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Utility of Parthenocarpy in Vegetable Crops: A Review

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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

Parthenocarpy is a phenomenon observed in vegetable crops where fruits are produced without fertilization or pollination. This process leads to the development of seedless fruits, which are highly desirable in the market due to their convenience and improved quality. In parthenocarpic vegetables such as cucumbers, tomatoes and eggplants, fruit development occurs without the need for pollination by insects or wind. This can be advantageous in areas with limited insect activity or in greenhouses where pollinators may not be present. The development of parthenocarpy in

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vegetable crops is influenced by both genetic and environmental factors. Certain cultivars have been bred to exhibit this trait, while others may require specific environmental conditions such as temperature and light to induce parthenocarpy. One of the key benefits of parthenocarpy is the production of seedless fruits. This is particularly important in seedless cucumber varieties as it eliminates the need for seed removal, making them more convenient for consumption. Seedless tomatoes and eggplants also offer improved texture and taste as the absence of seeds reduces bitterness and enhances sweetness. Parthenocarpy can help improve crop yields and reduce crop losses. Since parthenocarpic fruits develop without pollination, they are less prone to damage caused by pests and diseases that target developing seeds. This can result in higher yields and better overall crop quality. However, it is important to note that parthenocarpy may have some limitations. In some cases, seedless fruits may be less flavorful compared to their seeded counterparts. Additionally, parthenocarpic varieties may require specific management practices and careful monitoring to ensure optimal fruit development.

Keywords: Parthenocarpy; vegetable crops; seedless vegetable and PGRs.

1. INTRODUCTION

"The term parthenocarpy coined by Noll in 1902. The term parthenocarpy derived from two Greek word words Parthenos means virgin and carpy means fruit. Parthenocarpy defined as the development of the ovary into a seedless fruit without the need of pollination and fertilization" (Benoit Gorguet, 2007). Absence of pollination is due to Male sterility, Self incompatibility and adverse environmental condition. It may occur naturally or can be induced artificially by exogenous application of hormones or their enhanced endogenous level. Several vegetable crops have been successfully bred to exhibit parthenocarpy including cucumber, tomato, pepper, and eggplant. The development of parthenocarpic varieties involves selecting and breeding plants with specific genetic traits that promote fruit development without fertilization. These traits can be naturally occurring or induced through genetic engineering techniques. For example parthenocarpy in cucumbers is controlled by a single recessive gene known as Parthenocarpy (Pat). By selecting and breeding plants with the Pat gene, breeders have been able to develop cucumber varieties that produce seedless fruits. Similarly in tomato, the application of plant growth regulators such as auxins, can induce parthenocarpy and result in the production of seedless fruits [1].

2. IMPORTANCE OF PARTHENOCARPIC VEGETABLES

Parthenocarpic vegetables offer a solution to the problem of low fruit set in certain crops. In some cases, environmental conditions or lack of pollinators can hinder the natural fruiting process. However, with parthenocarpy farmers can still obtain a good yield of fruits even under unfavorable conditions. This is particularly significant in regions with unpredictable weather patterns or where pollinators are scarce. Parthenocarpic vegetables provide a consistent and high-quality harvest. Since they do not rely on pollination, the fruits are less likely to develop deformities or irregularities. This ensures that consumers receive visually appealing and uniform produce which is important for both marketability and consumer satisfaction. The absence of seeds in parthenocarpic fruits makes them more convenient for culinary purposes which reducing the need for seed removal. Furthermore, parthenocarpy allows for extended growing seasons and increased productivity. As these vegetables do not require pollination, they can be grown in protected environments such as greenhouses or polytunnels. This enables farmers to cultivate crops year-round, regardless of external factors that may affect pollination. Additionally, parthenocarpic vegetables often have shorter maturation periods which allowing for multiple harvests in a single growing season. Parthenocarpic vegetables contribute to food security and sustainability. By providing a reliable source of produce, they help meet the demands of a growing global population. Additionally, their ability to thrive in diverse conditions reduces the reliance on specific climates or pollinators, making agriculture more resilient and adaptable to changing environments. This is particularly important in the face of climate change, where traditional crop production may be compromised [2].

3. NEGATIVE EFFECTS OF PARTHENOCARPY

Followings are negative effect of parthenocarpy on vegetable crops [7].

1. Fruits become misshapen, smaller and duller in appearance, softer in texture.
2. Decreases biodiversity, which reduces plant species resistance to disease.
3. Transfer of genes from seedless crops may cause non-modified plants to become sterile or not produce seeds.
4. Early application of auxins like phytohormones before anthesis damages the flowers. It results in the abortion of seed and fruit drop.

4. TYPES OF PARTHENOCARPY

4.1 Genetic/Natural Parthenocarpy

4.1.1 Obligatory parthenocarpy

No external influence. It's commercially found in Ivy gourd.

4.1.2 Facultative parthenocarpy

It occurs due to adverse conditions for pollination and fertilization. It's found in Tomato, brinjal and cucumber.

4.1.3 Stimulative parthenocarpy

Pollination or other stimulation is required for parthenocarpy. It present in watermelon.

4.1.4 Vegetative parthenocarpy

Pollination or other external stimulation is not required to produce parthenocarpic fruit e.g. cucumber.

4.1.5 Stenospermocarpy

Pollination and fertilization occur but the embryo gets aborted. Also produces seedless fruits, but here the seeds are aborted and remains traces of seeds.

4.2 Artificial Induction of Parthenocarpy

4.2.1 Use of plant growth regulators

Plant growth regulators (PGRs) are organic compounds, other than nutrients that modify plant physiological processes. Many studies have shown that phytohormones play an important role in fruit set regulation, growth and maturation in complex way. The parthenocarpic fruits are associated with the endogenous auxin and gibberellins in the ovary. The exogenous applications of plant growth hormones, like auxins, cytokinins and GAs, can influence parthenocarpic fruits in vegetable crops.

4.2.2 Distant hybridization

"Interspecific hybridization have been utilized for producing a facultative parthenocarpic line suitable for a hot and dry climate (normal fruit at moderate temperature) was first introduced in tomato" [11]. "Altered ploidy through interspecific hybridization is a common approach to obtain parthenocarpic fruits in various crops such as banana, watermelon and citrus" [12].

4.2.3 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 [18] Soft–X-ray used successfully to generate parthenocarpic mutants in watermelon" [19]. "Gamma irradiation in *Citrullus lanatus* has been used successfully to generate parthenocarpic mutants" (Sugiyama and Morishita, 2001). "Alkylating agents (EMS and EES) has been used to generate parthenocarpic mutants of tomato" [20].

4.2.4 Alteration in chromosome number

"Unbalanced development of embryo and endosperm in triploid background has been utilized to yield parthenocarpic fruit. In watermelon seedless fruits with only residual integuments are obtained from F1 hybrid plants derived from cross between tetraploid and diploid parents" [3]. "Chromosome elimination in wide crosses may lead to the production of haploids, which are of enormous interest to the breeders. Haploid formation following interspecific hybridization is usually interpreted as parthenogenesis" [21].

5. MECHANISM OF PARTHENOCARPY

The diagram illustrates the mechanism of parthenocarpy in a simplified manner. It shows the key steps involved in fruit development without fertilization. Firstly, the ovary is stimulated to grow by the activation of auxins and gibberellins. This leads to the enlargement of the ovary, which eventually develops into a mature fruit. Meanwhile, the absence of fertilization prevents the formation of seeds, allowing the fruit to divert its resources towards growth and development. Finally, the fruit undergoes ripening, aided by the suppression of ethylene production by gibberellins.The seed and fruit development was control by phytohormones [24]. GA_3, auxin and cytokinin involve signaling process after fertilization for seed and fruit development [25]. Increase endogenous hormones during parthenocarpic fruit set not from source of seed [26]. Trigger the expression of auxin biosynthetic gene [27].

Table 1. Quality parameters of some parthenocarpic vegetables

Crops	Parthenocarpic	References
Watermelon	The shape, flavour and yield are as good as seed-producing cultivars and have a longer shelf life	Kihara, [3]
Gherkin	Seedless gherkins are more crunchy, firmer and fleshier than its seeded variety	Rudich et al., [4]
Tomato	Seedless tomato fruits are tastier, more dry-matter (up to 1%), contain more sugars, less acidity and less cellulose	Lukyanenko, [5]
	More soluble solids	Gorguet et al., [6]
Eggplant	High yield and fruit quality	Donzella et al., 2000

Table 2. Use of plant growth regulators for parthenocapic fruit development

Crops	Growth Regulator	Stage of Treatment	Types of Parthenocarpy	Reference
Brinjal	GA_3 @ 2700 ppm; 2-4-D@2.5 ppm	Foliar spray on freshly opened flower.	GA_3 induced the completely seedless fruits during all seasons. 2,4-D, induced the development of degenerated seeds	Nothmann and Koller, [8]
Kokrol	2-4-D/2-4-5-T @100mg/L	Pre-anthesis sprays	Complete parthenocarpy	Vijay and Jalikop, [9]
Cucumber	GA_3 @100mg/L	Pre-anthesis sprays	Complete parthenocarpy	Choudhury and Phatak, 1958
Bottle gourd	CPPU@ 10–100 mg/L	2 days before or after anthesis	Complete parthenocarpy	Jing, [10]

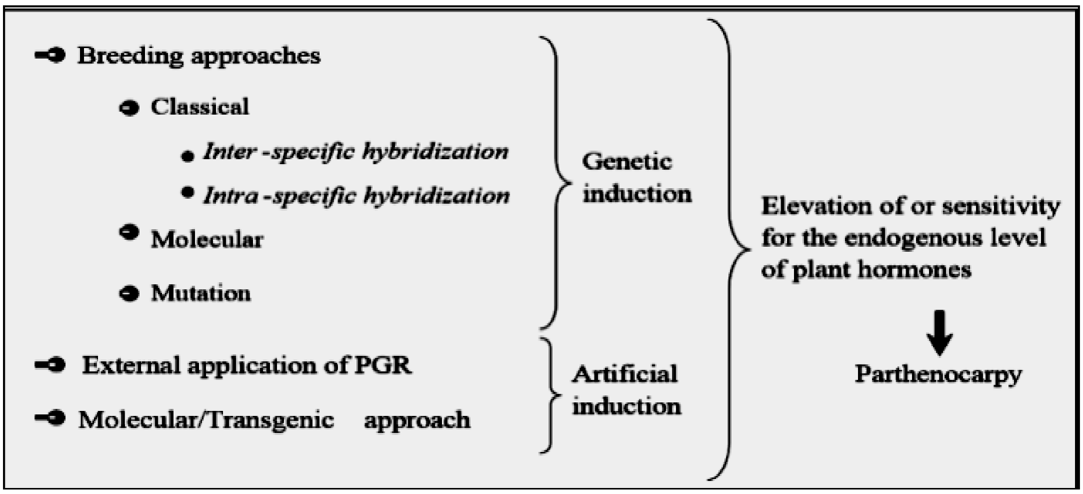

Fig. 1. Development methods of parthenocarpic variety

Table 3. Development of facultative parthenocarpy in tomato by distant hybridization

Parthenocarpic Line/Cultivar	Cross Involved	References
Line RP75/79	Multiple cross Atom × Bubjekosoko and Heinemanns Jubilaum × Priora (developed by R. Reimann-Philipp)	Philouze and Maisonneuve, [13]
Severianin	*L. esculentum and L. hirsutum (bred by N. Soloviova)*	Lin et al*.,* [14]
P-26, P-31, etc.	*L. esculentum and L. pennellii*	Stoeva et al*.,* [15]
Line RG	*L. esculentum and L. cheesmanii var. minor*	Mikhailov and Georgiev, [16]
IVT 1	*L esculentum and L. hirsutum*	Zijlstra, [17]
IVT 2	*L. esculentum and L. peruvianum*	Zijlstra, [17]

Table 4. Parthenocarpic vegetables associated with various ploidy levels

Vegetables	Species	Ploidy Number	References
Tomato	*Solanaum esculentum* (2n = 2x = 24)	Triploid (2n = 3x = 36)	Habashy et al*.,* [22]
	Solanaum esculentum (2n = 2x = 24)	Aneuploid	Lesley and Lesley, [23]
Cucumber	*Cucumis sativus* (2n = 2x = 14) (Amphidiploid × Diploid)	Triploid (2n = 3x = 21)	Habashy et al*.,* [22]
Watermelon	*Citrullus lanatus* (2n = 22) (Autotetraploid × Diploid)	Triploid (2n = 3x = 33)	Kihara, [3]

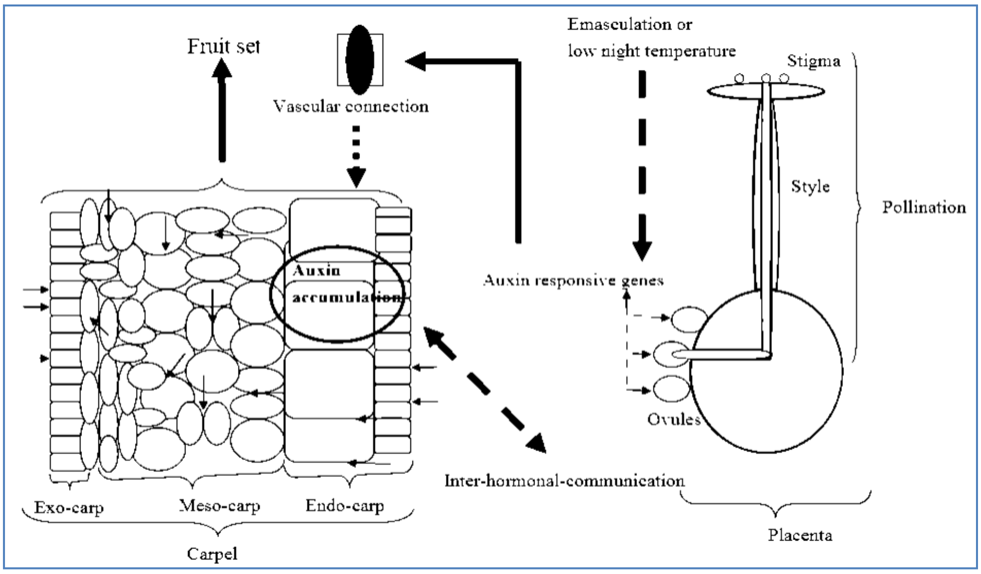

Fig. 2. Mechanism of parthenocarpy

Table 5. Genetics of parthenocarpy in vegetable crops

Crops	Genetics	References
Tomato	Several single gene recessive	Fos et al*.*, [25]
Brinjal	Single dominant gene	Kuno and Yabe, [45]
Capsicum	Single recessive gene	Tiwari et al*.*, [46]
Cucumber	Additive dominant epistatic gene and additive dominant polygenes	Yan et al*.*, [47]

6. FACTORS AFFECTING PARTHENOCARPY

6.1 Genetic Factors

One of the primary mechanisms of parthenocarpy is genetic factors. Certain plant species possess genes that allow them to initiate fruit development without the need for pollination or fertilization. These genes are responsible for the production of hormones such as auxins and gibberellins, which play a crucial role in fruit development. Mutations or alterations in these genes can lead to the occurrence of parthenocarpy. The SlAGL6 gene in tomato plants has been identified as a key regulator of parthenocarpy, as its mutation results in the production of seedless fruits [25].

6.2 Hormonal Factors

Hormones play a significant role in parthenocarpy. Auxins, particularly indole-3-acetic acid (IAA) are essential for the initiation and growth of fruits. In some cases high levels of auxins in the ovary can trigger fruit development without fertilization. Ethylene also has an impact on parthenocarpy. It can promote fruit growth and ripening and its application can induce parthenocarpy in certain plant species. Gibberellins, cytokinins and abscisic acid are other hormones that influence fruit development and can contribute to parthenocarpy [8].

6.3 Environmental Factors

Environmental conditions can also influence the occurrence of parthenocarpy. Temperature, light and water availability are among the key factors that can affect fruit development. High temperatures during the flowering period can stimulate the production of auxins which leading to parthenocarpy. Similarly, exposure to specific light conditions such as prolonged periods of darkness also can trigger hormonal changes that promote fruit development without fertilization. Adequate water supply is crucial for fruit growth and water stress can inhibit the occurrence of parthenocarpy [2].

6.4 Pollination and Fertilization

While parthenocarpy is defined as fruit development without fertilization, the presence of pollination and fertilization can still influence its occurrence. In some cases, the presence of pollination signals triggers the production of hormones that initiate fruit development. Additionally, fertilization can enhance the growth and quality of parthenocarpic fruits. The interaction between pollination, fertilization and parthenocarpy is complex and varies among different plant species [28].

7. UTILITY OF PARTHENOCARPY IN VEGETABLE CROPS

7.1 Tomato

Three source of facultative type parthenocarpy present in tomato *Viz*., Soressi or Montfavet-191 (*Pat*-1), Severianin (*Pat*-2) and RP75/59 (*Pat*-3/*Pat*-4) [29]. Thien et al. [30] Introducing *iaa9-3* mutation into tomato cultivar and they recorded that developed parthenocarpic cultivar retaining the normal stamen structure and fertile pollen, the parthenocarpic lines can produce sufficient seeds for self-pollinated propagation, average seedless fruit weight of experimental lines ranged from 25 g/fruit (small category) to over 50 g/fruit (intermediate category), together with good number of fruits/plant which can lead to a theoretical seedless fruit yield of over 3000 g/plant, which is acceptable for commercial varieties and increasing the quality of seedless fruits compared to seeded fruits which is attributable to an increase in the mass of placental area and a higher ºBrix level than locule and pericarp areas. Optimized the CRISPR/Cas9 system to introduce somatic mutations effectively into *SlIAA9* a key gene controlling parthenocarpy with mutation rates of up to 100% in the T_0 generation which studied by Ueta et al. [31]. Federico et al. [32] obtain parthenocarpic transgenic tomato plants (cv *MicroTom*) by the regulation of genes for auxin synthesis (*iaaM*) or responsiveness (*rolB*) driven by *DefH9* or the INNER NO OUTER (*INO*) promoter from *Arabidopsis thaliana.* Rotino et al. [33] recorded that minimum percentage of fruit with seeds and number of seeds per fruit in transgenic parthenocarpic line Ri4. Andrea et al. [34] revealed that 59% fruit with zero seeds in Pat genotype under 26 ºC days and 18 ºC night temperature.

7.2 Brinjal

Anupama et al. [35] recorded that parthenocarpic line 93213-PC-2-1 and 93213-PC-2-3 were earlier for days to first harvest, at the top for the number of flowers per cluster, number of fruits per cluster and maximum number of marketable fruits per plant when grown under net house conditions. Saito et al. [36] developed parthenocarpic cultivar Anominori 2 go which is an F_1 hybrid between two parthenocarpic inbred lines AE-P01 and AE-P24. Saito et al. [37] developed parthenocarpic cultivar Anominori from AE PO8 and AE PO1 parthenocarpic line through pedigree methods. Acciarri et al. [38] revealed that yield per plant and fruit weight recorded maximum in P_2 parthenocarpic hybrid.

7.3 Cucurbits

Nagamani et al. [39] noted that Alexious parthenocarpic hybrid of cucumber recorded maximum fruit length, fruit diameter, average fruit weight, fruit yield per vine and total yield under green house conditions. In cucumber maximum fruit firmness, fruit colour, fruit flavor and fruit texture revealed in JSCU 01 parthenocarpic cultivar under polyhouse which studied by Kumar et al. [40]. Kumar et al. [41] also in cucumber, they recorded that parthenocarpic hybrid KPCH - 1 perform superior related to yield parameters as compare to other parthenocarpic hybrid. Furthermore, Kumar et al. [42] recorded utmost LAI, fruit yield and crude fiber with application of 150% RDF through fertigation and single stem straining system in parthenocarpic cucumber under NVPH. Sravani et al. [43] observed minimum number of seeds per fruit with 2,4-D at 25 ppm concentration in watermelon. Rasul et al. [44] revealed that applications of 2,4-D at 100 ppm concentration observed parthenocarpic fruit development in spine gourd genotype Rangpuri (Cl3).

8. CONCLUSION

Parthenocarpy has proven to be a beneficial trait in vegetable crops. It allows for the production of seedless fruits, which are highly desirable in the market due to their improved taste, texture and convenience. Parthenocarpic varieties also have the advantage of being able to set fruit under unfavorable environmental conditions, such as low temperatures or high humidity. This trait has the potential to increase yields and improve crop productivity which contributing to food security and sustainability. However, further research is needed to fully understand the genetic and physiological mechanisms underlying parthenocarpy in vegetable crops and to develop new varieties that combine this trait with other desirable characteristics such as disease resistance and nutritional value. Overall, parthenocarpy holds great promise for the future of vegetable crop production and should be further explored and utilized to meet the increasing demands of a growing global population.

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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