal of the new variety is to replace the old but well-established cultivar of the area. One of the parents should preferably be best adapted so that the newly developed variety will better adapt the area. For example, cultivars, G22763-2C and FpExDz are developed from the national landrace collection. They are well adapted, stable and high yielding cultivar released for these merits. However, their seed size is small (about 145-156 g/1000 seed) and need improvement for seed size. Therefore, they make good parent materials for seed size improvement. Usually, such a local parent should be used as the seed parent or female base, commonly known as the agronomic base. The second parent, which should be used as the male counterpart of the cross, must complement for specific weaknesses of the agronomic base. In this regard, the introduced field pea materials from Burundi (Tegegnech), India (Mohanderfer) and USA (the famous PS series) have large seed size (200-250 g/1000 seed). Hence, these materials possess the complementing attributes (gene for large seed size) that should be present in a reasonable degree in the final genotype.

Homozygosity of parents

The parents chosen for hybridization must be pure lines. Hybridization programs are largely dependent on pure-lines; some of these pure-lines may not be suitable for commercial varieties. However, field pea is a self-pollinated crop and pure-line development is easily possible through selfing without problem of inbreeding depression.
Genetic divergence
Choice of parents based on genetic divergence offer substantial variability that is reflected in segregating generations. Thus, selection of desirable recombinants becomes easy. Hybridization of parents with similar genetic background is not likely to produce higher heterosis, desirable genetic recombination and segregation in progenies.

Traits of interest
One has to be sure about the existence of genes controlling the desired trait in one of the parents. In cases all the desired attributes are not present in the two parents, more than two parents can be chosen for crossing in three-way or four-way crosses. Traits of interest depend on the specific objective of the breeder. The traits of interest for crossing field pea in Ethiopia may include the following attributes:

Seed size: Large seed size is considered as an important seed quality for better market demand and value. The Ethiopian cultivars are small seeded (less than 200g per 1000 seed), but some introduced materials have large seed size more than 250g per 1000 seeds. Introductions from USA (Pullman University) such as 305PS21 series and 30/WA Alaska 81, DMR series from ICARDA, IFPI series from Australia and 061K from Brundi have been used as donor parents for large seed size for crossing at Holetta Research Center.

Seed color: White, cream, or green seed colors are considered as important quality for better market demand and value in field pea. The Ethiopian cultivars are mostly gray. Introductions from ICARDA or somewhere else have white seed color, cream or green. In general introductions have been used as donor parents for seed color at Holetta field pea breeding program.

Plant height: The Ethiopian field pea is tall and prostrate type which creates conducive environment for diseases such as Ascochyta bilight and they are difficult for mechanized harvesting. By crossing Ethiopian field pea with semi-leafless and relatively short varieties introduced from ICARDA, it was possible to reduce the height of field pea. However, as plant height decreased, yield was also decreased and crossing for plant height was not encouraged under Ethiopian condition where there is no mechanization that needs short and uniformly maturing plant types.
**Disease resistance:** Ascochyta blight and powdery mildew, caused by *Ascochyta species* and *Erysiphe polygoni*, respectively, are the major diseases. Ascochyta has three species that cause disease of field pea viz. *Ascochyta pisi*, *Mycosphaerella pinodes*, and *Phoma medicaginis* var. *pinodes*, of which *M. pinodes* is the most damaging of the three worldwide pathogens too. It contributes to grain yield instability and reduces farmers’ confidence in growing field pea. It occurs every year in all major field pea growing areas. This disease causes stem, leaf and pod spot on the mature plants and foot rot on seedlings. Yield loss on field pea due to this disease were reported to be 50-75% in USA, 45% in England, 33% in Canada and 20-53% in Ethiopia (Dereje Gorfu, 2000). It is stubble and seed born pathogen where inoculum infecting plant parts and adhering on seed surface as dormant mycelia, spores and fruiting bodies of the fungus, could be responsible for disease transmission. There is no field resistance of field pea cultivars to this disease. Breeding field pea for *M. pinodes* resistance is complicated because it is inherited as a complex polygenic trait (Worth, 1996). However, at Holetta, there are some lines identified as moderately resistant to Ascochyta blight (e.g., IFPI series introduced from Australia) that could be used in the breeding program as source of resistance gene. Seed treatment with fungicides such as carbendazin is one feasible alternative to eradicate the primary inoculums to avoid risk of epidemics (Dereje and Sangchote, 2003). Chlorotalonil (Bravo 500 50% or Daconyl 2787) at the rate of 2.5 kg active ingredient per ha could be used under field condition.

Powdery mildew on peas is a widely distributed disease as the crop. It is a troublesome disease when days are warm and dry, nights are cool enough for dew formation. Sever powdery mildew infection is reported to adversely affect plant and seed weight, number of seed per pod and per plant, plant height and number of nodes per plant. Studies have shown that where severe mildew was present, control of the disease increased yield 100%. Reports from Ethiopia indicated that it causes yield loss up to 37%. This disease is of less affect in high rainfall areas of Ethiopia where its spores are removed from the plant tissue by rain and cannot cause infection. However, late sown and off-season fields were reported to be severely affected by the disease. Areas like Adet, Denbi, Kulumsa, Bako, were considered to be hotspot for powdery mildew in field pea. Host resistance is one of the most widely used control measure for this disease. There are reported sources of genetic resistance available, which were controlled by single recessive gene. Also, some materials introduced from Australia, especially cultivar cooke that have resistance for powdery mildew. Research reports also indicated that there is genetic diversity in resistance to powdery mildew in Ethiopian landrace collections. These materials could be used as source of resistance in the
breeding program. The released varieties have moderate level of resistance to powdery mildew. Other control measures include early planting, sprinkler irrigation, chemical control with Benomyl 50% WP (Benlate 50% WP) 2 kg active ingredient per ha could be applied starting when 5% attack has been scored on the crop. However, this seems somewhat costly and unaffordable by poor farmers, as at least two sprays must be applied at 10 days intervals.

**Resistance to other biotic and abiotic stress:** Biotic stresses such as weed and insect pests and abiotic stresses like waterlogging, soil acidity, and low soil fertility are major constraints to field pea production. According to research reports, weed inflicts yield loss up to 15%. Sources of resistance to these factors have not been yet identified. However, genetic variability for most of the stresses is expected to exist and efforts to identify them must strongly be continued. Particularly parents having genes for efficient use of low soil fertility, low water requirement and low input such as fertilizer need to be identified for use in hybridization, as genetic manipulation is commonly preferred to the continual manipulation of the growing environment because of environmental concerns and cost particularly to the resource-poor farmers who cannot afford to apply more external inputs.

**Grain yield:** Better productivity in terms of grain yield is the ultimate target of developing a variety. In field pea grain yield consists of the number of pods per ha x number of seeds per pod and the average seed weight. Yield can be improved by improving any of these determinants. Since starting breeding works from the scratch may take long time, the improvement for certain traits of the otherwise high yielding varieties released for good adaptation could be advisable to achieve the desired goal within a short period of time.

**Evaluation of parents**

If there is no prior information as of the performance of the chosen parents, particularly for the desirable traits they are expected to donate, they should be evaluated in the new ecology where the new variety is developed. For instance, new parents to be employed as sources of resistance need to be evaluated for consistence of resistance (if possible under artificial inoculations) because they might be susceptible to changes in races of the pathogen, or even to other diseases in the region for which their reaction is not known at all.
Knowing the length of days to flowering of the new parent in the new region must also be set. This will assist in staggering or adjusting the sowing dates of the parents in such away that their flowering time will exactly coincide for effective crossing.

**Crossing techniques**

For successful crossing, practical skills are needed to make successful crosses and such skills require an understanding of the raising of parent materials and flower morphology. In addition, availability of crossing materials such as crossing stool, forceps, scissors, labels, colored threads, alcohol for disinfecting the crossing forceps, pencil, field book are crucial (figures 3).

**Planting the Parents:** The parent material can be grown in the field, greenhouse, probably in growth chamber. Proper agronomic practices are necessary for raising healthy parents. This will particularly include an adequate nutrient and water supply and appropriate plant protection measures. There are no special crop management and protection recommendations for crossing blocks of field pea that are different from those for grain production but the available recommendations should be more strictly followed to ensure good flowering and seed set.

The most common layout of the crossing block for field pea is a two-row crossing block where a male parent row is planted nearby the female parent rows. Wider plant-to-plant and row-to-row spacing of 10 to 15 cm and 1.5 m, respectively, is maybe required to facilitate free movement during crossing.

Crossing is made between two parents when they can produce flowers with viable gametes, i.e. viable pollen on the male parent and receptive stigma on the female with synchronization in maturity of the two gametes. Simultaneous flowering or overlapping of flowering period of the two parents is required for the successful crossing. In cases where natural overlapping is lacking, flowering has to be manipulated based on the flowering dates of the parents. Based on the flowering days of the parents, staggering of the sowing dates must be made to synchronize the flowering time of the male and female parents.
Emasculation: Artificial crossing involves the removal of anther from a flower known technically as emasculation before they dehisce. It prevents self-fertilization when preparing a female flower for crossing with other parents.

One has to identify the appropriate stages to make effective emasculation. If it is done early, the removal of anthers is difficult and the ovary is likely to be damaged, and if it is carried out late, the self-pollination would already taken place. Pollen from freshly opened flower should be used for pollination rather than the old flower. The appropriate flower stage for emasculation of female parent and taking pollen from donor male (Figure 4).
The detailed steps of emasculation are given below:

Select the proper bud for emasculation
- Select inflorescence nearest to the ground
- Select the flower on the inflorescence nearest to the stem
- Use the first or second bud on the inflorescence
- Use a bud in the pointed-bud stage.

Remove the sepals by holding the bud between your thumb and forefingers and tearing off two to three sepals covering the keel

Expose the staminal column.
- Insert the points of the forceps by sideways movement through the standard and wing petals
- Release the pressure on the forceps gently and fold back the standard and wing petals
- Slit open the keel petals with the help of the forceps along the suture of the two keel petals
- Press the calyx at the base gently and then seethe the staminal column.

Remove the 10 anthers carefully not to squeeze out pollen from the anther while removing the filaments (Figure 6). Avoid damaging the style as it is delicate and may break at the bend.
Rearrange the wing and the standard petals to cover the keel and label the emasculated bud.

![Image of emasculated bud]

The optimum time of emasculation and pollination specific to Ethiopian condition is not so far determined. It is generally believed that one can pollinate immediately or a few hours after emasculation but it is better to pollinate in the afternoon if the bud was emasculated in the morning.

**Pollination:** It involves the removal of pollen from freshly dehisced anthers of the male parent and putting them on the stigma of emasculated female parent. Like emasculation, one has to identify the appropriate flower stage when pollen should be taken and pollinated (figure 4). The flower in which the dehiscence has just started should be used as the male parent. The freshly opened flower is normally appropriate for field pea pollination. The detailed steps of pollination are given below:

- Select an appropriate flower of the male parent, expose the stamens and collect the sticky yellowish/orange pollen at the end of the forceps or mounted needle.
- Smear the pollen on the stigma of the emasculated bud. The emasculated bud already has a slit in the keel petal. Press down the wing and keel petals to expose the stigma. Now, apply ample pollen to the surface of the stigma with forceps.
- Close the keel petal after transferring the pollen to maintain humidity within the flower.
• Remove all the other buds and flowers from the inflorescence carrying the emasculated flower to encourage the development of the crossed bud.
• Always clean the forceps to be used for pollinating by dipping them into 95% ethyl alcohol before changing pollen donor (figure 7).
• After pollination, proper labeling of the crossed bud is essential to identify one cross from the other. Tie a rectangular tag of approximately 2x3cm on the pollinated flower with date of emasculation and pollination, plot number, plant number and pedigree or name of the parents crossed (first the female and then the male) written on; or tie a rectangular tag of approximately 3 x 5cm on each plant with date of emasculation and pollination, plot number, plant number and pedigree or name of the parents crossed written on or tie different colored thread of about 10cm on the peduncle of each pollinated flower to differentiate the crossed flower. In this case one color indicates crosses of the same date.

Data to be collected
- Effective nodes per plant, i.e., number of nodes bearing pods in one stem;
- Effective pods per nodes, i.e., number of pods per nod; and
- Total number of crossed flowers

Harvesting and Storage of F₁: After crossing the plants should be grown with appropriate care until maturity. Once pods have developed to a length exceeding 3 - 3.5 cm, they are likely to grow to maturity but unsuccessful crosses may abort. The recovery percent from hybridization (i.e. number of effective pods harvested divided by total number of flowers
crossed, multiplied by 100) at Holetta under field condition, between 1997 and 2002, ranged from 40 to 60% (53% average).

The pods of the crossed flowers are harvested and threshed by hand. As the crossed seeds obtained after the tedious operation of hand-pollination are expensive, they should be handled properly and stored to keep their viability intact.
Nursery Management

Handling of F₁ and Segregating Generations

The successful attainment of objectives of a judicious hybridization program underlies a careful handling of segregating materials. Since the selection of desirable genotypes may commence right from F₂ till F₅ or even later generations, the following guidelines are useful to field pea breeders to operate with segregating generations.

Planting density requires a close observation of individual plants, particularly in F₂ generation where a low population density is recommended. In generations, when family characteristics begin to appear, the planting rate might be space planting if only selection is to be carried out and commercial density planting if early generation testing, particularly of F₃ families are to be accomplished.

**Population size (F₂/F₃):** This is one of the important factors limiting yield improvement in crop plants. How many F₂ plants should be grown depends on two factors:
- Number of genes controlling the trait under selection
- How many F₃ families can be handled depending upon the availability of resources.

Theoretically, an extremely large population size is needed to be maintained in F₂ generation. But practically it is immensely difficult hence, generally not adhered to by plant breeders. The proportion of selected plants in F₂ varies from 1% to 10% depending upon the discriminating ability of the plant breeder.

**Ruthless rejection:** An attitude of ruthless rejection of even slightly defective individuals, particularly in F₂ generations, may be considered pragmatic for traits that are expected to be controlled by one or a few genes like powdery mildew resistance. In general selection should be start from simply inherited and highly heritable traits and later for more complex ones, as homozygosity increases due to fixation of alleles by inbreeding and selection.
**Rapid visual scoring:** Since population size in the segregating generations is large, more so in F<sub>2</sub>, the rapid selection of plants of high basic worth, and ruthless rejection; precise measurement of individuals, particularly in F<sub>2</sub> generations, is not possible and not remunerative. Therefore, a rapid visual scoring of plants will be of great help. This requires the knowledge of crop, which the breeder is handling, and of morphophysiological attributes of commercially acceptable variety.

**Reliable screening for disease reaction:** Selection for desirable traits is based on phenotype which requires the necessary environment for its phenotypic expression. To express this situation, the famous plant breeder and geneticist R.W. Allard states, ‘No amount of acumen will allow the breeder to select for specific characteristics when the conditions necessary for the expression of these characteristics do not occur’. Traits like disease incidence require a special environment for their expression. They require artificial epiphytotic conditions to be created where segregating materials can be grown and resistant genotypes could be selected. Ideally screening for disease resistance must start right from F<sub>2</sub> itself and maintain its intensity through advanced generations. Generally, three types of checks are necessary in screening for disease resistance. These checks are susceptible, resistant and a well known standard variety. A susceptible check is a proven susceptible material that would guide activities like when to make scoring and confirm uniformity and level of disease pressure in the nursery. These checks need to be repeated every ten test entry. A resistant check is the best material available in the breeding program. Comparisons would be necessary during selection for resistance. Any material that is better than the resistant check is promoted. A standard check is a material that helps during selection. Special considerations that would be mentioned include agronomic traits such as flowering, maturity time and plant height.

**Exploiting off-season facilities:** This is very important for advancing the generation rapidly in areas where growing the crop in off-season at some other or the same location is possible if the irrigation facilities are available.

**Screening for agronomic traits:** Out of the segregating generations at different stages (F<sub>2</sub> to F<sub>5</sub>), selection is made using pedigree, bulk or backcross method. The single plant selection (SPS) or bulk selection (BS) method is made for better agronomic characters such as number of pod
per plant, seed per pod, seed size, earliness and lodging resistance based on
the performance of the best commercial cultivar included as a standard check
in the nursery.

From F$_3$ or F$_4$ onwards, where selection is rather at family level (not at
individual plant level), data on important agronomic characters need to be
recorded. This includes yield and yield components (pod per plant and seed
per pod), number of days to flowering and maturity, plant height, percent
lodging, hectoliter weight and thousand seed weight. Each of this parameter
is described as follows.

**Grain yield:** The main objective in any crop improvement activity is to
increase the economic yield. Yield, in general, is a complex character
determined by a number of component characters which can be manipulated
to enhance yield potential. Such components, apart from their contribution
towards yield, can have *per se* effect on the acceptability of the final product.
In field pea experiment, yield is measured from the whole plot (gram per plot)
and this is later converted into grain yield per ha (kg ha$^{-1}$) to ease comparisons.
First the weight of the plot yield is adjusted to standard moisture content so that
the results from the same trials in different locations and years can be
compared. The standard moisture content used for field pea in Ethiopia is 9%.

Seed moisture content is basically determined as percent water content of the
seeds. It is measured either by drying seed samples in an oven or with the help
of moisture testers. The oven method involves weighing the seed samples and
drying them to a constant weight (zero moisture) in an oven. The dried seeds
are weighed again and any loss in weight represents the weight of water lost
due to drying. Then the percentage moisture content is estimated as:

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where $W_1$ is the weight of the seed sample before drying and $W_2$ is the
weight of the seed sample after drying.

The use of moisture meters may require calibrations and correction factors
which may need some technical skill. However, it is the most efficient and
faster method. The plot fresh yield, therefore, is adjusted to 9% moisture
content before statistical analysis.

**Date of emergence:** About 50% of the seedlings expected from the
plot, have emerged out of the ground or become visible above the ground.
Stand count: It is the number of plants in a plot counted after emergence and at maturity in relation to the number of seeds planted.

Days to flowering: It is the number of days from sowing (if sowing is done when the soil is wet enough to initiate germination) or from the crop emergence (in case of dry sowing) to flowering, i.e. number of days at which 50% of the plants flower. It is recorded when half the plants in the plot have had half the flowers emerged on the lower node of the main branch.

Days to maturity: It is the number of days to 95% physiological maturity counting from day of sowing or emergence to day of physiological maturity.

Days to grain filling: It is the number of days of flowering to day of 95% physiological maturity, i.e. days to maturity minus days to flowering.

Plant height (cm): Five plants randomly selected from each plot and their heights are measured from ground level to the tip.

Number of pod per plant: It is the number of effective pods on a plant. To determine the average number of pods per plant, five plants are randomly taken from each plot and the total number of pods is counted and divided by the total number of the same plants.

Number of seed per pod: It is the number of seed in each pod. Total number of seeds of five plants is counted and divided by the total number of pods of same plants to determine number of seeds per pod. In field pea, this number usually ranges between 3 and 6 (on average 4 or 5).

Disease reaction: Susceptibility to diseases such as ascochyta blight and powdery mildew are scored usually in a 1-9 rating scale using visual assessment, where 1 means no disease and 9 means severe infestation leading to plant death. For details of selecting appropriate scoring scale and other technicality see section 6.4 in this manual.

Percent lodging: It is the number of lodged plants expressed as a percentage of the total stand count in the plot.

Thousand seed weight (g): It is determined from the grain yield of the whole plot as the weight of 1000 seeds adjusted to 9% moisture.

Protein content: Normally, advanced lines that are in the final stage of variety trial are analyzed for crude protein content. First the seeds are grounded using ultra-centrifugal mill. One gram of the sample from each variety is taken for N analysis using macro-Kjeldahl method. Crude protein content is determined by multiplying N% value by a factor of 6.25. From many years’ data, it was observed that there is varietal difference in crude protein content of field pea varieties. Usually it ranges between 20 and 28% under Ethiopian condition. However, the essential amino-acid composition
and the relationship between the crude protein and the amino-acid content have never been determined for the varieties released so far.

**Screening for disease resistance**

Screening for disease resistance is a method of exposing breeding materials to uniform and high disease pressure. This could be obtained through natural happening (hot spot) or creating artificial conditions that brings up to high epidemics. When artificial inoculation is not possible or expensive, and when an area with naturally sufficient pressure of the disease exists, as in *Ascochyta spp.* diseases of field pea in high-altitude areas, or powdery mildew in mid-altitude areas screening for disease resistance is conducted in these places. Areas with high disease pressure every year are referred to as hot spot areas. Since the method is very simple breeders often use such areas for screening cheap. Screening of genotypes for ascochyta blight resistance is conducted in hot spot areas like Holetta and Adet, and for powdery mildew at Kulumsa.

**Selection environment**

**Artificial inoculation**

**Medium preparation and culture propagation:** *Ascochyta pinodes* (*Mycosphaerella pinodes*) infection in field pea can easily be cultured on malt extract agar (MEA) in laboratory. MEA is prepared following procedures described in any standard laboratory manuals of plant pathology. Accordingly, disease tissue showing advanced symptoms (spot or blight) on leaf, stem, pod or seed are soaked in 1% sodium hypochlorite solution for 1 minute. These surface sterilized or disinfected tissues are cut in pieces of about 0.5 cm (in length and width) and then aseptically plated on the newly prepared MEA, that eventually are incubated at 23 ºC to 25 ºC. This temperature was appropriate for the fungus at Holetta while light was not needed to grow *Ascochyta pinodes* in the lab. After 15 days of incubation, cultures give good growth and sporulation. This primary culture could be used to purify the culture either using single spore or hyphal tip transfer method. Pure cultures of the pathogen produced in this method are used to produce mass spores for field inoculation on the same medium, MEA and the spores mature in about two weeks of incubation.
Inoculum preparation and field inoculation: Matured culture of the pathogen in Petri dishes is soaked with tap water for about 30 minutes so that spores are released from pycnidia. Then repeated washing is done to harvest enough spores from each dish by rubbing with smooth brushes and wet fingers. The harvested spores are counted using hemocytometer under microscope and then adjusted to the desired number of spore/ml spore suspension by dilution method. A spore suspension with 150,000 spores/ml sprayed at flowering stage of the plant gave good disease pressure at Holetta. Adjusted spore suspension of *A. pinodes* is uniformly sprayed over nursery plots within the same date of inoculum preparation. Unnecessary delay on the inoculation may cause either the death of spores or may increase the chance of abortion during infection. Spraying is always done at the evenings when the sun goes down to avoid drying of the inoculated surface of the plants. Spraying water over the nursery in the next morning enhances infection. Several leaf and stem spotting (symptoms) develop after six days at Holetta.

Use of hot spots

When artificial inoculation is not possible or expensive and an area with naturally sufficient pressure of the disease exists, as is the case in field pea in Holetta and Adet areas, screening for disease resistance is conducted in these places. Areas with high disease pressure every year are referred as hot spot areas. Breeders often use such areas for screening as the method is very simple and cheap. *A. pinodes* disease is frequent in high altitude areas with warm and humid weather conditions where it causes significant yield reduction when it occurs early in the season. Screening of genotypes for ascochyta resistance is conducted in hot spot areas like Holetta and Adet where ascochyta develops to a serious level and starts early in the season.

Nursery disease data collection

Selection of individual plants on the basis of their phenotypic performances for yield and other characteristics continues for several cycles, but such selection is largely based on knowledge and experience of the breeder. Since comparison of yield, among selection parameters through rigorous statistical analyses is usually not possible in the early stages of segregations, practical skill and experience is a key factor to succeed. However, standard check varieties are grown at frequent intervals (e.g., every ten entries) to compare the performances of the test materials with these standard varieties under
uniform disease conditions or use them as spreader to ensure uniform pressure.

**Disease recording**

**Choice of scoring scale**

The choice of a particular scoring scale is dependent on many factors that include:

- Type of experiment to be evaluated and the level of precision required;
- The host-parasite relationship of the pathosystem;
- Growth stage and part of the host plant infected;
- Incidence and severity of the disease to be scored;
- Interaction with other diseases; and
- The resources available.

Hence, the researcher should optimize these conditions so that appropriate, correct and precise disease data could be collected with a minimum cost. In general, disease management and epidemiological studies require more stretched scales such as percentage area covered by the disease, 0-9 or 1-9 scoring scales while early breeding nurseries would only require 0-3, 0-5 or 1-5 rating scales since the objective is only to catch promising materials. Trials (such as PVT, NVT, etc) that require statistical analyses would preferably be scored in percentage, 0-9 or 1-9 rating scale as less than 9 point rating scale would not give accurate estimation of the disease severity in different treatments.

When rating disease in the field, the uses of diagrams or mounted scoring scales that are prepared from diseased samples increase the precision of scoring. Prepared diagrams are not available for all diseases. Hence, scoring aids could be prepared by collecting the diseased plant parts of different categories and arrange them in increasing gradient so that each sample represent one score group. After mounting this set and cover it with plastic, one can use it in the field during scoring. This increases the precision of scoring different materials.

**Disease scoring time and frequency**

Disease scoring time and frequency depend on the type of plant organ infected, stage of the plant, type and severity of a disease as discussed below.
**Foliar diseases:** Foliar diseases are best scored when the susceptible check or most susceptible entry in the trial receives about 75% infection by the disease based on foliage coverage. Most of the time, two scorings for breeding materials and several scoring for disease management trials are recommended. For early generations, one at early disease development stage (preferably when susceptible check receives about 50%) and another scoring at full pod stage (when the susceptible check receives about 75% infection) are important. Some trials may need more recordings due to their temporal nature.

**Root diseases:** These groups of diseases are difficult to observe and visually assess without destructive sampling. However, they could be assessed when a particular line (entry or variety) shows severe symptoms. Plants at the boarder lines could be used to correlate the symptoms and root damage in the plot. When the disease infects one plant and the other is healthy, disease incidence (percentage of diseased plants) could be counted and used as data. In general one scoring is sufficient for these types of diseases.

In both foliage and root diseases, scoring at the end of the season should be avoided, because, symptoms of senescence and other physiological reactions of the plant might interfere with the disease symptoms. This causes serious error in the scoring.

**Handling of different scoring scales:** Foliar diseases can effectively be scored using 0-3, 0-5, 1-5, 0-9, 1-9 and percentage area affected or covered by the disease. These scoring scales assist to estimate the proportion of diseased part of the plant. Some of the commonly used scoring scales are described for field pea diseases in Table 2.
### Table 2. Description of different scoring scales for rating of field pea diseases

<table>
<thead>
<tr>
<th>Scale</th>
<th>Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>Nil</td>
<td>No visible symptom of any sort observed on the plant</td>
</tr>
<tr>
<td>0</td>
<td>Slight</td>
<td>Infection with about 25% of the foliage damaged or showed symptoms of the disease</td>
</tr>
<tr>
<td>2</td>
<td>Medium</td>
<td>Moderate level of infection with about 75% of the foliage damaged or showed symptoms. Majority of the plants in a plot showed infection by the disease</td>
</tr>
<tr>
<td>3</td>
<td>Severe</td>
<td>High level of infection with about 90% of the plants showing severe foliage damage or severe symptoms</td>
</tr>
<tr>
<td>0-5</td>
<td>Nil</td>
<td>No visible disease symptom (immune)</td>
</tr>
<tr>
<td>1</td>
<td>Trace</td>
<td>Some plants with very few small lesions (highly resistant)</td>
</tr>
<tr>
<td>2</td>
<td>Slight</td>
<td>A few small discrete lesions (resistant)</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>Some coalesced lesions, many spotting and some defoliation (moderately resistant)</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Large coalesced lesions with about 50% defoliation, few dead stems/plants (susceptible)</td>
</tr>
<tr>
<td>5</td>
<td>Very severe</td>
<td>Extensive lesion, severe defoliation, stem girdling, many dead plants (highly susceptible)</td>
</tr>
<tr>
<td>1-5</td>
<td>Nil</td>
<td>No visible disease symptom (immune)</td>
</tr>
<tr>
<td>1</td>
<td>Slight</td>
<td>Some discrete lesions and a few large spots (resistant)</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>Some coalesced lesions, many spotting and some defoliation (moderately resistant)</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Large coalesced lesions with about 50% defoliation, few dead stems/plants (susceptible)</td>
</tr>
<tr>
<td>5</td>
<td>Very severe</td>
<td>Extensive lesion, severe defoliation, stem girdling, many dead plants (highly susceptible)</td>
</tr>
<tr>
<td>0-9</td>
<td>Nil</td>
<td>No visible disease symptom (immune)</td>
</tr>
<tr>
<td>1</td>
<td>Trace</td>
<td>Some plants with very few small lesions (highly resistant)</td>
</tr>
<tr>
<td>3</td>
<td>Slight</td>
<td>A few small discrete lesions (resistant)</td>
</tr>
<tr>
<td>5</td>
<td>Medium</td>
<td>Some coalesced lesions, many spotting and some defoliation (moderately resistant)</td>
</tr>
<tr>
<td>7</td>
<td>Severe</td>
<td>Large coalesced lesions with about 50% defoliation, few dead stems/plants (susceptible)</td>
</tr>
<tr>
<td>9</td>
<td>Very severe</td>
<td>Extensive lesion, severe defoliation, stem girdling, many dead plants (highly susceptible)</td>
</tr>
<tr>
<td>1-9</td>
<td>Nil</td>
<td>No visible disease symptom (immune)</td>
</tr>
<tr>
<td>3</td>
<td>Slight</td>
<td>Some small discrete and a few large lesions (resistant)</td>
</tr>
<tr>
<td>5</td>
<td>Medium</td>
<td>Some coalesced lesions, many spotting and some defoliation (moderately resistant)</td>
</tr>
<tr>
<td>7</td>
<td>Severe</td>
<td>Large coalesced lesions with about 50% defoliation, few dead stems/plants (susceptible)</td>
</tr>
<tr>
<td>9</td>
<td>Very severe</td>
<td>Extensive lesion, severe defoliation, stem girdling, many dead plants (highly susceptible)</td>
</tr>
</tbody>
</table>
**Percentage area affected:** Special consideration in rating disease in percentage area covered include only integers (whole numbers) are recorded for scores above 10% and less than 90%. Out of these ranges, fractions could be considered. In addition, using diagram or mounted disease scale, as aid of scoring is important, because the range scoring is very large that simple error could be done easily.

**Infection percentages (incidence):** In diseases like root rot or virus, all plants do not show infection. Only some of the plants show the disease while others are healthy. In this case, diseased and healthy plants are counted and the proportion or ratio of infected plants is used as a score for a material. This is referred to as incidence, which is often expressed in percentage.

**Handling of data from different scoring scales:** Data collected by different workers, using different scales, at different locations or times (etc.) could be combined and evaluated. Before combining, all the data should be converted to a desirable and useful scoring scale, the percentage value (Table 3). Conversion from higher to lower point-scoring scale is easier. However, one can also convert from lower to higher point scoring scale when there is clear division between the data values. This would give a chance to compare results of different observations. In combining the data, the following important considerations are worth mentioning as a procedure:

- Calculate the mean value of disease score for each experimental unit
- Convert the scores to a desired scoring scale using inter-conversion table (Table 3).
- Calculate the mean and use this value for further evaluation or
- Transform these percentage values using ARCSINE before statistical analysis.

Disease infection levels in plants should be evaluated using simple, reliable, objective and quick method depending on the level of precision required. Wide range of scales like percentage and 0-9 rating scale fairly show the difference in intensity in any disease. For experiments requiring high precision, percentage damage by the disease, 0-9 or 1-9 scale is appropriate. Usually experimental units receive one score for single scoring. However, large fields should be sampled at 3 to 5 spot and the average of these samples is the value for the field. Sometimes, 10 plants per plot are tagged and evaluated at regular interval for experiments requiring high precision (epidemiological and management option studies).
Table 3. Disease scoring scale inter-conversion table

<table>
<thead>
<tr>
<th>Rating scale</th>
<th>Percent area covered</th>
<th>Resistance class</th>
<th>SAS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>0</td>
<td>Immune</td>
<td>0</td>
</tr>
<tr>
<td>1-5</td>
<td>1-12</td>
<td>Highly resistant</td>
<td>4</td>
</tr>
<tr>
<td>1-9</td>
<td>12-30</td>
<td>Resistant</td>
<td>15</td>
</tr>
<tr>
<td>2-4</td>
<td>40-60</td>
<td>Moderately Resistant</td>
<td>30</td>
</tr>
<tr>
<td>3-5</td>
<td>50-70</td>
<td>Moderate infection</td>
<td>50</td>
</tr>
<tr>
<td>4-6</td>
<td>60-80</td>
<td>Moderately Susceptible</td>
<td>70</td>
</tr>
<tr>
<td>5-7</td>
<td>70-90</td>
<td>Susceptible</td>
<td>85</td>
</tr>
<tr>
<td>6-9</td>
<td>80-100</td>
<td>Highly Susceptible</td>
<td>96</td>
</tr>
</tbody>
</table>

NB: Disease severity is always converted when the values are easily converted from one scale to another. Hence, conversion is easier with mean values having one or more decimal places using rounding method in arithmetic. Scores in the 0-3, 0-5 and 1-9 scale are not amenable to statistical analysis. Statistically amenable score (SAS*) is given for each rating.

**Disease data analyses**

All disease data collected based on proportion of diseased parts as percentage infection is transformed before statistical analyses are considered. In this case because analyses must be valid and conclusions are correct. Data of counts expressed as percentage or proportions of the total sample require transformation before statistical analyses. Appropriate transformation for plant disease data collected by using 0-3, 0-5, 1-5, 0-9, 1-9 and percentage area affected by the disease is ARCSINE or ANGULAR transformation (Tables 4 and 5). Before transforming the data scores collected by using 0-3, 0-5, 1-5, 0-9 and 1-9 rating scales, they are pre-transformed to percentage values of equidistance, using Table 4. Then all the percentage values obtained by this pre-transformation procedure are transformed to arcsine using Table 5. Only these transformed values (TV) are amenable to statistical analysis. ARCSINE is obtained by finding the angle whose SINE is the square root of the percentage value observed.

Model: $TV = \text{ARCSINE} \sqrt{\text{Percentage}}$ or $\text{SINE}^{-1} \sqrt{\text{Percentage}}$

It is scarcely necessary to transform data whose range of percentage is less than 40. The need of transformation is checked by Bartlett's test using $\chi^2$. All tests of significance and mean separations should be carried out on the transformed data and reporting is done on values that transformed back to the original scales and are correctly weighed means.
Field pea Improvement through Hybridization

Table 4. Pre-transformed percentage values for commonly used rating scales of disease severities

<table>
<thead>
<tr>
<th>Rating scale</th>
<th>0-3</th>
<th>0-5</th>
<th>1-5</th>
<th>0-9</th>
<th>1-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>10</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>35</td>
<td>15</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>65</td>
<td>50</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>85</td>
<td>-</td>
<td>42</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>100</td>
<td>58</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>75</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>88</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>97</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

This pre-transformation method would help to obtain equally spaced data scales that give integer when transformed to arcsine (angular).

Table 5. The angular transformation of percentage to degrees

<table>
<thead>
<tr>
<th>% (two digits)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>5.7</td>
<td>8.1</td>
<td>10</td>
<td>11.5</td>
<td>12.9</td>
<td>14.2</td>
<td>15.3</td>
<td>16.4</td>
<td>17.5</td>
</tr>
<tr>
<td>10</td>
<td>18.4</td>
<td>19.4</td>
<td>20.3</td>
<td>21.1</td>
<td>22.0</td>
<td>22.8</td>
<td>23.6</td>
<td>24.4</td>
<td>25.1</td>
<td>25.8</td>
</tr>
<tr>
<td>20</td>
<td>26.6</td>
<td>27.3</td>
<td>28.0</td>
<td>28.7</td>
<td>29.3</td>
<td>30.0</td>
<td>30.7</td>
<td>31.3</td>
<td>31.9</td>
<td>32.6</td>
</tr>
<tr>
<td>30</td>
<td>33.2</td>
<td>33.8</td>
<td>34.4</td>
<td>35.1</td>
<td>35.7</td>
<td>36.3</td>
<td>36.9</td>
<td>37.5</td>
<td>38.1</td>
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<td>39.8</td>
<td>40.4</td>
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<td>51.9</td>
<td>52.5</td>
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<td>54.9</td>
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</tbody>
</table>

Pest control

Important insect pests that attack field pea in Ethiopia include pea aphids (*Acyrthosiphon pisum*), pod borer (*Helicoverpa armigera*) and bean bruchids (*Callosobruchus chinensis*). Reports in Ethiopia indicate that yield loss on field pea due to pea aphid ranges from 22 to 49% in hotspot areas.

Insect pests are better controlled with integrated pest management (IPM) involving tolerant varieties, regular monitoring of the crop and judicious use of pesticides. In general, it is dubious whether there is any level of practical gene-driven resistance exists to these insect in field pea for practical use. As best alternative, however, there are recommended chemicals in Ethiopia for the control of these insect pests pea aphids could be controlled by spraying...
Pirimicarp (Pirimor 50% powder) at the rate of 0.5 kg active ingredient, or Pirimiphos-methyl (Actelic 50% Ec) 0.5 kg per ha; pod borer could be controlled by single spray with 150g active ingredient of cypermethrin while bean bruchids could be controlled by seed dressing with Pirimiphos-methyl (Actelic 2% powder) at the rate of 40 g for 100 kg of seed.
Methods of Selection

An array of selection procedures may be used in field pea improvement. Among these procedures the pedigree, the bulk and the backcross methods are most widely employed. The main objective of all these methods is to develop superior and pure varieties. The detail of these methods is given below.

Pedigree

This is a method whereby individual plants are selected from F2 and subsequent segregating generations and their progenies are evaluated. In this method a record of all the parent-offspring relationships is recorded until the progenies become homozygous. In pedigree method of selection each progeny in every generation can be traced back to the F2 plant from which it is originated.

The pedigree record could be kept in many ways but the simplest way is giving a number to each cross: the first two digits of this number refer to the year in which the cross was made, and the remaining digits denote the serial number of the cross in that year.

Designation based on location of progeny rows

In this system the individual plant progenies in each generation are assigned row numbers corresponding to their location in the plot. In addition, each progeny in F4 and subsequent generation is assigned to the row number of the progeny in the previous generation from which it was derived. Thus each F3 progeny, derived from individual F2 plants, is given a number corresponding to the row number at which it is located in the F2 plot. Plants selected from F3 progeny are identified by the row number of the progeny. When individual plant progenies are grown in F4, each progeny is also given the row number of the F4 plot. After the F5 progenies are planted, the row numbers of the progenies in the F5 plot are added to the F4 row numbers. The same procedure is followed in the subsequent generation as outlined below (Table 6).
Table 6. Illustration of pedigree record keeping based on the location of the progeny rows in each filial generation in the field.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Progeny number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₃</td>
<td>9815-3</td>
<td>Progeny of the cross number 15 of the year 1998, that is the 3rd row in the F₃ plot that was selected from individual plant in F₂</td>
</tr>
<tr>
<td>F₄</td>
<td>9815-1-4</td>
<td>Progeny of the cross number 15 of the year 1998, which is in the 4th row in the F₄ plot, selected from the progeny in the 1st row of the F₃ plot</td>
</tr>
<tr>
<td>F₅</td>
<td>9815-4-10</td>
<td>Progeny of the cross number 15 of the year 1998, which is in the 10th row in the F₅ plot, selected from the progeny in the 4th row of the F₄ plot</td>
</tr>
<tr>
<td>F₆</td>
<td>9815-15-7</td>
<td>Progeny of the cross number 15 of the year 1998, in the 7th row in the F₆ plot, selected from the progeny in the 15th row of the F₅ plot</td>
</tr>
</tbody>
</table>

Thus each progeny can be traced back to the F₃ progeny (or the F₂ plant) from which it is originated. But for determining the pedigree of a progeny, the breeder has to consult the record of the previous year as well.

**Designation based on serial numbers of selected plants**

In each generation the selected plants are given a serial number within individual progenies: each progeny or selected plant get a serial number of all the plants in the previous generations related to it by direct descent. Thus each selected plant in F₂ is given a serial number. The F₃ progenies derived from these plants are given a serial number of their parent F₂ plants. Plants selected from progeny in F₃ are given the number of that progeny; in addition, each selected plant from that progeny is also given a serial number. These two numbers together make up the progeny number in the F₄ generation. Similarly, the plants selected from a F₄ progeny are given the F₄ progeny number, i.e., the serial numbers of the F₂ and F₃ plants from which the concerned F₄ progeny was derived, and a new number showing the serial number of the plant among those selected from F₄ progeny. This system is summarized in Table 7. In this system, the pedigree of a progeny is immediately known, and one should not have to refer to the previous year’s record. But there is a greater chance of error in this system since more numbers are to be recorded.
Table 7. Illustration of pedigree record keeping based on serial number of selected plants

<table>
<thead>
<tr>
<th>Generation</th>
<th>Progeny number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₃</td>
<td>9815-3</td>
<td>Progeny obtained from plant number 3 selected in F₂ from cross number 15 of the year 1998</td>
</tr>
<tr>
<td>F₄</td>
<td>9818-3-7</td>
<td>Progeny from plant number 7, selected from the F₃ progeny derived from the plant number 3 selected in F₂ from cross number 15 of the year 1998</td>
</tr>
<tr>
<td>F₅</td>
<td>9815-3-7-1</td>
<td>Progeny from plant number 1, selected from the F₄ progeny derived from plant number 7 selected from the F₃ progeny obtained from plant number 3 selected in F₂ from cross number 15 of the year 1998</td>
</tr>
<tr>
<td>F₆</td>
<td>9815-3-7-1-8</td>
<td>Progeny from plant number 8, selected from the F₅ progeny derived from the plant number 1, selected from the F₄ progeny of the plant number 7 selected from F₃ progeny of the plant number 3 selected in F₂ from cross number 15 of the year 1998</td>
</tr>
</tbody>
</table>

In both systems, the progenies are given a different serial number but in keeping a pedigree record the following should be kept in mind:

- Only promising progenies should be included in the record. Poor progenies may be simply marked “discard”. This would give enough chance for studying promising progenies.
- The pedigree record must be accurate. Keeping no record is better than keeping an inaccurate record, which will only create confusion.

The pedigree record is often useful in the elimination of some progenies. In later generations, e.g., F₅, F₆, etc., if some lines originated from the same F₄ or F₃ progeny and are similar, only one of these lines most preferred need to be maintained. Further, it may often be possible to obtain a general idea about the inheritance of characters by studying the pedigree record. A simplified schematic representation of the pedigree method of handling the segregating generation from cross in field pea is presented in Figure 8.

**Bulk method**

In the bulk method of selection, the F₂ and subsequent generation are grown in bulk, usually without artificial selection. In this case the population is carried to F₄ or F₅ as bulk. Then individual plants are selected and evaluated as in the pedigree method, i.e., pure-line selection. Since the selected plants are almost homozygous, most of the progenies will be homogeneous. Therefore, a preliminary yield trial may be planted in the second year after selection of individual plants. Look below a simplified schematic representation of the bulk method of handling the segregating generation from a cross (Figure 9).
Field pea Improvement through Hybridization

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Figure 8. A simplified schematic representation on the pedigree method of handling the segregating generation from cross in field pea

First year Parents

- Selected parents planted in a crossing blocks and crosses made

Second year F\textsubscript{1}

- 30-60 seeds space planted, harvested in bulk

Third year F\textsubscript{2}

- 1000-2000 plants space planted
- 5-10% superior plants selected

Fourth year F\textsubscript{3}

- Individual plant progenies space planted
- Superior plants selected

Fifth year F\textsubscript{4}

- Individual plant progenies planted in multi-row plots
- Superior plants selected from superior progenies

Sixth year F\textsubscript{5}

- Preliminary variety trial

Seventh to Eighth year F\textsubscript{6} - F\textsubscript{7}

- National variety trial
- Quality tests

Ninth year F\textsubscript{8}

- Variety verification
- Variety release

Tenth year F\textsubscript{9}

- Seed increase for distribution
Figure 9. A generalized schematic bulk method for the isolation of homozygous lines in field pea.
Backcross method

Past efforts in field pea breeding have resulted in identification of desirable genotypes as released varieties or parents for further improvement in field pea. As the starting of breeding works from the scratch may take a longer time, conversion of well adapted varieties into their tolerant versions through incorporation of desirable traits is advisable. Therefore, future breeding becomes building on the past successes through filling the shortcomings of previous varieties. When it is technically possible, the conversion of the otherwise well adapted varieties using the backcross breeding technique into their desirable versions through incorporation of missing desirable genes seems to be the best strategy. This is not only time saving but also effective and efficiency.

In the backcross method, the F₁ or a segregating generation is repeatedly crossed with recurrent parent (one of the parents). As a result, the genotype of back cross progeny becomes almost similar to that of the recurrent parent excepting for the gene being transferred. The objective of the backcross method, therefore, is to improve one or two specific defects of a high yielding variety, which is well adapted to the area and has other desirable characteristics. In the field pea breeding, this method has been commonly used for transfer of disease resistance and seed size from one variety into another. Backcrossing will be repeated (up to BC₅ or BC₆) depending on the level of homogeneity of backcross progeny to recover the desired behaviors of the recurrent parents except for the genes being transferred. The plan of backcross method would depend upon whether the gene being transferred is recessive or dominant.

Transfer of a dominant gene

Suppose variety A is a high yielding and adapted variety but lacking an important character while variety B has a character controlled by a dominant gene but lacking in the adapted variety are going to be worked together using backcross method. In our field pea breeding, this method has been commonly used for transfer of seed size from one variety into another. A generalized scheme of the backcross program is as follows

- Hybridization – variety A is crossed to variety B; in this case, variety A should be used as the female parent to facilitate the identification of selfed plants if any.
- F₁ generation – F₁ plants are backcrossed to variety A. Since all the F₁ plants will be homozygous for the character being transferred, selection for the trait is not necessary at this stage.
First backcross (BC₁) generation – half of the plants in BC₁ would be similar to variety A and the other half to variety B. Plants similar with variety B are selected and crossed with variety A. BC₁ plants with the character to be transferred may be selected for their resemblance to variety A.

BC₂ to BC₅ generation – in each backcross generation, segregation would occur for the trait being transferred. Plants with this trait are selected and backcrossed to the recurrent parent, variety A. Selection for the plant type of variety A may be practiced, particularly in BC₂ and BC₃ generations.

BC₆ generation – on an average, BC₆ plants are expected to have over 96% genes from variety A. Plants similar with variety A having the trait being transferred are selected and selfed; their seeds are harvested separately.

BC₆F₂ generation – Individual plant progenies from the selected seeds of the selected plants are grown. Plants similar with variety A having the trait being transferred are selected and their selfed seeds are harvested separately.

BC₆F₃ generation – Individual plant progenies are grown. Progenies homozygous for the trait of interest and similar to the plant type of variety A are harvested in bulk to constitute the new variety.

Transfer of a recessive gene

When the trait being transferred is controlled by recessive gene, all the backcrosses cannot be made one after the other. After the first backcross and every subsequent backcross, F₂ generation must be grown to identify plants having the trait of interest. In the field pea breeding, this method has been commonly used for transfer of powdery mildew resistance, which is most probably controlled by recessive genes, from introduced (exotic) varieties into released and promising varieties. Many good lines are in variety trials at present that developed following this method.

Suppose variety A is a high yielding and adapted variety but lacking an important character, say powdery mildew resistance, while variety B has powdery mildew resistance gene (recessive) lacking in the adapted variety. A generalized scheme of the backcross program is as follows:

Hybridization – variety A is crossed to a powdery mildew resistant variety B; in this case, variety A (the recurrent parent) should be used as the female parent.

F₁ generation – F₁ plants are backcrossed to the recurrent parent.

BC₁ generation – since powdery mildew resistance is recessive, all the plants will be powdery mildew susceptible and hence, there is no test for resistance and all the plants grown with no inoculation are selfed.

BC₁F₂ generation – plants are grown at hot spot areas of powdery mildew. Powdery mildew is an obligate parasite and it cannot be multiplied on media and sprayed to the plants. Resistant plants are selected and backcrossed with the recurrent parent. Selection is done for the plant type and other characteristics of the recurrent parent.

BC₂ generation – There is no resistance test. Plants are selected for their resemblance to the recurrent parent A and backcrossed with the recurrent parent.
- BC₃ generation – there is no disease test. Selection is usually done for the plant type of variety A.
- BC₃F₂ generation – plants are grown at hot spot areas of powdery mildew. Resistant plants resembling variety A are selected and backcrossed to variety A.
- BC₄ generation – there is no powdery mildew resistance test. Plants are backcrossed to variety A.
- BC₅ generation – there is no powdery mildew resistance test. Plants are backcrossed to variety A.
- BC₅F₂ generation – plants are subjected to powdery mildew epidemic. A rigorous selection is done for powdery mildew resistance and for the characteristics of variety A. Selfed seeds from the selected plants are harvested separately.
- BC₅F₃ generation – individual plant progenies are grown and subjected to powdery mildew epidemic. A rigorous selection is done for resistance to powdery mildew and for the characteristics of variety A.

Based on the above schemes of backcrossing, some considerations should be taken while making backcrossing. While transferring a character controlled by single gene, only few (about 10) plants are necessary in each backcross to involve. But for a character controlled by two or more genes, a large number of backcross progenies (preferably 50-100) would be required. However, it should be noted that high heritability of the trait being transferred is more essential than the number of genes controlling the trait. Quantitative characters with high heritability such as seed size, plant height, flowering or maturity time are suitable for transfer through backcrossing method.

The converted materials, for dominant or recessive gene, should be evaluated under multi-location variety trials for overall performance compared to the parents and standard cultivars. The genotype of the new variety is nearly identical with the recurrent parent, except for the genes transferred. Thus, it is not necessary to test the variety developed in a series of variety trials in a conventional way to save time and expense. Putting such varieties just in the final stage of variety trials could be adequate to identify promising candidates for release.
Variety Trials

After the attainment of homogeneity, usually at F$_5$ and above, variety evaluation for important agronomic traits follows. In this stage of variety evaluation, the test materials are planted and evaluated in multi-locations (usually three or more locations) to select consistently high yielding varieties that have wide or specific adaptation in different agro-ecologies of the country. Incomplete block design, particularly simple lattice, or randomized complete block design (RCBD) are employed while conducting the multi-location variety trials depending on the number of genotypes to be tested.

The stepwise multi-location variety evaluation involves Preliminary Variety Trial (PVT), National Variety Trial (NVT) and Variety Verification Trial (VVT) for release. In the PVT, the varieties are evaluated at least at three locations each for one season using simple lattice design or randomized complete block design (RCBD) in two replications. Twenty five genotypes or may be more are included in evaluation. The materials are planted in two rows of 4 m length. In NVT, the varieties are evaluated at as representative locations as possible but in at least six environments (in at least three locations and two years) using RCBD in four replications. Ten to fifteen genotypes including the standard checks are included in the evaluation. The plot sizes used are 6.4 m$^2$ (4 x 0.8 m, 4 m long in 4 rows of 0.4 cm between rows). The whole plot of 6.4 m$^2$ is harvested for yield data recording. If a new variety is found to be superior to standard checks, it is planted in the final stage of variety trial, i.e., VVT, both on-station and on-farm in the recommendation domain and evaluated by the national variety release committee for release. The detail of variety trials is beyond the scope of this manual.
Glossary

**Adapted variety** – a variety that survived a local environment and transmit its genotype to following generation.

**Advanced generation** – commonly F₃ or F₆ at which time segregation will have virtually ceased.

**Androecium** – the aggregate of the stamens in a flower.

**Anthers** – the terminal portion of a stamen bearing pollen sacs.

**Anther dehiscence** – the release of pollen from the pollen sacs.

**Anthesis** – the process of dehiscence of the anthers; the period of pollen distribution; the time of flowering.

**Axillary raceme** – an inflorescence formed in the axils of a leaf

**Back-cross** – a cross of hybrid with one of its parents.

**Bud** – an underdeveloped plant shoot, consisting of a short stem bearing crowded, overlapping, immature leaves.

**Bulk selection** – seeds harvested in the F2 and succeeding generation are bulked and grown, with selection delayed until advanced generation, commonly F5 or F6, at which time the segregation will have virtually ceased.

**Calyx** – the sterile, outer whorl of floral parts composed of sepals.

**Double cross** – a cross between two single crosses, e.g. (AxB) x (CxD); the F1 progeny of a cross between two single crosses

**Emasculation** – the removal of anthers from a flower.

**Embryo** – an organism in early stages of development, especially before hatching from the egg when it is dependent upon its own yolk supply for nutrition.

**Embryo sac** – the female gametophyte of angiosperms; It contains several haploid nuclei formed by the division of the haploid megaspore nucleus.

**Endosperm** – triploid nutritive cells surrounding and nourishing the embryo in seed plants.

**Family** – a set of parents (father and mother) together with their children (progeny, offspring) constitutes a nuclear family.

**Filament** – a stalk of stamen bearing the anther at its tip.

**Forceps** – small pincers or tongs used by breeders when taking pollen from the anther.

**Gametes** – a haploid germ cell.

**Genetic Variability** – the phenotypic variability of a trait in a population attributed to genetic heterogeneity.

**Genotype by environment interaction** – differential performance of genotypes in different environments leading to change of ranks or even relative performance.

**Genotypes** – a hereditary unit that, in the classical sense, occupies a specific position (locus) within the genome or chromosome; a unit that has one or more specific effects upon the phenotype of the organism.

**Germplasm** – the hereditary material transmitted to offspring through the germ cells; the potential genetic stock within a species, taken collectively.
**Gynoecium** – the collective term for all the carpels of a flower.

**Heritability** – a familial phenomenon wherein biological traits appear to be transmitted from one generation to another.

**Heterosis** – the greater vigor in terms of growth, survival, and fertility of hybrids usually from crosses between highly inbred lines. Heterosis is always associated with increased heterozygosity (the condition of having one or more pairs of dissimilar alleles).

**Homozygosity** – the condition of having identical alleles at one or more loci in homologous chromosome segments.

**Hybridization** – the mating of individuals belonging to genetically disparate population or different species.

**Inflorescence** – a flower cluster with its mode of arrangement on a floral axis.

**Inoculums** – the spores or other propagules of the pathogen or parasite to which plants are exposed, and from which infection can take place.

**Intervarietal** – between varieties

**Intraspecific** – within variety

**Isolate** – a sample of a pathogen or parasite that is stored alive or maintained in isolation on plants or in nutrient media.

**Keel** – a structure of the legume type of flower made up of two petals loosely united along their edges.

**Landrace** - A diverse plant population developed in a specific geographical location by farmers themselves.

**Megasporas** – in angiosperms, one of four haploid cells formed from a megaspore mother cell during meiosis.

**Megasporocyte** – megaspore mother cell.

**Megasporogenesis** – the production of megaspores.

**Meiosis** – in most sexually reproducing organisms, the doubling of the gametic chromosome number, which accompanies syngamy, is compensated for by a halving of the resulting zygotic chromosome number at some other point during the life cycle.

**Micropyle** – a canal through the covering of the nucleus through which the pollen tube passes during fertilization.

**Microspore** – the first cell of the male gametophyte generation of seed plants. Each becomes a pollen grain.

**Microsporogenesis** – the production of microspores.

**Ovary** – the female ovule containing region of the pistil of a flower.

**Parents** – male (pollen donor) and female (pollen receiver) plants during crossing.

**Pathogen** – organism belonging to the micro-organisms that exploits the plant as source of nutrition.

**Pathosystem** – combination of host species and pathogen

**Pedigree** – ancestral history or genealogical register.

**Pedigree selection** – selection procedure in a segregating population in which progenies of selected F2 parents are selected in succeeding generation until genetic purity is reached.

**Phenotypic variation** – the total variation observed in a trait.
Pollen grain – a microspore in flowering plants that germinates to form the male gametophyte (pollen grain plus pollen tube), which contains three haploid nuclei. One of these fertilizes the ovum; a second fuses with the two polar nuclei to form the 3N endosperm, and the third (the vegetative nucleus) degenerates once double fertilization has been accomplished.

Pollination – the transfer of pollen from anther to stigma.

Population – a local (geographically defined) group of nonspecific organisms sharing a

Progeny - Offspring in any generation.

Qualitative trait – traits controlled by one or few genes with effects which is large enough to produce distinct classes for each genotype.

Quantitative trait – traits which show a complete range of values from one extreme to another without noticeable discontinuity; such traits are controlled by large number of genes (polygenes) with small and similar effects

Resistant variety – a variety that reduces or stops the growth, development and reproduction of the natural enemy after the establishment of intimate contact

Seed - Seed in this context means any grain that is produced for raising a crop. Harvested seed that has not been cleaned and graded is also called raw seed.

Segregating generations – the F2 and the subsequent generations obtained through continued selfing of a hybrid between two or more parents

Self-fertilization – the fusion of male and female gametes from the same individual.

Self-pollination – the transfer of pollen to the stigmas of the same plant.

Selfing - self-pollination without tripping

Sepals – outer most flower structure that usually enclose the other flower parts in the bud.

Severity – character of the host plant to develop relatively severe symptoms or severe damage per unit of the pathogen.

Single cross – a cross between two inbred lines, or pure-line cultivars (in self-pollinated species); the progeny of a cross between two inbred lines or pure-line cultivars.

Spore – sexual spores of plants and fungi are haploid cells produced by meiosis.

Stigma – the receptive surface usually at the apex of the style of a flower on which compatible pollen grains germinate.

Style – a slender column of tissue arising from the top of the ovary and through which the pollen tube grows.

Susceptible variety – a variety that is incapable of reducing the growth, development and reproduction of a pathogen.

Suture – the junction or line of junction of continuous parts.

Three-way crossing – the progeny of a cross between a single-cross and an inbred line or pure-line cultivar.

Tolerant variety – a variety that restrict the symptoms or the harmful effects of the pathogen by restricting the amount of infection

Transgressive segregants – progeny phenotypes outside the range of that which occurs in the parents; usually attributed to polygene segregation.

Variety – a group of plants within a species which are distinctly different for some structural features and performance from other varieties of the same species. It is also a crop strain officially released for commercial cultivation by the National Variety Release Committee (NVRC).
**Waterlogging** – characteristics for heavier textured soils (e.g. Vertisols) with poor drainage.

**Wing petals** – lateral petals of legume type of flower.

**Yield limiting factors** – factors such as water, nutrients (nitrogen, phosphorus, etc.) that limit attainable yields in crop production.

**Yield reducing factors** - factors such as weeds, pests, diseases and pollutants that reduce actual yields in crop production.
References


