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Review Article: Principles and Practices of Certified Seed Production

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Abstract

The genetic purity in the commercial seed production is maintained through a system of seed certification. Seed certification implies that the crop and seed lot have been duly inspected and that they meet requirement of good quality pedigree seeds. To achieve this purpose, qualified and well-trained personnel of seed certification agencies carry out field inspection at appropriate stages of crop growth. They also make seed inspections to verify that the seed lot is of the requisite genetic purity and quality. In addition to inspections, seed certification agencies also lay down the field and seed standards which the seed crop and seed lot respectively must conform to get approval as certified seed. The field standards include land requirements, isolation requirements, maximum permissible off-types etc. Thus, seed certification programs, along with foundation seeds tock programs, provide a vital link between plant breeders who develop public (and some private) crop varieties and farmers or other users who plant them.

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Introduction

Seed certification is a quality control system whereby seeds and propagating materials of improved crop varieties are maintained at a high level of genetic purity and made available to the public. It is a legally recognized program for increasing small quantities of seed of genetically pure varieties into large supplies adequate to meet the demands for planting. The genetic purity in the commercial seed production is maintained through a system of seed certification. Seed certification implies that the crop and seed lot have been duly inspected and that they meet requirement of good quality pedigree seeds. Production of genetically pure and otherwise good quality pedigree seed is an exacting task requiring high technical skills and comparatively heavy financial investment. During seed production strict attention must be given to the maintenance of genetic purity and other qualities of seeds in order to exploit the full dividends sought to be obtained by introduction of new superior crop plant varieties. In other words, seed production must be carried out under standardized and well-organized condition.

Seed certification is a legalized program that applies different practices and principles to the production of specific seed-propagated plant cultivars to ensure the maintenance of seed purity. The system was established in the United States and Canada during the early 1920s to regulate the commercial production of new cultivars of agricultural crops then being introduced in large numbers by state and federal plant breeders (McDonald *et al.,* 1986). The principles (as described for the pedigreed stock system) and accompanying regulations of seed maintenance were established through the cooperative efforts of public research, extension, regulatory agencies, and seed-certifying agencies known as Crop Improvement Associations, whose membership included commercial producers.

These organizations were designated by law through the Federal Seed Act (1939) to conduct research, establish production standards, and certify seeds that are produced under these standards. Individual state organizations are coordinated through the Association of Official Seed Certifying Agencies (AOSCA) in the United States and Canada. Similar programs exist at the international level where certification is regulated through the Organization for Economic Cooperation and Development (OECD).

The principal objective of seed certification is to provide standards to preserve the genetic qualities of a cultivar. Other requirements of seed quality also may be enforced as well as the eligibility of individual cultivars. The seed-certifying agency may determine production standards for isolation, maximum percentage of off-type plants, and quality of harvested seed; make regular inspections of the production fields to see that the standards are being maintained; and monitor seed processing.

Principles and practices of Quality Seed Production of Certified Seed

Use of quality seed of improved variety of notified variety of hybrids is a basic input in cultivation of any crops as it ensures high crop stand, vigorous and healthy crop growth and thereby it ensures high productivity of that crop. Use of certified seed assures the cultivators in getting quality seed, as certified seed production is subjected to the process of seed certification, and as per provisions of the seed Act only those seed lots which are offered for certification and which meet minimum certification standards are certified and other lots are rejected from certification.

Production of certified seed of any notified variety or hybrids or parental lines of hybrids requires technical knowledge of the principals' involved and timely adoption of provisions of seed certification.

It is therefore essential for the seed producer to acquaint with the principles of certified seed production. Certified seed production can be undertaken for foundation stage (for varieties, and inbred or parental lines of hybrids) and for certified stage for only notified varieties and hybrids.

Before undertaking certified seed production either of foundation or certified stage, it is necessary to get well acquainted with the basic principles of seed production and formalities required to be completed.

Genetic Principle

Deterioration of varieties

Genetic purity (Trueness to type) of a variety can deteriorate due to several factor during production cycles. The important factors of apparent and real deterioration of varieties are as follows:

Developmental variation

When the seed crops are grown in difficult environment, under different soil and fertility conditions, or different climate conditions, or under different photoperiods, or at different elevation for several consecutive generations, the developmental variation may arise some times as differential growth response. To minimize the opportunity for such shifts to occur in varieties it is advisable to grow them in their areas of adaptation and growing seasons.

Mechanical mixtures

This is the most important source of variety deterioration during seed production. Mechanical mixtures may often take place at the time of sowing, if more than one variety is sown with same seed drill; through volunteer plants of the same crop in the seed field; or through different varieties grown in adjacent fields.

Often the seed produce of all the varieties are kept on same threshing floor, resulting in considerable varietal mixture. To avoid this sort mechanical contamination it would be necessary to rogue the seed fields, and practice the utmost care during the seed production, harvesting, threshing and further handling.

Mutations

This is not a serious factor of varietal deterioration. In the majority of the case s it is difficult to identify or detect minor mutation.

Natural crossing

In sexually propagated crops, natural crossing is another most important source of varietal deterioration due to introgression to genes from unrelated stocks which can only be solved by prevention.

Natural crossing occurs due to following three reasons

Natural crossing with undesirable types.
Natural crossing with diseased plants.
Natural crossing with off- type plants.

Minor genetic variations

Minor genetic variations may exist even in the Varieties appearing phenotypically uniform and homogeneous at the time of their release. During later production cycle some of this variation may be lost because of selective elimination by the environment.

To overcome these yields trials are suggested. Selective influence of diseases: The selective influence of diseases in varietal deterioration is also of considerable importance. New crop varieties often become susceptible to new races of diseases often caused by obligate parasites and are out of seed programmes. Similarly the vegetatively propagated stocks deteriorate fast if infected by viral, fungal and bacterial diseases. During seed production it is, therefore, very important to produce disease free seeds/stocks.

Techniques of plant breeders

In certain instances, serious instabilities may occur in varieties due to cytogenetically irregularities not properly assessed in the new varieties prior to their release. Other factors, such as break down in male sterility, certain environmental conditions, and other heritable variations may considerably lower the genetic purity.

Agronomic principles

Selection of an Agro-climatic Region

A crop variety to be grown for seed production in an area must be adapted to the photoperiod and temperature conditions prevailing in that area.

Selection of seed plot

The plot selected for seed crop must be free from volunteer plants, weed plants and have good soil texture and fertility the soil of the seed plot should be comparatively free from soil borne diseases and insects pests.

Isolation of Seed crops

The seed crop must be isolated from other nearby fields of the same crops and the other contaminating crops as per requirement of the certification standards.

Preparation of Land

Good land preparation helps in improved germination, good stand establishment and destruction of potential weeds. It also aids in water management and good uniform irrigation.

Selection of variety

The variety of seed production must be carefully selected, should possess disease resistance, earliness, grain quality, a higher yielder, and adapted to the agro climatic conditions of the region.

Seed treatment

Depending upon the requirement the following seed treatment may be given a. Chemical seed treatment.

Bacterial inoculation for the legumes.

Seed treatment for breaking dormancy.

Time of planting

The seed crops should invariably be sown at their normal planting time. Depending upon the incidence of diseases and pests, some adjustments, could be made, if necessary.

Seed Rate

Lower seed rates than usual for raising commercial crop are desirable because they facilitate rouging operations and inspection of seed crops.

Method of sowing

The most efficient and ideal method of sowing is by mechanical drilling.

Depth of sowing

Depth of sowing is extremely important in ensuring good plant stand. Small seeds should usually be planted shallow, but large seeds could be planted a little deeper.

Rouging

Adequate and timely rouging is extremely important in seed production. Rouging in most of the field crops may be done at many of the following stages as per needs of the seed crop.

Vegetative / preflowering stage

Flowering stage

Maturity stage

Supplementary pollination

Provision of honey bees in hives in close proximity to the seed fields of crops largely cross pollinated by the insects, ensure good seed set thereby greatly increase seed yields.

Weed control

Good weed control is the basic requirement in producing good quality seed. Weeds may cause contamination of the seed crop, in addition to reduction in yield:

Disease and insect control

Successful disease and insect control is another important factor in raising healthy seed crops. Apart from reduction of yield, the quality of seeds from diseased and insect damaged plants is invariably poor.

Nutrition

In the nutrition of seed crops, nitrogen, phosphorus, potassium, and several other elements play an important role for proper development of plants and seed. It is, therefore, advisable to know and identify the nutritional requirements of seed crops and apply adequate fertilizers.

Irrigation

Irrigation can be important at planting for seed crops on dry soils to ensure good uniform germination and adequate crop stands. Excess moisture or prolonged drought adversely affects germination and frequently results in poor crop stands.

Harvesting of Seed crops

It is of great importance to harvest a seed crop at the time that will allow both the maximum yield and the best quality seed.

Drying of seeds

In order to preserve seed viability and vigour it is necessary to dry seeds to safe moisture content levels.

Storage of raw seeds

The best method of sowing seed for short periods is in sacks or bags in ordinary buildings or godowns.

Practices in Producing Certified Seed

Planning

First time certified seed producers should visit with their local county extension agent, certified seed conditioning plant manager, state seed certification agency or other certified seed producers for suggestions. Obtain a copy of your state's Seed Certification Standards from a local county extension agent or the state seed certification agency. All requirements and standards of certified seed production are in this standards publication. If possible, select a field for certified seed production the preceding year. This allows time to reduce weeds, volunteer crops or other potential problems.

Choose a field free of noxious weeds and infestations of other weeds. If this is not possible, use fall-applied herbicides to control weeds such as Canada thistle, field bindweed, and perennial sow thistle.

Field bindweed plants that are setting seed and leafy spurge are not allowed in seed fields. Do not plant a seed crop on land seeded to the same crop the previous year, unless the field is planted to the same kind and variety of crop and passed field inspection the previous year. Study NDSU test plot results and talk to local elevators, seed suppliers or your local extension agent to choose the certified seed variety to produce. Newer varieties are generally easier to market. In some cases the variety you pick may require special contracts. Be sure you know this ahead of time. When planning to plant foundation seed, order seed well in advance. The seed stock program may have limited amounts of seed for sale. Registered class seed is usually available from producers of registered seed or approved seed conditioning plants.

Seed Purchasing

Keep extra tags or a copy of your bulk certificate on file for each lot of seed purchased. You will need a tag or bulk certificate when you apply for field inspection application and one for a back Keep a sample of seed for at least a year to document quality of seed planted. Carefully examine samples of seed to be sure the seed is not contaminated with other crop or weed seeds. Bulk seed must be hauled, conveyed and stored in a manner that prevents contamination. Use clean storage facilities.

Planting

Carefully select fields for producing certified seed. Fields that were seeded with cover crops can be a source of contamination. Use a high pressure air hose and a strong vacuum cleaner to clean seeding and other seed handling equipment. Establish isolation strips at time of planting if needed. Isolation strips are needed if planting next to an inseparable crop. See your Seed Certification Standards for isolation details for each crop. Check everything added to the field for contamination. Make sure bulk fertilizer and granular herbicides mixes do not become sources of contamination. Disk opener drills and air drills have many places for seed to go undetected; be sure that all other seed is cleaned out.

Before Field Inspection

Complete and mail field inspection application forms, along with field inspection fee and tag or bulk certificate, to the state seed certification agency before application deadlines. Generally, there are different deadlines for early and late seeded crops. Check with your certification agency or county extension office for field inspection application deadlines. Application forms can be obtained from your local extension office or state seed certification agency. If you miss the deadline date it is still possible to have fields inspected prior to harvest, but late charges will be assessed. Control problem weeds before field inspection. Control means that the weeds will not set seed before harvest. Field bindweed is the greatest challenge to keep from setting seed by harvest. Have prohibited noxious weeds under control. Rogue (this means removed from field; not just pulled and thrown on the ground) undesirable plants (examples: barley in HRSW or durum in barley) from the field. Correct problems before the inspector arrives. If possible, walk the field with the field inspector. Inspectors are a good source of information on weed identification, diseases and other problems you might encounter. Contact your field inspector, the state seed certification agency or your local county extension agent when you have a question or problems that require correcting. Make sure your fields are inspected and pass before harvest.

Harvest

Use an air hose with good pressure and a vacuum cleaner to clean harvest and storage equipment. If while inspecting any part of the combine, trucks or bins you can tell what was harvested, hauled or stored in them previously, then you haven't done a good enough job of cleaning. Combines and handling equipment must be carefully cleaned. Grain hangs up on braces, augers, etc. Be prepared to shut down for three to four hours or more for proper cleaning. Some certified seed growers have modified their combines with trap doors at strategic locations (clean grain auger, unloading auger, etc) to save time during cleaning. Even after thorough cleaning many certified seed producers will take the first harvested round from a certified field and haul the grain to their elevator to be sold as grain, not seed. This may reduce the risk of contaminating seed. Growers who have contamination (i.e. a mixture of other crops or varieties) along the ends or sides of a field should not mix it with seed to be certified. Clean the combine thoroughly before harvesting seed acres or delay harvest of contaminated areas until the clean area is harvested for certified grain.

Seed Conditioning

Remember that having your field approved does not mean you have successfully grown certified seed. Several more steps remain in the process: Locate an approved seed conditioning plant. Not all seed conditioning plants are approved to condition certified seed. Find out if the plant has the equipment to handle and condition your kind of seed properly. Also check out the general housekeeping of the plant. This will give a good indication of how well the seed conditioning operation is managed. Keep samples of seed before conditioning. A good representative sample of the seed lot can help all parties answer the questions about contamination should that problem occur. Be sure you have clean storage for seed after conditioning. After certified seed is conditioned, it will most likely have to be taken back to the farm or some other warehouse for storage. Most conditioning plants do not have adequate on site storage to store grower's seed after conditioning. Keep samples of each conditioned lot of seed. A good representative sample of the conditioned seed lot can help all parties answer any problems in the lot of seed, such as germination, purity and other types of contamination.

Tags must be attached to bags of certified, registered or foundation seed. A bulk certificate must accompany each load of certified seed sold in bulk. Work with the seed conditioning plant manager; some of the items needed from the grower are: Field inspection report, listing any kinds of weeds in the field and any admixtures (i.e., barley in wheat) that were noted during field inspection. Review a sample of unconditioned seed with the conditioning plant manager.

Cost of conditioning seed at most seed conditioning plants it costs more to have certified seed conditioned than common seed. Reasons for these charges are conditioning certified seed involves more labor keeping mills and handling equipment clean to avoid contamination; it also requires more sampling and record keeping.

Marketing Your Seed

If you are going to sell seed from the farm, don't forget advertising and other costs. If you are contracting with a seed plant, work with the plant before planting the crop. Agree on variety and approximate number of bushels to be delivered. Select a fall date to lock in on price, typically $.50 to $.75 premium on net bushels. This will depend on supply and demand.

Sell a quality product. It takes years to build a good reputation for quality, but it takes only one bad lot to ruin years of hard work. Payment for seed. There is a cost involved in selling seed. Most producers you sell to are honest, but be prepared for bad checks and other payment problems.

Seed Certification Procedure

Seed certification is a legally sectioned system for quality control of seed during seed multiplication and production. Seed certification is a scientific and systematically designed process to secure, maintain, multiply and make available seeds of notified and released varieties to the farmers.

Good quality seeds refer to seeds having optimum genetic and physical purity, high germination percentage and seed with optimum moisture content. It also includes seeds free from noxious weed seed and other crop seeds and free from seed borne diseases. To meet these criteria there is a need of certification procedure.

Procedure of Seed Certification

Receipt and security of application with notarized agreement for registration of seed plot for certification.

Verification of seed source, class used for raising the crop by checking certification tags, lablels, seed containers, cash memo or bills.

Field inspections of the seed plot to verify conformity to prescribed field standards.

Post harvest supervision of seed crop including sealing raw seed, issue T.C. supervision during seed processing at registered seed processing plant.

Seed sampling and sending sample to STI for analysis to verify conformity to prescribed seed standards as well as genetic purity (field test).

Grant of certification, tagging and sealing of the containers – Release of seed lot for seed multiplication or marketing for commercial.

Classes of Certified Seeds

Breeder’s seed

That which originates with the sponsoring plant breeder or institution and provides the initial source of all the certified classes.

Foundation seed

Progeny of breeder’s seed that is handled to maintain the highest standard of genetic identity and purity. It is the source of all other certified seed classes but can also be used to produce additional foundation plants. Foundation seed is labeled with a white tag or a certified seed tag with the word “foundation.”

Registered seed

Progeny of foundation seed (or sometimes of breeder’s seed or other registered seed) produced under specified standards approved and certified by the certifying agency and designed to maintain satisfactory genetic identity and purity. Bags of registered seed are labeled with a purple tag or with a blue tag marked with the word “registered.”

Certified seed

Certified seed is produced from foundation, registered, certified, or other approved seed stocks. This seed is two generations from foundation seed. Certified seed cannot be used to produce certified seed again without the approval of the state certification agency which can approve production only under extreme conditions (Ulmer, 2010).

Seed Production Systems

Traditional seed selection of herbaceous plants utilized a portion of the seed from one year's crop to plant a crop for the next year. This system would be satisfactory for self-pollinated cultivars that are easy to maintain genetically. For cross-pollinated cultivars, knowledge of the production requirements of individual crops is needed and specific conditions are practiced depending upon the plant (3). Note, however, that inadequacies of this method led to its replacement by the pedigree system.

Pedigreed Stock System (McDonald, *et al.,* 1986) Commercial seed production of most self-pollinated and cross pollinated lines is carried out in three steps. The purpose of a pedigreed stock system is to maintain genetic purity through consecutive seed generations following appropriate standards of isolation, inspection, and rouging (with high costs) at the initial release with decreased standards (and lower costs) in the distribution of commercial seed. The overall program includes three phases. Phase 1 includes the development phase, which ends with the production of a small quantity of seeds (breeder's seed) that is maintained by the originating institution as the primary reference for the cultivar. Phase 2 is a maintenance phase in which a quantity of seed called foundation seed (for certified seed classes) or stock seed (in commercial enterprises) is maintained under high standards of isolation, inspection, and rouging. Phase 3 is the *distribution* phase, which may include two steps*:* a second-generation increase block and a *third-generation* block to produce commercial seed for distribution to the public. A foundation planting originates only from breeder's seed or another foundation planting. An increase block originates only from a foundation seed or another increase planting. A seed production planting originates from foundation seed or increase block seed. This entire production process is carried out either by large commercial firms or groups of independent growers joined within a Crop Improvement Association to produce certified seed.

Control of Genetic Variability during Seed Production

Isolation

Isolation is used to prevent mechanical mixing of the seed during harvest and to prevent contamination by unwanted cross-pollination with a different but related cultivar. Isolation is achieved primarily through distance, but it can also be attained by enclosing plants or groups of plants in cages, enclosing individual flowers, or removing male flower parts (i.e., de-tasseling corn) and then manually applying pollen of a known source by hand or various other devices. On a large scale, this goal can be achieved by using male-sterile parents (Lasa *et al.,* 1993). In a number of crop species [e.g., tobacco *(Nicotiana)* and onion *(Allium)*], specific genes have been identified that prevent normal formation of the male (pollen) reproductive structures. This means that no viable pollen is produced. The most common form of pollen sterility is cytoplasmic male sterility, which is a complex interaction between nuclear and mitochondrial plant genes (Chase, 2006b). Such traits can be bred into parental lines of specific cultivars for the production of hybrid seed. Using molecular biology to induce male sterility has also become a potential strategy to limit gene flow from transgenic plants into the environment (Chase, 2006a).

Self-pollinated cultivars of herbaceous plant species need only to be separated to prevent mechanical mixing of seed of different cultivars during harvest. The minimum distance usually specified between plots is 3 m (10 ft.), but may be up to 50 to 65 m (150 to 200 ft.) depending on the degree of cross-pollination capacity in the crop.

For example, bell pepper is a self-pollinating crop but, given the opportunity, will cross-pollinate to a high degree from bee pollinators. Careful cleaning of the harvesting equipment is required when a change is made from one cultivar to another. Sacks and other containers used to hold the seed must be cleaned carefully to remove any seed that has remained from previous lots. More isolation is needed to separate cultivars cross-pollinated by wind or insects. The minimum distance depends on a number of factors:

The degree of natural cross-pollination

The relative number of pollen-shedding plants

The number of insects present

The direction of prevailing winds

The minimum distance recommended for insect pollinated herbaceous plant species is 0.4 km (1⁄4 mi) to 1.6 km (1 mi). The distance for wind-pollinated plants is 0.2 km (1⁄8 mi) to 3.2 km (2 mi), depending on species.

Effective cross-pollination usually can take place between cultivars of the same species; it may also occur between cultivars of a different species but in the same genus; rarely will it occur between cultivars belonging to another genus. Since the horticultural classification may not indicate taxonomic relationships, seed producers should be familiar with the botanical relationships among the cultivars they grow. It is also important to isolate GMO (genetically modified organisms) crops from non-GMO seed crops of the same cultivar or species.

Rouging

The removal of off-type plants, plants of other cultivars, and weeds in the seed production field is known as rouging (Laverack, *et al.*, 1995). During the development of a seed-propagated cultivar, positive selection is practiced to retain a small portion of desirable plants and to maximize the frequency of desirable alleles in the population. During seed production, rouging following visual inspection exerts selection by eliminating the relatively small population that is not "true to type," thus keeping the cultivar "genetically pure."

Off-type characteristics (i.e., those that do not conform to the cultivar description) may arise because recessive genes may be present in a heterozygous condition even in homozygous cultivars. Recessive genes arising by mutation would not be immediately observed in the plant in which they occur. Instead, the plant becomes heterozygous for that gene, and, in a later generation, the gene segregates and the character appears in the offspring. Some cultivars have mutable genes that continuously produce specific off-type individuals (Pearson, 1968). Off-type individual plants should be rogued out of the seed production fields before pollination occurs. Systematic inspection of the seed-producing fields by trained personnel is required.

Other sources of off-type plants include contamination by unwanted pollen due to inadequate isolation or volunteer plants arising from accidentally planted seed or from seed produced by earlier crops. Seed production fields of a particular cultivar should not have grown a potentially contaminating cultivar for a number of preceding years.

Weeds are plant species that have been associated with agriculture as a consequence of their ability to exploit disturbed land areas when cultivation occurs (Harlan, 1992). Some weed species have evolved seed types that closely resemble crop seeds and are difficult to screen out during seed production.

Seedling Progeny Tests

Planting representative seeds in a test plot or garden may be desirable to test for trueness-to-type. This procedure is used in the development of a cultivar to test its adaptability to various environments. The same method may be necessary to test whether changes have occurred in the frequency of particular genes or new gene combinations may have developed during seed increase generations. These changes can result from selection pressure exerted by management practices or environmental interaction. For example, intensive rouging may result in a genetic drift due to changes in the frequency of particular genes or gene combinations (Garrison, *et al.*, 1961). Shifts may also occur due to environmental exposure in a growing area which is different from the initial selection area. Seedlings of particular genotypes may survive better than others and contribute more to the next generation. If sufficiently extensive, genetic drift could produce populations of progeny plants that differ somewhat from those of the same cultivar grown by other producers. Or the cultivar may have changed from the original breeder's seed.

Problems can result if seed crops of particular perennial cultivars are grown in one environment (such as a mild winter area) to produce seed to be used in a different and more severe environment (such as an area requiring cold-hardiness). This situation has occurred, for example, with alfalfa (Garrison, *et al.*, 1961) where rules for production of forage crop seed in a mild winter area can specify only one seedling generation of increase.

Categories of Seed Propagated Cultivars and Species

Landraces

Historically, farmers throughout the world have maintained seed-propagated plants by saving selected portions of the crop to be used to produce the next cycle. These populations, called landraces**,** evolved along with human societies and are still found in some parts of the world (Teshome, 2001). These populations are variable but identifiable and have local names. This practice results in genetic populations adapted to a localized environment. Their inherent variability provides a buffer against environmental catastrophe and preserves a great deal of genetic diversity. Changes in cropping patterns have occurred during the 20th Century, particularly since about 1960. Many of the older populations around the world are being replaced by modern cultivars, which tend to be uniform and high yielding, particularly when grown in conjunction with high irrigation and fertility inputs. Sometimes, new cultivars lack adaptation to local environments. Although the trend has been to increase the world supply of essential food crops, concerns have been raised that a parallel loss of genetic diversity and germplasm has occurred. Exploration and conservation efforts have expanded to maintain these important raw materials for future use.

Cultivars

A cultivar is a uniform and stable plant population that possesses recognizably distinct characteristics. Stated another way, a cultivar is a plant population that shows a minimum of variation, that can be propagated true-to-type for at least one characteristic, and is unique compared to the wild species or other cultivars. The term variety is often used interchangeably with cultivar especially when describing flower and vegetable populations. Care should be taken not to confuse variety with the concept of a true botanical variety (*varietals* or *var*.) that describes a type of naturally occurring population. Categories of seed-propagated cultivars include open-pollinated, lines, hybrids, synthetic, F2, and clonal cultivars.

Open-pollinated cultivars

Open-pollinated cultivars can be maintained in cross-pollinated species that produce a relatively homogeneous population for specific traits important for production of that crop. Open-pollinated seed is often cheaper to produce compared to hybrid seed because they do not require hand pollination to maintain the cultivar. However, because open-pollinated cultivars are a genetically heterogenic population, they can be more variable than hybrids (Maynard, *et al.*, 1997).

Historically, many open-pollinated vegetable and flower varieties were maintained by families in their "kitchen gardens." Many of these varieties have since been maintained by generations of gardeners and local farmers and are being offered as heirloom varieties. The preservation and distribution of information concerning these varieties has been an objective of certain groups including Seed Savers Exchange, Inc., in Decorah, Iowa (Seed Savers, 2001). There are also numerous commercial flower and vegetable crops produced as open-pollinated cultivars including *Begonia*, marigold (*Targets*), cucumber (*Curcumas*), and squash (*Cucurbit*).

Lines result in seedling populations whose genotype is maintained relatively intact during consecutive generations. These may be maintained as self- or cross-pollinated lines. An important type of seed population in this category is the inbred line, which are mainly used as parents for later production of F1 hybrids.

Hybrid Cultivars include groups of individuals reconstituted each generation from specific parents. F1hybridsare the first generation of a planned cross. For seed production, they result from the cross between seedling populations of two or more inbred lines. When crossed with another inbred line, the result is a population of uniform, but heterozygous, plants. Often these populations exhibit greater vigor than the parents due to hybrid vigor (heterosis), depending on the combining ability of the parents. Hybridization is a means of "fixing" the genotype of the population similar to that described for self-pollinated lines. Hybrid lines were first produced in corn (*Zea mays*) but have since been applied to many agronomic, vegetable, and flower crops (Acquaah, 2008).

Hybrids may be produced between two inbred lines (single-cross), two single-crosses (double-cross), an inbred line and an open pollinated cultivar (top cross), or between a single-cross and an inbred line (three-way cross). Seeds saved from the hybrid population normally are not used for propagation line A population of seedling plants whose genotype is maintained to a specific standard in consecutive generations. Hybrid line A seedling population that is produced by cross-pollinating two or more parental lines. Because in the next generation, variability in size, vigor, and other characteristics may appear.

Synthetic cultivars are derived from the first generation of the open cross-fertilization of several lines or clones. For example, 'Ranger' alfalfa seed is made from intercropping five seed propagated lines that results in genetically distinct but phenotypically similar seedlings in the seeded crop. Other crops in this category include pearl millet (*Pennisetum glaucus*), bromegrass (*Bromus*) and orchard grass (*Dactylis*). F2 cultivars are derived for open-pollination of an F1 hybrid. Some flower crops, (*Petunia*, pansy (*Viola*), and *Cyclamen*) and vegetables (tomato and melon) can be maintained as F2 populations.

Clonal seed cultivars are maintained through apomictic seed production (Geneve, 2006). Apomixes occurs when an embryo is asexually produced and does not develop from fertilization of two gametes (Hanna, *et al.*, 1987). The result is a clonal copy of the parent plant. Apomixesis discussed in detail in Chapter 4. The degree of clonal seed production depends on whether the species has a facultative or obligate form of apomixis. In species with facultative apomixes, both apomictic and sexual seeds are produced, sometimes within the same seed. Bluegrass (*Poa pratensis*) falls into this category. Other species show essentially 100 percent obligate apomictic seed production. Examples include Bahia grass (*Paspalum notatum*) and buffelgrass (*Pennisetum ciliare*).

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