(1) FLOWER SEED PRODUCTION (slide number in parenthesis at time of presentation)

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Seed quality is defined as seed that is genetically uniform, highly viable, and free from seed-borne pathogens. (2) Recent advances in plug production technology have increased the demand for high vigor seed. Professional bedding plant and cut flower growers demand not only seeds with high viability, but ones that will yield a very high percentage of uniform seedlings. This high seed vigor requirement puts an additional challenge before the seed producer. (3) To see this difference, here is a picture of a typical plug flat at a bedding plant company.

Note the number of non-uniform seedlings in the flat. From the perspective of the bedding plant company, this flat is not marketable because consumers find the lack of uniformity unattractive. (4) Here is a table reflecting the % non-useable seedlings and the loss in value of the flat due to these seedlings.

For example, if 30% of the flat were non-useable seedlings and the plug had a potential value of $0.07, this would be a loss in potential revenue to the bedding plant company of $10.75. To meet this new challenge, the leading seed companies are investing research efforts in the production function. Continuous improvement of the production techniques is now seen as a necessary part of the production work.

(5) FLOWER SEED PRODUCERS

Compared to the production of agronomic and vegetable seeds, it is done in relatively small scale. (6) Most growers and home gardeners have little knowledge of the origins of their seeds. They buy seeds from seed distribution companies, which in turn purchase their seed supplies from breeding and production seed companies. In general, there are three categories of seed producers:

1. (7) Breeding companies. Because of the relative small scale of production and the high level of skills involved, many leading seed breeders set up their own production facilities where they can exercise full control of the production details. Most of these are greenhouse facilities specialized in the production of high valued bedding and cut flower seeds.
2. (8) Contract seed production companies. These companies are located in areas with favorable climates and long traditions of seed production activities. The greenhouse producers are usually seed growers themselves. Those that specialize in open field production often subcontract the production to other farmers in the

areas that they operate. They provide on site supervision of the production activities for the original contracting parties.

3. (9) Seed growers taking production contracts from either the breeding or contract production companies. These growers are usually not full time seed producers. Their main business is crop production. The greenhouse contract growers are normally in the ornamental business, and some of them are experts in one to a few specialty crops.

Taking these three categories of seed producers together, there are a large number of growers participating in flower seed production. (10) From a management standpoint, flower seed companies have the most direct control in their own proprietary production locations, and they can influence the quality of contract production through grower selection and the terms of the production agreements. Due to the vast diversity of crops required in different quantities, contract production is a necessary part of the seed business.

On an individual crop level, the production quantities for most flower seeds are small. (11) A typical seed crop ranges from a few benches in the greenhouse for begonia to a few hectares in the field for marigold. The high valued seeds of hybrid bedding plants and cut flowers are produced in units of grams or seed count, (12) whereas the less expensive, open-pollinated crops are produced in pounds and kilograms. A seed producer usually grows a range of seed crops in a single facility.

(13) PRODUCTION AREAS

The ideal location for greenhouse seed production is in the tropical highlands and the best place to produce an open-field seed crop is in an irrigated dessert. (14) The major areas for commercial production of flower seeds are listed in Table 1. (15) Most greenhouse operations set up by major breeding companies are located in the tropical highlands where weather conditions are favorable year round. These production areas supply the majority of the high valued bedding plant seeds (e.g. Impatiens, Petunia and Geranium) in the market today. In the last decade, significant amounts of seeds are also being produced in greenhouses located in Chile, China and India.

(16) For open field production, the most important production countries are France, Holland, the United States and Mexico. (17) Here you see Lompoc, California, one of the major areas for open field flower seed production. Increasing amounts of open field flower seeds are now being produced in China and some East European countries such as Hungary.

(18) In addition to a good climate, flower seed companies consider other factors to be important in the development of a stable seed production location. For example, seed companies will have to invest in land improvements, buildings, and specialized machines for producing and cleaning the seeds. They also must train a workforce particularly for hybrid seed production. To accomplish this often tedious and important process of hybridization, a workforce that has low labor costs is an advantage. The country must have a satisfactory transportation infrastructure to move to the production sites and move the seed from production site to export shipment elsewhere. Ease of communication is important so that the parent company can monitor issues with respect to decisions on the optimum procedures for seed harvest. Finally, the country must have

social and economic stability so there is assurance that disruptions in the flow of seed do not occur due to political uncertainties.

(19) SEED PRODUCTION PROCEDURES

A generalized flower seed production routine has the following components:

1. Parental plant culture
2. Genetic quality control
3. Pollination management
4. Seed harvest and seed extraction
5. Seed cleaning and conditioning

(20) Substantial differences exist between greenhouse and open field seed production, both in the scale of production and the amount of control over the production environments. For example, let's make a comparison seed production comparison between an F-1 hybrid flower crop such as Impatiens and an open-pollinated flower crop such as marigold. The amount of seed produced in the open-pollinated crop is large scale (kilograms) while the hybrid crop is produced on a small scale (grams). As a result, marigold is produced in the open field where large equipment can be used. In contrast, impatiens is produced in the greenhouse under labor intensive conditions. Since many hybrid crops are insect pollinated, they must be in insect-proof facilities so out-crossing does not occur. In the field, isolation requirements using either distance or geographic barriers such as hills/mountains or trees minimize out-crossing. Hybrid crops produced in the greenhouse can be grown under specific environmental control. Field produced crops require site selection so appropriate temperature and moisture conditions are optimal for crop growth. Most hybrid production requires hands-on culture for pollination and this is conducted under proprietary production practices while the open pollinated crops are generally produced under grower contracts with the seed company who monitors their quality control.

As a result of these differing production practices under greenhouse and open field production, it is convenient to discuss methods used in these two types of production separately.

(21) Greenhouse Production of Hybrid Seeds. Most hybrid flower seed crops are produced in greenhouses. The capital requirement for building suitable facilities is high, and the work is labor intensive. In return for these investments, the producer gains protection from the elements, and some flexibility in crop scheduling. Given the correct training programs, the labor pool can provide valuable human resources to ensure reliable high quality hybrid seed production. Since the scale of production for each hybrid crop is typically small, close monitoring of plant development on a daily basis is possible.

(22) Parental plant culture. In principle, cultural handling of greenhouse-produced seed crops follows established guidelines for commercial bedding plants or cut flowers. However, most of the available published references are based on crop production in temperate climates, using largely peat-based growing mediums. When the production is done in areas where peat moss is not readily available, especially in the tropics, these cultural guidelines are not directly applicable. A key initial study in developing seed production programs in these areas is identifying a workable growing medium utilizing

inexpensive components available locally. Coconut fibers and rice hulls are useful medium ingredients. Other organic materials and volcanic rocks are also included in these soil mixes. The use of different growing media greatly affects the irrigation and fertilization regimes because of differences in water- and nutrient-holding capacities. The growers in each production location have to develop unique irrigation and plant nutritional programs according to the soil mix being used and the climatic conditions of the area.

(23) Parent plants of most hybrid flower seeds are raised from seed. The seeds are sown in seedling flats or plug trays in a specialized section of the greenhouse serving as the nursery. Parents of male sterile lines, for example some Impatiens and Petunia varieties, are propagated by vegetative cuttings. Tissue culture propagated plants are sometimes used for special parent lines of Primula and Dianthus. These plants are also raised in the nursery. When a hybrid is produced from a cross between a seed- and a vegetative-raised parent, the timing in starting the plant materials has to be adjusted to ensure synchronization of flowering.

(24) Well-developed young plants are transplanted into pots and put on benches in the production greenhouses. In this example, you can see a bench of Matthiola plants place in pots on benches in a greenhouse. (25) The types of pots commonly used include heavy-gauge plastic bags, thin-walled plastic pots and thick-walled Styrofoam pots. The size of the containers chosen is crop dependent, with five to ten liter capacities being the most widely used. Traditional greenhouse benches can be made from wood or metal frames. Some benches are specially designed to facilitate easy access to the plants during pollination and seed harvest.

(26) Plant nutrition, disease control and pest management are the most important components in parental plant culture. Most seed producers have professionally trained horticulturists on staff to manage these functions. Regular soil and foliar analyses are used to provide data to guide nutritional management. Each location tends to develop its own unique fertilizer programs based on the environmental conditions and grower experience. Generally, there is a lack of research information as it pertains to plant nutrition and seed yield/quality.

(27) Integrated pest management routines are commonly used for effective insect and disease control. The soil medium, growing spaces and containers are sterilized in between crops. Crop scouting is a daily routine. Yellow sticky boards are widely used in the greenhouses to detect potential build up of insect pests. Fungicide applications are used to control fungal disease. Virus- and bacteria-infected plants are taken out once symptoms are found on the plants. Many flower seed producers also disinfect stock seeds by surface sterilization or hot water treatment if they suspect seed-borne pathogens.

(28) Genetic quality control. Genetic purity tests are conducted on stock seed lots and only seeds of high genetic purity are used in production. When the parent plants begin to flower, they are further checked for the presence of off-types. Roguing is based on plant habit, foliage color, earliness to flower, flower color and flower form as some of the key features. All greenhouses used for hybrid seed production are equipped with insect-proof screens to prevent accidental pollination by insects from the fields.

(29) Pollination management. Pollination is the most essential part of seed production. It defines both the seed yield and genetic purity aspects of the commercial seeds. For hybrid seed production, pollination work is very labor intensive and requires the most training. Consequently, it is also the most expensive part of the production process. The pollination process consists of three separate steps: 1) pollen collection, 2) emasculation, and 3) pollination. Detailed procedures vary greatly between crops depending on their unique flower morphology and flowering behavior.

Pollen collection can be a simple procedure for plants that shed large quantities of loose pollen grains. For cyclamen, the flowers can be shaken by a mechanical device and the pollen collected on a flat dish or in a glass vial. For up-facing flowers like marigold, pollen can be harvested by a suction device. Some production facilities have installed centralized vacuum pumps to allow pollen collection by suction in the entire greenhouse as shown here. The anthers of some flowers can be collected prior to anthesis. These anthers are then dried, ground, and pollen grains extracted from the remaining tissue by sieving. This method has been successfully applied in Petunia and Snapdragons.

The stage of flower development at the point of anther collection, and the anther drying conditions are major factors influencing pollen yield and quality. Extracted pollen can be cold-stored and used for weeks and months. The pollen should be held in air-tight containers such as glass vials during cold storage in frostless freezers to maintain proper pollen moisture content. When pollen quantities are limited, inert materials can be added to allow pollination of a large number of flowers.

(30) Emasculation is the process by which the anthers of each flower in the female parent line are manually removed. Next to genetic purity of the parental plants, this is the most important factor in obtaining genetically pure commercial hybrid seed. In order to completely prevent selfing, emasculation must be carried out prior to anthesis, usually in the young bud stage. The petals are gently peeled back to expose the immature anthers, which are removed by hand. This process requires a great deal of precision and care, as the flower organs are very small and any damage to the stigmas will result in poor seed set. Some female lines of Petunia and Snapdragon are male-sterile. Since no pollen is produced by the male sterile flowers, emasculation is not required.

(31) The flowers are ready for pollination one or two days after emasculation. Flower to flower pollination is practiced when fresh pollen is applied. Either the entire flower (e.g. Impatiens) or the filament with the dehisced anthers attached from the male parent is held by hand and the pollen contents smeared onto the exposed stigma of the female flower. For crops pollinated with extracted pollen, the pollen is placed on the stigmatic surfaces by means of a brush as seen here.

Identifying the correct location of the stigma requires training. The receptive surface is located at the tip of the gynoecium for most flowers. In a pansy flower, however, it is found on the lower side of the globular head of the stigma. The timing of pollination is important for seed yield. Optimal seed set is obtained when the flowers are pollinated at the peak of stigma receptivity.

(32) Seed harvest. Subsequent to successful pollination, the seed develops and matures on the mother plant. Because of the small scale, most greenhouse produced seeds are hand-picked seed pod by seed pod. Determining the correct stage of seed development for seed harvest is the first consideration. Immature seeds are usually low in seed vigor.

Harvesting the seeds too late allows the inclusion of deteriorated seeds. The timing of harvest may also influence the proportion of seeds with primary or secondary dormancy in the population.

Traditionally, seeds are harvested close to the time of seed dispersal, i.e. when the seed pods are dry and cracked open, or when the fruits are soft in the case of fleshy berries. Seeds are considered mature at the point of maximal dry weight accumulation (physiological maturity) and there may be a strong link between chlorophyll degradation and seed vigor. Physiologically mature seeds are desiccation tolerant as they progress into a quiescent state. All sizable greenhouse seed production facilities are equipped with proper seed drying devices such as heated drying chambers. After the seed pods are dried, the loose seeds are separated from other plant parts by sieves. Seed pods that are hard and do not break open naturally are crushed mechanically before the sieving process.

(33) Seed cleaning. There is little field debris in greenhouse produced seed lots. Seed cleaning is generally a simple process and involves mainly removing the very small or light seeds in order to improve the overall quality of the seed lot. Hand screens and small air columns are commonly used to remove the small amounts of plant parts and small seeds.

(34) FIELD PRODUCTION OF OPEN POLLINATED VARIETIES

There are substantial differences between the management of open field and greenhouse flower seed production. Most of the crops produced in the field are open-pollinated varieties, though hybrids with self-incompatible parents can also be produced. Unlike greenhouse production which can be a year-round activity, outdoor production is seasonal. Identifying locations with suitable climates and producing the crops in the appropriate season are keys to reliable seed supply. There are generally less precise controls in crop management. The following discussion represents some of the unique features and challenges of open-field flower seed production.

(35) Site Selection. Site selection is probably the most important factor in outdoor seed production. The production area should provide the required period of appropriate temperature and moisture conditions for the parent plants to develop and the seeds to ripen fully. There should be a dry period at harvest to allow field drying. The soil type is also an important factor in site selection. Some crops, e.g. Pansy, tolerate heavy soils while others, e.g. nasturtium, only do well in well-drained fields. One should consider the crop history of the plot as well as crops being grown in the neighboring fields to make sure that insect pests and diseases (especially seed-borne diseases) can be avoided.

(36) Isolation distance. In the open field, pollination is done by wind or insects, depending on the specific floral morphology and properties of the crop species. These natural means of pollen transfer are random in nature. Varieties of the same species will inter-cross with each other. To ensure varietal purity, care has to be taken that different seed crops of the same species are not grown closely together. The isolation distance requirements generally range from 360 to 720 meters or more, depending on whether the crop is mostly insect- or wind-pollinated. The topography of the production site, as well

as the direction of prevalent winds should be considered when determining how far different varieties of the same species should be separated from each other. Some crops, like sweet pea, have flower structures that allow self-pollination as the flowers develop and mature. For this reason, different varieties of these crops can be produced as close as 100 meters apart. Seed producers have to keep the required isolation distances in mind when they plan the placement of production fields. Different seed companies operating in the same production area normally exchange information on their production plans prior to planting so that unintended cross pollination does not occur.

(37) Crop culture. After field preparation, stock seeds are sown directly in the production plots. Some growers raise the young plants in a propagation area before transplanting the young plants into the production fields. The parent plants are usually grown in beds to facilitate irrigation, fertilizer application, and fungicide and insecticide sprays. The plants are checked for genetic uniformity when they begin to flower. Removal of off-types in the population is an intensive activity. This is usually accomplished by a seed company representative possessing detailed knowledge of variety characteristics. A few rounds of roguing are often necessary to ensure high genetic purity because not all plants begin to flower at the same time. Weed control is another labor-intensive aspect of field production. If left uncontrolled, weeds lower seed yield due to competition for nutrients. The presence of weed seeds also complicates the seed cleaning process, and noxious weeds, if not removed, can make the seed lot unmarketable. There is an increasing use of plastic mulches in seed production fields for weed control and moisture conservation.

Good seed yield and quality occur when the environmental conditions are favorable for optimum parent plant growth. Low vigor plants resulting from erratic irrigation and fertilization management are more susceptible to diseases and pests.

(38) Pollination. Pollination management for open pollinated crops begins with selecting production locations naturally conducive to good seed set. Optimum climactic conditions must fit the crop's temperature and light requirements for flowering, pollen production and stigma receptivity. Insect-pollinated crops are best placed in locations where natural pollinator populations are high. In marginal cases, bee hives can be placed in production fields to increase pollination activity.

Note the silver bee hive boxes adjacent to this Gazania field. Honey bees are the most common pollinators. Other commercially available insect pollinators include bumble bees, leaf-cutter bees and flies. Application of fungicides and insecticides during the flowering period can negatively affect seed set. Some pesticides and fungicides cause damages to the stigma and interfere with pollen tube development. Insecticides commonly used for insect pest control also kill pollinating insects and potentially lower seed yield.

(39) Harvest and Drying. Many popular bedding plant varieties continue to flower and set seed over a long period if the environmental conditions are favorable. Since the seed is harvested only once in the field, determining the proper time to harvest is a critical decision and is based on a compromise between optimum yield and potential seed

quality. The onset of unfavorable climatic conditions, such as a rainy season or cold weather, also defines when the crop must be harvested. With the exception of very small production plots and production in countries with low labor costs, harvesting is done by machines. When the crop is judged ready for harvesting, the plants are cut and placed on canvas tarps to dry in the field. The dried plant materials are threshed by a commercial combine. Here is an example of Alyssum being moved from a trap in the field and threshed with a combine.

There are also custom-made harvesting machines for special crops. (40) This picture shows a vacuum harvester used by PanAmerican Seed for crops like marigold and gazania. The field-harvested seed is partially cleaned by scalpers in the open air before being transported to the seed company mill. A crop that is harvested too early may germinate well initially, but the seed does not store well. It will also be high in seed moisture content and require further slow drying. (41) Seed drying of flower seed can be accomplished using a tunnel dryer as seen here. (42) In other cases, the seed cannot be threshed from the parent plant with a combine because the plant is too green and moist. In those instances, the entire plant is harvested with the seeds and a rotary dryer used to first dry the plant and subsequently thresh the seeds from the dried plant material.

(43) Seed cleaning. Field-grown seed contains substantial debris, from less than 20% to over 80% by volume, depending on the crop and the harvest method. The seed of low growing plants harvested at the soil line, e.g. alyssum, contains more field dirt. To remove this debris, the harvested seed is first put through an air-screen cleaner, which is the most widely used equipment for removing both plant parts and soil particles. (44) Additional size separation by screening machines and density separation by gravity table or (45) air column may be needed before the seed is cleaned to a commercially acceptable level. After the initial removal of plant and field debris, additional rounds of seed cleaning are required if the seed contains outer coat structures that impede singulation in packaging and sowing, or water uptake during germination. It is customary to remove hairy layers on the seed coats of Gazania and other seeds. The tail-like structure of Marigolds is removed to facilitate sowing by automatic seeders. Seeds with hard seed coats (e.g. Pelargonium) are routinely scarified. Proprietary procedures are developed by different seed companies for each of these situations.

(46) Review. F-1 hybrid flower seed and open-pollinated crops have differing approaches to seed production. These are contrasted in the following ways:
Crop Culture. F-1 hybrids are produced in greenhouses where they are grown as potted plants with structured regimes that include irrigation, fertilizer application, pest/disease control and, because they are grown in the greenhouse, there is more flexible time to produce the crop. Open-pollinated crops are typically produced in the field, grown as most field crops where the environment is less predictable causing less structured cultural routines and seasonal start/finish dates.

(47) Pollination. F-1 hybrids are hand pollinated, a practice that requires collection of pollen, its storage, emasculation of flowers, and pollination where the timing, tools, and mechanism are important to minimize flower damage and maximize successful hybridization. Since these practices occur in controlled greenhouses, there are no crop

isolation requirements. Open-pollinated crops are insect or wind pollinated. When the former, placement of beehives can be helpful. In both cases, crop isolation is important to avoid out-crossing.

(48) Seed Harvest. F-1 hybrids are harvested multiple times, often by picking the fruit or seed pod. For these reasons, the timing of harvest, drying of the seed pod and seed extraction methods can be precisely controlled. In other instances, shattering may occur in the greenhouse so a mechanism and facilities of harvesting the dispersed seeds need to be developed. These precise methods of F-1 seed harvest leave little plant debris. Open-pollinated crops can be harvested either once or multiple times. If once, the timing and mechanism of harvest is important. If multiple times, the mechanism of harvest must be developed. Because open-pollinated crops are harvested in the field, there often is considerable debris collected with the seeds.

(49) Seed Drying/Storage. F-1 hybrids are dried mostly as either seeds or seeds in pods using driers. Because of their value, F-1 hybrid seeds are stored in rooms with controlled relative humidity and temperature. Open-pollinated crops contain considerable plant material harvested with the seed. Other approaches are to allow the seeds to dry in the fields and, if necessary, use driers to finish the drying. These crops are typically stored in bulk storage.

(50) Seed Conditioning. F-1 hybrids contain only a small amount of plant debris to be cleaned from the seeds. Light seeds are routinely removed, there are extensive weight/size separations and some seeds require detailing, defuzzing and/or scarifying. Open-pollinated seeds contain a considerable amount of plant debris that must be cleaned from the seeds. Light seeds are routinely removed and there is some grading according to weight/size. When necessary, seeds are also detailed, defuzzed or scarified.