Chapter 5

Production and Handling of Vegetable and Flower Seeds

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Abstract

Good quality seed is a pre-requisite to achieve a high quality good yield of vegetables and flowers. It contributes almost 5 to 20% in the final yield of vegetables and flower crops. Vegetable and flower seed production is highly technical and need professional skills. Currently, focus of national seed companies is on seed production of agronomic crops with least focus on vegetable and flower crops. One of the limitations is lack of skilled manpower. This chapter provides necessary basic information regarding seed production of vegetable and flower seed crops starting from planning up to storage and marketing.

Keywords: Certification, marketing, maturity indices, seed program, seed test, storage, vernalization.

5.1. Introduction

There are numerous factors which influence the production and quality of vegetable and flower crops. The seed is insignificant input in the total cost of production yet,

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one of the major factors and requisite item to ensure successful crop production. Therefore, importance of good quality seed can be hardly over-emphasized. There are two options with farmers and nurserymen to ensure a supply of seed *viz.,* either saving seed from their own crop that is usually termed as ‘on-farm seed production’, or purchasing seed from elsewhere. The proportion of ‘on-farm seed’ generally depicts the level of seed industry development in a country. But, for some vegetables and annual flowers, it also depends on how easily seed of optimum to good quality can be produced in the local environment (George 2009). It is relatively simple and easy to save seed of some vegetable and annual flower crops which do not require any special treatment to set seed such as vernalization *e.g.* peas, okra, cucurbits, kochia, zinnia and gomphrena. Other crops require an extra season and start flowering after exposure to low temperature and therefore, seed production is not as easy as for annuals *e.g.* onions, carrot, cabbage, and winter annual flowers. Another problem in local seed production is low quality due to faulty production, harvesting, threshing, packing materials and storage techniques.

In Pakistan, most of vegetable growers and nurserymen purchase seeds from seed companies (national and multinational) and/or corporations with hope to have better production. The price of imported seed is very high as compared to locally produced seeds and a huge amount of foreign reserve is used for import of seeds of vegetable and floricultural crops. During 2009-2010, 3553 metric tons of vegetable seed, worth Rs. 1085 million, was imported that comprised about 64% of the total seed requirements, (Hussain 2011); recently, the import volume increased to about 96% of the total seed requirement (Rana 2014). Sometimes, imported seeds are of inferior quality, *i.e.,* low germination and presence of seed borne diseases, such as cucurbit yellow stunting disorder virus (CYSDV) and New Delhi Virus. In this scenario, there is a dire need to increase awareness among the farming community as well as of capacity building so that the trained manpower can be employed in the indigenous seed industry of Pakistan.

5.2. Development of a Seed Program

The development of a seed program is one of the most important steps to promote vegetable cultivation or flower production in any region. Thus, a seed program should be carefully devised depending upon prevailing climatic conditions, suitability and importance of the vegetable or flower crops in the region, and its economics and profitability.

5.2.1. Criteria for Success

There are three bases for success of a seed program. These include; high level support, productive plant breeding program and coordinated effort. No seed program can be successful without desire and determination of government at decision making level. Administrative support and potential contribution is needed at all the levels of seed program including from all those involved in planning and responsible for implementation of the program. Introduction, selection and cultivar development is a vital component of seed program. A seed program on existing indigenous cultivars is seldom successful, as it may result in slight increase in yield just for a short term. Therefore, cultivar improvement is the corner stone of a seed program. To meet the growers' demand and prepare and implement an effective seed program, a coordinated effort is necessary from planners to growers' level.

5.2.2. Types of Seed Program

Basically, there are three types of seed programs, *i.e.,* official, semi-official and private. In an official seed program, government is fully responsible for developing a seed program, producing good quality seed and providing to the growers. Such seed programs are not very efficient and not always successful due to political interference, transfer of technical staff involved in the seed program. Further, no return, even the cost of seed, is expected from the investment.

In a semi-official seed program, the responsibility of producing, processing and distribution of seed lies with a national agency, established for such purpose. In such type of seed programs, direct government participation is limited as such agencies are semi-government or autonomous units, commercial in nature and more efficient in their operation.

In a private seed program, seed is produced, processed and distributed by private enterprises as in USA and Western Europe. Such programs are usually very successful as private companies are interested in return on the investment. However, growers have to pay more for the seed. Therefore, in developing countries, the best approach is that in which government, semi-government and private agencies are involved and cooperating in developing and implementing a coordinated seed program, with the responsibilities fixed for each partner and no duplication of efforts.

5.2.3. Program Development Process

The planning, organizing and implementing a seed program is a highly technical job. While preparing a plan, relevant data should be thoroughly examined, resources and inputs required be worked out, and targets should be fixed. The main steps involved in development of a seed program are; a) collection of pertinent data, b) role of various agencies involved in the seed program, c) basic strategy and development of physical infrastructure and other facilities, and d) planning and organization of seed program.

The first step in developing a seed program is collection of data regarding availability of superior cultivars already adapted in the region with their yields, other promising cultivars and growers' preference towards a particular cultivar and its demand. Statistics on availability of other inputs like fertilizers, pesticides and irrigation sources will also help in fixing the targets of seed production. Sometimes national or provincial government may fix a target of area for a specific vegetable or flower crop, so by using seed rate per unit area, demand for seed can be estimated.

To avoid duplication of activities, the role of different agencies (institutions/ organizations) involved in the seed program must be defined. Depending upon the national policy, multiplication and distribution of certified seed on large scale may be carried out by the government agencies, semi-government/autonomous bodies or by the private sector. However, the role of seed certification agency, seed law enforcement agency, national agricultural research council, national or provincial seed corporations, agriculture department, agricultural universities and other national or provincial agricultural research institutes must be demarcated. For detil see section 5.9.

The basic strategy should be comprehensive in its scope with provision for development of physical infrastructure and other facilities required for production and distribution of quality seed. There should be integrated development approach involving land development, farm mechanization, adequate availability of inputs (fertilizers, pesticides and other agro-chemicals), and development of irrigation resources, credit facilities, and collective crop protection measures. The seed should be produced or multiplied in a compact area with favourable agro-climatic conditions for production and storage of seed. Seed production can be organized through registered growers on contract basis or other progressive growers making them shareholders of the seed company or corporation. Only superior cultivars, with growers' demand and already adapted to the agro-climatic conditions of the region should be selected for seed production.

During planning, the scope of the seed program must be defined, its objectives and goals determined, and targets fixed on the basis of pertinent data already collected and growers' demand. Then basic strategy and role of various agencies involved, as discussed earlier, is decided and a flow chart of the production system is prepared. Equipment and structural facilities needed for seed production with their costs should be worked out and manpower requirements, *i.e.* personnel for field, seed plant, laboratory, marketing and administrative etc., be determined. Seed marketing and pricing structure should be adequately chalked out. It is highly recommended that a calendar of operations should be prepared to complete the tasks at proper time. The prepared plan must be reviewed by the experts before its implementation. If needed, the seed program can be amended at this stage to avoid future problems during its execution.

5.3. Associated Problems

There are different types of problems associated with a seed program, these include; a) problems associated with planning and organization, b) problems due to insufficiently trained manpower, and c) technical and operational problems. During planning and organization, lack of coordination among various agencies can seriously hamper the success of the seed program. Some faulty planning without comprehensive review, some aspects may not be properly addressed in the plan, purchase of equipment without proper specification and these may or may not correspond to actual requirements of the program, and differences in opinion or conflicting advice from consultants/advisors, may also impede the progress.

As developing and implementing a seed program is highly technical job; therefore, insufficiently trained or untrained personnel/manpower also contribute to the problems associated with its development and implementation. In a seed program, there may be some complex problems which become hopeless when no knowledgeable and experienced personnel are available to guide in the proper direction.

There are also many technical and operational problems faced. Climatic factors such as dry and wet conditions, rainfall, high humidity and high temperature may affect seed procurement and storage. Lack of competent supervision, skilled labour and deficiencies in management cannot be compensated by the modern machinery and equipment. The maintenance and repair of seed machinery and equipment, especially imported ones, is also a serious problem as their repair may take several months. Even, when seed program is going smoothly, seed marketing and distribution may face several problems due to inexperience or insufficiently trained marketing staff, lack of proper seed storage facilities, transportation and publicity etc. (Agrawal 1980).

The availability and use of quality seed play an important role in enhancing the productivity of vegetables and other crops. The existing seed production and supply system in the country is inadequate to meet the national vegetables' seed requirements. The seed programs for major agronomic crops like wheat, cotton, rice, maize, sunflower etc. are progressing in the country; however, vegetable and flower crops are far behind in this regard.

5.4. Principles and Practices of Seed Production

5.4.1. Photoperiod and Temperature Requirements

Flowering is a prerequisite for seed production. It starts after floral induction which provokes a meristem to start flower bud formation (also referred to as flower initiation) after certain internal or external signals. Plant age or size and more specifically endogenous level of certain hormones are considered as internal cues; while, length of day/night and low temperature are external signals. These external stimuli allow synchronized flowering in a population at optimal time during a year to ensure successful pollination and seed setting before inclement weather conditions. In some conditions, two different developmental signals are required in succession, such as, two different photoperiods or low temperature treatment (vernalization), followed by certain photoperiod. Vegetables and flowering annuals vary in their vernalization and/or photoperiodic requirements to pass from juvenile (vegetative) phase to reproductive phase, which is a transitional process. For some species, vernalization (exposure to low temperature) is obligatory for flower induction and differentiation. These species are biennial and cannot start flowering without completion of their vernalization for examples, crucifers (cabbage, Chinese cabbage, cauliflower, turnip, kale, and kohlrabi), carrot (European types), onion, red beet, parsnip, celery and lilium (*Lilium logiflorum*). In such species, vernalization and day length synergistically promote floral induction. Some obligate species such as celery, globe artichoke, and carrot, require short days during vernalization for floral induction and long days after vernalization (during flower differentiation). While, some other species have facultative vernalization requirement and cold exposure is required just for flower induction and flower differentiation, and bolting is regulated by long days. In facultative vernalization requiring species, long days also compensate for unstable vernalization due to very short exposure to cold temperature. Examples of facultative species are leek, broccoli, radish, spinach, lettuce, and peas.

Usually, a temperature of 0–5°C is required to fulfill vernalization requirements of several crops. Higher vernalization temperature can results in delayed, incomplete and/or poor flowering, even de-vernalization in some species. However, summer cauliflower and broccoli can flower at 20-30°C without vernalization. Onion requires 2-13°C, temperate types vernalize at low temperature, while tropical types can vernalize at 9-13°C. Several vegetables and herbaceous (annual flowers) species respond to vernalizing temperature at certain developmental stage. Most of the crucifers can be vernalized when stem diameter is 10-15 mm. Carrot, onion, cauliflower, cabbage, coreopsis (*Coreopsis grandiflora*), gaillardia (*Gaillardia* × *grandiflora*), rudbeckia (*Rudbeckia fulgida*) and tobacco must have 8-12, 4-7, 4-12, 4-15, 8, 16, 10, 37 leaves, respectively, to respond to vernalization temperature. Seeds of some crops, if exposed to low temperature during imbibition, can be vernalized, for example lettuce, turnip, spinach, Chinese cabbage, red beet, and white mustard (*Sinapis alba* L.). Exposure of ripening beetroot seeds (on the mother plant) to low temperature can also reduce the vernalization requirements. Moreover, vernalization requirement (duration of exposure to low temperature) of various cultivars of a crop are different. Therefore, sowing time should be adjusted according to the vernalization requirements *i.e.* cultivars requiring prolonged exposure should be planted earlier than those requiring short exposure time.

Vernalization response is common in winter annuals and biennials. Summer vegetable crops and summer annuals (flowers) usually require long days. Cucurbits are long day plants but, long days and high temperature promote production of staminate flowers and mild temperature and relatively short days promote gynoecy (femaleness). Flowering in short day plants, the native of low latitude on both sides of the equator, starts when day length is less than a particular critical time. Amaranth (African spinach), chrysanthemum, and poinsettia are short day plants.

Some vegetables like eggplant, tomato, cucumber and watermelon do not have specific day length requirement for flower initiation. Although cucumber is day insensitive but, long days promotes maleness and short days favour gynoecy (femaleness). Similarly, Asiatic carrot cultivars under long day conditions behave as annual and do not require vernalization temperature. In some crops, such as radish, cultivars without vernalization and specific day length requirement flower earlier when grown under long day conditions. So, for successful seed production, one must be familiar with photoperiod and low temperature requirements of crop(s).

Other components of climate, such as irradiance and precipitation, also have significant role in flowering. Length of juvenile period can be reduced in pelargonium (*Pelargonium* × *hortorum*) by increasing the irradiance, through supplemental lighting or by providing growth promoting conditions (Armitage and Tsujita 1979).

Among other climatic requirements of flowering and seed setting is the prevalence of suitable temperature and absence of rainfall during flowering. Continuous rainfall during flowering can wash out stigmatic fluid and suppress anther dehiscence. High as well as low temperature can result in slow growth of pollen tube and/or embryo abortion. Increase in average daily temperature reduces number of flowers per inflorescence, *e.g.,* in *Pelargonium spp*. Temperature during seed maturation can also affect germination. Some seeds have higher germinability when matured under higher temperature, while others showed more germination when matured at lower temperature. This effect is due to pre-conditioning effect of high or low temperature on seed development.

5.4.2. Pollination and Pollinating Agents

After flowering, successful pollination followed by fertilization is also necessary for seed setting. Pollination is carried out by different biotic and abiotic agents, of whom insects and wind are more important in vegetables and annual flowers. Crops vary in their pollination mode and broadly grouped into self- and cross-pollinated crops, mainly due to their flower morphology. Detail description of these groups has been given in Chapter 3. Here, pollination mechanisms are not discussed in detail. However, it is a well-established fact that chances of cross-pollination can increase with change in locality and/or environmental conditions, due to change in population of pollinating insects. It is also worth mentioning here that most of vegetables and annual flowers are cross-pollinated, specifically insect-pollinated (entomophilous). Even in self-pollinated crops, abiotic (gravity, wind) and biotic (animals, insects) agents facilitate self-pollination. Therefore, researchers have listed a large number of insects (pollinators) species directly involved in pollination of these crops, *e.g.* 334 insects visited carrot and 267 insects in onion (George 2009). Among these pollinators, insect from two orders *viz.,* Hymenoptera (bees, wasps and ants) and Diptera (flies), play very important role in seed setting of these crops. Population as well as activity of insect pollinators has direct impact on seed yield. Their population is affected by various agricultural practices such as pesticide sprays, and availability of alternate natural flora and climatic conditions (temperature, rainfall and wind speed) of the area. Seed producers must ensure adequate populations of pollinators or place artificial honeybee hives on the perimeter of seed production field after two to three days of pesticide spray (George 2009). Activity of pollinators can be enhanced by planting wind-pollinated crops, such as sweet corn, which improves microclimate. Other crops such as sunflower can also be used, but their flowering time should not coincide with flowering of the seed crop. Rainfall during flowering can also suppress or completely inhibit pollinators' activity and thus affect seed production.

5.4.3. Nutritional and Irrigation Requirements

There is paucity of research on impact of fertilizer application rates on flowering and seed production of flowering annuals and also in some vegetable crops, especially the leafy vegetables. Studies regarding impact of nutrients supplied to root crops on subsequent seed yield and quality is also scarce. It is a general assumption that there is antagonism between mineral nutrient requirements for optimum vegetative growth and reproductive growth. Usually, high nitrogen application rates delay flowering and decrease seed dormancy and thus shorten the storage life of seed (Gutterman 2000). Phosphorus application at higher rates tends to increase number of flowers, while potassium has role in improving quality of seed, especially when applied in combination with nitrogen during seed/pod filling. Similarly, calcium and trace elements (especially boron) have important role in successful seed setting, germination and seed vigour (Delouche 1980). Deficiency of specific elements cause crop specific disorders and also renders the crops susceptible to diseases.

Although scientists have described critical stages of various crops, which are prone to moisture stress, yet studies regarding impact of soil moisture deficit on yield and quality of seed are also scarce. Most of the annual vegetable crops and flowering annuals are sensitive to drought/moisture stress at the time of flower initiation, during anthesis (flower opening), and fruit and seed development; anthesis being the most sensitive stage. Drought stress during seed filling decreases the germination percentage (Dornbos et al. 1989). Plants growing in soil with adequate moisture, if provided with supplemental irrigation during anthesis, propduce more number of seeds per pod (silique, fruit, capsule, etc.) of large size, and ultimately the seed yield. Supplemental irrigations are more beneficial in those crops where root activity is reduced during flowering, for example the plants of leguminosae family (Salter and Goode 1967). Biennials also respond to such supplemental irrigations. The vegetative (first season) growth of biennials is also affected by irrigation; size of vegetative organ such as curd (cauliflower), head (cabbage), or root (carrot, radish, turnip, parsnip) will remain small that will decrease flowering proportionately.

Water stress during seed maturation, particularly last 5 to 15 days, has beneficial effect because it helps to switch the seed from developing phase to germination phase and decreases or increases dormancy in several species. This switch involves changes in proteins and mRNA concentration (Kermode et al. 1989).

5.4.4. Isolation

One of the important characteristics of good quality seed is its genetic purity. As mentioned earlier, most of the vegetables and flowering annuals are cross-pollinated crops and there are also chances of cross-pollination even in self-pollinated crops. This demands strict control on pollination between different cultivars of the same crop, grown for seed production, so that genetically pure (true-to-type) seed of a specific cultivar can be produced. One of the approaches to produce true-to-type seeds is by isolating two or more cultivars of a crop. Isolation is not only required from crops raised for seed production but also from those grown for fresh consumption (especially the vegetables whose fruit is consumed *e.g.* tomato, pepper, eggplant, okra) or aesthetic beautification. Isolation can be achieved by one of the following methods.

Isolation in time: Two cultivars of a crop are planted at different times to avoid synchronization of flowering. It is possible if two cultivars vary, to some extent, in their requirements of flowering, for example, duration of vernalization temperature in onions, carrots, cabbages, etc. Isolation by time can be easily done in areas with long growing season by growing one cultivar early in the season (spring) and other cultivar is sown late in the season (late summer).

Isolation by distance: The isolation distance recommended for flowering annuals is dependent on mechanism of pollination and pollinating agent involved. There are recommendations for maintaining distance between two cultivars of a crop in cross- as well as self-pollinated crops. In self-pollinated vegetables and flowering annuals, distance between two cultivars should be 50-250 m to avoid admixture. Isolation distance in cross-pollinated vegetable crops should be 1000-1500 m. The isolation distance recommended for flowering annuals is 360 to 720 m (even up to 1000 m), depending on pollinating agent (insect or wind) involved (Reheul 1987 a, b). The isolation distance between two cultivars from the same group is less (720 to 1000 m) as compared to isolation distance in two cultivars from different groups *e.g.* onion groups on the basis of bulb skin colour, groups of flowering annuals within a specie on the basis of petal colour.

Isolation by caging: This method can be practiced only for limited number of plants or on small area by breeders. Farmers can also select the outstanding plants in their field for seed production and cover these plants using screens or netted cages. However, in such cages honeybees cannot perform pollination because they keep on trying to escape from the cage rather doing pollination. Growing plants in enclosed structures such as polythene tunnels and greenhouses also provides isolation.

Isolation by zoning: In some countries, zoning schemes are there which ensure the cultivation of a specific crop, either for market or seed crop, in a specified area. The main objective is to prohibit the cross-pollination between cross-compatible crops, for example different types of *Beta* species (sugar beet, red beet, Swiss chard and fodder beet), turnip, cole crops and *Allium* species. Zoning is more applicable for crops which start flowering during the course of development of the marketable vegetable crop.

Discard Strip Technique: Most of the pollen contamination in insect- and wind-pollinated crops occurs around the perimeter of the seed field. Therefore, discard strip technique can be employed if recommended isolation distance cannot be maintained properly. Most of the insects visiting the seed crop land on the edges/borders of the seed field. In wind pollinated crops, the concentration of pollen in the air is high on the windward side and decreases on the leeward side. Sometimes, wind is blowing from all four directions during anthesis. Under such conditions, it is advisable to remove a 5 m wide strip around the perimeter of the plot or harvest it separately. If wind is unidirectional, then 5 m wide strip should be discarded only windward side. The seed from inner area of seed field is bulked and saved. It is better to keep the seed field in square shape so that fewer seeds are produced as a result of pollen contamination and thus minimum amount of seed is discarded (George 2009).

5.4.5. Roguing

True-to-type seed is mandatory in seed production program. Isolation does not ensure that the seed crop of a particular cultivar, isolated properly from other cultivars, will set true-to-type seed. It is due to some variation in the parent material (seed). If such variation is not checked properly, then trueness to type (genetic purity) of an open pollinated cultivar is lost after some years. Therefore, seed crop should be inspected at various stages to ensure the removal of undesirable/off-type plants that do not match the characteristics of the cultivar. This removal of off-type plants is termed as roguing. One should observe plant growth habit, colour of foliage, flowering time, flower colour and form during roguing of annual flowers (Kwong 2005). While, colour of seedlings, colour of young leaves, shape of leaves (Fig. 5.1), duration of vegetative and reproductive growth, early bolters, colour, shape and size of flower/head/curd/bulb/root (Fig. 5.1), colour and size of immature and mature fruit/pod/silique, and time of maturity should be observed during roguing in vegetable crops (George 2009).

Fig. 5.1 Rogue out offtype plants: (A) Turnip root showing multiple growing points, and (B) Radish plants with lobed leaves from field of 40-days cultivar.

Roguing must be performed at specific stages by skilled personnel to observe all characteristics of a seed crop discussed in previous paragraph. Sometimes, roguing cannot be performed if cultivars of a crop are not grown in locations suitable for their proper development. One such example is of heart type lettuce that does not produce heart if not grown in conditions specified by the breeder.

5.4.6. Crop Rotation

There should be substantial interval between plantation of one crop or its closely related species on one piece of land. It helps to prevent buildup of insect-pests and diseases of the crop(s). Crop rotation also eliminates the risk of appearance of off-type plants, if other cultivars have been cultivated during the previous growing season and some of the dormant seeds of that crop remained in the soil. It is a general recommendation that seed crop should not be grown on a land where the same crop specie was grown during the last (i) two years for fresh consumption and (ii) five years for seed crop. It is advisable to include leguminous crops in the rotation so that fertility of the soil can also be increased. Otherwise, rotate with those crop(s) which do not have common insect-pests and diseases.

5.4.7. Synchronization of Flowering

It has been observed during hybrid seed production of annual flowers and vegetables that flowering time of the two parents do not coincide with each other. It is common when i) parents are of distant origin, or ii) one parent is propagated by vegetative means (cuttings or tissue culture) and other is raised using seeds, as in case of annual flowers like impatiens, petunia, primula and dianthus. Planting time must be adjusted in such cases to synchronize flowering so that pollination and successful seed setting is possible. This synchronization of flowering is also termed as nicking.

5.4.8. Pest and Disease Management

Both, seed yield and quality are affected if insect-pests and diseases are not properly controlled. For annual flowers, potting medium, containers and growing spaces should be sterilized. Seeds and other propagules should also be sterilized using hot-water treatment or surface sterilization method. Scouting for insect-pest and diseases should be performed on daily basis. Yellow sticky cards should be hanged in greenhouse to detect the build-up of insect-pests. Use fungicides, insecticides or bactericides as per requirement.

5.4.9. Methods of Vegetable Seed Production

Two types of vegetable seeds are available in the market, *i.e.,* open pollinated and hybrid seeds. Both types of vegetable seeds are usually produced under open field conditions with some exceptions where production is done in greenhouses. Vegetables are divided into two broad groups on the basis of their nature, annuals and biennials. Based on their nature, there are two seed production methods in vegetable crops namely, seed-to-seed (direct) and replanting method. In seed-to-seed method, crop (parent plant on which seed is to be produced) is raised in field, which flower and produce seed in the same field and does not require any shifting after completion of juvenile phase or before flowering. Seed of annual vegetables like, tomato, peppers, eggplant, all cucurbits, and okra is usually produced by seed-to-seed method. Seed of some biennials such as coriander, spinach, lettuce and fenugreek, is also produced by seed-to-seed method. Seed of biennial vegetables like, turnip, radish, carrot, etc. is usually produced by replanting method; seed-to-seed method can also be used but has some demerits. Replanting allows evaluation of root shape and size, root internal texture, root internal and external colour, and thus roguing can be effectively performed. In seed-to-seed method, roguing for these characteristics cannot be performed effectively. Replanting method is also effective in areas with heavy snowfall for several months. In such areas, stumps of cabbage and cauliflower, bulbs of onions and root vegetable crops are lifted from field and stored after roguing. These stored parts are replanted in field after snowfall. Replanting method is recommended for commercial production of certified seed of vegetable crops.

5.4.10. Methods of Seed Production in Annual Flowers

There are basically two seed production systems in annual flowers *viz.*, open pollinated seed production in fields and hybrid seed production in greenhouses. Open pollinated seed crop is grown in open fields where genetic purity is maintained by roguing and maintaining suitable isolation distance. France, Netherlands, USA

(California), Mexico, some eastern European countries and China are famous for open field production of annual flowers (Kwong 2005). Some African countries such as Kenya, Tanzania and Zimbabwe were also producing flower seeds in large quantities during last four decades, but production has declined due to political and social changes. For hybrid seed production, annual flowers are grown in greenhouses or at least in mesh houses, so that entry of pollinators is restricted. Emasculation and pollination is mostly done manually in these greenhouse crops. Most of the breeding companies have their greenhouses in the tropical highlands such as Guatemala, Kenya, Costa Rica, Indonesia and Sri Lanka, where mild weather throughout the year favours seed production without much expenditure on power supply for maintaining controlled conditions. Bedding annuals, for example, geranium, impatiens, and petunia, are usually grown in these greenhouses. Greenhouse production of cool-season annuals, such as pansy, primula and cyclamen, is practiced commercially in the Netherlands, Denmark, Germany and France (Kwong 2005).

Only seed-to-seed method is practiced in seed production of annual flowers because these do not have underground storage organs and their production is feasible in indoors and thus do not need replanting.

5.5. Harvesting and Handling

5.5.1. Maturity Indices

The harvesting of crop at proper stage of maturity is paramount in obtaining optimum seed yield of high quality. Seed crops can be divided in to two groups depending in their type of fruit harvested; namely fleshy fruit and dry fruit. Fleshy fruit are usually harvested when ripe or over ripe, the time when seed is fully mature. Examples of such crops are tomato, cucumber, eggplant, watermelon, bitter gourd, and muskmelon. Some vegetables initially have fleshy or semi-fleshy fruit but become dry at the time of seed maturity like hot pepper, sponge gourd, bottle gourd, and okra. Some vegetable and annual flower crops have their seeds enclosed in dry fruits; these crops are further divided in to two categories: i) crops in which dry fruit splits at maturity to release seeds, and ii) crops in which dry fruit remains intact. Decision of harvesting is difficult in crops prone to shattering as earlier harvesting will lead to inclusion of immature seed, while late harvesting may cause loss of seed. Shattering is common in crops in which seeds mature sequentially and not at one time. Examples of such crops are carrot, turnip, cabbage, cauliflower, peas, onion, lettuce and fenugreek. The ideal time for harvesting of such seed crops is before the loss of mature seeds exceeds the amount of seeds yet to reach maturity. These crops should be harvested when 70% of the pods/fruits per plant are mature, while 30% are still immature and may have green seeds. Crop should be cut at this stage and placed on tarpaulin for drying so that the remaining 30% seed can get matured, a process known as curing. These crops attain golden colour at the time of seed maturity. Maturity indices of some crops are given in Table 5.1.

Seed moisture contents are indicators of crop maturity and help in deciding the correct time of harvesting the seed crop. Level of pentose sugars has also been regarded as indicator of seed development (Gurusinghe and Bradford 2001). Seed pods are usually fleshy and green when pentose accumulation reached a plateau. Impatiens seeds harvested after this stage have very high quality. Seeds are considered mature when they lose chlorophyll, attain maximum dry weight, and are desiccation tolerant.

5.5.2. Harvesting and Seed Extraction

When seed crop is at optimum stage of maturity, it should be harvested without any delay; otherwise there will be continuous loss of seed quality and quantity. Seed can be harvested earlier or later than the above mentioned maturity indices if weather conditions do not permit harvesting. Harvesting should be adjusted keeping in view the weather conditions as strong winds can cause lodging of tall growing seed crops with weak flowering stem like carrot, turnip, radish, coriander, spinach etc. Rain at maturity badly affects seed quality and increases chances of disease attack. If there are chances of rains or humidity is high, crop can be harvested earlier and allowed to mature and dry under cover. While in dry areas, the crop can be left in field for proper drying if it is not prone to shattering. Shattering is a problem in some crops that can be avoided by harvesting early in the morning when their pods or capsules are not very brittle due to dew or by using desiccants such as diquat (George 2009). Harvesting should be adjusted according to the prevailing pests such as birds and rodents in the seed production area. These pests attack the seed crop just near or at the time of maturity.

On a small scale, seed crop can be harvested manually using sickle or cutters. Seed heads or pods of some crops such as onion, okra, marigold, calendula, sunflower, and poppy, can be clipped off into buckets. Other crops like carrot, radish, turnip, and cabbage can be cut and tied into bundles. On large acreage, crop can be harvested using combine harvesters. Fruits of cucurbits are picked and placed for drying except bitter gourd, melons and watermelon, in which seeds are extracted from flesh and processed.

Dry seed: Seed crops having their seeds in capsules, pods, or seed heads change their colour at maturity and most of these storage organs/fruits develop a split to release the mature seeds, such seeds are termed as dry seeds. Harvesting of such seeds should be followed by air or sun drying so that these become brittle and seeds can be extracted from storage organs. Seeds should be threshed out on a dry day. On a small scale, seeds are separated from plant material by flailing, beating, tedding, jogging or rubbing. While on large scale, dried seed crop is threshed by a commercial threshing machine *i.e.* belt thresher or combine harvester. Speed of cylinder is very important in threshing; it should be 1100 rpm (revolutions per minute) for small seeded crops, while 700 rpm for large seeded crops such as legumes. There is a possibility of surface and sub-surface damage to seeds if: i) cylinder speed is high, ii) cylinder clearance is too narrow, and iii) the mesh of concave is too small.

Table 5.1 Harvest indices of some dry seeded vegetable and annual flower crops.

Crop	Crop/foliage/floral colour at maturity	Threshing method	Curing	
			Period (weeks)	Condition(s)
Beet family (Beet-root, spinach, Swiss chard)	When seed stalks are yellow and 60 to 80% seed balls on 90% plants in seed field attain tannish brown shade.	Threshing.	2-3	Cool, dry, shady place.
Cole crops (cabbage, cauliflower, broccoli)	Plant starts to dry out and attain orange-brown colour; 60-70% pods turn brown to orange brown; majority of the seeds are light brown and firm.	Beating, flailing, and threshing.	2	Dry, shady place.
Turnip	Bases of flowering stalks turn straw coloured; seeds are light brown and firm.	Beating, tedding, flailing, and threshing.	---	---
Radish	Pods are brown coloured or parchment-like and brittle; 60-70% pods reach maturity.	Threshing.	1-2	In shallow windrows in dry field or tarpaulin; clear, warm, dry weather.
Carrot	When primary umbels turn brown and seeds are earthen brown coluored, while secondary umbels are in midway. Others harvest when secondary umbels are brown and tertiary umbels are in midway.	Beating and threshing.	---	Place umbels with seed stalks in loose thin layers in airy shady place; or piled in windrows not higher than 0.6 m.
Onion	When a patch of black seed can be observed against silvery capsules at the top of umbel; or 5% capsules on individual heads are shedding mature seeds. Mature seed is dull black, hard and dry.	Rubbing of seed heads by hand or by using wooden float and wooden box with corrugated rubber floor mating.	1-2	Place umbels in drying racks or spread on dry ground/tarpaulin in sunlight or in shades with good ventilation; piling should not be more than 15 cm.
Lettuce	When 50-70% seed heads are mature and feathered.	Bagging, harvesting and hanging of plants when seed dispersal starts.	1	Crop is cut and windrowed.
Peas	Cut the crop when 70 to 80% pods on a plant are dry and crispy. For small scale production, when earliest pods attain parchment-like colour and foliage has started to lose its chlorophyll.	Threshing.	1-2	Cut the stems of plant just above soil surface; leave plant at its place, rake the plants in windrows with continual turnings.
Okra	Pods become dry brittle, grey or brown coloured and splits along the ridges and fruit tip.	Flailing and threshing.	---	Sundry for one or two days if rainfall precedes harvesting.
Annual flowers	Pod/capsule/seed head along with supporting stem (1/2 to 1 inch) dry up and change its colour; seed change colour from green to brown or black.	Rubbing of seed heads or pods by hand or by using wooden box and float with corrugated rubber floor mating.	1-3	Uproot the plants at about 70% seed maturity, dry in shade.

Wet seeds: Seed from fleshy fruit, also temed as wet seeds, are extracted in three steps *viz.*, i) extraction from fruit, ii) seed washing, and iii) seed drying. All three steps vary from crop to crop as well as with production scale. Fruit of cucumbers and melon are cut in to two halves and seeds are scraped out along with surrounding pulp.

Tomato fruit are mashed after cutting or without cutting. Fermentation is necessary for extraction of seeds from fleshy fruit of most of the vegetables, which helps in removal of gel surrounding the seed and to eliminate seed borne diseases. The gel contains germination inhibitors and cause difficulty in washing and drying of seeds besides causing seeds to be clustered after drying. Duration and temperature affects fermentation process; the former is dependent on the later one. Fermentation for a short or too long time has negative effects on seed quality. Fermentation time varies from crop to crop and cultivar to cultivar; those with high sugar contents require long period for fermentation. Generally, fermentation time is three days at 21-24°C. Pepper and eggplant seeds, if extracted from fruits by mashing, require fermentation for only 24-48 and 48 h, respectively. It is necessary to stir the mashed fruit 2 to 3 times a day to speed up fermentation and avoid foul-smelling due to mold growth on surface of mash. Watermelon fruit are macerated, washed in running water using screen, but without fermentation because it causes discolouration of seed. When fermentation is over, liquid (juice of fruit or mixture of juice and water) should be poured off and the seeds are washed to remove small and broken seeds, pulp, and pieces of fruit. Generally, good quality seeds sink to the bottom, while inferior seeds float on the surface of water, but in some crops like peppers and some cultivars of watermelon, highest quality seeds float on the surface. Seed sinking is dependent on specific gravity. Therefore, it is better to use sieves/screens to avoid loss of seeds during washing. Seeds should be dried immediately, at moderate speed, after washing to avoid sprouting and mold growth. Seeds, especially the dark coloured, should not be dried in direct sunlight or where temperature exceeds 35°C. Spread the seeds out in thin layers, usually 1.0-1.5 cm for small and 2.5-5.0 cm for large seeds, on non-sticky surface such as plywood or window screen.

5.5.3. Seed Processing

Seed of crops grown in open field can have debris, ranging from 20 to 80% of the total volume, depending upon specie and method of harvesting and threshing. Such inert matter, plant debris, soil pieces, weed or other crop seeds, seed appendages, and damaged seeds, degrade visual quality of the seed lot and should be removed. This removal of debris from seed is termed as seed conditioning or processing. It involves pre-conditioning, cleaning and finishing processes as described in the following sub-sections.

Pre-cleaning or pre-conditioning

Seeds of low growing flowering annuals such as alyssum, candytuft and ice-plant, and vegetables such as peas may contain stones, clods and trash. Such seeds should be passed through a single screen (scalper) or double screen (rough cleaners), which removes soil particles and plant debris (Kwong 2005), and allow rough seeds to pass readily. Pre-cleaning machines have sieves (vibrating or rotating) and air flow. It is better to use threshers equipped with sieves or screens and aspirators that help in initial separation of plant debris from seed. De-bearding and de-hulling is also a part of pre-conditioning in which beard (of carrot seeds), tail-like structure (of marigold seed), hairy layers (on seed coat of gazania) and husk (from grass seeds) are removed, and seed is polished.

Cleaning

It is a refined form of pre-cleaning and is carried out by using one machine, the air-screen cleaner. The aim of this operation is to remove all those materials from seeds which should be absent from final seed lot, *i.e.,* a separation process. Generally, a seed cleaner has two components, *i.e.,* air blasts (using fans) and screen. Air system separates the seed on the basis of seed weight. There are usually two vibrating screens that help to separate the seeds on the basis of width and thickness (George 2009). Cleaning of different kinds of seeds is dependent on one or more physical characteristics such as shape, size, length, weight, texture, affinity to liquids, electrical conductivity etc. It is very important to determine the most important physical character of seeds of a specific specie and then select machine which can separate the seeds on the basis of that property. Various types of machines used are: vibratory separator, spiral separator, disk/intended cylinder separator, electrostatic separator, electronic colour sorters, inclined draper, magnetic separator, roll mill and gravity separator.

Finishing

It is the final process, also referred as upgrading that improves mechanical and genetic purity and physiological quality of a seed lot. It facilitates precision drilling of the seeds, a pre-requisite in modern commercial vegetable production systems. By this method, seeds of uniform size and shape are obtained and undersized, empty, cracked, defective or dead seeds are removed from the seed lot.

5.5.4. Seed Drying

Seed must be dried to adjust moisture content safe for storage and packaging so that high quality can be maintained. High seed moisture content can increase rate of respiration, encourage mold growth and insect (weevils, mites, beetles, etc.) attack. Seeds of all flowering annuals and vegetables are orthodox for which 6-8% seed moisture content is considered safe for medium term storage. Seeds with low moisture content (2-4%) can be safely stored at sub-zero temperature. However, such excessively low seed moisture content during storage at room temperature (25°C) favours production of free radical species, which causes cellular damage. Specifically, seed moisture contents of starchy and oily seeds should be reduced to 12% and 9%, respectively for open storage, while 9% and 6%, respectively for sealed/containerized storage. Seed moisture content of a lot can be determined by a calibrated seed moisture meter or oven method. Both, natural and artificial drying can be practiced. Depth of the material to be dried is an important consideration. If seed moisture contents are less than 30-40%, this depth should be less than 2 m for unthreshed peas and 4 m for radish crop to be dried by hot air having flow rate of 350 $m^3/min/m^2$ (Sparenberg 1963). Various kinds of dryer are used; warm-air drying tunnel and rotary dryers are the most common one. Temperature of the air should be adjusted according to the seed moisture contents; moist seeds cannot tolerate high temperature. Colour indicating silica gel or drying beads can also be used on small scale, *e.g.* by breeders and small farmers. Seed should be placed in a desiccator over silica gel for seven days that will reduce seed moisture contents from 12% to 5% and 7% in small and large seeds, respectively. After drying, seed should be immediately stored in air-tight containers. Drying beads are better than silica gel for decreasing seed moisture contents.

5.5.5. Seed Treatments

Seed treatment is a broad term that encompasses various measures to: i) adjust seed moisture contents for better storage, ii) control seed borne pathogens like hot water treatment of seeds, iii) protect the seeds, and to some extent seedlings, from various soil borne and foliar pathogens, by using systemic pesticides and non-chemicals, iv) increase plant productivity by incorporating beneficial microorganism(s) and essential nutrients (particularly trace elements), v) improve seed physical characteristics (shape and size), and vi) enhance seed performance (emergence rates and vigour) using physiological seed treatments (Taylor and Harman 1990). These treatments must be cheap and easy to perform so that cost of production is not significantly affected.

These days, coating of vegetable seeds with various fungicides is a common practice; sometimes film coating technique is used that allows incorporation of several coatings of fungicides and insecticides (for control of sucking insect-pests) with minor increase in weight of seed (1 to 10%). Pelleting improves size and shape of seed, besides incorporating those chemicals used in coating. Pelleting facilitates drilling in modern agriculture. Onion, spinach, beet and cole crops' seeds are pelleted. Somatic embryos, generated through tissue culture techniques, can be encapsulated for sowing in fields. Fluid drilling, using germinated seeds suspended in viscous gel, is a regular practice in some countries, which helps in achieving a good crop stand. Colour is added in both coating and pelleting materials as an indication of seed treatment. The use of microorganisms (*Azotobactor*, *Rhizobium, Bacillus* and *Pseudomonas*) is increasing as a practice of sustainable agriculture.

There is a lot of research on use of physiological seed enhancements such as, seed soaking, seed priming, thermal hardening and magnetic seed treatments (Ahmad et al. 2017; Khan et al. 2012; Ziaf et al. 2014, 2015 & 2017). Provision of aeration is the difference among soaking and priming of seeds; air is passed through solution in case of priming and is necessary for seeds requiring more oxygen during germination process (verbena) and those with mucilaginous seeds (pansy). These seed enhancements help in uniform germination and/or early crop stand establishment and trigger plant growth and development under both favourable and stress conditions (Bruggink 2005). A variety of chemicals such as growth regulators (auxins, cytokinins, gibberellins, polyamines etc), osmoprotectants (proline and glycinebetaine), osmotica (Polyethylene glycol [PEG 6000, 8000 and 10000], mannitol and sorbitol), salts (potassium nitrate, sodium chloride, calcium chloride) and even simple water has been used in various seed enhancements techniques. Concentration of chemicals, temperature and duration of priming is crop specific, and even sometimes cultivar specific.

5.6. Seed Storage

After harvesting, extraction, conditioning and drying, seed must be stored properly so that its quality can be maintained at least till next growing season or for a long duration (several years as in germplasm banks). Seed storage is also necessary to cope with demand after natural or man-made disasters like drought, flood, fire, etc. Moreover, seed requirement fluctuates year to year; therefore, high quality seeds stored during previous years can also be used. Seed is a living entity but in dormant or resting condition; therefore, its deterioration during storage is inevitable. Seed deteriorate to varying degrees depending upon several pre- and post-harvest factors as well as storage method. According to an estimate, 25% of the flower seed is deteriorated annually that costs about US$ 1 billion (McDonald 2005).

5.6.1. Factors Affecting Storage

There are several factors that affect the storage life of seeds. These are: genetic make-up, mother plant environment, harvest and postharvest pre-storage factors, seed viability and quality at the time of storage, and storage environment.

Genetic make-up: Seeds can be classified according to their drying and storage potential into orthodox and recalcitrant seeds. As mentioned earlier, seeds of most of the vegetable and flowering annuals are orthodox *i.e.* they can be safely dried to low moisture content and stored for long duration (less than one year to more than three years). Recalcitrant seeds cannot tolerate desiccation below a certain moisture level and survive for short time, ranging from 1 to 6 months under the most suitable storage conditions. Orthodox seeds can be grouped into short-lived (< 1 year), medium-lived (2-3 years) and long-lived (> 3 years) on the basis of their storage lives. A list of vegetables and flowering annuals with their storage lives is given in Table 5.2.

Storage life of seed has been correlated with genetically controlled traits such as chemical composition of seed, seed coat permeability and size/surface area ratio. Seeds containing high protein and starch contents have more storage potential than seeds containing high oil contents (onion and impatiens), especially high oil contents in embryo than other storage reserves. Large sized (zinnia, sunflower, cucurbits) seeds have greater surface area due to seed shape and/or due to presence of appendages as compared to small sized (petunia, cabbage, turnip, onion, etc.) seeds and therefore, absorb more moisture if relative humidity is high. Mucilage present around the seed coat, for example in salvia, also absorbs water at high relative humidity in the storage environment. Testa of some seeds is very hard, impermeable to water and therefore, restrict ready uptake of water by the seed *e.g.* okra, bitter gourd.

Table 5.2 Relative storage life of vegetable and annual flower seeds under satisfactory storage conditions.

Crop	Storability (years)		
Vegetables	Short-term (up to 1 year)	Medium-term (>1 and <3 years)	Long-term (>3years)
	Onion	Beet	Cabbage
		Broccoli	Cauliflower
		Carrot	Cucumber
		Celery	Eggplant
		Kohlrabi	Lettuce
		Leek	Muskmelon
		Okra	Pumpkin
		Pea	Radish
		Pepper	Tomato
		Spinach	Turnip
			Watermelon
Annual Flowers			
	Aster	Ageratum	Calendula
	Begonia	Alyssum	Celosia
	Coneflower	Antirrhinum	Centaurea
	Coreopsis	Brachycome	Chrysanthemum
	Gaillardia	Campanula	Gypsophila
	Helichrysum	Capsicum	Mimulus
	Impatiens	Cineraria	Morning glory
	Limonium	Clarkia	Shasta daisy
	Nemesia	Coleus	Sweet pea
	Pansy	Cyclamen	Zinnia
	Phlox	Dahlia	
	Primula	Delphinium	
	Salvia	Dianthus	
	Viola	Gomphrena	
		Helianthus	
		Lathyrus	
		Lobelia	
		Lupinus	
		Marigold	
		Matthiola	
		Nicotiana	
		Papaver	
		Pelargonium	
		Petunia	
		Portulaca	
		Rudbeckia	
		Saintpaula	
		Scabiosa	
		Verbena	

Mother plant environment: Growing conditions of mother plant have strong impact on initial viability and quality of seed. Seed produced on plants growing in nutrient (macro- or micro-nutrient) deficient soils is of poor quality. Seed from crop grown in soils deficient in nitrogen, potassium and/or calcium does not store well. Deficiency of specific element induces crop specific defects. Excess of nitrogen also reduces the storage life of seed. Seed quality is also affected by over as well as under irrigation. High temperature during seed development and maturation, excessively high relative humidity, rainfall and hailstorm affect quality of the maturing seed and has profound effect on seed storability. Healthy and mature seeds produced in dry environment are ideal for longer storage. Lodging of seed crop near or at the time of seed maturity ruins its quality.

Maturity of seeds: Initial viability and vigour of the seed has great impact on its storability and is affected by several factors; seed maturity is one those factors. Some species have indeterminate, while others have determinate flowering habit. Seeds of indeterminate species do not mature at one time and therefore, seeds mature in different weather conditions. Seeds from such crop are heterogeneous, a mixture of mature and immature, and therefore, there is no uniformity in viability and vigour of these seeds. Even the seeds of determinate species, which mature sequentially, vary in their quality. However, performance of all seeds in a fresh lot is uniform because deteriorative processes have not yet started. With the passage of time in storage, deterioration rate increases in poor quality (immature) seeds as compared to high quality (mature) seeds. This demands the analysis of seed vigour besides germination test before storage.

Presence of pathogens and insect-pests: Presence of seed borne diseases and insect-pests at the time of storage shorten the life span of seeds. Storage fungi are mostly from genera *Aspergillus* and *Penicillium*, which are saprophytes. Storage fungi grow when relative humidity in storage is between 65 to 90% and temperature is between 30 to 33°C, up to a maximum of 50°C. These fungi feed on the embryo of seed and also produce toxic metabolites. Bacteria do not attack during storage because of free water requirement for their growth. Insect-pests, like mites, weevils, beetles and borers, can become a serious problem in hot humid climates. These feed on seeds tissues and provide entry points for pathogens. Insect-pests cannot continue their activity if seed moisture content is 8% and storage temperature is 18 to 20°C. Insect-pests become a serious problem when seed moisture content at the time of storage is 15% and storage temperature is 30 to 35°C.

Mechanical damage: After harvesting, seed is also damaged during threshing, processing and drying. Sometime the damage is observable with naked eye while, some damages (cracks in seed coat) can be seen only under microscope. Cracking of cotyledons is common in French beans, onion and radish seeds during threshing. Such cracking and abrasions on seed coat can be controlled by adjusting cylinder speed during threshing. Processing damages are more pronounced in immature seeds than mature seeds. If temperature or duration of seed drying is increased, seeds become brittle and such seeds are more prone to cracks or breaks than the seeds dried for appropriate period at suitable temperature. Damaged seeds continue to deteriorate progressively because it is inexorable process. Cracks and abrasions provide entry sites for storage fungi which further speed up the process of deterioration.

Relative humidity, temperature and seed moisture contents: During storage, temperature and relative humidity are the critical factors that determine the storage life of seeds. Seeds tend to equilibrate with moisture in the storage environment but species vary in their behaviour. At 75% relative humidity, seeds rich in carbohydrates will have 13-15% moisture content, while oily seeds will have 9-11% moisture content. Once the seed moisture content reaches above 14%, respiration (resulting in heating of seed lot at 18-20% seed moisture content), storage fungi and insect-pests become major problems. If relative humidity decreases afterwards, seeds will lose moisture but they cannot attain the initial moisture level and tend to retain more moisture than the initial moisture level, this phenomenon is known as hysteresis.

According to Harrington (1972), seed storage life is doubled for each 1% reduction in seed moisture contents with initial seed moisture contents between 5% and 13%. Therefore, relatively humidity in the storage environment should be kept low (60%) for safe storage of seed. Relative humidity in combination with high temperature also has negative effect. Temperature determines the capacity of air to hold moisture *i.e.* higher the temperature higher will be the relative humidity and vice versa. Harrington (1972) stated that seed storage life doubles for every 5°C reduction in temperature between 0°C to 50°C. Temperature alone also enhances the speed of catabolic reactions in cells of seeds. Harrington (1972) suggested that the sum of temperature (in °F) and relative humidity (%) should not exceed 100. Seeds with 2-4% moisture content can be stored at low temperature (5°C) and low relative humidity (50 to 60%) for at least 10 years without a significant loss of viability while, deterioration rate is high in seeds stored at 35°C (Alhamdan et al. 2011). In conclusion, low seed moisture content coupled with low storage temperature and low relative humidity is the pre-requisite for safe storage of seeds. Temperature and relative humidity in storage rooms can be controlled by proper designing of the building, considering the ventilation and usage of structural material to avoid internal heating of the room.

5.6.2. Types of Storage

There are four basic methods of seed storage *viz*., conditioned storage, hermetic storage, containerized storage and cryogenic storage.

Conditioned storage: Seeds of some species can be safely stored by manipulating temperature and relative humidity in the storage houses. Usually, this costly method has been employed in tropical areas to maintain high seed quality. Seeds with less than 11% moisture content should be stored at less than 20°C. Therefore, conditioned storage must be equipped with refrigeration and dehumidification facilities. For germplasm conservation, seeds should be stored at -15°C to -20°C.

Hermetic storage: This storage method maintains seed moisture content by using moisture-proof or hermetically sealed containers filled with specific gases to prolong the storage life of seeds. Concentration of oxygen is decreased (1.4%), while concentration of carbon dioxide is increased (up to 12%). Moisture content of seeds to be stored must be low (2 to 3%). Starchy and oily seeds, if stored at seed moisture content of 12% and 9% (safe for ordinary storage) in hermetically sealed seed containers, deteriorate at higher rate than the same seed lot placed in non-sealed storage containers. However, seed companies cannot store their bulk seed by this method.

Containerized storage: Complete control of relative humidity in store house is very difficult; however, if seeds are properly dried then they can be stored for a long period in moisture-proof containers. Seed moisture content can be lowered to a point by using chemical desiccants such as sulfuric acid, nitric acid, saturated solutions of various salts and cobalt chloride treated silica gel. Temperature maintenance is necessary while using saturated solutions for humidity control. Silica gel should be used @ 1 kg per 10 kg of seed. After attaining certain seed moisture level, seeds must be stored in moisture-proof metal containers to avoid moisture equilibrium of seeds with storage environment. Cellophane bags, polyethylene bags and drums should not be used for long-term storage. Aluminium pouches are the best for safe and long-term seed storage.

Cryogenic storage: Seeds are placed in gaseous phase (-150°C) of liquid nitrogen (-196°C) for ease in handling. This method ensures long term storage of seeds. This method is not suitable for storage of huge seed lot produced by seed companies but is a viable option for maintaining important germplasm over a long period of time. There is another limitation of this method that all seeds cannot survive at such ultra-low temperature. In this storage method, freezable water in seed is replaced with sugars or glycol, the cryogenic protective compounds, which avoid injury to stored seeds.

5.7. Seed Quality Standards

Seed quality is the possession of seed with required genetic and physical purity that is accompanied with physiological soundness and health status. The major seed quality characters are summarized as below.

5.7.1. Physical Quality

It is the cleanliness of seed from other seeds, debris, inert matter, diseased seed and insect damaged seed. Seed is considered of good physical quality if it has uniform size, weight, and colour and is free from stones, debris, dust, leaves, twigs, stems, straw, and other crop seeds. Moreover, it should not contain shriveled, diseased, mottled, discoloured, damaged and empty seeds. The seed should be easily identifiable as being seed of a specific species. Lack of this quality character will indirectly influence market value, establishment in the field and planting value of seed.

5.7.2. Genetic Purity

It depicts the true to type nature of the seed, *i.e.* the seedling/plant from the seed should resemble its mother plant in all aspects. This quality character is important for achieving the desired goal of raising the crop, *i.e.,* either yield, resistance or quality traits.

5.7.3. Physiological Quality

It is the actual expression of seed in further generation/ multiplication. Physiological quality characters of seed comprise of seed germination and seed vigour. The liveliness of a seed is known as viability. The extent of liveliness for production of good seedling or the ability of seed for production of seedling with normal root and shoot under favourable condition is known as germinability. Seed vigour is the energy or stamina of the seed to produce elite seedling. It is the sum total of all seed attributes that enables its regeneration under any given condition(s). Hence, it is understood that all viable seeds need not be germinable but all germinable seed will be viable. Similarly, all vigourous seeds will be germinable but all germinable seed need not be vigorous. Physiological quality of seed could be achieved through proper selection of seed (mature seed) used for sowing and by caring for quality characters during extraction, drying and storage.

5.7.4. Seed Health

Health status of seed is nothing but the absence of insect infestation and fungal infection, in or on the seed. Seed should not be infected with fungi or infested with insect pests as these will reduce the physiological quality of the seed and also the physical quality of the seed in long term storage. The health status of seed also includes the deterioration status of seed, which is expressed through low vigour status of seed. The health status of seed influences the seed quality characters directly and warrants their soundness in seed for the production of elite seedlings at nursery/field.

5.8. Seed Testing

Seed testing is mandatory to evaluate the seed quality before storage as well as before packaging of seed for marketing. Seed testing can be performed as per described procedures of anyone of the two well-known seed associations, the Association of Official Seed Analysts (AOSA) and the International Seed Testing Association (ISTA). Seed testing should provide information regarding seed viability and purity. Although, vigour is more important than the viability alone, and should be mentioned for a seed lot, but generally, seed sellers do not mention seed vigour. Different steps in seed testing are as under.

5.8.1. Sample Collection

As seed lot is heterogeneous with respect to seed quality; therefore, proper seed sampling is necessary to have an exact idea of seed quality. Sample must be a true representative of the whole seed lot under observation. There are two steps in sampling. In first step, sample is collected from seed lot for submission to seed laboratory, known as submitted sample. In laboratory, submitted sample is further divided so that it can be subjected to analysis, and is termed as working sample. Submitted sample must be taken from both top and bottom of the container to cover both light and heavy seeds. Probes up to 180 cm long are used for sampling. If seeds are in six or less than six bags, each bag must be sampled. If number of bags is more than six, then sample is taken from five bags and 10% of the remaining bags, for example there are 100 bags in a lot, sample should be collected from 15 bags. But, this quantity will be too much to be submitted as a sample and must be reduced by subdivision without any biasness by using Boerner or Gamet dividers. Do not remove stones, damaged seeds or weed seeds during subdivision. In laboratory, submitted sample is further subdivided by pie method or by Boerner divider into working samples to have seeds for various tests. For basic viability (*i.e.* standard germination or tetrazolium) test, four replicates of 100 seeds (total 400 seeds) are recommended (AOSA 2003; ISTA 2004). The working sample for purity test must comprise of 2500 seeds. While, other tests to complement germination test require 200 seeds.

5.8.2. Purity Test

Seed purity indicates pure seeds, other crop seeds, weed seeds and inert matter on percentage basis. Pure seed is the actual seed of the concerned specie/cultivar. Other crop seed should be less than 5%. Any material, like stone, pieces of stem and pods, broken and damaged or immature seeds, in a seed lot other than seed (living material) is regarded as inert matter. Sometimes genetic purity of seed is also tested using morphological characteristics, chemical assays, chromosomal counts, ELISA, and PCR techniques.

5.8.3. Viability Test

The most obvious purpose of seed testing is to provide information regarding its germination potential. Standard germination test provides the planting value of seed in terms of percentage. Only pure seeds are used for germination test. At least, 400 seeds are used in four replicates, *i.e.,* 100 in each replicate. Duration of germination test varies among species; some require a week while others require two to three week. Seedlings are separated into normal and abnormal seedlings. Non-germinated seeds should be evaluated for dormancy. If proportion of dormant seed is high, seed must be treated to break dormancy, for example pre-chilling or treatment with potassium nitrate (0.1 to 1.0%) solution.

5.8.4. Vigour Tests

A standard germination test indicates the ability of seeds to produce normal seedlings under optimal or near-optimal conditions but does not provide information at sub-optimal or unfavourable conditions. Seed vigour denotes those properties of seed that determine its potential for rapid and uniform emergence and development of normal seedlings under a wide range of field conditions. Each seed sown in field, plug cell or nursery bed, must germinate rapidly to give rise to a uniform crop stand. Plug trays of annual flowers or nursery pots are acceptable by buyers if 100% filled. Therefore, vigour testing has become very important these days. A vigour test must indicate the deterioration in seed through quantifiable parameters. Vigour can be evaluated using biochemical markers (Tetrazolium and electrolyte leakage tests), germination test performed by imposing stress (cold test, ageing tests, and thermal gradient germination), assessment of germination speed (rate of germination and seedling emergence), and seedling growth rates (seedling size and vigour index).

5.9. Seed Certification and Marketing

Seed certification is a legally sanctioned system for quality control of seed production and multiplication (Arya 1999). The main purpose of seed certification is to maintain and make available high quality seed and propagating materials of superior cultivars to the public so as to grow and distribute with ensured genetic identity and genetic purity (Singh et al. 2006). Generally, seed certification process has four phases, which include: a) verification of crop cultivar/hybrid and its seed source, b) field inspections to confirm prescribed field standards, c) seed testing to verify prescribed seed standards, and d) appropriate tagging, labelling and proper sealing of seed packs. Field standards and seed standards may vary from crop to crop under certification and are prescribed by the seed certification agency or the appropriate authority set up for this purpose. Seed certification is the function of certification agencies (FSC&RD) and seed testing laboratories established under the Seed Act in the country (FSC&RD 2001).

The Federal Seed Certification and Registration Department (FSC&RD) is the main organization in the country responsible for seed quality control, certification and law enforcement. The Department is attached to the Ministry of National Food Security and Research, and performs its regulatory functions through its 28 laboratories located in various parts of the country. All seed quality control activities have been enforced under the legal framework of the Seed Act, 1976. Seed (Truth-in-Labeling) Rules (1991), were also introduced under the same Seed Act to encourage the emerging private sector. Two new bills; Seed Amendment Bill (2009), to enhance participation and investment of private sector in seed industry and safeguard farmers interest; and Plant Breeders Rights Bill (2009), to encourage plant breeders/seed organizations/multinational seed companies to invest in research and plant breeding and develop superior cultivars of field, vegetable and ornamental/horticultural crops have been proposed, and are still under process. Seed certification is compulsory for domestic production of the notified crop varieties/cultivars, registered and approved either by the National Seed Council or Provincial Seed Councils. Four classes of seed are recognized in the system: Pre-basic, Basic, Certified and Approved seed. The quality of all these classes is controlled by the FSC&RD. Seed quality control is mainly based on crop inspection and laboratory testing to ensure that the seed meets minimum standards laid down in the regulations. The FSC&RD plays a key role in maintaining quality at all stages of seed production. Pakistan has not been able to produce enough quantity of vegetable seed for the growers. Presently, Pakistan is spending millions of rupees to import seed of different vegetables, potatoes, and flowers. Under the Seed (Truth-in-Labeling) Rules (1991), private sector was allowed to import and export seeds. The FSC&RD is also authorized to regulate the quality of the seed imported and to be exported (FSC&RD 2001).

In past, cultivar development had been the domain of public sector plant breeders, either in research or teaching organizations. After developing the pre-basic seed, they passed it on to public sector seed agencies in their provinces. Almost 54 cultivars of different vegetables have been released, including 12 cultivars of potato, by the public sector research organizations of the country. Recently, some national and multinational firms have developed infrastructure to produce basic seed, with the permission of Ministry of National Food Security and Research, but these are mostly working on cash crops. The production of certified seed is also developing rapidly in the private sector.

In Pakistan, vegetables (except tuber crops) are grown on an area of about 490,000 ha that requires 9,198 tons of seed with a worth of 110.65 million US dollars. Tuber crops are planted on an area of about 120,000 ha that requires 242,800 tons of seed with a worth of 161.05 million US dollars. The statistics for floral crops is not available in the country. In 2007-08, about 6,176 tons seed of different vegetables (except potato) was locally produced and distributed. However, only 8,348 tons of seed potatoes were produced and marketed, which fulfilled just 2% of our seed requirements. Therefore, we are importing vegetable and flower seeds every year and spending millions of rupees, which is a huge burden on our foreign exchange. Statistics show that Pakistan imported 2,674 and 3,553 tons seeds of different vegetables worth of 763.53 and 1,085 million rupees during 2008-09 and 2009-10, respectively. Besides that, 308.48 and 545.0 million rupees were spent on import of seed potatoes during 2008-09 and 2009-10, respectively (Hussain 2011). During 2012-13, this value increased to 5177 and 4558 tons, for vegetable seed and potato, respectively (Rana 2014).

After 1994, there was a tremendous interest of private sector in seed business. Since then, the seed sector has flourished well and a large number of seed companies have been registered and there is a tremendous boost in supplying certified seed to the growers. Presently, in private sector there are 720 national seed companies involved in seed distribution throughout Pakistan. Among these, 600 are in Punjab, 91 in Sindh, 20 in Khyber Pakhtunkhwa, 7 in Balochistan and 2 in Gilgit Baltistan. There are also 5 multinational companies (Monsanto, Pioneer, ICI, Syngenta and Bayer) and 4 public sector organizations involved in seed marketing in the country. In Punjab and Sindh provinces, the respective seed corporations are responsible for seed production and supply. The Agriculture Development Authority (ADA) in Khyber Pakhtunkhwa and the Department of Agriculture (DA) in Balochistan are responsible for managing seed supply in these two provinces (Hussain and Bhutta 2002).

The public sector failed to produce enough quantity of vegetable seed to meet the seed demand from the vegetable growers. In Pakistan, seed production is carried out both by the public and private sectors. The Government no longer controls seed prices in the market and various companies price seed differently based upon their own specific production and procurement circumstances. The private sector prices are invariably higher than the public sector and every company has a different price for the same vegetable or flower seed. Imported seed is much more expensive than that produced locally. Seed imported by multinational companies are sold at around 4-5 times the price of locally produced open-pollinated cultivars.

Now a day, vegetable cultivation and flower production is heavily reliant on imported hybrid seeds as local agricultural research organizations have been unable to manage production of such seeds. Hybrid vegetable and flower seeds are mostly imported from India, Thailand, USA and Malaysia, and a huge amount is spent every year on such imports. During the recent years, due to trend in off-season vegetable production/tunnel farming and interest in commercial flower production, there exists a tremendous potential for growth in the seed market and import of hybrid seed has been increased, which is more expensive than the seed of regular cultivars. But now, Ayub Agriculture Research Institute is releasing first indeterminate tomato hybrid, which seems to be a good initiative of public sector.

Recently, Government of the Punjab took initiative to promote kitchen gardening in the province. The provincial Department of Agriculture (Research Wing) is responsible to procure vegetable seeds, while Extension Wing of the same has been given the task to create awareness and provide seeds to the gardeners/growers. Seed packets of winter and summer vegetables separately, each containing seeds of six to ten vegetables, which are enough for sowing 5 to 10 marlas, are being distributed with a subsidized price of Rs. 50 only.

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