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An Overview of Seed Production Methodologies in Selected Flowering Annuals

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This review provides a comprehensive overview of flower seed production, emphasizing the significance of the floriculture industry. Flower crops, especially annuals, contribute significantly to the beautification of surroundings and have become a lucrative agricultural business globally. The demand for quality flower seeds has led to the establishment of production facilities, particularly in India, catering to both domestic and international markets. The climatic requirements for seed

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production vary across different flower crops, with considerations for mild, sub-tropical, and tropical climates. The review delves into the nature of pollination for various flower crops, emphasizing the need for isolation to prevent contamination. F1 hybrid seed production is discussed, highlighting its merits and demerits, along with techniques for creating cross-hybrid seeds. The agronomic principles involved in hybrid seed production, including variety selection, seed pre-conditioning, planting time, sowing methods, and density, are detailed. The role of plant growth regulators, irrigation, and nutrition in optimizing seed yields is explored. Harvesting methods and the critical importance of proper timing are addressed, along with insights into seed storage conditions. The review concludes by emphasizing the multifaceted aspects of flower seed production, from climatic considerations to agronomic practices, pollination, and post-harvest processes. The knowledge presented serves as a valuable resource for practitioners and researchers in the floriculture and seed production sectors.

Keywords: Flower seed production; floriculture industry; hybrid seed production; agronomic principles; seed storage.

1. INTRODUCTION

Flower crops, particularly those which are annual in nature, have always been in use in the entire world for beautifying our surroundings. The growth of the Alsmeer market in The Netherlands in 1910 made it possible for floriculture to become a prosperous agricultural business industry. The floriculture industry has seen a sharp rise in demand and consumption, thereby making it a feasible source of revenue for the third-world nations [1]. So, with such an increasing demand, quality seeds of flower crops must be made available. Every kind of flower crop farmed for seed purpose has unique needs for planting time, culture, pollination, harvesting and storage. Majority of flower crops and ornamental crops thrive in mild climate coupled with moderate rainfall [2]. In the past, majority of the seeds were imported from the European countries. With the aim to target both, domestic as well as international market, a number of top flower seed producers established production facilities in India. As a result, some of the Indian growers became interested in beginning the commercial seed production in certain regions like Karnataka in South, West Bengal and Bihar in east, Punjab, Jammu & Kashmir and Himachal Pradesh in North [3]. Income per acre is two to five times more than that of the grains, but the cost of production is also higher. Over half of the expenses are related to field labor, which demands such proficiency that the work is done almost at the level of trade. Standardization of processes for large-scale seed production, improving the germination of seeds, along with relatively cheap labor, technical know-how, and other resources could help to overcome the prohibitive cost of these seeds. So, with these systems, a robust seed production program could be established either for export or domestic use [4]. India’s primary regions for seed production are: Sangrur, Patiala and Ludhiana (Punjab), Kullu (HP), Panipat and Sirsa (Haryana), Sri Nagar (J &K), Bengaluru and Rani Banur (Karnataka) and Kalimpong (West Bengal). Punjab alone supplies 45-50% or 450 hectares of these seed production areas, with a revenue of 60 million.

2. CLIMATIC REQUIREMENTS FOR SEED PRODUCTION

There are a wide range of flowering annuals available in India. They comprise summer, winter and rainy season annuals. A huge diversity is seen among the winter season annuals, whereas a limited diversity in the summer and the rainy season annuals. Thus, the seed production of the winter season annuals holds more importance. An extended period of cool and dry weather condition is ideal for seed production as it promotes more and larger seed setting. In north Indian plains, however an excessively hot and dry season hinders the seed setting of the summer season annuals. When the flowers are blooming, too much rain washes away the pollen grains, thus reducing the seed set.

The production of flower seed is split into the following climatic zones based on the climatic needs:

1. **Mild climate:** Delphinium, Zinnia and Giant Pansy
2. **Sub-tropical area:** Antirrhinum, Ageratum, Calendula, California Poppy, Candytuft, Carnation, Nasturtium, Petunia and Portulaca
3. **Tropical area:** Tagetes, Salvia, Ipomea.

Table 1. Nature of mode of pollination of flower crops

Mode of pollination	Flower crops
Self-pollinated	Balsam, Lupin, Sweet Pea, Clianthus
Often cross-pollinated	Antirrhinum, Aster, Dahlia, Salvia, Wall flower, Linum
Cross-pollinated	Alyssum, Calendula, Gazania, Stock, Zinnia, Cineraria
Outbreds	Ageratum, Corn flower, Delphinium, Marigold, Verbena

2.1 Isolation Requirements

Since the seed production of most of the crops is generally done in open fields, so, appropriate precautions must be taken to prevent any sort of contamination via the other crops belonging to the same species or other varieties of the same crop [5]. Isolation distance plays a comparatively more important role in cross pollinated crops than that of self-pollinated crops. Since the extent of natural outcrossing is more in cross-pollinated crops, so more isolation distance is to be provided in case of cross-pollinated crops. In most of the self-pollinated crops, an isolation distance of 10-100 meter is to be provided which may vary depending upon the land availability. In case of facultative outbreeders, a minimum isolation distance of 250 meters must be kept between the seed production fields, and on the other hand, in case of obligate outbreeders, a minimum isolation distance of 600 meters must be provided. However, the isolation distances may also vary from crop to crop.

2.2 F1 Hybrid Seed Production

The enormous demand of the seeds of flowering annuals in the seed industry cannot be neglected. Not only the seed industry, but also in the floriculture industry, they have a huge and emerging demand. Thereby, it is becoming essentially important to provide high quality seeds. So, opting for the hybrid seed production is a must. Two homozygous yet genetically different parental lines are crossed to produce F1 hybrids. F1 hybrids have certain merits and demerits of their own [6].

Merits

- **i.** Consistency in growth and output
- ii. Better performance than the parents with respect to yield.
- iii. Wide adaptability in various environmental conditions.
- iv. Remain stable even after several years.
- v. Known to possess resistance against various biotic and abiotic stresses.

Demerits

- i. High cost
- ii. Need comparatively higher input
- iii. Needs more technical knowledge.

Techniques for creating a cross-hybrid seed production include Ashok and Velmurugan, [2].

- i. Hand emasculation and hand pollination
- ii. Hand emasculation and natural pollination
- iii. Manually removing male plants
- iv. Genetic male sterility
- v. Cytoplasmic male sterility
- vi. Self-incompatibility
- vii. Chemical emasculation
- viii. Using marker genes

3. METHODOLOGIES OF PRODUCING HYBRID SEEDS

3.1 Making use of Self-Incompatibility

It is defined as the non-capability of a functioning pollen to fertilize the ovum of the same flower. By limiting self-pollination, it promoted cross-pollination. It is further categorized as sporophytic and gametophytic self-incompatibility [6]. Amongst the ornamentals, *Nicotiana* and Petunia are known to exhibit gametophytic self-incompatibility whereas Gerbera and Verbena [7] exhibit sporophytic self-incompatibility. An additional benefit is the profusion of seeds produced by Nicotiana and Petunia, which can sufficiently offset the high cost of F1 hybrid seeds. The dominance of two self-incompatible alleles influences the seed set.

3.2 Double Flower Condition

All the anthers in double type of flowers are altered to create ray florets. It is a peculiar characteristic of Asteraceae family, comprising of members like, chrysanthemum, asters, cornflower, dahlia, sunflower, marigold etc. accordingly, one could consider the double bloom trait to be a type of male sterility.

3.3 Triploidy

A few or no seeds are set by triploids. Tagetes is a genus of flowering plants. A cross in between *Tagetes erecta* (2n=2x=24) and *Tagetes patula* (2n=4x=48) produces a commercial triploid hybrid i.e. 2n=3x=36. Nugget, a triploid hybrid, which is produced by a cross between *T. erecta* and *T. patula* as female and male parent respectively, possesses a special capacity to keep the blooms on the plant for an extended period of time. Nonetheless, in *Begonia semperflorens,* there is a lack of regularity in triploids [8].

3.4 Pollen Sterility

Male sterility in sunflower has been utilized to create decorative cultivars such as Sunrich Orange in countries like Japan and Orit in Israel, which don't have pollen grains or cause allergies like in different fertile male cultivars raised for their seeds. Ageratum possesses both male sterility as well as self-incompatibility. Although, in case of petunia, cytoplasmic male sterility has been documented however this form of male sterility is not frequently employed because of breakdown of male sterility in the maternal parent or flower malformation in F1 plants. Maintaining the genetic stock is challenging in situations where a single recessive gene controls pollen sterility since fertile and sterile individuals will always segregate in ratio of 1:1. This phenomenon is exhibited by Tagetes, Antirrhinum, Zinnia, Delphinium, Salvia and Impatiens.

4. AGRONOMIC PRINCIPLES INVOLVED IN HYBRID SEED PRODUCTION

4.1 Selection of Variety

The most important step prior to opting for seed production is the selection of a variety which is not only high yielding in terms of seed set but also well adapted to the particular area's environmental conditions. Choosing the most appropriate variety, will not only give a higher seed yield but will also possess better characteristics with respect to seed germination, seed viability and seed longevity. In China aster (*Callistephus chinensis* L.*)*, genotype Kamini was proved to give the highest seed yield with better parameters like diameter of the capitulum, weight of the capitulum, per cent of filled seeds, test weight (weight of 1000 seeds), seed yield per plant and per hectare etc. as compared to Poornima and Sarpan purple genotypes [9]. Similarly, in China aster, cultivar Arks Poornima has the highest seed set and gave the highest seed yield as compared to Arka Aadya in New Alluvial zone of West Bengal [10]. In African marigold (*Tagetes erecta*), genotypes TEG-20 was found to give the highest seed yield [11]. In snapdragon, the maximum number of seed set per pod was obtained in Vilmorin × AG-4, however the maximum test weight was seen in AG-1 × AG-4 Singh et al., [12].

4.2 Seed Pre-Conditioning

Seeds ought to be obtained from official seed agencies with authorization and must possess established purity percentage. There might be a need to treat the seeds prior to their planting either in the main field or in the nursery. So, this methodology of treating the seeds before their planting is called pre-conditioning. Conditioning the seeds of zinnia with moringa leaf extract, results in the fastest and the highest rate of germination. Treating the seeds with moringa leaf extract along-with untreated water or magnetically treated water leads to a better growth of plants and also results in a better yield [13]. Treating the seeds of zinnia with high levels of humic acid or with low level of humic acid along-with high level of $FeSO_4$ leads to better performance of the plants in the field with improved characteristics and a higher flower yield [14]. Priming the seeds of snapdragon with bio-control agent like *Trichodera harzianum* before planting leads to better germination, growth, flowering, and a higher seed yield coupled with better seed parameters [15].

4.3 Time of Planting

The area's geographic location and the environmental factors affect the planting dates. Generally, it is recommended to sow the seeds of winter season annuals during mid-September and mid-November whereas the seeds of summer season annuals must be sown in between mid-April and mid-May. Opting for the planting of snapdragon on 17 September under mid-hills of HP significantly gives the maximum seed yield, coupled with better plant parameters like, height of the plant, spread of the plant, highest flower duration, highest pods per stem and the highest seeds per pod etc. Sharma et al., [16]. Going for the sowing of pot marigold (*Calendula officinalis* L.) on 15 September gave the maximum seed yield accompanied with high fresh weight of flower per plant, high number of seeds per head etc. Shahrbabki et al., [17]. Dahlia planted on 25 September gave the highest seed yield as compared to the one sown on 10 October. However, the crop sown as late as 25 October gave the lowest seed yield. Thus, it can be inferred that the delayed the sowing of the crop, the lesser will be the seed yield [18]. *Gaillardia pulchella* when planted in January's first week gave the highest seed yield per plant, per plot as well as per hectare. However, the best percentage of germination was obtained when planted in first week of October. Therefore, for producing seeds, the best amongst all the other planting times is planting in 1st week of January [19]. Planting candytuft on 17 September eventually produces more siliquae per plant and thereby results in a higher yield as compared to the ones which are planted late in the season. Large sized flowers gave a higher yield [20]. October planting of China aster leads to better plant characteristics like bolder, higher and heavier capitula [9]. A significant decrease in seed yield has been observed with a delay in the sowing of *Coreopsis lanceolata* after 1st week of November. So, planting the same in 1st week of November significantly results in a higher seed yield [21].

5. METHOD OF SOWING AND DENSITY OF PLANTS

Seed crop is often sown in the rows using mechanical drillers, which allows for consistent planting of required number of seeds at a given appropriate depth. The sowing equipment must be well cleaned to avoid any sort of infection. The sowing depth is usually 1.5 5times the diameter of the seed, which means that smaller seeds are sown less deep than bolder seeds.

For annual flowers, the number of plants per unit area greatly affects the amount of seeds produced in the end. To maintain a proper air circulation and proper light penetration, proper spacing in between the plants and between the rows must be ensured. In Ageratum, spacing of 45 × 45 cm leads to production of more capitulum, which eventually leads to a higher seed yield in contrast to a spacing of 30 × 30 cm [22]. In *Coreopsis tinctoria*, a higher seed yield was obtained when plants are maintained at a spacing od 60 × 60 cm than those spaced at 60 × 30 cm [21].

5.1 Pollination and Roguing

Efficient and sufficient roguing is the most important step in the seed production step. Unusual rogues like ill or weak plants, bolters and off-types are pulled and disposed off as soon as feasible. Also, to get an ample seed set, pollination is also a crucial step. Understanding the floral biology thoroughly, pollination mechanisms, and how they affect the seed set will help in increasing the success of seed production. To ensure sufficient and effective pollination installation of bee hives can also be opted for. It is discovered that hand pollination works the best in case of glory lily, leading to better pod parameters viz., better weight of seeds per pod, higher seeds per pod, high germination rate of the seeds produced etc. Venudevan et al., [23]. In China aster, it was noticed that open pollination in cultivar Phule Ganesh Pink was the best in case of mixed seed production whereas, on the other hand, in case of pure seed production close planting accompanied by bagging method works the best [24].

5.2 Use of Plant Growth Regulators

PGR's can operate either as bio-stimulant or bio-inhibitors and they have the power to change the growth and development of plant cells even at extremely low doses. Amongst the chemically modified plant growth methods that are garnering increasing interest in floriculture are the use of plant growth regulators to inhibit vegetative development, lower plant height, alter plant shape, size and form and induce and enhance flowering. When plant growth regulators are used before the flowers bloom, they improve not only the amount and quality of the blossoms but also the number of seeds produced. If Paclobutrazol @1 kg a i./ha is sprayed on Unwins Mixed, a hybrid dahlia, at first bud, a higher seed yield per plant along-with higher quantity of seeds per seed head is obtained [25]. Opting for the foliar spray of Malic hydrazide @ 1000 ppm coupled with boron @ 0.2% in African marigold, yields in a higher seed recovery per flower, highest number of filled seeds with a maximum of flower head weight, with better seed parameters like, seed germination, seedling vigor and a better test weight of the seeds [26]. In case of annual chrysanthemum, going for the use of GA_3 in the form of spray @ 200 ppm leads to increase in the quantity of capitulum per plant, more seeds in a single capitulum and an increased seed yield [27]. Use of gibberellic acid @ 250 ppm in the form of foliar spray in marigold after 25 days of transplanting, gives a better and a higher seed yield [28].

5.3 Irrigation and Nutrition

In order to achieve high seed yields irrigation at regular intervals must be ensured. The intensity of irrigation must be such that it caters to the water requirement of the crop. Irrigation intensity depends on several factors like availing environmental conditions, texture of the soil, growth stage of the plant etc. Excessive as well as under irrigation can lead to changes or a decrease in the amount of seed set. Similarly, catering to the needs of nutritional requirement of the plant is also a must. The primary, essential elements such as nitrogen, phosphorus and potassium must be supplied in sufficient quantities and only at a recommended dosage. Other micro-nutrients like zinc, boron etc. can also be supplied to the crop for better results. Chemical fertilizers serve as a good source of the major nutrients. However, they may prove to be quite expensive and also might cause serious soil health concerns. Different doses have been standardized from time to time for different crops. Marigold is said to provide a high seed yield when the major nutrients, ie, NPK are applied in the proportion of 270:72:72 with a distance of 60 × 30 cm [29]. In China aster, it has been observed that if NPK is applied to the crop @ 240:180:80 then, there is an increase in the seed yield, along-with parameters like, number of capitulum per plant, its weight, seed weight in a single capitulum etc. Doddagoudar et al., [30]. In calendula, it was found that the extent of seed yield increased with an increase in the dose of nitrogen coupled with proper irrigation and also led to an improvement in the parameters like seeds in a single head, test weight of the seeds etc. It was further concluded that a delay in the water supply causes a significant decrease in the yield [31]. Studies on petunia led to the conclusion that a combined use of nitrogen, phosphorus and potassium led to a higher seed yield as compared to their individual doses [32].

5.4 Harvesting

The harvesting or the extraction of the seeds from the plant must be done only at proper maturity stage by using a correct methodology. Delay in harvesting leads to shattering of the seeds. Whereas, on the other hand, an early harvest leads to lesser seed yield with an inferior quality. There are different maturity indices for each flower. So, following those indices, the harvest is to be commenced. In the crops, where the pods bear the seeds, the harvesting must be done once the pods start splitting. Since the maturity of the seeds is not uniform, so, accordingly 3-4 harvests can be done. Generally, in case of winter annuals, seed harvesting can be done in 1st week of April whereas in summer annuals, extraction can be done in Aug-Sep. there are different methods by which seeds can be harvested. They are listed in the Table 2 given.

Not only the method of harvest but also the stage of harvest determines the seed quality parameters. In China aster, if the seeds are separated after 42 days from blooming, then the seeds possess a better root and shoot length along with a high seedling vigor. Also, extraction after 42 days gives the highest seed yield [33]. In African marigold, the seed yield was gradually higher when the seeds are harvested after 28 days after anthesis as at this time it has reached its maximum physiological maturity with a high food reserves, proteins acids etc. Gopichand et al., [26].

Table 2. Method of harvesting

Method	Description	Examples
Hand picking	The seeds are separated by collecting them individually from the flower or the pods.	Cosmos, Calendula, Gaillardia, Gazania, Helichrysum, Voila, Petunia etc.
Shattering	Using your hand, gently tap a group of flowers either on a plastic sheet or trays to separate the seeds.	Celosia, Amaranthus, Dianthus, Alyssum etc.
Manual collection by removing inflorescence	Generally done, when more than half a seeds in the flower reach maturity. Firstly, the flower bearing the seed is removed and then placed in a basket or tray to avoid shattering and then collected.	Antirrhinum, Delphinium, Verbena, Coreopsis.
Whole plant harvesting	It is the easiest method. In this method, removal of the entire plant is done followed by manual collection of the seeds.	Linaria and Tropeolum.

5.5 Storage of the Seeds

The main factors that ensure a safer storage of the seeds are temperature and moisture content of the seeds. Earlier, the research was mainly focused in maintaining a safer temperature for storage rather than the moisture of the seeds. But now importance is also being given to the seed moisture as well. In order to store the seeds safely, the moisture of the seeds is ought to be brought down to safer levels to ensure its longevity at the time of storage. Generally, the seeds are dried to a moisture content of 5-6% and stored at almost zero temperature. However, moisture less than 4-5% is also not suitable and might affect the viability. Although in some cases, the moisture content can also be brought down to 1%. Storage must be done in well ventilated areas. Different seeds have different storage needs. In China aster, it was found that in order to achieve good storage, the seeds must be stored at 15° C and 30% RH [34]. In addition to storage temperature and seed moisture, the type of storage material also determines the storage life of the seeds. The seeds of China aster when stored in a foil made up of aluminium for about 4 months, still exhibits the highest rate of germination as compared to other packaging materials [35].

6. CONCLUSION

The review accurately assessed the seed production in flower crops. The use and importance of flowers for various purposes cannot be neglected. Their use in religious purposes is also highly valued. Opting for the production of flower seeds under suitable environmental conditions, with sufficient knowledge of other aspects as well will help in obtaining higher seed yield.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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