Parthenocarpy and its Utilization in Vegetable Crops

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ABSTRACT

Parthenocarpy refers to the development of seedless fruits without pollination and fertilization and is an important trait for improving fruit quality, yield stability, and consumer acceptance in vegetable crops. In many vegetables, seeds negatively affect texture, taste, shelf life, and processing quality, making seedless fruits highly desirable. Parthenocarpy occurs naturally or can be artificially induced through phytohormones, environmental factors, hybridization, mutation, polyploidy, and biotechnological approaches. This trait is particularly valuable under unfavorable environmental conditions such as temperature extremes, low light, water stress, and limited pollinator activity, which restrict normal fertilization. Auxins and gibberellins play a central role in initiating and regulating parthenocarpic fruit development by substituting hormonal signals normally supplied by developing seeds. Genetic studies have revealed diverse inheritance patterns of parthenocarpy in crops such as tomato, eggplant, cucumber, and capsicum. Overall, exploitation of parthenocarpy through breeding and biotechnology offers a promising strategy for enhancing fruit quality, productivity, and sustainability in modern horticultural systems.

INTRODUCTION

Parthenocarpy is the growth of ovary into seedless fruit in the absence of pollination and fertilization. Developing seeds are source of phytohormones and stimulate the fruit growth and development. However, in some vegetables presence of seeds in fruit are undesirable due to hard or leathery texture, bitter taste and presence of toxic compounds and allergens which affect on the palatability. Seedless fruits are desirable for improving the quality of fresh as well as of the processed fruit and it has been observed in cucumber, eggplant watermelon and tomato. Therefore, replacing the seeds and seed cavities with edible fruit tissue is an attractive offer to the consumers and challenge to the researchers. Hence, genetic tool of parthenocarpy can play important role in this direction, wherein, ovary developed into a fruit without fertilization.

Parthenocarpy may occur naturally or can be induced artificially by exogenous application of hormones or their enhanced endogenous level. Parthenocarpy trait proved highly useful to develop fruits under environmental conditions that are unfavorable for successful pollination and fertilization, particularly in green house cultivation and especially in cross-pollinated crops. It is an established fact that phytohormones play important role in fruit setting and their genetic manipulation can lead to seedlessness. A plant is known to be parthenocarpic when its fruits are completely devoid of seeds or contain a very minute number of seeds or aborted seeds. Null coined the term Parthenocarpy. The word parthenocarpy comprises of two words Parthenos - Virgin and Carpy-fruit.

Reasons for occurance of Parthenocarpy

- Fruit development without pollination
- Fruit development due to stimulus received by pollination followed by unsuccessful fertilization
- Abortion of embryos
- Degradation of fertilized ovules
- Chromosomal irregularities
- Male sterility and self incompatibility

ADVANTAGES OF PARTHENOCARPIC VEGETABLE CROPS

1. **Stability in production and productivity-** Pollination and fertilization are negatively affected by environmental stresses such as low/high temperatures, but parthenocarpic vegetables produce fruits in absence of pollination and fertilization, resulting in stability in development and productivity.
2. **Consumer acceptance increases-** Seedless fruits such as parthenocarpic cucumber, seedless watermelon and seedless pickled gherkin are preferred by consumers (Baker *et al*. 1973).
3. Parthenocarpy prompts creation of novel vegetables like seedless tomato, parthenocarpic cucumber and seedless water melon.
4. **Improves fruit quality of vegetables-** Parthenocarpy increases quality and shelf life in brinjal because seeds are linked to fruit bitterness (Dalal *et al*. 2006).

5. **Increases the shelf life** of the vegetables for better conservation

6. Parthenocarpy improves taste, total soluble solid content in vegetables e.g. seedless tomato

7. It increases profitability for processing industries because seedless fruits do not need seed removal during processing. For example, a seedless tomato (Lukyanenko 1991)

8. **Vertical fruit harvesting-** by growing parthenocarpic cucumbers in green houses, more gains can be realized by continuous fruit set on vine. This will reduce the cost and time spent on pollen vibrators and manual pollination, both of which are needed in the production of greenhouse vegetables.

Table.1 Quality parameters of parthenocarpic vegetables compared to seeded vegetables

Crop	Parthenocarpic quality	Reference
Watermelon	The shape, flavor and yield are as good as seed producing cultivars and have a longer shelf life	Kihara, 1951
Watermelon	Bear more fruit/plant and tough rind	Tiwari *et al.*,2014
Gherkin	More crunchy, firmer and fleshier	Varoquaux *et al.*, 2000.
Tomato	More tasty, contain more drymatter, contain more sugars, less acidity, have fruit size and jelly fill in the locules.	
Brinjal	High yield and fruit quality	Donzella *et al.*, 2000
Bell pepper	Parthenocarpic fruit growth reduces yield fluctuation and blossom- end rot	Heuvelink and Korner, 2011.
Cucumber	Total sugar content of parthenocarpic fruits to be significantly lower than that of the pollinated fruits, with significant negative effects in the sweet taste of fruit	

Ideotype of Parthenorpic Trait

Rotino *et al.*, (1999) suggested that in order to improve the productivity of vegetable crops, the ideotype of the parthenocarpic trait should has to satisfy the following features:

1. Production of marketable fruits without pollination

2. Percentage of fruit setting under adverse conditions should be similar to that obtained under favorable growth conditions

3. Phenotypic expression of trait should not display any negative effect on both intrinsic and extrinsic fruit quality

4. Multi- pistillate parthenocarpic (e.g. Cucumbers)

TYPES OF PARTHENOCARPY

Genetic / Natural parthenocarpy

1) **Obligatory** : when expression of the partenocarpic trait is not affected by external influences it is called obligatory partenocarpy

Eg- Ivy gourd

2) **Facultative :** parthenocarpic fruit growth occurs only in absence of pollination and fertilization such as in tomato and brinjal it is reffered as facultative parthenocarpy

3) **Vegetative parthenocarpy** : plants that do not require pollination or other external stimulation to produce parthenocarpic fruit that have vegetative parthenocarpy Eg- Seedless cucumber

4) **Stimulative parthenocarpy** : in some plants pollination or other stimulation is required for occurance of parthenocary. Eg- Watermelon

5) **Steno-spermocarpy** : pollination and fertilization occur but the embryo gets aborted and produces parthenocarpic fruits. Eg- Seedless Grapes

RTIFICIALLY INDUCED PARTHENOCARPY

1. Irradiated pollen
2. Auxin - IAA
3. Gibberellins – GA_3

It involves the stimulation for the growth of a fruit using both natural and artificial plant hormones. The induction of parthenocarpy is a common agricultural practice for some horticultural species. The exogenous use of irradiated pollen, natural or synthetic auxins and gibberellins increased IAA content during ovary development. This resulted in elevated levels of endogenous phytohormones during parthenocarpic fruit set and development from sources other than seeds.

Nitsch (1970) defined that a plant is parthenocarpie, if it exceeds a threshold in the concentration of growth regulators during a critical period at anthesis. In eggplant, the first increase takes place during the first five days after anthesis, while a major peak of IAA appears at 20 days after anthesis in both pollinated and auxin treated flowers.

GENETIC INHERITANCE OF PARTHENOCARPY IN DIFFERENT VEGETABLES

Table.2 Genetic inheritance of parthenocarpy in different vegetables

Crop	Gene
Tomato	Several single recessive genes (*pat, pat-2, pat-3/pat 4*)
Brinjal	Single dominant gene
Capsicum	Single recessive gene
Cucumber	Single incompletely dominant gene (Pc)
Summer squash (cv. Whitaker)	Single gene with incomplete dominance
Muskmelon	Recessive genes

GENETICS OF PARTHENOCARPY

Parthenocarpy is heritable, but does not fit in a simple genetic model. Molecular and physiological basis of parthenocarpy have showed involvement of genes controlling auxins and gibberellins biosynthesis, self-incompatibility, histones and alcohol dehydrogenase activity.

TOMATO

Parthenocarpy is controlled by several single-gene recessives. In tomato, pat gene responsible for parthenocarpy is single recessive mutation with pleiotropic effects. The pat gene enhance the growth rate of ovary during the first 10 days of anthesis, which correlates with a precocious onset of cell divisions in the pericarp and higher auxin, gibberellin and DNA contents in the ovaries. In addition to parthenocarpy, the pat gene causes aberrations that affect male floral organs. The androecium of pat flowers is short, irregular and apparently unfused anthers that leave the stigma exerted and preferentially external dehiscence. The pat syndrome describes that parthenocarpy caused by a secondary effect of a gene controlling at early stages organ identity and development. Three alleles i.e. pat, pat-2 and pat-3/pat-4 have altered hormonal balances in the ovary of parthenocarpic tomato plants as compared with that of wild type and these alleles are considered natural source of facultative parthenocarpy.

Genetics of parthenocarpy in two different lines of tomato i.e. IL.5-1 and IVT-line-1, both carrying *Solanum habrochaites* chromosome segments, confirmed that parthenocarpy in tomato is controlled by two QTLs. In IL5-1, one QTL is on chromosome 4 (pat4.1) and other on chromosome 5 (pat5.1), whereas, in IVT-line 1, one on chromosome 4 (pat4.2) and one on chromosome 9 (pat9.1). It is likely that pat4.1 from ILS-1 and pat4.2 from IVT-line located near the centromere of chromosome 4 are allelic.

Micro synteny between tomato and Arabidopsis in this genetic region also identified that ARFS as a potential candidate gene for these two QTLs. ARF8 is known to act as an inhibitor for further carpel development in Arabidopsis in absence of pollination/fertilization. Expression of an aberrant form of the Arabidopsis ARF8 gene in tomato has also caused parthenocarpy.

EGGPLANT

Genetic causes of parthenocarpy in eggplant was first reported in 1998 by Yoshida and co-workers in a cross between European parthenocarpic cultivar Talina and a Japanese non-parthenocarpic cultivar EPLI. Their segregation tests in F_2 and BC_1F_1 populations confirmed that it is controlled by a single major gene. Later on, a cross between an European parthenocarpic cultivar Mileda and a Japanese non-parthenocarpic line ASL-1 also confirmed the presence of single dominant gene in eggplant. Using this information intraspecific linkage map in eggplant was developed. Quantitative trait locus (QTL) analysis of eggplant by using co-dominant simple sequence repeat and single nucleotide polymorphism markers revealed that two QTLs on chromosomes 3 and 8, which are controlling parthenocarpy 3.1 (Cop3.1) and Cop8.1, respectively.

- Capsicum (*Capsicum annum* L.): single recessive gene.
- Pepino (*Solanum muricatum*): single dominant gene.
- Cucumber: 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

1. **ENVIRONMENTAL FACTORS:** Adverse environmental conditions inhibit fruit set and growth of several vegetable crops. High or low temperature, humidity, low light intensity, heavy rain and strong wind are all factors, which negatively influence several steps of the reproductive process, such as formation, dispersal and germination of pollen, fertilization and seed maturation, consequently fruit production is impaired. On the other hand, these environmental factors are known to induce parthenocarpy also. Among these factors, the most important is temperature stress, which induces parthenocarpic fruit growth in tomato plants due to flower abortion and in pepino due to inability to produce viable pollen. The maximum expression of parthenocarpy in tomato was related with high temperature stress above the optimal 24-25°C.

Under high temperature stress most of the tomato flowers were aborted, but 4% remained on the plant and developed into fruit without the seed due to failure in production and release viable pollen (Sato *et al.*, 2000). Sato *et al* (2001) added that under high temperature, most of the tomato flowers (53%) developed into parthenocarpic fruit and remainder (43%) stayed on the plant as undeveloped flowers with a transition phase to parthenocarpic fruit.

The development of flowers to parthenocarpic fruit may be correlated with carbohydrate availability or the presence of seeded fruit on the vine. Photosynthetic rate declined in tomato at high temperature, so carbohydrate availability declined too and may cause parthenocarpic fruit development (Sato *et al.*, 2000). Carbohydrate content affects the expression of flower abortion genes through hexokinases, which have roles in sugar metabolism and signal transduction to other genes. In peppers, induction of parthenocarpy was also observed due to climatic stress like low irradiance, severe water stress and high irradiance or high temperatures.

2. **PHYTOHARMONES:** Plant growth regulators except ethylene and abscisic acid

induced the fruit development; however, gibberellins, auxins and cytokinins induced parthenocarpy. Exogenous auxin application to flowers for induction of parthenocarpy was first reported by Gustafson (1936), while, the effects of various growth regulators on its initiation was studied later in a wide variety of horticultural crops, such as watermelon, cucumber, sweet pepper (Heuvelink and Korner, 2011) kakrol and teasle gourd. The exogenous application of auxin triggers the expression of auxin-biosynthetic genes in ovaries and ovules to induce parthenocarpic fruit (Carmi *et al*., 2003). When the auxin-biosynthetic iaaM gene expressed in ovaries and ovules under the control of the placenta and ovule-specific DefH9 promoter, parthenocarpic fruit in tobacco, eggplant, tomato, strawberry and raspberry was induced. Auxin is the major inducer of fruit set that acts in part by inducing gibberellin biosynthesis. Interestingly, gibberellin does not significantly contribute to the final fruit size, but seems to play an important role in preventing flower and fruit abscission. Therefore, gibberellin along with auxin seems to be playing an important role in parthenocarpy.

The pollen produce gibberellins, while the exogenous application of gibberellins augments the auxin level in the ovary of an unpollinated flower to trigger the fruit setting in absence of fertilization. The developing embryo reins the rate of cell division in the contiguous fruit tissue. As considered that developing seeds support cell expansion within the fruit by the production of auxin. Gibberellin that triggers fruit setting in the course of ovary auxin increase is supported by its increased transcription at the time of fruit set and by its expression in the mitotic cell layers of the placenta.

3. **DISTANT HYBRIDIZATION:** There are two basic steps in distant hybridization

1. Creating a breeding population that segregates for one parental genotype's parthenocarpy phenotype
2. Selecting progeny from a segregating population with parthenocarpy and the attractive traits of the non-parthenocarpic parent

Two types of crosses are used to create a breeding population :

1. Intraspecific hybridization

- Intraspecific hybridization was used for the first time in tomato to produce a facultative parthenocarpic line suitable for a hot and dry climate (normal fruit at moderate temperature).
- Following that, intraspecific hybridization was used to build various other parthenocarpic lines, such as Severianin, Oregon T5-4, Oregon Cherry, Oregon 11, Line P-26, Line P-31, Line RG and IVT-line 2 in tomato and 'AE-P' lines and 'Talina2/1' in eggplant.

2. Interspecific hybridization

- IVT-line 1 in tomato was created from a cross between *S. habrochaites* and *S. lycopersicum* (Zijlstra 1985), while as Obligate parthenocarpy in aneuploid tomato was created from a cross between *Solanum esculentum* and *S. peruvianum*.
- Interspecific hybridization to alter ploidy is a popular method for obtaining parthenocarpic fruits, as stated in banana, watermelon and citrus.
- Triploid plants are usually sterile because they are unable to pass through meiosis. Despite the fact that the mechanisms of fruit initiation in triploid plants are largely unknown, perceptions suggest that sterility is an important requirement for parthenocarpy to manifest.

3. BIOTECHNOLOGICAL TOOLS

- Phytohormones, auxins and GA_3 plays important role in parthenocarpic fruit development
- Increased level of these hormones in ovules and ovary substitutes for pollination for fruit development

4. MUTATION

Spontaneous mutations occur naturally and are used in classical breeding programmes. Good example of this is the parthenocarpic sha-pat mutants in the tomato line Montfavet 191. Various radiation treatments, such as helium accelerated ions in tomato (Masuda et al., 2004), soft-X-ray in watermelon (Sugiyama and Morishita, 2000) and gamma irradiation in *Citrullus lanatus* (Sugiyama and Morishita, 2000) have been used successfully to generate parthenocarpic mutants. Alkylating agents (EMS and EES) has been used to generate parthenocarpic mutants of tomato.

5. POLYPLOIDY

Polyploidy induces parthenocarpy. In other words, a seedless watermelon is a sterile hybrid which is created by crossing male pollen for a watermelon, containing 22 chromosomes per cell, with a female watermelon flower with 44 chromosomes per cell. When this seeded fruit matures, the small, white seed coats inside contain 33 chromosomes, rendering it sterile and incapable of producing seeds resulting in parthenocarpy.25% of pollinizer should be planted in the field for obtaining seedless watermelon fruit.

CONCLUSION

Parthenocarpy represents a valuable biological and agronomic trait for improving yield stability, fruit quality, and consumer acceptance in vegetable crops. The ability of plants to develop fruits in the absence of pollination and fertilization is particularly advantageous under adverse environmental conditions such as temperature extremes, low light, water stress, or poor pollinator activity, which frequently limit successful fruit set. Seedless fruits produced through parthenocarpy are preferred by consumers due to their improved texture, taste, shelf life, and suitability for processing, thereby increasing market value and profitability for growers and industries. The trait can occur naturally or be induced through environmental factors, phytohormone application, hybridization, mutation, polyploidy, and modern biotechnological approaches. Extensive studies have demonstrated that phytohormones, especially auxins and gibberellins, play a central role in initiating and sustaining parthenocarpic fruit development by substituting the hormonal signals normally supplied by developing seeds. Advances in genetics and molecular biology have further clarified the inheritance and regulation of parthenocarpy in crops such as tomato, eggplant, cucumber, and capsicum. Overall, effective exploitation of parthenocarpy through breeding and biotechnology offers a promising strategy to enhance productivity, fruit quality, and resilience of vegetable crops, contributing significantly to sustainable horticultural production and future food security.

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