AGRI MAGAZINE
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Publish with Pride..
www.agrimagazine.in
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 11 (November, 2025)
Available online at http://www.agrimagazine.in
©Agri Magazine, ISSN: 3048-8656

Parthenocarpy: A Modern Approach and its Applications in Horticultural Crops

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Parthenocarpy—the development of fruit without fertilization—has emerged as one of the most innovative and demand-driven technologies in modern horticulture. The global preference for seedless fruits such as watermelon, banana, grapes, citrus, tomatoes, cucumbers and eggplants has significantly increased due to better consumer appeal, enhanced eating quality, convenience and higher market value. Beyond consumer preference, parthenocarpy also provides practical advantages to growers, including assured fruit set under adverse climatic conditions, higher yield, uniform fruit quality and reduced dependency on pollinators. With climate change becoming a major threat to agricultural productivity, the relevance of parthenocarpy has strengthened further. Stress conditions such as high temperature, extreme rainfall, low humidity and declining pollinator populations are increasingly affecting natural pollination and fruit set. Parthenocarpy offers a powerful biological solution by enabling fruit formation even in the absence of viable pollen or active pollinators. This article discusses the mechanisms, current challenges, climate-related problems, technological advancements and future opportunities of parthenocarpy, highlighting its crucial role in seedless fruit production and yield enhancement (Chavan *et al*., 2025).

Understanding Parthenocarpy: Basic Concepts and its types

Parthenocarpy (literally meaning a virgin fruit) is the formation of fruits without the process of fertilization (Patel *et al*., 2022). It occurs naturally in some plant species but can also be triggered artificially through different techniques. Fruits produced through parthenocarpy are typically seedless or contain very few seeds. The major types include natural, obligatory, facultative, vegetative, stimulative and artificially induced parthenocarpy. Several factors, particularly temperature and genetic makeup, play a key role in its expression. Artificial induction involves the use of plant growth regulators, distant hybridization, mutations, irradiated pollen, chromosomal manipulation, gene silencing, genetic modification and modern genome-editing tools. Growth regulators such as auxins, cytokinins and gibberellins are commonly applied to stimulate parthenocarpic fruit formation in horticultural crops (Gowd and Vadde. 2023).

The process of parthenocarpy

1. **Natural Parthenocarpy:** This can be a natural occurrence due to genetic mutations or environmental conditions that disrupt the fertilization process. Occurs naturally in crops such as bananas, grapes, citrus, fig, pineapple and some tomato varieties.

- **Vegetative Parthenocarpy:** The fruit develops without any pollination or fertilization stimulus, as seen in some varieties of cucumbers and bananas.
- **Stimulative Parthenocarpy:** Pollination is required, but fertilization doesn't happen. The stimulus from pollination can trigger the ovary to develop into a fruit anyway, often with aborted seeds.

- **Stenospermocarpy:** This condition often results from incomplete fertilization or abortion of embryos during seed development (e.g., Seedless grapes and Watermelon)
- **Facultative parthenocarpy:** is a type of fruit development where seedless fruits form only if pollination and fertilization are prevented. Such as tomatoes, cucumbers and eggplants.
- **Obligatory parthenocarpy:** is a natural trait where a plant's fruits develop and mature without pollination or fertilization, always producing seedless fruits regardless of external conditions. Fruits like banana, seedless grapes, pineapple, cucumber, ivy gourd and certain oranges.

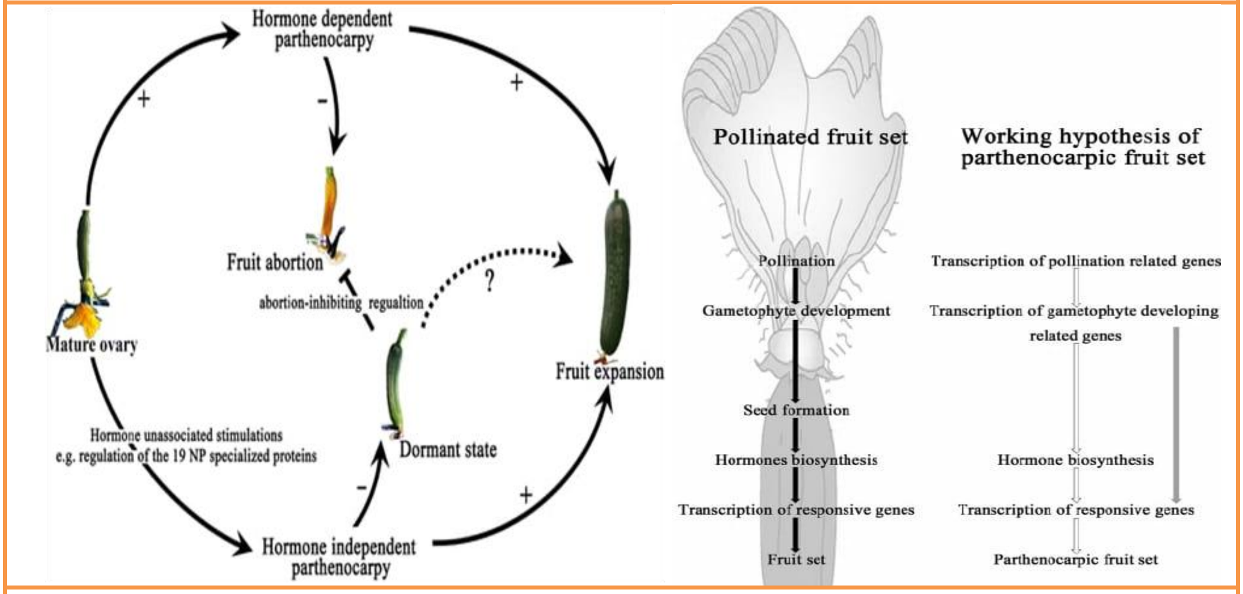

Fig. 1.1 A proposed model for parthenocarpy process in cucumber and a working hypothesis of cucumber parthenocarpic fruit set

2. **Artificial Parthenocarpy:** This is a process used in agriculture to induce the development of seedless fruits. Achieved through human intervention using various techniques which are mentioned above (Joshi *et al*., 2025).

- **Use of plant growth regulators:** These hormones stimulate cell expansion and fruit development, mimicking the hormonal signals that normally occur after fertilization.

Table 1: Usage of plant growth regulators for development of parthenocarpic fruit

Crop	Growth regulator	Stage of treatment	Type of parthenocarpy
Brinjal	GA_3 @ 2700 ppm; 2,4-D @ 2.5 ppm	Foliar spray/cut end styles at freshly opened flower stage	GA_3 induced the completely seedless fruits during all season. 2,4-D induced the development of degenerated seeds
Cucumber	GA_3 @ 100 mg/L	Pre-anthesis sprays	-
Bottle gourd	CPPU @ 10-100 mg/L	2 days before or after anthesis	Complete parthenocarpy
Watermelon	CPPU @ 0.5 ml/L	At the time of anthesis	Parthenocarpy
Pumpkin	GA_3 @ 150 ppm	Slightly before anthesis	96.9% seedless
Muskmelon	CPPU @ 150 ppm	Full flowering	-
Kakrol	2,4-D/2,4,5-D @ 100 mg/L	Pre-anthesis sprays	Complete parthenocarpy
Kakrol	2,4-D @	At the time of anthesis	90.0% parthenocarpy

- **Distant Hybridization:** Intraspecific hybridization has been utilized for producing a facultative parthenocarpic line suitable for a hot and dry climate. Different facultative parthenocarpic tomato lines/cultivars developed through distant hybridization. The parthenocarpic fruits resulting from bottle gourd pollen were deformed but had similar weight, rind thickness, flesh colour and Brix as control fruits.
- **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.
- **Gene Modifications:** Biotechnology offers enhanced opportunities and simplified approaches for producing parthenocarpic varieties compared to traditional breeding. Phytohormones play a crucial role in regulating seed and fruit development. Manipulating the gene's regulatory region(s) can impact the spatial and temporal expression of target genes, leading to modified fruit development or ineffective fruit set. Techniques such as transgenesis, RNA interference (RNAI), and antisense RNA technology can effectively silence genes. For example, DefH9-iaaM transgenic tobacco and eggplants produce parthenocarpic fruits without pollination (Manikandan, 2022).

Table 2: Seedless fruit production by gene silencing, transgenic and RNA interference

Gene	Function	Gene modification	Crop
DeH9-iaaM	Auxin synthesis	Ovule specific transgene expression	Tobacco, eggplant, tomato, raspberry, and cucumber
SEP1/TM29	Cytokinin	Antisense or co-suppression	Tomato
rolB	Auxin response	Ovary/Fruit specific transgene expression	Tomato
SIIAA9	Auxin signaling	Antisense down regulation	Tomato
SIDELLA	Gibberellin signaling	Antisense down regulation	Tomato

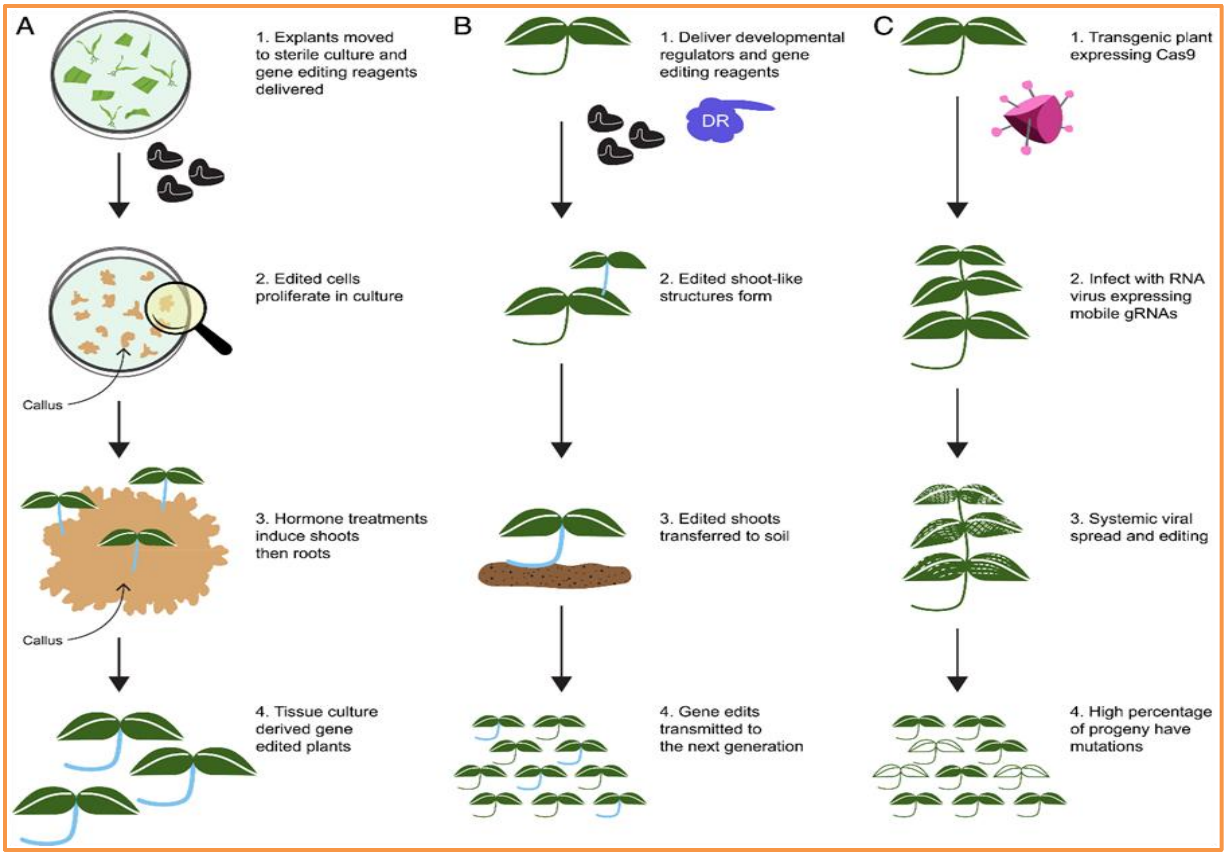

Fig. 1.2 Parthenocarpic Attaining the Promise of Plant Gene Editing at Scale

Why Parthenocarpy is Important Today

- **Rising Consumer Demand for Seedless Fruits:** Consumers prefer seedless watermelon and grapes for ease of eating, citrus for juice quality, tomatoes for processing, cucumbers for salads.
- **Declining Pollinator Populations:** Pollinators such as bees are rapidly declining because of pesticide misuse, habitat loss, climate stress, diseases and mites.
- **Climate Change and Poor Pollination:** Climatic stress affects, pollen viability, anther dehiscence, stigma receptivity and pollinator activity.

How it differs from normal fruit development: In a typical fruit, pollen fertilizes the ovule, leading to the ovule developing into a seed and the ovary developing into the fruit. Parthenocarpy bypasses this, preventing fertilization and consequently the development of seeds.

Fig. 1.3 Parthenocarpic fruits

Future Prospects of Parthenocarpy

- Climate-Resilient Agriculture
- Development of New Gene-Edited Seedless Varieties
- Integration with Smart Farming
- Expansion in High-Value Crops

Conclusion

Parthenocarpy is an efficient, climate-resilient method for producing seedless fruits and improving yield in horticultural crops. With challenges like declining pollinators, rising temperatures, irregular rainfall and poor fruit set, it offers a dependable solution by enabling fruit development without fertilization. Advances in genetics, biotechnology, plant growth regulators and controlled cultivation environments are strengthening its role in modern horticulture. Parthenocarpy provides major benefits—seedless fruits, higher yield, uniform quality, reduced reliance on pollinators and better climate adaptability. Though issues such as high seed cost, limited genetic diversity and improper hormone use remain, ongoing research and precision breeding are helping to overcome them. Overall, parthenocarpy is emerging as a key technology for sustainable, high-quality and climate-resilient horticultural production.

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