Chapter

Directing for Higher Seed Production in Vegetables

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Abstract

Vegetables are essential for human health and well-being. For sustaining an excellent production of vegetable crops, the seed is a primary input. Moreover, good quality seed is an important requirement for the vegetable industry, and there is a huge demand that has been expanding, considering the fact that seed multiplication is economically pertinent for vegetable cultivars to contend commercially. But the healthy seed production is usually a sumptuous trait and tormented by agricultural tactics, genetics as well as by the environmental factors. Features like seed output of the vegetables, sizeable genetic variation, the prerequisite for advancement and acceptance of a good quality vegetable seed. Here different mechanisms for seed production in vegetable crops has been presented, also vital areas and factors influencing seed production, and eventually discourses regarding the opportunity of plant breeding to sustainably make improvements to vegetable seed production.

Keywords: vegetables, self-incompatibility, male sterility, seed

1. Introduction

Vegetables play a critical role in food security and are rich in mineral and vitamins. Vegetables can prevent several chronic diseases, including cancer [1]. But the successful production of vegetables depends on the first primary input that is the seed. Seeds are the consequences of sexual reproduction in the plant, and not all plants produce. Besides, the seeds are of tremendous organic and financial value. They have abundant protein, starch and oil reserves that assist during the early stages of development of a plant. These reserves are what make several portions of cereal and legumes main foods resources for any considerable proportion in the world's inhabitants [2]. Vegetable seeds signify a crucial organ intended for the multiplication of vegetables. Seeds accumulate well-balanced free of charge amino acids, which stored inside the seed storage proteins (SSPs). The seed quality is determined by the kind of amino acids, specifically crucial amino acids [3].

Vegetables require two successive processes, namely pollination and fertilisation, to produce the seeds. Pollination refers to the transfer of pollen from the androecium (male flower part) to the gynoecium (female flower part). Generally, flowers contain two other parts, the sepals and petals, which may be helpful to attract pollinators, namely insects. It is not necessary for flowers to have all of these four structures mentioned. Flowers either may be complete, having all four or incomplete, not having all four parts. Likewise, flowers may be grouped into perfect and imperfect flowers [4]. There are two main types of pollination, namely, self and cross-pollination. Self-pollination refers to the deposition of pollen from the anther on the stigma located on the same plant (geitonogamy). It is the closest form of inbreeding which leads to homozygosity. Species having this type of pollination develop homozygous balance and do not exhibit significant inbreeding depression [5].

Whereas the transfer of pollen from the anther of one flower to the stigma of another flower on a different individual is called cross-pollination. It is the form of outbreeding which leads to heterozygosity. Outbreeder species develop heterozygous balance and exhibit significant inbreeding depression on selfing. In addition to these two types of pollination, there is one a different kind of pollination, often called cross-pollination, where cross-pollination often exceeds 5% and may reach 30%. Various mechanisms such as bisexuality, homogamy, cleistogamy and position of anthers promote self-pollination, whereas other mechanisms such as dicliny (namely monoecy and dioecy), dichogamy, heterostyly, herkogamy, self-incompatibility (namely sporophytic and gametophytic) and male sterility promote cross-pollination [6].

Nearly one-third of the current global population is suffering from some form of malnutrition. Moreover, with a constant rise in the world population the food demand tends to increase up to 60% [7]. Vegetables being shorter duration crops can play a crucial role in providing more food per unit of cultivated area [8]. Similarly, climate change is a result of human activities primarily related to the emission of greenhouse gases. It means that there must be a focus on vegetable production and lowering the per capita emissions of greenhouse gases [9]. Vegetables are sensitive to temperature fluctuations, and environmental stresses have also been found to affect the nutrient composition of vegetables [10].

Monoecious, that is, cucurbits have both male and female flowers on different branches of the same plant. Dioecious (like spinach) have male (staminate) and female (pistillate) flowers on separate plants. Generally, both of these monoecious and dioecious plants require cross-pollination. Pollen grain germinates and penetrates the style to reach the ovary and then fertilises the ovule. This fertilised ovule changes into seed and the surrounding ovary develops into the fruit [11]. There are different agents for pollination such as insects, wind and water, etc. Insects are main agents for pollination in vegetables; they visit flowers to collect pollen and nectar as food and transfer this pollen unknowingly to the stigma of other flowers on the same plants or different plants. In this review, we have tried to comply with the important aspects for the successful and mass production of healthy vegetable seeds [12].

2. Pollination in vegetable crops

Crops can be classified into three categories depending upon the mode of pollination, that is, naturally self-pollinated, naturally cross-pollinated and both self and cross-pollinated crops. Naturally self-pollinated: In such plants, same floral structure or different flowers on same plant houses both pollen and embryo sac. Examples are tomato (*Solanum lycopersicum* L.), lettuce (*Lactuca sativa* L.), parsnip (*Pastinaca sativa* L.), peas (*Pisum sativum* L.), dwarf bean (*Phaseolus vulgaris* L.) (**Table 1**).

Naturally cross-pollinated: in cross-pollinated plants, male and female flowers are present on different plants. While in some cases, the stigma may not be receptive at the time of pollen availability. For example, cabbage (*Brassica oleracea var. capitata* L.), cauliflower (*Brassica oleracea var. botrytis* L.), onion (*Allium cepa* L.), broccoli (*Brassica oleracea* var. *italic* L.), carrot (*Daucas carota* L.), radish (*Raphanus sativus* L.), pumpkin (*Cucurbita moschata* Duchesne), squash (*Cucurbita pepo* L.), beet (*Beta vulgaris* L.), muskmelon (*Cucumis melo* L.), cucumber (*Cucumis sativus* L.).

Crops	Techniques used for hybrid seed production
Onion	*S and T type-cytoplasmic male sterility (CMS) with natural pollination
Carrot	Brown anther and *petaloid sterility-cytoplasmic male sterility (CMS) with natural pollination
Cole crops and radish	Oguro type-cytoplasmic male sterility (CMS) and *Sporophytic self-incompatibility (SSI) with natural pollination
Cucurbits	Genetic male sterility mainly in muskmelon and *hand emasculation with natural (pinching and use PGR for staminate flower) or hand pollination
Pepper	*Genetic male sterility with hand pollination or natural pollination
Tomato and Brinjal	*Hand emasculation and hand pollination

**Commercial use of techniques in hybrid seed production.*

Table 1.
Techniques of hybrid seed production.

Crop	Pollination type	Mechanism
Solanaceae		
Tomato (*Solanum lycopersicum*)	Self	Bisexual, stigmas surrounded by anthers
Eggplant (*S. melongena*)	Self	Bisexual, stigmas surrounded by anthers
Potato (*S. tuberosum*)	Self	Bisexual, hypogynous
Peppers (*Capsicum annuum*)	Self	Bisexual, hypogynous
Cucurbitaceae		
Bottle gourd (*Lagenaria siceraria*)	Cross	Monoecious
Watermelon (*Citrullus lanatus*)	Cross	Monoecious
Cucumber (*Cucumis sativa*)	Cross	Monoecious
Gherkin (*C. anguria*)	Cross	Monoecious
Muskmelon (*C. melo*)	Cross	Monoecious
Snake gourd (*Trichosanthes cucumerina*)	Cross	Monoecious
yellow-flowered gourd (*Cucurbita pepo ovifera*)	Cross	Monoecious
zucchini (*C. pepo*)	Cross	Monoecious
Cole crops		
Brussels sprouts (*Brassica oleracea var. gemmifera*)	Cross	Sporophytic self-incompatibility
Cabbage (*B. oleracea* var. capitata)	Cross	Sporophytic self-incompatibility
Cauliflower (*B. oleracea* var. botrytis)	Cross	Sporophytic self-incompatibility
Kale (*B. oleracea* var. sabellica)	Cross	Sporophytic self-incompatibility
Broccoli (*B. oleracea* var. italica)	Cross	Sporophytic self-incompatibility
Turnip (*B. rapa* subsp. Rapa)	Cross	Sporophytic self-incompatibility
Fabaceae		
Common Bean (*Phaseolus vulgaris*)	Self	Self-fertilisation before opening the flowers (Cleistogamous)
Faba bean (*Vicia faba*)	Partial cross pollination	Partly cleistogamous

Crop	Pollination type	Mechanism
Lima bean (*P. lunatus*)	Self	Cleistogamous flower structure
Chickpea (*Cicer arietinum* L.)	Self	Cleistogamous flower structure and stigmas surrounded by anthers
Cowpea (*Vigna unguiculata*)	Self	Cleistogamous flower structure
Fenugreek (*Trigonella foenum-graecum*)	Self	Cleistogamous flower structure
sweet pea (*Lathyrus odoratus*)	Self	Cleistogamous flower structure and stigmas surrounded by anthers
Pea (*Pisum sativum*)	Self	Cleistogamous flower structure and stigmas surrounded by anthers
Soybean (*Glycine max*)	Self	Cleistogamous flower structure and stigmas surrounded by anthers

Table 2.
Different kind of pollination mechanisms in the vegetable crops.

Other cucurbits (bitter gourd, bottle gourd, ridge gourd, sponge gourd, snake gourd, pointedgourd, ash gourd, etc.), amaranths.

Both self and cross-pollinated: Plants are primarily self-pollinated, but cross-pollination occurs to varying extents. Examples include brinjal (*Solanum melongena* L.), okra (*Abelmoschus esculentus* (L.) Moench), chilli (*Capsicum annuum* L.), sweet pepper (*Capsicum* spp.). After landing on stigma, pollen grains germinate and grow down the style of the flower, and this process is called fertilisation. Sperms of the pollen unite with ovules in the ovary which leads to seed production. In the event of pollen incompatibility, a fully pollinated flower does not get fertilised. Some plants are capable of producing fruit without fertilisation and seed production, and such species are called parthenocarpic [13, 14].

Among the different pollination agents like wind, birds, insects, gravity, water and mammals, the most important are insects. Insects contribute 80–85% of the pollination, out of which a hefty proportion of 75–80% is attributable to honey bees. Because of their body characteristics and behaviour patterns, solitary bees, bumblebees and honey bees constitute the largest group of pollinators. Pollination by insects is indispensable for improvement of plant and yield characteristics like seed set, quality of produce, early flowering, oil content, rubber content, pyrethrin content, etc. Managed pollination of crops by honey bees is a surest and most effective way of increasing yield and quality of the produce. Honey bees enhance productivity of crops through cross-pollination along with additional income through production of honey and beeswax, etc. Honey bees and other cross-pollinating agencies like bats, small mammals, birds, etc. owing to its body modifications to pick pollen, floral fidelity, efficiently communication among the colony members and their adaptability to different climates [15]. Cross-pollination results in hybrid vigour, thus improving the quality as well as quantity of the produce which is a boon for vegetable seed production (**Table 2**).

3. Effects of insect pollination on seed yield of vegetables

Inadequate pollination has been a major constraint to the potential returns of vegetables. Different insect pollinators have been identified in various vegetable crops, which increased the seed yield by increasing the pollination. Vinícius-Silva et al. [16] found fifteen floral visitors with *Exomalopsis analis* being the most representative in tomato crop. They also reported the presence of the other two effective pollinators, namely *Apis mellifera* and *Trigona spinipes* in tomato crop. Shah et al. [17] observed the highest population of honey bees among all tracked pollinators in cucumber and showed that insect pollination in cucumber acts as additional input in enhancing the yield [18].

Similarly, the highest weight of fruits, number of seeds per fruit, fruit size and TGW was achieved in honey bee pollination compared to others. Azmi et al. [19] observed heavier, longer and larger fruits in cucumber when pollinated by stingless bee (*Heterotrigona itama*) and hand compared to those produced from pollination without *H. itama*. Rouf et al. [20] reported an increase of 45.46 and 23.17% in seed yield of cauliflower plants pollinated by honey bee over plants grown inside net without bees and open pollination, respectively. Further, they showed that maximum yield attributes of seed could be achieved if planned bee pollination and central curd cutting employed together.

4. Plant ideotype for seed production

For the first time in 1968, Donald introduced the concept of ideotype in plant breeding. Later in 1976, the concepts of isolation, competition and crop ideotypes were proposed by Donald and Hamblin [21].

4.1 Ideotypes for solanaceous vegetables

Manipulation of plant architecture of tomato may provide increased fruit yield resulting in increased seed yield. Suarma et al. [22] suggested emphasising on traits such as fruit yield (q/ha), plant height, average fruit weight for ideotype construction in tomato. Direct selection for these traits, having high heritability and genetic advance, may yield expected genetic up-gradation of a genotype. Sarlikioti et al. [23] suggested a new plant ideotype for optimization of light absorption and canopy photosynthesis in tomato. This new ideotype with more spacious canopy architecture due to long internodes and long and narrow leaves led to an increase in crop photosynthesis of up to 10%. Recently, Zsögön et al. [24] suggested that vital monogenic traits whose physiology has been revealed thoroughly can be molecularly tailored using genome editing techniques to achieve the target ideotype for elite cultivars of tomato. They also proposed that wild relatives or progenitors harbouring polygenic traits of interest could be de novo domesticated by manipulating monogenic yield-related characters through these techniques to get 'model type' plants which would perform expectedly in a defined environment. It has been suggested that shifting of crop plants from annuals to perennials may provide an additional advantage in seed yield. Eggplant ideotypes characterised by a radical change in plant architecture, with an arborescent or shrubby habit and perennial instead of annual fruit set using somatic hybridization [25–27].

4.2 Ideotypes for cucurbits

Plant architecture of muskmelon has also been manipulated to get increased fruit yield. Two different plant ideotypes have been proposed to get increase fruit set in muskmelon: "bush" or "birdnest" type possessing multilateral branches of the same length and bearing uniform sized fruits near the centre of plants and short internodes types having indeterminate growth behaviour and shorter internodes which can be planted at higher densities [28].

4.3 Ideotypes for fabaceous vegetables

Manipulation of the architecture of plants to achieve high seed production has been accomplished in various fabaceous species such as common bean, broad bean and pea; and also in the underexploited species of this family [29, 30].

Isaacs et al. [31] employed participatory plant breeding approach and together with farmers, identified specific traits that constitute a bean ideotype: adaptation, restricted height, columnar plant structure, even distribution of pods, fewer leaves, and earlier maturity. Plants with this ideotype produced good seed yield and were suitable for maize-bean cropping systems. Polania et al. [32] 2017 evaluated 36 bean genotypes to test the relationships between shoot traits and root traits under drought conditions. They identified two ideotypes related to efficient water use: water savers having a shallower root system and water spenders presenting more in-depth root system. Both showed greater root vigour under drought stress and produced high grain yield. Recently, Bodner et al. [33] identified ideotypes, having higher average yield, taller structure, more pods per node and longer flowering duration, suitable for Northern Europe. They considered Baltic landraces as promising ideotypes for increased *V. faba* yields in Nordic target environments as well as the other workers [34].

5. Seed set and development

Since all vegetables are angiosperms, so a standard procedure of fertilisation, seed set and development is followed in all vegetables with few modifications. We are presenting here a general mechanism of fertilisation, seed set and development. At the time of fertilisation, protective coats, known as integuments and a central tissue called nucellus are present in the angiosperm ovule. If we see the structure of ovule, clear differentiation of these two integuments and nucellus can be found in the region of the micropyle, it is a minute pore in the integuments through which, the pollen tube enters the nucellus and move towards egg cell and polar nuclei. A stalk, funicle, attaches the ovule to the wall of the ovary. In general, megaspore mother cell inside the nucellus once divides meiotically and then divides mitotically three times to produce embryo sac or female gametophyte, a haploid eight-nucleate, seven-celled structure which comprises of one egg cell, two synergids, three antipodal and two polar nuclei. Although among angiosperms, the female gametophyte has a variety of forms, it may not necessarily encompass all these seven cells. On the other hand, inside the anther, microspore mother cell first divides meiotically and then mitotically to produce pollen grain or microgametophyte, which comprises two sperm cells enclosed with one vegetative cell [35].

These two female and male gametophytes play essential roles in the reproductive process of angiosperm. Sexual reproduction starts with the transmission of male gametophyte or pollen grain from anther to the carpel's stigma. Subsequently, pollen grain begins to germinate on stigma and a pollen tube carrying two sperm cells is formed, which penetrates the style. Growth and development of pollen tube is controlled by vegetative nucleus which disintegrates after serving its duty. Pollen tube enters into the embryo sac through micropyle, in general, and releases two male gametes. One male gamete fertilises the egg cell, called syngamy, and the second male gamete fuses with the central cell or polar nuclei [36]. Since two successive fertilisations take place, the procedure is known as double fertilisation. The zygote is formed after uniting of one sperm cell with egg cell, and this zygote gives rise to seed's embryo which is the starting of the sporophyte generation. Following fertilisation, central cell's polar nuclei produce seed's endosperm, which is the nutrition source for developing embryo. These two embryos and endosperm encompass the central portion of the seed. Two synergids and three antipodal, remaining five nuclei, do not play any further role in seed development. For the development of viable seed, successful fertilisation of egg cell and the central cell is necessary [37]. All seeds mostly contain an embryo, a protective cover-seed coat and a reserve of food materials or any other specified tissue such as perisperm. Occasionally, polyembryony condition refers to development of more than one embryo in a single seed, may also be observed in some families such as Solanaceae and Amaryllidaceae families.

6. Advances in the understanding of molecular mechanisms underlying seed/fruit set and development

Underlying molecular mechanisms of seed set and development in angiosperms is becoming clear rapidly with the advancements of various omics studies such as genomics, transcriptomics and proteomics etc. and genetic transformation techniques. These mechanisms are generally conserved across all the angiosperms and may also be operated in vegetables. Various studies have been conducted in vegetables such as tomato (and cucumber to explore the underlying molecular mechanism of seed set and fruit set) [38]. In 2016, isolated and characterised two allelic mutants, twisted seed1-1 (tws1-1) and tws1-2 of a single copy gene (TWS1). This gene encodes a small protein of 81 amino acids which regulates embryonic development and accumulation of storage compounds in the seed [39].

This gene is specifically conserved among angiosperms and can be cloned from vegetables to explore its function in seed development in vegetables. The importance of AN3-MINI3 gene cascade in seed embryo development. Their regulatory model provided a deep insight into the seed mass regulation, which may be further explored to increase seed yields of vegetables [40]. Role of mitochondrial reactive oxygen species homeostasis in gametophyte and seed development has also been highlighted in angiosperms. It was reported that the effect of the mutation in *AtHEMN1* gene which encodes for coproporphyrinogen III oxidase. They showed adverse effects of *Athemn1* mutant alleles on gametophytic and seed development. Adverse effects included the development of nonviable pollen and embryo sacs with unfused polar nuclei, defects in endosperm development due to abnormal differentiation of the central cell and arresting of embryo development at the globular stage [41].

To ensure successful sexual plant reproduction, fruit set or transformation of flowers to fruits is very critical. Role of hormones (i.e. auxin and gibberellins) in controlling fruit set after pollination and fertilisation have been well understood. It was shown that the role of microRNA-based (microRNA159/GAMYB1 and −2 pathway) regulation ovary development and fruit set in tomato. They initiated fruit set by modulating auxin and gibberellin responses using SlGAMYBs. On the other hand, proteins such as TIR1-like proteins have also been shown to have essential roles in auxin-mediated fruit development processes. Two TIR1-like genes have been identified in cucumber and designated as CsTIR1 and CsAFB2 [42]. Xu et al. [43] used tomato as a model plant to investigate the effects of these two genes on fruit/seed set. They highlighted the crucial role of the miR393/TIR1 component in fruit/seed set and concluded that post-transcriptional regulation of these two genes mediated by miR393 is vital for fruit set initiation in both cucumber and tomato. The different stages of seed development and the structure of a dicot seed is presented in **Figure 1**.

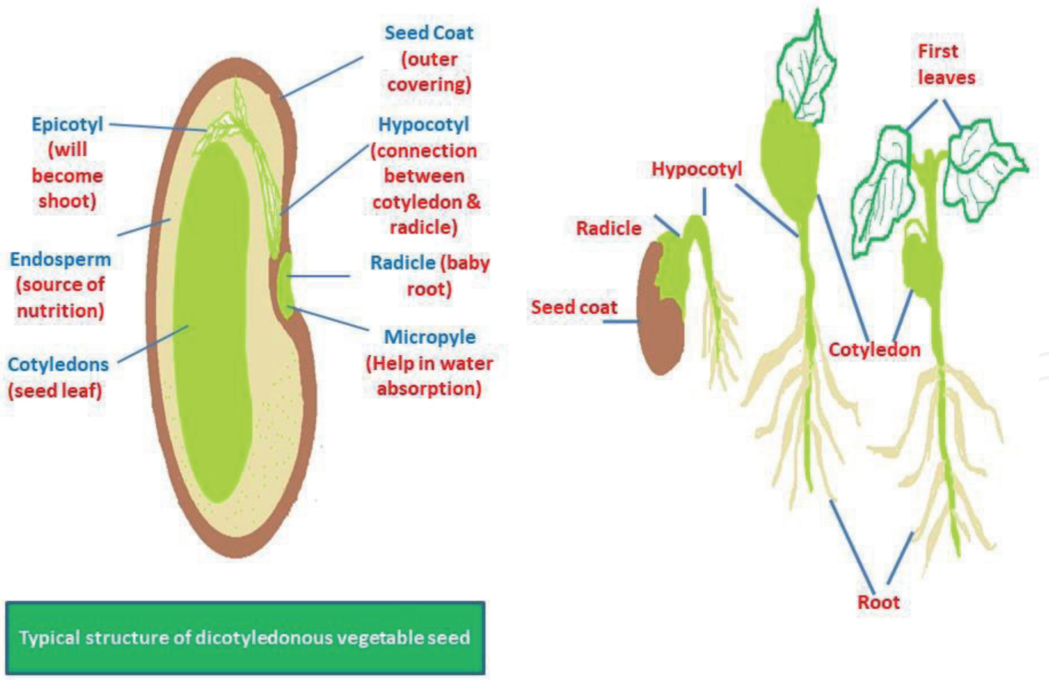

Figure 1.
Different stages of seed development.

7. Role of male sterility in vegetables

7.1 Family: solanaceae

7.1.1 Pepper/Chilli (Capsicum annuum L.)

Peterson (1958) first reported the cytoplasmic genetic male sterility (CGMS) in chilli in an introduction of *C. annuum* from India (PI-164835) and found its instability under fluctuating conditions, particularly temperatures and natural cross-pollination. Genetic male sterility in chilli well exploited on a commercial scale in hybrid seed production. Male sterile plants easy to identify in the field at a comparatively early stage. Nearly 20 genes governed genetic male sterility. The ms-10 gene is linked with taller plant height, erect growth and dark purple anther. MS-12 (ms-509/ms-10) and ms-3 genes are commercially utilised in India and Hungry, respectively [44].

7.1.2 Tomato (Solanum lycopersicum L.) *and brinjal* (Solanum melongena L.)

Tomato crop has different types of male sterility identified, but presently commercial hybrid seed production in tomato and brinjal possible with manual emasculation and hand pollination and it is economically viable and dominates in the seed industry. Though, the availability of different sterility methods can be used to avoid selfing and optimise crossing resulted in reducing the cost of hybrid seed production [45].

7.2 Cucurbitaceous vegetables

To exploit heterosis in cucurbits the essential requirement is heterotic combination potential of crops from flower size to pollination and fruit set resulted in proper seed setting to economic feasibility. The cucurbit vegetables have a more substantial size of male and female flowers and allow following other systems of pollination control strategies. The hand emasculation with hand and natural pollination mechanism used in hybrid seed production in bottle gourd, pumpkin, squash, cucumber, muskmelon and bitter gourd with specific planting ratio. Genetic male sterility mainly uses in muskmelon, and most of the genetic male-sterile mutants in cucurbits are monogenic recessive. There are many types of male sterility identified in cucurbits, but commercial exploitation is still lacking. Gynoceious lines based on genetic male sterility (GMS) stability gene and use of different plant growth regulators are also useful in hybrid seed production of cucurbits with sex modification [46].

7.3 Cole crops (*Brassica oleracea* L.) and radish (*Raphanus sativus*)

Cole crops and some root crops are a significant group of vegetables in the brassica family, and they are cabbage, cauliflower, broccoli, turnip and radish. GMS, CGMS and self-incompatibility (SI) are important pollination mechanism available in Brassica family to get a higher percent of heterosis in crops. In which, self-incompatibility (Sporophytic self-incompatibility) system is most useful in hybridisation program. But, CGMS method also developed with some self-pollination occurrence [47]. In cole vegetables, sterile cytoplasm (CMS system) derived from *B. nigra* through interspecific hybridisation between *B. nigra* and *B. oleracea* var. italica and Ogura type CMS also identified and reported in cultivar Japanese radish of *Raphanus sativus*. First, introgression of this sterility cytoplasm to *Brassica oleraceae* genome through repeated backcrosses with broccoli. Some plant physiological problems were found in Ogura based CMS lines of broccoli, cauliflower, cabbage, Brussels sprout and it has been solved using protoplast fusion, and this technique is also used in transfer Ogura cytoplasm from broccoli into cabbage [48].

7.4 Carrot (*Daucus carota* L.)

Cytoplasmic male sterility in carrot can occur in two morphologically (brown anther and petaloid) distinct phenotypes. The brown anther male sterility was first discovered in the cultivar Tendersweet, and this is, characterised by shrivelled, yellow-to-brown anthers with no pollen. It is a homeotic mutation. This is established as the white petaloidy or green petaloidy. It is stable male sterility across a wide range of environments as compared to brown anther type. Seed yield of the brown-anther CMS are generally higher because of petaloid sterility shows less frequent deterioration to male fertility [49].

7.5 Bulb crops—onion (*Allium cepa* L.)

Male sterility in onion, first reported in the progenies of an onion cultivar Italian Red plants and is controlled by the combination of a cytoplasmic factor "S" together with a recessive nuclear restorer locus in its homozygous form (ms) and "T"-cytoplasm has been reported. Onion (*Allium cepa* L.) hybrid seed production has been produce in all over the world through CGMS-based systems in which mostly hybrids are derived from S-cytoplasm because of its stability in various environments [50, 51].

8. Self-incompatibility

Self-incompatibility can be a widespread phenomenon in vegetable crops that forestalls inbreeding and encourages outcrossing. The response of self-incompatibility is genetically managed by several multi-allelic loci and depends on many intricate interactions among the self-incompatible pollen and pistil combinations. It is genetically regulated phenomena that function as a barrier to self-pollination in the big selection of vegetable crops like cabbage, cauliflower, tomato and many others. Self-incompatibility can be a critical system by which crops avert self-fertilisation and keep a broad genetic range. Self-incompatibility is considered to present in 30–50% of flowering plant species [52]. Many SI programs have now been discovered. In all situations, incompatible (self-) pollen is considered by a distinct system usually genetically managed that brings about inhibition on the pollen while in the stigma or on the pistil. Using SI in F1 hybrid generation has key gain over other approaches. Usage of Self-incompatibility in cole crops for hybrid seed generation is commercialised due to the availability of a robust mechanism/method to create large-scale F1 seeds employing picked parental strains is undoubtedly a critical issue, which in the long run establishes the professional viability on the hybrid varieties [53].

Self-incompatibility is classified as namely gametophytic and sporophytic. In gametophytic technique self-incompatibility response of pollen and stigma is decided with the genotype of the female plant on which pollens are developed (e.g. tomato) even though in sporophytic technique, pollen phenotype (self-incompatibility response) is identified with the genotype on the female plant on which pollens are developed (e.g. cole greens). In Brassicaceae, sporophytic self-incompatibility (SSI) has been ideally characterised and productively used for that growth of commercial hybrids. Using SI in F1 hybrid generation has key gain over other approaches; equivalent portions of seed on the two inbred strains can be blended jointly for demonstrating, along with the total crop is harvested for seed. For hybrid seed generation, equally the parental inbreds need to have two diverse S alleles for sturdy self-incompatibility in the event of one cross hybrid. Among the cole greens like cabbage, cauliflower, broccoli and many others, sporophytic self-incompatibility system is currently being used for the hybrid seed generation at many spots in India [54]. Usually in cauliflower self-incompatibility is weak, and its response is broken at substantial temperature. Self-incompatibility can be a technique employed by a lot of flowering plant species to forestall self-fertilisation and thus encourage outcrossing. Above the several years, considerable perception in the mechanisms regulating self-incompatibility has become attained for that Solanaceae gametophytic self-incompatibility programs at the same time as for that sporophytic self-incompatibility technique of the Brassicaceae in vegetable crops. A mix of genetic and molecular reports have resulted while in the identification and characterisation of the self-incompatibility genes associated with this particular reaction.

Moreover, careful investigation on the factors in the signalling cascades of equally the Solanaceae along with the Brassicaceae is necessary for an entire idea of the self-incompatibility reaction in these people. Several mechanisms and approaches have not been exploited for that growth of professional hybrids in vegetable crops between that SI is of crucial relevance. While in the light-weight of the quick progression of biotechnology, it could be expected that SI programs are going to be ever more used near foreseeable future, in vegetable crops [55].

9. Growth regulators

Growth regulators are organic chemical substances which, when applies in small quantities aid in the regulation of plant growth and modify the physiological response in plants. Growth regulators have immense importance in enhancing vegetable production and have been used to improve seed germination, increase in yield and tolerance against diseases and unfavourable conditions [56]. Apart from these functions growth regulators have usefulness in vegetable seed production by altering sex expression, increasing fruit set as well as seed yield and inducing male sterility, without exerting any harmful effects on the environment and human health [57]. Classification and functions of different plant growth regulators (PGRs) are listed below:

1. Auxins (IAA, NAA, IBA, 2,4-D, 4-CPA): apical dominance, root induction, control fruits drops, regulation of flowering.

2. Gibberellins (GA3): seed germination, stimulates flowering, increase flower and fruit size.

3. Cytokinins (kinetin, zeatin): bud initiation and root growth, storage life prolongation of vegetables.

4. Ethylene (etheral): uniform ripening in vegetables, promotes abscission, senescence of leaf.

5. Abscisic acid (dormins, phaseic acid): stress hormone, dormancy, seed development and germination.

6. Flowering hormones (florigen, vernalin).

7. Natural substances (vitamins, phytochrome tranmatic).

8. Synthetic substances (synthetic auxins, synthetic cytokinins).

Role of different PGRs in vegetable production of different vegetable crops are reviewed in **Table 3**:

PGR	Target/response	Crop
GA3	Fruit setting, seed yield and quality	Bittergourd, muskmelon, tomato, chilli, capsicum, brinjal, cauliflower, cabbage, okra, cucurbits, potato, pea
GA3	Abnormalities in pollen development and induced the carpelization of stamens	Pepper
GA3	Leaf morphogenesis, promote normal stamen and pollen development	Tomato
GA3	Production of male sterile flowers	Onion, Brussels sprouts, cabbage, cauliflower and kale
GA3	Increased number of female flowers	Bitter gourd
GA3	Lower male and female flower ratio	Cucumber
GA3	Induce parthenocarpy	Bitter gourd
Ethrel	Decreased number of staminate flowers	Cucumber, bittergourd, pumpkin, sponge gourd
Ethrel	Increased number of pistillate flowers	Cucumber, pumpkin, pointed gourd, melons, snake gourd, sponge gourd, bottle gourd, bitter gourd, summer squash

PGR	Target/response	Crop
Ethrel	Lower male female flower ratio	Cucumber
Ethrel	Increased yield	Cucumber, bitter gourd, cucurbits, potato, pumpkin
Ethrel	Induction of male sterility	Lettuce, eggplant, squash
TIBA (triiodobenzoic acid)	Induction of male sterility	Tomato
TIBA (triiodobenzoic acid)	Producing a favourable female to male ratio and increased number of fruits	Cucumber, squash, watermelon
MH (maleic hydrazide)	Induction of male sterility	Tomato, coriander, pepper, okra, onion, squash, chilli, eggplant
MH (maleic hydrazide)	Decreased number of male flowers	Cucumber, sponge gourd
NAA (naphthalene acetic acid)	Induce male sterility	Tomato and squash
NAA (naphthalene acetic acid)	Reduce staminate-pistillate flower ratio	Cucumber, squash
NAA (naphthalene acetic acid)	Increased number of female flowers	Cucurbits, sponge gourd
NAA (naphthalene acetic acid)	Decreased number of male flowers	Cucumber
NAA (naphthalene acetic acid)	Induce parthenocarpy	Bitter gourd
NAA (naphthalene acetic acid)	Increased fruit set/yield	Cucumber, bottle gourd, tomato, chilli, capsicum, brinjal, cauliflower, cabbage, onion, garlic, cucurbits, okra, tomato
Dalapon (dichloropropionic acid)	Induction of male sterility	Pea, tomato
Dalapon and a-chloropropionate	Supression of anther dehiscence	Pepper tomato
FW-450 (sodium 2,3-dichloroisobutyrate)	Induction of male sterility	Tomato
CCC ((2-chloroethyl) trimethylammonium chloride)	Selectively inhibited the development of stamen or suppressed pollen	Tomato
ABA (abscisic acid)	Selectively inhibited the development of stamen or suppressed pollen	Tomato
Indole acetic acid (IAA)	Increased pistillate flowers	Cucurbits, cucumber
Indole acetic acid (IAA)	Decreased male flowers	Cucumber
Indole acetic acid (IAA)	Improved yield and quality characteristics	Okra, cauliflower

Table 3.
Growth regulators used for higher seed production in the vegetables based on Prajapati et al. [58].

10. Conclusions

The essence of any seed programme is the excellent quality of seed, and this trait varies from the standpoint of genetic purity. The seed programme with no proper quality management of the seed will tend to fail. For that reason, the quality of vegetable seed is a necessary consideration. Underneath a standard seed technology chain, breeder seed is multiplied from nucleolus seed. The exercise of bulk enhance of breeder seed and endless multiplication cycles of basis seed with no likely again to breeder seed may severely influence the standard of seed and may be discontinued. Importance of good quality seed can be determined from the fact that seed is the indispensable input for crop production. The top-quality seed is the carrier of the resistance gene or good genes selected by the breeder. Seed ensures food supply under adverse production sites; therefore, the importance of seeds for vegetable production cannot be denied.

Conflict of interest

The authors declare no conflict of interest.

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