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Parthenocarpy in Vegetables: Genetic Aspects, Induction Methods, and Utilisation in Vegetable Crops

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Developing seeds are key sources of phytohormones that stimulate fruit growth and development. However, in some fruits, seeds are undesirable due to their rough texture, bitter taste, or presence of toxic compounds and allergens, impacting palatability. Parthenocarpy, the production of fruits without pollination or fertilization, offers a solution by eliminating seeds, enhancing fruit quality and processing characteristics. This trait has been observed in cucumber, eggplant, watermelon, and tomato, where seedlessness improves shelf life, extends preservation, facilitates fruit set under unfavourable conditions, supports early and offseason production. Parthenocarpy is valuable in environments with challenging pollination conditions, such as greenhouses. Seedless fruits are favoured by consumers for fresh consumption, processing, and canning. Parthenocarpy can be induced through various methods, including plant growth regulators, hybridization, mutations, irradiated pollen, chromosome alterations, gene transfer, gene silencing, and genome editing. This article provides a comprehensive overview of parthenocarpy, covering its types, genetic basis, achievements, and the various methods used to induce this trait in vegetable crops to avail the benefits.

Keywords: Parthenocarpy, Vegetables, Phytohormones, Pollination

Introduction

A plant is said to be parthenocarpic when its fruits are absolutely without seeds or may consist of a totally minute range of seeds or aborted seeds. Fritz Noll in the year 1902 coined the term Parthenocarpy. The word parthenocarpy consists of two words Parthenos - Virgin and Carpy - fruit. This process often involves applying phytohormones to the ovary, suggesting that specific genes influence hormone production and sensitivity, promoting fruit growth in the absence of fertilization. Key phytohormones like gibberellins, cytokinins, and auxins are crucial for fruit development. Parthenocarpy becomes especially valuable when pollination is impossible due to environmental conditions. It is preferred for producing high-quality fruits in vegetables like cucumber, eggplant, watermelon, and tomato. Parthenocarpy, including stenospermocarpy and apomixis, is genetically regulated. Stenospermocarpy involves initial fertilization but leads to seedless fruits due to early embryo abortion, while apomixis produces fruit without fertilization.

Types of parthenocarpy

Parthenocarpy can be divided into natural/genetic and artificial parthenocarpy.

- **Natural or genetic parthenocarpy** can be further divided into obligatory and facultative. Increased endogenous hormone concentration in the ovary in absence of pollination and fertilization leads to natural parthenocarpy. Natural parthenocarpy can clear up the constraint of low pollen viability and terrible pollen release, which often occurs under low light conditions, low or high temperatures under open and greenhouse conditions. Natural parthenocarpy has been reported in various crops like tomato, eggplant, cucumber and capsicum. When the expression of parthenocarpic trait is not influenced by the external factors is called obligatory whereas, when it is influenced by adverse environmental conditions is referred to as facultative parthenocarpy.

- **Artificial parthenocarpy** involves the stimulation of the growth of fruit by natural and artificial plant hormones. The exogenous use of irradiated pollen, natural or artificial auxins, and gibberellins at ovary development which resulted in elevated levels of endogenous phytohormones during fruit set and development from sources other than seeds. Plant is parthenocarpic, if it exceeds a threshold in the concentration of growth regulators during a critical period at anthesis.

Genetics of parthenocarpy

Parthenocarpy is heritable, but does not fit in a simple genetic model.

- **Tomato** (*Solanum lycopersicum*)**:** Parthenocarpy is controlled by several single-gene recessives. In tomato, pat gene (pat, pat-2 and pat-3/pat-4) responsible for parthenocarpy is single recessive mutation with pleiotropic effects.
- **Brinjal** (*Solanum melongena)*: The genetic cause of parthenocarpy in eggplant was discovered through crosses between European parthenocarpic cultivars (Talina and Mileda) and Japanese non-parthenocarpic cultivars (EPL1 and ASL-1). Segregation tests confirmed the presence of a single dominant gene responsible for this trait.
- **Capsicum** (*Capsicum annum* L.): Single recessive gene.
- **Pepino** (*Solanum muricatum*): Single dominant gene.
- **Cucumber** (*Cucumis sativus*): Parthenocarpic trait of cucumber is controlled by two major additive- dominant-epistatic genes and additive-dominant polygenes, in either monoecious or gynoecious forms.

Methods to induce parthenocarpy

- **Environmental factors:** High temperatures reduce the photosynthetic rate by lowering carbohydrate content, possibly causing parthenocarpic fruit development. Carbohydrate levels affect flower abortion genes through hexokinases, which are involved in sugar metabolism and signal transduction. Temperature stress causes flower abortion (Tomato), inability to produce viable pollen (Pepino). Transcriptome analysis in cucumber (*Cucumis sativus* L.) reveals that auxin and ethylene play important roles in parthenocarpy under low-temperature stress condition (Meng *et al*., 2024).
- **Phytoharmones:** The processes of seed and fruit development are intimately connected, synchronized and controlled by phytohormone. Plant growth regulators like auxins, gibberellins and cytokinins induces parthenocarpy. The auxin-responsive gene IAA14 and the cytokinin-responsive genes encoding histidine-containing phosphotransfer protein 4 and two-component response regulator 17 were upregulated in sugar-induced parthenocarpic cucumber fruits (Wang *et al.*, 2021). Spraying N-(2-chloro-4-pyridyl)-N-phenylurea (CPPU), an exogenous cytokinin (CK) growth regulator, is the conventional method for inducing parthenocarpy in melon (Cucumis melo L.) by promoting the accumulation of gibberellin (GA) and auxin and decreasing the level of abscisic acid (ABA) during fruit set (Liu *et al.*, 2023).
- **Conventional breeding:** This method comprises of two fundamental steps. i) Generating a breeding population (IVT- line 1, Severianin, IVT-line 2 of tomato) that is segregating for the parthenocarpic trait of one parental genotype ii) Selecting individual progeny from

the segregating population that combine parthenocarpy with the desirable traits of the non- parthenocarpic parent.

- **Biotechnological tools:** Seedless fruit can be produced by gene silencing, transgenic and RNA interference approaches.

Table 1: Biotechnological approaches in production of parthenocarpic fruit

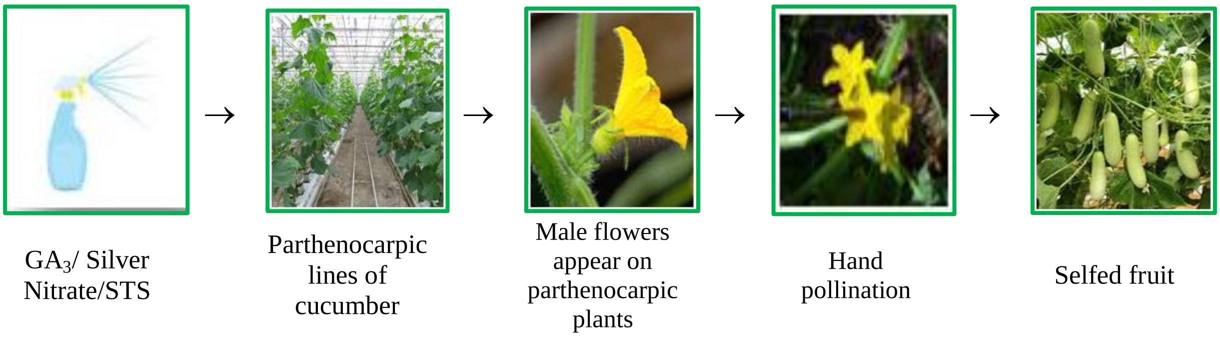
Crop	Gene	Function	Gene modification
Tomato	rolB	Auxin response	Ovary/ Fruit Specific transgene expression
	SlChs	Flavonoid biosynthesis	RNAi-mediated silencing
	AUCSIA	Auxin response	Gene silencing
	amiSlARF5	Auxin signaling	m RNA down regulated
Brinjal	ARFs	Auxin response	RNA interference
	IAA	Auxin	Differential expression found in natural parthenocarpic mutant
Brinjal, Tomato, Cucumber	DeH9-iaaM	Auxin synthesis	Ovule Specific transgene expression

Seedless tomatoes can be produced by expressing the iaaM gene from *Pseudomonas syringae* using the DefH9 promoter from Antirrhinum majus. Parthenocarpic fruits are also achieved by transforming tomatoes with the rolB gene from *A. rhizogenes*, driven by the TPRP-F1 promoter. Silencing the Chalcone synthase (Chs) gene may lead to seedless fruits due to altered auxin distribution. Silencing the Aucsia gene results in parthenocarpic fruit development and increased sensitivity to auxin transport inhibitors. ARFs regulate auxin-responsive genes and fruit development. RNA interference of SmARF8 in eggplants induces parthenocarpy, indicating that SmARF8 negatively regulates fruit initiation (Table 1).

- **Mutation:** Spontaneous mutants like parthenocarpic sha-pat (short anther- tomato) mutants are used in classical breeding programme. Alkylating agents such as EMS and EES, helium accelerated ions (tomato), soft–X-ray (watermelon) and gamma irradiation (*Citrullus lanatus*) are used successfully to produce parthenocarpic mutants in vegetable crops. The eggplant mutant pad-1, accumulated high levels of auxin in the ovaries (involved in auxin homeostasis) resulted in parthenocarpic fruit. Further, Suppression of the orthologous genes of pad-1 induced parthenocarpic fruit development in tomato and pepper plants (Matsuo *et al*., 2020).
- **Polyploidy:** Seedless fruits can be obtained by using polyploidy as a tool as in case of seedless watermelon which is a sterile hybrid obtained by crossing female tetraploid (2n=44) with male diploid (2n=22). Sterile watermelon hybrid obtained has small, white seed coat with undeveloped seeds.

Maintenance of parthenocarpic lines

- The maintainance of parthenocarpic strains is a constraint. The male flowers are induced by using plant growth regulators *e.g.* GA_3 @ 150 ppm (3-4 spray at 2-3 true leaves stage), silver nitrate @200ppm (1-2 spray) or GA_3 + GA_7. Parthenocarpic fruits produce fewer seed per pollinated fruit than the non- parthenocarpic fruits.



Advantages of parthenocarpic vegetable crops

1. Pollination and fertilization are negatively influenced by environmental stresses like low/excessive temperatures. As parthenocarpic vegetables does not require pollination and fertilization to set fruits, stability in production and productivity is seen.
2. Consumer acceptance towards seedless fruits has been increased. Example: Parthenocarpic cucumber, seedless water melon and seedless gherkin.
3. Improved quality and shelf life in brinjal as seeds are associated with bitterness of fruit
4. Improved taste, high total soluble solids, increased profitability for processing industries as they can skip the process of removal of seeds for preparation of juice, puree, paste and other processing products. Example - Seedless tomato.
5. Cost and time incurred on pollen vibrators and manual labors for pollination in green house grown vegetables are cut down by growing parthenocarpy vegetables. Eg: Vertical fruit harvest is done in parthenocarpic gynoecious cucumber in green houses.
6. Crown set inhibition is observed in cucumber, watermelon and muskmelon wherein first formed fruit inhibit the formation of further fruits. No effect of crown set inhibition in parthenocarpic vegetables so, fruits are continues. Several parthenocarpic lines and varieties have been developed in vegetables worldwide and in India (Table 2).

Table 2: Parthenocarpic lines and varieties developed in vegetables worldwide and in India

Achievements in world		
Tomato	Severianin, Santium, Oregon Pride, Oregon Star, IVT line-1, IVT line -2, Oregon T5-4, Oregon Cherry, Oregon 11, Oregon spring	
Brinjal	AE-P 01, AE-P 08, Talina 1, Talina 2, Michael	
Cucumber	Sweet Success, Euro- American, Socrates, Tyria, Diva, Tasty Jade, County Fair 83, Excelsior, Taurus	
Watermelon	Red Rock, Amiga, Round Trip	
Zucchini	Easy Pick Gold Squash, Easy Pick Green Squash, Partenon, Cavili, Argo	
Achievements in India		
Cucumber	IARI, New Delhi	DPaC-6, 4 DPaC- 9, 5 DPaC-10
	GBPUAT, Pantnagar	Pant Parthenocarpic Cucumber-2, Pant Parthenocarpic Cucumber-3
Water melon	IARI, New Delhi	Pusa Bedana
	KAU, Kerala	Shonima (Red), Swarna (Yellow)
	IIHR, Bangalore	Arka Madhura
Pointed gourd	IVRI, Varanasi	IIVRPG- 105

Conclusion

Parthenocarpy proved especially beneficial in yield, processing trends and protected cultivation, in particular in cross-pollinated vegetable crops. Besides phytoharmones, further exploitation of biotechnological equipment can beautify the performance and identity of parthenocarpic genes throughout the plants for the gain of mankind.

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