Amhara Regional Agricultural Research Institute (ARARI)

Techniques of Cool Season Vegetable Crops Seed Production

A Guide for Seed producers and Development Practitioners

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1. Introduction

Cool season vegetable crops are those like carrot, beet root, head cabbage, swiss chard and others that require cool soil and air temperatures to germinate, grow and mature with maximum yield and quality. They are usually grown for their leaves or roots and respond well to nitrogen side dressings. These crops fit in multiple cropping systems and give high yield and good return per unit area compared to cereals and other crops.

Produced both under rainfed and irrigation conditions the production of cool season vegetables is growing steadily in Ethiopia. For instance, from 2001/02 to 2003/2004 (meher season) area under head cabbage, carrot, beet root and swiss chard has increased by about 227 %, 92 %, 200 % and 21 %, respectively (CSA, 2004). The rise in production of these crops is attributed to the growing demand by urban community and expansion of irrigation.

Nonetheless, the development of cool season vegetables is constrained by lack of sustainable seed supply; currently, all these crops are produced from imported seeds. Citing Ministry of Agriculture and Rural Development (MoARD), Lemma *et al* (2008) reported that in the year 2004 more than 70, 000 kilograms of carrot, beetroot, head cabbage and swiss chard seeds (70 % of the total volume of vegetables seeds) were imported from different sources. Consequently, cool season vegetables seeds are very expensive in Ethiopia, reaching up to 15 to 20 % of the total cost depending on the type of crop. Besides, vegetable growers do not have access to adequate and good quality seeds in the local markets. These situations necessitate the production of seeds of these crops in the country.

Research results indicated that seed production of these crops is possible in distinct higher elevations in Ethiopia, above 2700 m.asl. (IAR, 1986; Fentahun *et al.*, 2003; Semagn *et al.*, 2008). Nonetheless, seed production of this group of vegetables requires specific techniques or conditions like climatic and edaphic conditions, field management practices, pollination methods, seed harvesting, processing and storage about which detail knowledge is required.

Drawing from in-country pragmatic research results and experiences elsewhere this manual is prepared to provide researchers, extension experts and seed and vegetable producers information about seed production techniques of cool season vegetables under Ethiopian condition.

2. Importance of cool season vegetables as food

Vegetables especially cool season vegetables have important contributions to our diet. They enrich the diet with important minerals and vitamins, which are not found in most of cereal and other crops. They render the staple food more palatable and hence improve the intake. They are also source of roughage, which promotes digestion and prevents constipation.

Carrot, cabbage, spinach, broccoli, beet greens, leaf lettuce and Swiss chard are good sources of vitamin A which is essential for a healthy skin and other tissues. A lack of this vitamin may predispose the skin and epithelial tissues to infection by disease organisms. Vitamin A deficiency also leads to poor night vision (Williams *et al.*, 1991).

Vitamin C is also another very important vitamin which is abundantly found in cabbage, cauliflower, head lettuce, broccoli and swiss chard. Vitamin C is water soluble and hence daily intake of it is important in maintaining good nutrition. It is required for the formation and maintenance of intercellular materials in the tissues and bones; a lack of this vitamin leads to a condition known as Scurvy, characterized by the decay and bleeding of the gums, weakening of the bones and also internal hemorrhage. Overcooking vegetables can lead to almost complete loss of this important vitamin.

Vitamins E, K, B_1(thiamine), B_2 (riboflavine) and B_6 (pyridoxine) are also abundant particularly in dark green leafy vegetables. Vitamin E is required for the maintenance of the reproductive system and vitamin K in the blood clotting mechanism. Both these vitamins abound in spinach, cabbage, lettuce and so on. Deficiencies of Vitamins B_1 and B_2 are responsible for the two prevalent diseases called Beri-beri and pellagra, respectively.

(3100 m.asl) showed that seeds of such crops could be successfully produced (IAR, 1986, Fentahun *et al.*, 2003 and Semagn *et al.*, 2008). These studies further ascertained that the edible produce from domestically produced seeds were comparable in yield and quality to that of imported seeds (Semagn *et al.*, 2007, Lemma *et al.*, 2008). The seed yield produced from domestic seeds was slightly higher than that of imported seeds. In view of the above, it is possible to surmise the availability of high domestic seed production potential in Ethiopian highlands (above 2700 m.asl.) where crop diversity and farmers income is limited. Despite this potential, however, the production still depends on imported seed which is expensive.

Since domestically produced vegetable seeds have a higher germination percentage (up to 100 %), the demand of these seeds is likely to be high. This will benefit seed producers and local dealers in the country. Furthermore, in crops like swiss chard, farmers can be benefited from both the vegetable and seed crop since it is possible to harvest leaves at least once before seed stalk development. In addition, since costs associated with import and transportation will not be incurred, relatively low price is expected from domestically produced seeds over imported ones. This in turn reduces the cost of production. Consequently, the availability of these vegetable crops will increase that helps to improve the diet and health of the society.

Locally produced seed supplies would also help avoiding phytosanitory risks incurred on by importing seeds from outside source. It also reduces the expenditure on foreign currency. It might even possible to generate income by exporting excess seeds since most of the tropical countries are not in a position to produce seeds of these crops. Generally, domestic seed production can improve the economic status of farmers and other stakeholders involved in the value-chain.

Nonetheless, currently the country lacks adequate seed production capacities to meet the huge demand of these vegetables. Therefore, motivation and awareness creation is needed for producing seeds of cool season vegetables. Legislation governing all aspects of seed production and quality control is a basic requirement if the seed industry has to grow rapidly in the country.

4. Important Aspects of Seed production of cool season vegetable crops

Cool season vegetables have a clearly defined transition between the vegetative and reproductive phases. They have special requirement or stimulus to pass from the vegetative to reproductive phase which depends on several factors. The following factors determine the success of seed production of cool season vegetables.

4.1 Vernalization (Low temperature stimulus)

Cool season vegetables require cold stimulus to initiate flowers. These vegetables are biennials and flower only once following a cold stimulus. In some of these vegetable crops such as beetroot and swiss chard, germinating seeds can receive sufficient cold stimulus to promote flowering. In others such as head cabbage, plants have to achieve a certain size or stage of development before responding to low temperature. Furthermore, response of chilling increases with the increasing time of low temperature treatment and degree of cold treatment. For instance, head cabbage shows a gradation of time to flowering after vernalization in relation to the amount of cold treatment. Therefore, sowing time of these vegetables for seed production should be adjusted to ensure that the plants will respond to low temperature.

4.2 Photo period response

The requirements of cool season vegetable crops for specific photoperiods before induction of flowers also limits the success of seed production. This effect is dependent on the latitude and the length of photoperiod which greatly affects seed yield. Even when appropriate photoperiods are present, temperatures must be suitable for the completion of the entire life cycle of the crop during the growing season. Interaction of photoperiod and vernalization is also important for the success of seed production of these crops. Some of these vegetable crops require long days following vernalization before the inflorescence emerges. Beet root, for instance, requires a day length of at least

12 hours following vernalization (George, 1985).

4.3 Use of growth regulators

Growth regulators have been used to promote flowering of cool season vegetable crops by substituting or reducing the required cold stimulus of these crops. The development of this technique can be a useful aid to seed production of these crops in the tropics. So far gibberellic acid has been the most promising growth regulator and seems especially useful for these crops to bolt (Luckwill, 1981). According to Wareing and Phillips (1981) carrot and cabbage can initiate flower under non-inductive conditions in response to gibberellic acid.

4.4 Synchronization of flowering

Where the pollen donor (male) and pollen receptor (female) parts are on separate plants as in the production of hybrid seeds, it is essential that the shading of pollen and receptiveness of stigma occur simultaneously that assures successful pollination. Matching of flowering of parental lines for hybrid seed production is referred to as synchronization of flowering or nicking. This requires planting of genetically different male and female lines at different times. Synchronization of flowering between parent lines of some vegetable seed crops can some times be assured by time of sowing of the pollen parent in relation to the female as well as successive sowings to ensure a satisfactory overlap of anthesis. For most broccoli hybrid production, staggered plantings are necessary for the male and female lines to ensure proper nicking. For hybrid cauliflower, they are planted in a relay fashion where the late flowering lines are planted first followed by the earlier flowering lines.

4.5 Pollination

4.5.1 Pollination methods

Pollination, the movement of pollen from the anthers to the stigma, is essential for seed set and therefore crucial in seed production. An important consideration for any seed grower is to know whether the seed crop species that he is producing is predominately self-pollinated or cross-pollinated. Generally, self-pollinated crops are much easier to breed and maintain genetically pure than cross-pollinated crops. For cross-pollinated crops isolation distances are often critical in maintaining purity and uniformity. Selection in cross-pollinated population will be a slower process, and it is not usually possible to obtain the same degree of uniformity as in self-pollinated crops. The other very important point to be noted is that forced self-pollination in cross-pollinated crops decreases plant vigor and performance-this is known as 'in breeding depression'. However, the crossing of plants inbred for some generations produces hybrid vigor (heterosis) in the progenies, giving very superior performance in the F_1 (Williams *et al.*, 1991).

Natural pollination mechanisms of most cool season vegetables are indicated in Tables 1 and 2. Cool season vegetables such as carrot, cabbage, beetroot, swiss chard and others are mainly cross pollinated crops. The most important pollinating agents are insects (cabbage and carrot) and wind (Spinach, Beetroot and swiss chard). Some times both agents are used for pollination. Flowers which are wind pollinated are said to be anemophilous while those of insect pollinated are called entomophilous. Ants, Bees, wasps and flies are the most important pollinators of these vegetable seed crops (Table 2). The level of pollinating insect activity can be increased by providing suitable conditions for the movement of these insects. A wide range of pesticides are toxic to bees and other beneficial pollinating insects. Therefore, protection of these insects from pesticides should be ensured by using the safest recommended chemical.

There are several mechanisms in plants which encourage out crossing. Self-incompatibility (S.I) is an important one which impedes self-pollination and provides a means for cross pollination. Self-incompatibility is the inability of functional pollen to set seed after self-pollination. This ascertains heterozygosity in the population. It is some times recognized in kale, cabbage and beets (Kallo, 1988). Another mechanism which encourages out crossing is male sterility (pollen grains are sterile). This is sometimes found spontaneously in the plant population but it is mostly artificially induced through physical or chemical mutagens. Male sterility is recorded in cabbage, broccoli, brussels sprouts and cauliflower (Kallo, 1988).

Table 1. Pollination mechanisms and systems in common cool season vegetable crops

Common Name	Primary pollinating mechanism	Pollinating system	*Wild crossable Species
Beet root	wind	cross	Y
Swiss Chard	wind	cross	Y
Mustard	insect	cross	Y
Kale	insect	cross	Y
Broccoli	insect	cross	N
Brussels Sprouts	insect	cross	N
Cabbage	insect	cross	N
Cauliflower	insect	cross	N
Collards	insect	cross	N
Kale	insect	cross	N
Chinese Cabbage	insect	cross	N
Turnip	insect	cross	Y
Carrot	insect	cross	Y
Lettuce	self	self	Y
Radish	insect	cross	Y
Spinach	wind	cross	N

* 'yes' indicates the availability of wild crossable species, 'No' indicates otherwise

Source: Extension initiative (Educational partnerships of 74 Universities in USA) http://WWW.Extension.org **(Accessed on 22 January 2009)**

Table 2. The level of natural cross pollination and pollination agents in cool season vegetable crops

Common Name	*Natural cross pollination (%)*	**Pollinating vector**
Broccoli	95	Honey bees, bumble bees & blowflies
Brussels Sprouts	72	Honey bees, bumble bees & blowflies
Head Cabbage	73	Honey bees, bumble bees & blowflies
Cauliflower	40- 50	Honey bees, bumble bees & blowflies
Kale	83	Honey bees, bumble bees & blowflies
Chinese leaf Cabbage	19	Honey bees
Chinese head cabbage	85- 100	Honey bees
Carrot	97.6- 98.9	-
Lettuce	1.33- 6.22	Helictus Spp
Radish	Highly cross pollinated	Bumble & honey bees
Spinach	2.21- 56.41	Wind

Note: Isolation distance for seed production or maintaining different populations may be followed on the basis of degree of Natural cross pollination as under: 0- 10 %: 100- 150 m; 11- 25 %: 200- 300 m; 25- 50%: 300- 500 m; 50- 75 %: 500- 1000 m; 75- 100%: more than 1000 m.

Source: Kallo (1988)

4.5.2 Factors affecting pollination

Upon release of the pollen from the anthers, the environmental conditions must be suitable such that the pollen grain remains viable until it reaches the stigma of a flower of the same species. If it is too hot, the pollen may be denatured; if it is too dry, the pollen may desiccate and lose viability before reaching a receptive stigma. If it is too cool or rainy, the activity of pollinating insects can be reduced; honey bees are especially sensitive to these conditions and will not fly when it is too cool or wet. Rainy conditions can also impede the movement of pollen in wind-pollinated species as it can wet the pollen as anthers open and wash much of the pollen to the ground or make it immobile in wind pollinated species. Another condition that can impede pollination for wind-pollinated cross-pollinated species is to have little or no airflow at the time of pollen maturation and release. When wind-pollinated crops like spinach or beets are grown in the absence of normal wind and airflow during flowering, several days of unusually still air can hinder full seed set (or random mating across the population for the genetic mixing that is essential for crossers) due to low pollen flow in the air.

4.6 hybrid cultivars

Hybrids are produced by crossing two distinct parent lines which are produced as a result of inbreeding. The advantages of Hybrid cultivars include uniformity, increased vigor, earliness, higher yield and resistance to specific pests and pathogens, although all these factors are not always present in any one cultivar (George, 1985). Many vegetables which are fully or partially cross-pollinated can be improved by the production of hybrids. It should be noted that fresh hybrid seeds must be obtained each year. Saving of seed from hybrids by farmers results in a varietal mess, with production degenerating by around 25 % each time the seed is saved (Williams *et al.*, 1991). Brussels sprouts, cabbage, carrot and others have noticeably high number of Hybrid cultivars adopted by vegetable producers in the world.

In addition to the problems associated with segregation due to subsequent production, hybrid seeds cost very high compared with open-pollinated seeds due to the factors such as the development of the initial breeding programmes, subsequent maintenance of the inbred parents, extra land required for to allow for male parents, high labor input during flower emasculation, etc. However, this high cost can be compensated by the higher benefits achieved from production of hybrid seeds.

5. Seed production methods

Seed production of cool season vegetables can be achieved using two production techniques: 'seed-to-seed' and 'root-to-seed'. The 'seed-to-seed' method is done by direct sowing the seed and /or transplanting the seedlings and the plants remain *in situ* till seed maturation. Finally the seed crop is harvested the following season. This method does not permit selection or rouging of roots or other genotypic characters. However, the method is less expensive and less complex. The 'root-to-seed' method is done by planting the seed (in some cases seedlings transplanted), the plants are lifted at their appropriate stage in the first season and replanted after discarding the undesirable material and the seed harvested the following season. In some areas the materials are stored after lifting for some time before replanting (in case of carrot). Unlike the 'seed-to-seed' method, this method permits the selection or rouging of roots or other genotypic characters. This is the most expensive method of vegetable seed production due to transportation, handling and replanting costs, but the benefits of checking for minimum genetic quality standards before replanting are important.

6. General requirements of cool season vegetables seed production

Cool season vegetables are biennials and require two seasons to produce seeds. In most cases seed crop production requires different environmental and agronomic techniques to fresh market production.

6.1 Climate

6.1.1 Precipitation

Precipitation amount and distribution varies between seed crop and fresh market crop. Large amounts of early season rainfall is required for most rapid development for vegetative yield of these crops. Seed crops, in contrast, demand uniform precipitation during flowering followed by dry conditions during seed maturation to provide favorable conditions for seed harvest and to minimize pathogen infestation. Therefore, more frequent irrigation is required from planting to maturity during dry conditions.

Therefore, distinct seasons are required for seed production of cool season vegetable crops. In Ethiopia, there are two distinct seasons, main rain and dry season (with low rainfall) that makes production of seeds in the highlands possible. During dry season seed crops can be irrigated. Since the crops have shallow root system, they should not be allowed to suffer moisture stress. They require fairly frequent irrigation to ensure that the soil does not dry out less than 50 % available water. Soil moisture should not be limiting, otherwise seed yield will be drastically reduced and seed maturation time will be delayed. Therefore, during dry season seed producers should be sure that they have adequate water source like spring, river or water harvesting ditch.

6.1.2 Temperature

Temperature has very different effect on seed production and fresh market production of cool season vegetables. Adequate period of cool temperature followed by warm conditions for flowering and maturity is required for seed production. These vegetable crops must develop sufficient vegetative growth prior to cool temperature exposure in order that vernalization successfully induces flower the following season. That is why these vegetables seed production occurs in limited cool environmental areas while fresh market production of these crops is geographically more diverse.

In the highlands of Ethiopia low temperature condition (from October to January) is favorable for cool season vegetables to achieve vernalization requirement for flowering while the warm and dry condition (from February to June) is suitable for seed maturity.

Some times occasional light frost occurs in these areas during October to January and it can affect the yield and quality of seeds of these crops. This frost can be controlled by watering. Ground water is at a higher temperature than the air; consequently watering at night or in the very early hours of the morning can prevent the frost (Williams *et al.*, 1991).

6.2 Soil

The soil quality plays a part in the development of seed production. A soil site for seed production of these crops should have high water holding capacity and acidity level in an acceptable range to encourage uniform vegetative growth. A soil with high organic matter is preferred for vegetable seed production for most tropical soils. In the more porous, well drained tropical soils application of organic matter will improve both nutrient-holding ability (CEC) and moisture-holding capacity; while in the heavier soils organic matter will improve drainage and soil stability by improving the soil structure.

6.3 Agronomic practices

6.3.1 Seed testing

Seeds should be first tested for germination capacity and vigor before planting, especially for seeds which are stored a year long and may have been kept in poor conditions. Seed test indicates the true germination capacity and vigor of the seed stock and determine seed rates to achieve optimum plant populations. Seed rates can then be adjusted on the tangible facts of a properly executed and interpreted seed test. Furthermore, seed test enables us to get an indication of disease status and to give appropriate treatments before sowing. Many vegetable diseases can be picked up during a germination test, for instance, leaf spots, cankers and black rot of crucifers (Williams *et al.*, 1991).

Seed testing may not need sophisticated laboratories. Basic items for this purpose are a soil sterilizer, plenty of metal bowls and gravy tins, Petridishes, paper pads and some dissecting instruments, plus the back-up of plant pathology and entomology divisions for diseases and pests identification (Williams *et al.*, 1991). In areas where seed testing services are absent, a vegetable seed grower can test his own seed germination by placing 100 seeds on a wet medium such as cotton, news paper or wet sand. In one or two weeks, depending on species, he/she can obtain a reasonable estimate of the normal plants to be grown in his/her field.

6.3.2 Nursery management and propagation

The agronomic methods and systems used to obtain a satisfactory plant stand for seed production are generally the same as for the production of fresh vegetables. Two types of planting methods: direct sowing and raising seedlings and transplanting are used according to the vegetable crops and local conditions.

Direct sowing enables the seedlings to grow quickly as possible without interruption. However, cost incurred for land preparation, thinning and weeding is high. The seed demand for this method is relatively very high. Raising seedlings and transplanting, on the other hand, enable the seedlings to grow slowly due to interruption during transplanting. It incurs additional cost for transplanting. However, this method saves seed and demands relatively low input for weeding and other operations. Various kinds of spinach, carrots and beetroots are sown directly in lines and then thinned. Head cabbage and other brassica types are raised in nurseries and transplanted later on.

For direct planting seeds should be sown at the recommended spacing in the field and at appropriate depth. Accurate spacing of seeds will aid weeding and other operations easier later on. The depth of planting depends on the size of the seed; for larger seeds like swiss chard and beetroot a depth of about 2 cm is satisfactory, and for small seeded crops like carrot a depth of 0.5 to 1 cm is required. For most direct sown vegetables, soaking for a few hours in a shallow pan of water will advance establishment. This is because it takes much longer for seeds to imbibe sufficient water for germination in the soil. After soaking, seeds should be surface dried and sown promptly before they dry out. However, leaving seed to soak too long (more than eight hours) will reduce germination and establishment and may even kill them. To give an even distribution, very fine seeds like carrot seeds may be mixed thoroughly with sand before planting.

Watering should be light but sufficient to prevent surface drying during the establishment phase of the seedlings. Crusting occurs in many types of soil.

and should be combated by working the soil gently during seedling emergence. Mulching the surface can reduce this problem in such soils, and reduce surface water evaporation.

For those vegetable crops which demands seedling transplanting, the correct stage of transplanting varies with the density of sowing or the size of containers, and with the vigor of the seedlings. For head cabbages and other cabbage subspecies seedlings from the seed beds can be transplanted when they have reached 5 to 7 leaf stage.

6.3.3 Effect of sowing dates on flowering and seed maturity

Sowing date is one of the important factors to produce quality seeds of cool season vegetable crops. Planting these crops too early or too late causes frost kill or late season heavy rainfall and pest infestation or result in a lack of vernalization which limits flowering and final seed production. Therefore, seeds of these crops should be planted at optimum planting time to ensure optimum seed yield. Planting time differs between locations due to difference in climatic conditions. A study conducted at Ankober indicated that appropriate planting dates for high seed production are mid July for swiss chard and head cabbage, early March for carrot, and from mid May to mid July for beetroot. Beet root and swiss chard took relatively shorter days while carrot and cabbage took much longer time to flower and first seed harvest. A sowing date identified optimum may not always be appropriate for the weather variability between seasons. To avoid this risk vegetable seed producers opt not to start the seed crop by seed. Rather, planting developed portion of egetative structures like in root-to-seed method helps to ensure optimum vegetative growth for vernalization.

6.3.4 Spacing and planting densities

Row spacing and planting densities of vegetable seed crops differ from those for fresh market crops. Sufficient space is required for seed crop for flower development, air movement to reduce pathogens, unrestricted access to inflorescences by pollinators, and to ease cultural cultivation and harvest operations. Since these vegetables produce sizable seed stalks, they require plant densities much less than for fresh market production. Optimum spacing of widely grown cool vegetable crops are indicated later in this manual.

6.3.5 Fertilization

Generally the same principles of crop nutrition apply in seed production as for the fresh market crop (George, 1985). However, in view of the increased time required to produce a seed crop, the loss of nutrients due to leaching must be taken in to account by the application of appropriate top dressings in the late stages of plant development. Where possible, nutrients that stimulate reproductive development (potassium and boron) can be supplemented. Another approach to stimulate reproductive development is to split the application of fertilizers at planting (or seedling transplanting) and before flowering. This avoids luxury consumption of nutrients at the time of application, improves crop uptake efficiency and increase the formation of reproductive structures. Generally, excess nitrogen and phosphorus levels should be avoided in seed production because these nutrients encourage vegetative growth and delay flowering and seed set.

6.3.6 Crop rotation

Satisfactory intervals over time between related or similar crops is an important and standard agronomic practice widely adopted in the world to maintain soil physical and chemical properties and to minimize the risk of soil-borne pests, diseases and weeds common to individual crop or crop groups. In addition, crop rotation is used to minimize the risk of cross-pollination or admixtures and in turn increase the quality of seeds to be produced.

6.3.7 Use of Shelter and wind breaks

Local gradations of climate are resulted from differences in altitude, topography and presence of natural shelter belts. Further improvement in a seed crop's micro climate can be provided by wind breaks. Wind breaks are beneficial to the crop to reduce water loss caused by transpiration and evaporation from the soil. In addition, this microclimate will enhance flower development, increase insect activity to pollen transfer and decrease mechanical damage to flowers and seed stalks.

Solid barriers such as walls should not be used as wind breaks because they cause turbulence which can damage the plants. Wind breaks which offer approximately 50 % obstruction provide a relatively extensive shelter with a minimum of wind gusts. A permeable wind break can decrease the wind speed in a horizontal direction for a distance equivalent to up to thirty times its height (George, 1985). Use of wind breaks is advisable for better production of seeds of these crops in highlands of Ethiopia where wind stress is a major problem.

6.3.8 Lodging

Lodging is used to describe the falling of the crop before harvesting. It is one of the factors that reduce seed yield and quality of these crops. Extra weight of inflorescences or seed stalks enhance vulnerability for lodging of seed crops (See fig 1). Several cultural and environmental factors contribute to the incidence of lodging; these include wind, high nitrogen regimes during earlier plant development and heavy rain. Adopting a wide use of wind breaks to prevent wind speed and application of optimum nitrogen may help to reduce lodging. Supporting the flowering plants with stake is also important to avoid lodging.

Fig. 1. Lodging of Swiss chard plants before seed set at Ankober

7. Diseases and insect pests control

The management of pests in vegetable seed production poses additional problems due to their longer growing season not encountered in fresh market production. Since seed crops remain more than a season pests of other vegetables or the same vegetable for fresh market will migrate to the seed crop. These pests feed on developing seed embryos and subsequently reduce seed yield and quality.

Damages by diseases and insect pests of these vegetables can be minimized by separating the seed crop from pests. Physical separation occurs by producing the seed crop in an isolated region from fresh market production or from disease causing organism. Weeds that serve as alternate hosts to insect vectors should be controlled timely and frequent rouging of diseased suspected plants has to be practiced. Use of disease-free seeds can also aid to avoid the diseases. Hot water and chemical treatments are widely used to control diseases of vegetable crops; nowaday's Thiram suspension is widely used for the treatment of seeds of these crops.

8. Seed harvesting

Cool season vegetable crops require long periods of fruit ripening and seed maturation. Harvesting seeds of these crops needs great care since there is a strong tendency for earlier maturing seeds to drop before later ones have developed. This loss of seeds before harvesting is known as shattering. Other sources of seed loss before harvesting include birds, small rodents and inclement weather. For instance, there have been several instances of head cabbage seed production experimental failure at Lai Gaint due to bird damage (Fentahun Pers. Com.). Therefore, measures that reduce the damage by birds and rodents should be practiced. Netting is successful for small areas of basic seed production to prevent the damage caused by birds.

8.1 Stage of Seed harvesting

Harvesting stage determines the quality of seeds of cool season vegetable crops. Ripening of seeds is accelerated by relatively high temperatures, a low soil moisture level and a low relative humidity. Conversely, the rate is reduced by the reciprocal of these factors. The ripening process is interrupted if the seeds are harvested too early, and seed quality may be adversely affected. Generally the latter the harvest, the higher the seed yield; losses increase as harvesting is delayed once the optimum percentage of seeds reach maturity. Thus, the ideal harvest time is immediately before the loss of mature seeds exceeds the amount of seeds yet to reach maturity. Stage of harvesting of individual vegetable crops such as carrot, cabbage, beetroot and Swiss chard are indicated later in this manual.

8.2 Methods of harvesting

The potential for loss of seed yield due to seed shattering when harvesting occurs after physiological maturity needs great concern for cool season vegetables seed production. To minimize seed loss, two approaches are employed. Since most of these vegetables achieve physiological maturity before harvest maturity, the seed stalk is cut while the plant is still green and placed in rows where the wind further dries the plant and its reproductive structure. This permits more uniform maturation and seed quality is enhanced compared to the more costly option of sequential harvest of mature fruits. This method is widely adopted by some farmers who produce onion seed around Shewa Robit, north Shewa. Later, after the seeds have reached harvest maturity, they are extracted from the seed stalks by hand. The second approach is to visually monitor the development of the fruits and sequential harvest of the seed before shattering occurs. This approach, however, takes more labor and incurs relatively higher cost.

9. Seed Cleaning

Proper post-harvest processing is critical to maximize yield, longevity, vigor, and overall quality of the seed crop. While production of vegetable seeds is similar in many respects to fresh market crop production, post-harvest practices require special skills and knowledge unique to seed production. Seed processing is used by seed industry to include a wide range of operations to improve seed lots after threshing of seeds. The objectives of seed processing include removal of a wide range of materials including plant and non-plant debris, seeds of other crops and weeds or unacceptable seeds of the same origin. These materials can be separated from the pure seeds based on physical differences such as relative size, shape, length, density, surface texture, color, affinity to liquids. Seed cleaning based on relative size and density are indicated below.

Separation based on weight (or specific gravity)

Cleaning seeds by differences in specific gravity is one of the oldest seed cleaning techniques. When done by hand in the wind it is commonly referred to as winnowing. On the simplest scale, seed and materials are dropped before a wind source (either natural wind or a fan). The heavier materials fall closer to the wind source while lighter materials are carried further from the wind source. On a small-to-medium scale this is a very effective method to quickly clean seed. Many screen cleaners have a fan to assist in blowing off some dust and chaff.

Separation based on size

Screens with various hole sizes are commonly used to separate seeds based on size either by hand or by machine. Screens are used to either permit the crop seed to pass through the screen (collect and discard material larger than the seed that does not pass through), or to retain the crop seed on top of the screen and permit smaller-sized materials to pass through and be discarded. Hand-held screens are very useful for small to medium scale seed cleaning.

10. Seed drying

It is necessary to dry seeds before or after seed cleaning and before storage and packing since seed drying enhances seeds to have longer storage life and prevents occurrence of diseases and pests. The rate at which a seed lot can be dried depends on the packing character of crops and the initial moisture content of the seed. Lettuce is generally considered to be relatively quick drier; carrot, beetroot and swiss chard medium driers; but cabbage is slow drier (George, 1985). Artificial driers can be used to dry seeds (fig 2a and b). For instance, this drying system is adopted by Tera farm (a private fruit and vegetable grower) around Debre Birhan to dry vegetable and spice seeds. Seeds are placed in trays at the back side of the drier and dried by blowing hot air current from the front. Since the front part of the drier is covered with black plastic film, hot air is produced in this part of the drier. This hot air passes through the drier and circulates within seeds, removing the moisture to the outside.

Figure 2a. Seed drying structure, rear view

Figure 2b. Seed drying structure , front view

11. Seed Storage

When seed processing is completed it is necessary to keep the seed under the best possible conditions to ensure that the maximum potential germination and other seed quality factors are maintained. The storage life of seeds is dependent on natural longevity of seeds which varies between crop types, storage temperature and relative humidity, exposure to light, moisture content of seeds and pre-harvest mechanical damages on the seeds.

Temperature and relative humidity are the two most important factors that can affect seed quality in seed storage. The reduction of seed viability is slower at lower temperature. As a 'rule of thumb', for every rise of 5 ^{O}C in the range of 0 to 40 ^{O}C, seed life is reduced by half, though there is a great variation between species (Williams *et al.*, 1991). Thus, to store vegetable seeds for longer period of time low temperature storage should be taken in to account.

Relative humidity is also another main factor which affects the storage life of vegetable seeds. Seeds will absorb moisture from the storage environment. High humidity levels cause seeds to increase their respiration rate and use their storage energy. Furthermore, the incidence of storage fungi and insect pests will be increased with the increase in relative humidity. Thus, the seeds should be dried (seed moisture content around 5- 8 %) depending on type of crops (Table 3) before storage and they need to be stored in air tight containers as indicated in fig 3. Life expectancies of seeds of some vegetables under favorable conditions are given in Table 4. It is also possible to keep the seeds longer than this, but germination capacity will be progressively lowered.

Exposure to sun light and mechanical damage on seeds are also important factors which contribute to shorten the storage life of vegetable seeds. Dark-color jars or non-transparent containers are required to protect the seeds from sun light. Mechanical damage on seeds during different operations can reduce the potential storage life because the damaged seeds lose vigor sooner. In addition, damaged seeds are vulnerable to storage pests and pathogens. Thus, care should be exercised to avoid seed damage during seed cleaning.

Storage containers

Sealed and moisture proof containers are used to store a relatively small lots (up to 1 kg) of vegetable seeds. Seeds of cool season vegetables are imported from European countries with such storage containers.

Table 3. *Satisfactory moisture level of seeds to be stored in vapor proof containers

Vegetable types	Maximum seed moisture (%)
Cabbage & other Brassicas	5
Carrot, celery, parsnip, parsley	7
Beetroot and Swiss chard	7.5
Spinach	8
Lettuce	5.5

*Source: George, 1985

Table 4. *Life expectancy of vegetable seeds under favorable storage conditions

Vegetable types	Years
Beetroot, Cabbage, Cauliflower, Swiss chard	4
Carrot, Celery, Chinese cabbage, Kohl rabi	3
Lettuce	6
Radish	5

*Source: Williams *et al.*, 1991

The seed lots are dried to a moisture level slightly lower than they would be prior to normal open storage, and are then sealed in metal cans, packets or other suitable moisture-proof containers (Table 3). With these containers the seed lots can be stored for one or more years at ambient temperature and relative humidity. See the type of containers in fig 3.

Fig. 3. Seeds stored in air-tight containers to prevent them from absorbing moisture from outside environment

Source: Sukprakarn *et al.* (2005)

12. Carrot Seed Production

The carrot, *Daucus carota*, var. sativa, belongs to the family Umbelliferae. It is a close relative to a wild species, commonly known as Queen Annes's lace (see fig 4). Carrot is a widely cultivated vegetable both under irrigation and rainfed condition in Ethiopia. Though it is a biennial, carrot is grown as annual for fresh market production. The roots are either eaten raw or may be cooked. In India the leaves are also eaten (Tindall, 1983). Carrot root contains *B*-carotenes, orange coloring matter of the root, a prolific source of vitamin A.

Fig. 4. Queen Anne's lace, wild carrot

12.1 Climate and soil requirements

Carrot seed production requires more than a year. Roots are formed during the first season and then require a cold period to stimulate flowering and seed production. Carrot is a cool weather crop and is tolerant to cold and frost. During cool months the plant develops more slowly than during the warmer months. However, high soil temperatures tend to encourage the production of short roots. Carrots grow best in a deep, well-drained sandy loam or slightly acid loam soil. In heavy humus-rich soils carrots tend to have too much growth in the leaves and to form forked roots. The soil should be well drained and have a pH of 5.7 to 7. If manure is used, it should be applied several weeks in advance since fresh manure or commercial fertilizer placed to near the roots will cause deformed or forked roots.

12.2 Cultural requirements

12.2.1 Planting

Carrot seed is sown directly on well-prepared, even and fine soil at a depth of 1 cm. The seeds are sown in drills 30- 40 cm apart and seedlings later thinned when 5- 8 cm high to 5- 10 cm apart. To encourage seed germination, mulching of the seed beds is often recommended. Flood irrigation before emergence of the seed could cause the soil to crust and this could lead to a poor stand. A system of crop rotation is important to eliminate problems with diseases. Carrots fit very well in a crop rotation system where plants like cabbage, cauliflower, lettuce and tomatoes are grown. A general recommendation is that carrots should not be planted in the same soil more than once every 3 to 4 years. About 4 kg of seed is required to cover one hectare of land. Carrots are preferably sown in rows instead of broadcasting the seeds, because it makes weed control easier.

12.2.2 Time of Sowing and spacing

Sowing of carrot seed is timed so that the cultivar receives sufficient vernalization (if required) and also to allow for the plants to flower and to give seed in suitable weather conditions. The seed yield and quality depends on the growing seasons and specific locations. Planting date studies were conducted in the highlands of Ankober (North Shewa) and Lai Gaint (South Gondar). The results indicated that carrot sown in March and September gave the highest and good quality seed yield at Ankober and Lai Gaint, respectively (Semagn *et al.*, 2008 and Fentahun *et al.*, 2003).

Since plants for seed crop produce sizable seed stalks, carrot requires plant densities much less than for fresh market production. Research results on plant spacing for seed crop are not available in Ethiopian condition. But, research results elsewhere in cool areas of the tropics and sub-tropics indicated that after seed stalk appears, superior plants are thinned up to 75 cm apart (Sukprakarn *et al.*, 2005).

12.2.3 Fertilization

Research results on fertilizer requirement of carrot for seed production is no yet available in Ethiopia. However, 175 kg/ha of DAP fertilizer, which is recommended for fresh market production (ARARI, 2005), is adopted for seed production too.

12.3 Carrot varieties

The Nantes strains are the best from the stand point of quality. Chantenay and Danvers half-long strains yield heavily but the roots are not of the best quality. Shin Kuroda and Nantes improved are also better varieties for fresh market production in the highlands. However, seed production experiences available in Ethiopia are on Nantes and Chantenay varieties which are suitable for seed production in Ethiopian cool highlands (Lemma *et al.*, 1994 and Semagn *et al.*, 2008).

Fig. 5 (top). Nantes Carrot variety 3 months after sowing
Fig. 6 (bottom). Shin Kuroda carrot variety 3 months after sowing

12.4 Method of seed production

Production of carrot seeds is a two year project making it much more difficult than seed production of annual crops. Two types of seed production methods are available, i.e. seed-to-seed and root-to-seed methods.

Seed-to-seed method

This method is practiced in areas where distinct cool season (for vernalization) and warm condition (for flower and seed development) is available. Seeds are directly sown in seed beds of the permanent field of the same area where seed is produced. Early in the growing season plants should be thinned 10 cm apart. At usual harvest time for fresh market use, superior plants are thinned up to 75 cm apart. If the length of chilling period is long (above 10 weeks), dead or drying leaves must be removed and tops can be cut back at the usual harvest time of 5 cm to reduce transpiration and covered with mulch if necessary. When warm weather resumes, mulch is removed and leaves will re-grow and after several weeks a seed stalk will appear. Losses are very high with this method and off types can not be eliminated since roots are not harvested and visually examined.

The root-to- seed method

In this method sound roots must first be produced. Then these roots are harvested and off types discarded. The tops are trimmed back to 2- 4 cm, air dry until no surface moisture remains, and packed in paper bags with an equal volume of wood shaving (Sagatura) and placed in closed polyethylene bags at 2- 5 ^{O}C. Better storage survival is realized if lateral and fibrous roots and senescing leaves are removed before storage. Vernalized roots should be planted during appropriate planting time. Care should be exercised to keep plants well watered. Seed stalk development will be evident in 4 – 6 weeks.

12.5 Conditions that stimulate flowering in carrot

Carrot roots require 6 - 8 weeks cold treatment (2- 5 ^{O}C) in root-to-seed method of seed production for floral induction. Cool growing conditions can reduce the cold storage requirement of carrot roots. At least 10 weeks of average temperature below 15 ^{O}C is required to stimulate flowering in seed-to-seed method of carrot seed production. The response to cold stimulus is not necessarily related to root size (George, 1985). Very low temperature is a common experience from October to January in cool highlands of Ethiopia. This low temperature stimulus creates favorable condition to the crops to flower and seed set. The warmer air temperature starting from February to Mid of September also favors seed maturity. Therefore, carrots seeds should be sown at the right time so that plants receive adequate vernalization. The appropriate sowing dates for high and good quality seed yield in different parts of Ethiopia are indicated in section 6.3.3.

12.6 Pollination and isolation distance

Individual carrot flowers are normally protandrous and much cross pollination occurs between plants in a seed crop (Table 2). However, because of the extended flowering period resulting from several successive umbels per plant and the succession of flowers on individual umbels, the possibility of self pollination always remains (fig. 7). Cultivated carrots cross-pollinate very readily with the wild carrot (Queen Anne's Lace). Precaution is, therefore, required to avoid out-crossing with wild carrot.

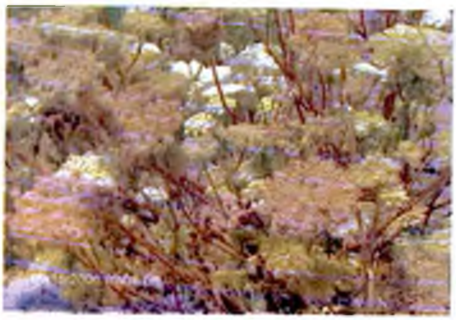

Fig. 7 Carrot plants, at flowering, seed setting and seed maturity stages from the same sowing date

Because of the high chance of cross-pollination, isolation distances between different varieties of carrot should be a minimum of 800 m. For basic seed production the isolation distance should be greater, about 1600 m (George, 1985).

Fig. 8 Carrot, cluster of mature seeds
Source: Sukprakarn *et al.* (2005)

12.7 Harvesting, seed processing and seed yield

The king or top-most umbel is the first to ripen. The seed will turn from a dark green to brown and will actually begin to detach from the umbel, but because of the racemes, or little hooks that cover the seed, they latch together and stay with the umbel surface (See cluster of mature seeds in fig 8). Smaller umbels further down on the plant will ripen a few days later, but waiting until all of the lower umbels are ripe is seldom economically viable as this seed tends to be of lower quality and strong winds may begin to lodge the king umbels, which generally contains the best seed. Research results showed that early harvesting of carrot seeds before the seed is physiologically ripe results in lower seed quality. Because the embryo forms last, early harvested seed is generally of poor germination. Therefore, carrot seeds should be harvested at the right time before the seed shatters. At this time, the umbels should be cut and placed into paper bags and stored in a cool, dry place for additional 2-3 weeks to allow the seeds to mature and dry completely. Then spines will be removed by rubbing. Winnowing will be followed to clean the seeds. Seed is now ready to plant since carrot has no seed dormancy. Dry seeds should be stored in a moisture-proof container as indicated in fig. 3..

Seed yield of carrot depends on varieties and locations. A good average seed crop can yield about 600 to 800 kg/ha seed (George, 1985). Research results conducted in different areas of Ethiopia indicated that good quality seed could be harvested on Nantes and Chantenay varieties. Carrot gave about 1000, 1070 and 586.20 kg/ha at Meraro, Lai Gaint and Ankober, respectively (Lemma *et al.*, 1994, Fentahun *et al.*, 2003 and Semagn *et al.*, 2008).

13. Head Cabbage Seed production

Head cabbage, *Brassica oleracea,* var. capitata, belongs to the family cruciferae. It has related types such as Brussels sprouts, broccoli, cauliflower, kale, kohlrabi and Chinese cabbage. The head cabbage (common cabbage) has a dense head of leaves, a short stem and additional edible leaves. The shapes of the heads, depending on the type of cabbages, are oblong, oval or nearly circular. In wide spread use as a cooked vegetable, it is sometimes pickled (red cabbage) or preserved by steaming or drying (Tindall, 1983). The nutritional value of head cabbage is relatively high in vitamin C and A. It is one of the important vegetables in Ethiopia.

13.1 Climate and soil

Cabbage prefers cool climate, and temperature is the most important factor for seed production. Cabbage is a biennial crop when it is grown for seed. It grows best in soils that are well drained sandy loam to clay loam and a pH of 6- 7. High nitrogen levels result in 'soft' plants less able to withstand frost.

13.2 Cultural requirements

The planting time of cabbage is critical. The crop should be sown such that the plants face the coldest temperature at time of head formation or head maturity. Research conducted at Ankober indicated that cabbage sown in Early September and Mid July flowered and matured earlier (Table 5). However, the highest and quality seed was obtained from mid July sowing (580.01 kg/ha) followed by mid May sowing (385.22 kg/ha) (Table 6). Head cabbage sown in these dates started flowering in the next March and February, respectively while harvesting was started in August for both planting dates. Nevertheless, this time was not favorable for seed harvesting because of the prevalence of heavy rainfall. This happened because growth rate of plants is slow in this area even during relatively warmer months, February to June. Thus, care should be taken when cabbage seeds are harvested during rainy season to maintain the seed quality. Use of head-to-seed method is also another option to obtain high yield and good quality cabbage seeds. Head-to-seed method is further discussed in section 13.4.

Seeds of cabbage are sown normally in seed beds at a seed rate of 400 gm per hectare. Young plants from the seed beds are planted out when they have reached 5 to 7 leaves stages. Plants with obvious off types and any showing signs of serious pathogens are discarded at this stage. The final spacing depends on the vigor of the cultivar. Though there is no research results concerning plant spacing for seed crop, 40- 60 cm between rows and 40- 50 cm between plants in the row is widely adopted in other part of the world for cabbage seed production (George, 1985). As that of carrot, research results are lacking on fertilizer requirement of cabbage for seed production. However, 150- 200 kg/ha of DAP and 50–100 kg/ha Urea, which is recommended for fresh market production (ARARI, 2005) is adopted for seed production too. Half of the nitrogen should be applied when plants show signs of head formation since the extensive leaf production requires a relatively high soil nitrogen reserve. Twenty five ton well decomposed farm yard manure or compost can alternatively be applied for cabbage seed production.

Special techniques may be used to facilitate the emergence of cabbage seed stalks which are hindered by the mechanical barrier of the tightly folded leaves which encase it. For example, when the heads mature, the selected heads are removed just below the base by a sharp knife. After a certain period of dormancy the buds start to sprout. Another option is making a X-cross cut of heads downwards carefully not to damage the growing point of the inner core.

13.3 Cabbage Varieties

So many hybrid and open pollinated cabbage varieties are grown in the world; out of which Copenhagen Market (open pollinated variety) is popular in Ethiopia. Research results proved that this variety performs best in Ethiopian condition for fresh market production (IAR, 1986). Seed production studies also indicated that this variety could give optimum yield in cool highlands of the country (Semagn *et al.*, 2008).

Copenhagen is a good early maturing variety that produces uniform, globe-shaped heads that are firm and solid. The plant is compact and short-stemmed and the heads are a lovely light green. Copenhagen has good wrapping leaves and can stand for a long while without splitting. It is very productive and is an excellent early season cabbage for the home garden (See fig 9).

Fig. 9 Cabbage, Copenhagen market variety

13.4 Seed production methods

Cabbage seeds can be produced in two methods, i.e. seed-to-seed and head-to-seed. It is possible to exploit both methods under Ethiopian condition.

Seed-to-seed method

This method is used for areas where distinct cool season (for vernalization) and warm condition (for flower and seed development) is available. Seeds are sown in seed beds and the seedlings are transplanted to the permanent field of the same area where seed is produced. After the cabbage reaches maturity for fresh market use, mature heads should be incised. This method is usually practiced in temperate areas and very high altitude areas in the tropics or sub-tropics.

Head-to-seed method

This method is used for areas where there is no suitable condition for flower and seed development. Seeds are sown and seedlings are transplanted as that of the first method. Mature heads are harvested and the stems are left in the field. After satisfactory exposure to low temperature for vernalization, the remaining plants are then transplanted to warm conditions of the mid altitude areas to accelerate flowering and seed maturity. The method of transferring plants to favorable environmental conditions to adjust the development of the first and second phases, with its resulting smooth vernalization and flowering, appears ideal for cabbage seed production in the tropics and subtropics (Sheen, 1982). The problem of cabbage seed production in Ethiopian highlands is that despite availability of sufficient low temperature in the first phase, sufficient condition is lacking in the second phase due to presence of rain fall and insufficient warm temperature for flowering and seed setting. Rainy conditions interfere pollination and cause self-rot and sclerotia rot resulting in poor seed quality. Thus, identifying the right sowing and transplanting dates is very crucial to the success of seed production in Ethiopia.

13.5 Conditions that favor Flowering and maturity in cabbage

Flower initiation in cabbage is dependent on low temperature stimulus. A temperature of 4.5 - 10 ^{O}C for nearly 60 days vernalization is required for flower initiation (Singh *et al.* 1959). Insufficient vernalization, however, induce only incomplete flowering, and thus seed yields are much lower than those obtained in temperate regions.

Chilling requirement varies between the different types and between cultivars. The plants age and leaf number are also important in its receptiveness to low temperature (George, 1985). Perfect vernalization not only accelerates bolting and flowering but also promotes complete seed setting.

Seed production of cabbage in the tropics and subtropics is difficult because of insufficient winter chilling to promote flower development. However, at high elevations in Ethiopia, the temperature prevailing from October to January is sufficient to attain complete flowering, though the cabbage grows much slower and, therefore, flowers towards the rainy season. After vernalization, cabbage require warm temperatures for bolting and flowering (Bowswell, 1929). So, there is a need to identify appropriate sowing dates that induce plants to flowering and seed maturation. Otherwise, one has to use different altitudes corresponding to the phasic requirements of cabbage for seed production (Head-to-seed method) as indicated in section 13.4.

There are also some chemicals that are used for flower initiation. Work in Kenya indicated that the incidence of flowering of some cabbage cultivars at an altitude of 1941m was increased by application of Gibberlic acid (GA_3) for one to two months after planting out (Kahangi and Waihaka, 1981).

13.6 Pollination, isolation distance and selection

Cabbage is predominantly cross-pollinated. Bees and diptera pollinate cabbage flowers (See fig 10). Cabbage can cross-pollinate easily with other Brassicas (broccoli, brussels sprouts, kohlrabi, collards, cualiflower and kale). Therefore, sufficient isolation distance should be maintained for seed production. It is important to have greater isolation distance upto 1500 m between different types of Brassicas than between different cultivars of the same type (up to 1000 m) (George, 1985). In addition to isolation, rouging should be done to keep trueness to type of the cultivars of cabbage and to produce healthy and vigorous seed. Rouging is done during planting out or before heading by checking for general foliage characteristics. Rouging also done when heads have formed in the crop by checking head characters including shape, relative size and firmness.

Fig. 10 A honeybee foraging cabbage flower

Source: Sukprakarn *et al.* (2005)

13.7 Diseases, Insect pests and birds

Black rot caused by *Xanthomonas campestris*, powdery mildew and downy mildew are important diseases recorded under Ethiopian condition (Temam, 2008, Beneberu *et al.*, 2008). According to Temam (2008) black rot is widely distributed disease of cabbage in Eastern Ethiopia. It can be controlled by crop rotation, good hygiene and use of clean seed. Hot water treatment of seeds (50^{O}c for an hour) can also be used to control the disease. Mercury seed dressing will eliminate the disease (Williams *et al.*, 1991)

From insect pests aphids, diamond back moth and chafer grub are considered as important pests of cabbage in Ethiopia (Adane *et al.*, 2008). Aphids feed in colonies on the foliage, on heads or in buds resulting in plant decline. In case of heavy attack plants get devitalized, leaves and shoots curl up and become yellow and finally die. Cloudy weather with high humidity is favorable for its multiplication. Aphids can be controlled with 0.03 % spray of Dimecron in the vegetative phase and 0.2 % spray of Thiodan or Sumithion at the flowering stage. Diamond back moth (*Plutella xylostella*) can be controlled by several insecticides and Bacillus thuringiensis, a biological agent (Williams *et al.*, 1991). Bird damage is severe during seed maturity especially in locations where trees are prevalent for birds shed. Measures, therefore, should be taken to protect bird damage. Netting of the seed crop is very successful, in this case.

13.8 Harvesting, processing and Seed yield

It is necessary to harvest fully mature seed pods, as they will not mature any further after harvest. Since cabbage seeds shatters easily, harvesting is done carefully when 60- 70 % of the pods have turned brown and most of their inner seeds are light brown and firm (Sukprakarn *et al.*, 2005). Harvested seed stalks are cured for 1-2 weeks. Pods are then threshed with sticks and sifted by hand. The smaller chaff can be separated simply by general winnowing. Seed is brittle and care should be taken not to crush during handling. Seed is dried in partial sun, and then stored in air tight container.

Seed yield of cabbage depends on growing conditions and varieties. A good average seed crop can yield about 700 kg/ha seed else where in the world (George, 1985). About 580 kg/ha seed was recorded at Ankober, north Shewa, Ethiopia, during July sowing (Semagn *et al.*, 2008).

14. Beetroot Seed production

Beetroot, *Beta vulgaris* susp. esculenta, belongs to the family Chenopodaceae. It is closely related with other beets (Swiss chard, sugar beet and fodder beet). Beetroot plants are great space savers occupying small amounts of space. The ball is usually round and small with thin red-brown skin and notably sweet flavor. It is usually cooked, steamed or boiled whole with some of the greens left intact. Even when sliced after cooking it has a tendency to stain other ingredients, an effect which is sought for soups and salads. The leaves, in addition to the roots, are often used as a cooked vegetable; they are rich in vitamins A and B.

14.1 Climate and soil

Béetroot prefers cool weather but is widely adaptable. It is grown as annual for its swollen root tubers and biennial as seed crop. Seeds can be produced in cooler regions of Ethiopia. Beetroot gave reasonable seed yield at Meraro (Arsi highlands), Lai Gaint (South Gondar highlands) and Ankober (North Shewa higlands) (Lemma *et al.*, 1994, Fentahun *et al.*, 2003 and Semagn *et al.*, 2008). The crop thrives well on most soils except clay but it prefers rich friable loam soil. Beetroot is slightly tolerant to acid conditions and can be grown in soils with a pH between 6 and 7.

14.2 Cultural techniques

Beetroot seeds are clustered together with each cork-like fruit containing 2-3 potential offspring. The seeds require plenty of moisture to germinate. Soaking seeds in warm water for 2 or 3 hours prior to planting speeds up germination. Seeds may be sown directly into prepared beds to a depth of 1-2 cm or into seed trays for later transplanting as seedling. Seeds should be well firmed to ensure good contact with soil. Poor stands are often a result of planting too deeply or the soil's crusting after a heavy rain. The seedlings may emerge over a relatively long period of time, making a stand of different sizes and ages of seedlings. Frequent shallow cultivation is important because beetroots compete poorly with weeds, especially when small. Because beets have extremely shallow roots, hand weeding and early, frequent and shallow cultivation are the most effective methods of controlling weeds in the rows. Deep cultivation damages the beet roots. Frequent and adequate irrigation should be given to the crop during off season to produce good quality seed with early seed maturation.

Planting dates recommended for fresh ball production purpose may not be suitable for seed production in beetroot (Muhammad *et al.*, 2003). Like Carrot and cabbage, planting of beetroot is adjusted in such a way that the cultivar receives sufficient vernalization so that the plants flower and give seed in suitable weather conditions. Sowing dates for seed production seems to differ by location. Fore instance, at Ankober and Lai Gaint highlands beetroot gave the highest and good quality seed when sown from mid May to mid July and October, respectively (Semagn *et al.*, 2008 and Fentahun *et al.*, 2003).

Although research evidence is lacking on the optimal plant spacing for seed crop, 30- 40 cm between rows and 15-20 cm between plants in the row is adopted in Ethiopia for beetroot seed production. As that of carrot and cabbage, research recommendations on fertilizer requirement of beetroot for seed production is no yet available. However, 175 kg/ha of DAP fertilizer which is recommended for fresh market production (ARARI, 2005) is adopted for seed production too.

14.3 Beetroot Varieties

There are so many varieties grown world wide for fresh market production. Detroit Dark Red is said to be the most popular garden variety today. It is globe shaped, sweet, smooth and tender, and has excellent color. In Ethiopian condition, this variety is widely known. Detroit Dark Red and Crimson Globe varieties are suitable for seed production in Ethiopian cool highlands.

14.4 Seed production methods

There are two basic methods of seed production; 'seed to seed' and root to seed'. The 'seed to seed' method is normally used only for the final stage of seed multiplication while the 'root to seed' method is used for the production of basic seed. This latter technique allows for inspection and rouging of roots.

Seed to seed method

This method is used in areas where there is no severe frost. It can be widely practiced in Ethiopia. Seeds are sown in a four row bed of 80- 120 cm width and 30- 40 cm between rows. Seeds are normally drilled directly into the soil and thinned later. Thinned seedlings may be used for transplanting to fill any gaps. Another option of this method is transplanting stecklings (seedlings). Unlike other root crops, grownup beetroot seedlings transplant reasonably well provided that they are not too large and are kept moist during transplanting. The stecklings are transplanted after achieving an optimum size of 2.5- 2.75 cm. The planting distance of stecklings is 30- 40 cm between rows and 15- 20 cm between plants in the row.

Root to seed method

This method is widely used for areas that have severe frost. Seeds are sown in a similar manner to seed-to-seed method. Then the roots are lifted before frost damage, selected for desired root characters and stored in door at 4- 5 ^{o}C or in the field. These roots are planted again as early as local conditions allow, in rows 30- 40 cm apart and 20 cm in the row.

14.5 Conditions that favor flowering

Beetroot and other related beets are long-day biennials with a cold requirement for flower initiation. Exposure of the ripening seeds of these vegetables to low temperature can reduce the subsequent low temperature requirement (George, 1985). This early vernalization sometimes contributes to the incidence of bolting in the first year.

14.6 Pollination, isolation distance and selection

Flowers of beetroot are perfect and borne in groups of 2-3 in axes of leaves. Flowers produce pollen that is carried long distance by wind; thus it is predominantly wind pollinated although some level of insect pollination by Diptera occurs.

Since pollen of beetroot is wind-borne over relatively long distances, sufficient isolation distance should be ensured. Hence, isolation distance of 500 -1000 m is needed when different varieties of beetroot are grown. Beetroot is cross-compatible with other subspecies of *Beta vulgaris* (i.e sugar beet, mangolds, spinach beet and swiss chard). Therefore, adequate isolation distance (more than 1 km) should be maintained (George, 1985). Rouging should also be done to keep trueness to type of the cultivars of beetroot and to produce healthy and vigorous seed. Rouging out off-types can be practiced based on the shape and color of leaves and roots. Plants that bolt and go to seed early should be removed.

Fig. 11 Seed stalks of beet root
Source: Sukprakarn *et al.* (2005)

14.7 Diseases of beetroot

Powdery mildew, caused by *erysiphe betae, and* rust, caused by *Uromyces betae*, are important diseases of beetroot and swiss chard in Ethiopia. Powdery mildew is a seed borne disease. It can be effectively managed by dusting sulphur or spraying wettable sulphur, benomyl, carbendazim, thiabendazole lactate and others (Thind, 2001).

14.8 Harvesting and processing

Seeds of beetroot do not ripen uniformly on the plant and shatters easily when mature. Seeds ripen successively from the base of the side shoots to the terminal point. Beetroot seed reaching full maturity at time of harvest will usually not exceed 75 % of the total seed crop. Care should be taken to determine the optimum time for cutting. This is because the immature seeds shrivel if cut too early or if cut too late seeds are lost due to shattering. Cutting of seed stalks commence when most flowering clusters and stalks have turned yellow and dried, the first seeds shed at this time. The stalks should be stored in a cool dry condition for 2-3 weeks to encourage further seed ripening. Seed stalks should not be heaped on top of one another since this causes seeds to ferment and reduce the quality of seeds. To thresh the seeds, seed stalks can be put into a bag and beat with a stick. Chaff is winnowed away.

14.9 Seed yield and seed dormancy

In most areas of the world a satisfactory yield of beetroot seed is approximately 10 quintal, although up to twice of this figure was recorded in USA (George 1985). Seed yield appears to differ from one environment to the other. At Ankober (3100 m.asl) a seed yield of up to 18 quintals was recorded in July sowing (Table 6), while at Lai Gaint, about 11.7 quintal beetroot seed was recorded (Fentahun *et al.*, 2003).

Seed germination can be erratic and dormancy can make seed testing difficult. The seed is contained within a fruit structure and this is where the problem lies. Germination inhibitors are present within the structure, and the tight ovary cap acts as a physical barrier for germination (Heydecker, et al., 1971). Therefore, to enhance germination of beetroot seeds 2 hours pre-soaking at 20 ^{O}C (250 ml of water per 100 fruits) or 3 hours pre-washing at 20 ^{O}C is recommended.

15. Swiss chard seed production

Swiss chard or chard, *Beta vulgaris* var. cicla, also known as spinach beet, is a biennial but it is grown as annual. It is commonly, but incorrectly called spinach, and is a very close relative to beetroot. It belongs to Chenopodaceae family. Swiss chard furnishes a considerably higher yield and is grown with less trouble. It has small roots and highly developed leaves that are cooked for greens, and thick leaf stalks are also edible. It is possible to harvest these leaves upto a year or flower stalks emerge. Swiss chard is a good source of important minerals such as magnesium, iron and potassium as well as vitamin A and C, but it gives low calories and fat.

Half of the ascorbic acid (vitamin c) is lost in cooking and some of the minerals and vitamins are released to the cooking water, so the volume of water could be reduced.

15.1 Climate and soil

Swiss chard thrives in completely cool climate and does best at a temperature range of 7 to 24 °C. It is half-hardy and can withstand light frosts, although its growth will be retarded at low temperatures. Prolonged exposure to temperatures less than 5 °C will induce bolting. During hot weather, leaves remain small and are of inferior quality. Foliage of plants is subject to a fungal leaf spot which may be a production limiting factor, given climatic conditions conducive to its development.

Swiss chard can be grown on a wide variety of soil types, provided it is well-drained, free of root knot nematodes, reasonably fertile and amply supplied with water. Soils should have a high water holding capacity to encourage uniform growth.

15.2 Cultural techniques

Planting is done on raised or flat surfaces which require appropriate soil preparation. In all cases, the seed bed must be uniform. Seeds are normally drilled directly into the soil in rows spaced 40 to 60 cm apart and later thinned to a spacing of 30 cm within the row. Thinned seedlings may be used for transplanting to fill any gaps. The depth of sowing should not exceed 2 cm. Seven to eight kilo gram of seed is sufficient to plant one hectare.

Sowing of Swiss chard seed needs to be timed so that the cultivar receives sufficient vernalization and the plants flower and seed in suitable weather conditions. Under Ankober climatic conditions, swiss chard sown in July gave the highest and good quality seed yield (Table 6). Swiss chard, like other leafy vegetable crops, should not be allowed to suffer moisture stress, and it requires fairly frequent irrigation to ensure that the soil does not dry out to less than 50 % available water. Adequate irrigation not only improves yield and quality of seeds produced but also shortens the date of maturation. It is possible to harvest swiss chard seeds 11 months after sowing provided that adequate irrigation is supplied in the growing season. Otherwise, date of maturation will be delayed. Rainy condition and insufficient warm temperature negatively affect seed setting and maturation and encourage diseases resulting in poor seed quality.

The crop responds well to organic manure. It responds well to periodic side-dressings of nitrogen to ensure continuous rapid growth. Research recommendations on fertilizer requirement of seed crop of swiss chard is not yet available. However, 100 kg/ha of urea fertilizer which is recommended for fresh market production (BOA, 2002) is adopted for seed production too.

15.3 Variety

Ford hook Giant is a widely known variety. It is well adapted to Ethiopian environmental condition. It has darker green leaves and broader leaf stems. Ford hook giant variety can produce seeds in Ethiopian cool highlands (fig. 12 and 13).

15.4 Seed production methods

As with the production of beetroot, both seed-to-seed and transplanting methods are used. The transplanting technique allows a better opportunity for plant inspection and is the only method for production of basic seeds. Unlike beetroot, the transplants are not stored. Flowering and pollination methods are similar to that of beetroot. Swiss chard seed production by a seed-to-seed method is relatively easy to adopt. For example, farmers at Ankober and Baso districts in North Shewa are producing seeds of Swiss chard with this method by having technical support from Debre Birhan Agricultural Research center (fig 12). In a single crop they can harvest both the fresh product and seed. That is, before seed stalk development they can use the leaves, later they can harvest seeds.

Fig 12 Swiss chard at heading stage at Ankober

15.5 Isolation distance

The minimum isolation distance between any similar colored cultivar is 1 km. This is doubled for different colored cultivars. The recommendation for swiss chard isolation distance from other types of

Beta vulgaris is at least 5 Km (George, 1985).

15.6 Harvesting and seed yield

The stage of ripening of seeds for harvesting is similar to beetroot. Swiss chard inflorescences are 2 to 3 m high, but after fertilization tend to become more horizontal and meshed together.

In most areas of the world a satisfactory yield of swiss chard seed is approximately 11 quintal, although up to 20 quintal can be obtained. In Ethiopia (at Ankober) about 16.77 quintal of Swiss chard seed was recorded on July Sowing (Table 6). Research results at Sheno (2800 m.asl) also indicated that Swiss chard seed crop could be harvested 11 months after planting or three months after flowering. The seed was planted in 3rd week of July, the plants gave flowers in 1st week of March and the seed harvested between 2nd week of May to 1st week of June. Farmers at Ankober and Baso districts produced good quality seeds of swiss chard (up to 1000 kg/ha with 100 % seed germination capacity and 21 g of 1000 seed weight) after utilizing the fresh market crop at least twice. World average 1000 seed weight of swiss chard seeds is 17 g (George, 1985). Plants grown from domestic seeds are shown in fig 13.

Like that of beetroot, seed germination can be erratic and dormancy can create difficulty for seed testing. To enhance germination of swiss chard seeds 2 hours pre-soaking at 20 ^{O}C (250 ml of water per 100 fruits) or 3 hours pre-washing at 20 ^{O}C and surface drying is recommended (Heydecker, et al., 1971).

Fig. 13. Swiss chard plants, raised from local seeds of Ford hook giant variety around Debre Birhan

Table 5. Days to first harvest of some cool season vegetables at Ankober (3100 m.sal) during 2000-2001

Sowing date	Swiss chard	Cabbage	Carrot	Beet root
Mid May	428	459	471	387
Mid July	425	395	589	351
Early September	685	338	685	Not tested
Early December	626	590	622	448
Early February	560	534	571	456
Early March	504	504	504	389

Source: Semagn *et al.* (2008)

Table 6. Seed yield (Kg/ha) of some cool season vegetables at Ankober (3100 m.asl), 2000- 2001

Planting date	Swiss chard	Cabbage	Carrot	Beet root	Mean
Mid May	342.5	385.22	244.16	1878.32	712.55
Mid July	1677.87	580.01	207.75	1709.89	1043.88
Early September	249.12	277.53	100.79	Not tested	
Early December	770.30	322.90	271.94	139.11	376.06
Early February	111.87	98.30	247.16	118.98	144.08
Early March	1029.92	41.31	586.20	129.23	446.67
Mean	**696.93**	**284.21**	**276.33**	**795.11**	

Source: Semagn *et al.* (2008)

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