Plant Growth Regulators: A Boon for Inducing Parthenocarpy in Horticultural Crops

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Plant growth regulators (PGRs) are organic compounds, other than nutrients, that affect physiological processes of plants when applied in small concentrations. The five primary plant growth regulators are auxins, cytokinins, gibberellins, abscisic acid and ethylene. Each plant growth regulator functions in different ways. Flowering plants must go through the process of fertilization to achieve successful fruit setting. However, some plants can produce fruits without fertilization by adopting the parthenocarpy mechanism (Knapp *et al*., 2017). Plant hormones are closely associated with parthenocarpy because ovaries that generate parthenocarpic fruits show higher endogenous hormonal contents (Su *et al*., 2021). Such fruit production has received increasing attention from farmers, breeders, and scientists. Parthenocarpy in a broad sense includes those processes that allow the production of seedless fruits. Such fruits are favorable to growers, because they are set independently of successful pollination, and to processors and consumers, because they are easier to deal with and to eat. The condition in which fruits are developed without the formation of seeds is called parthenocarpy. This is mainly due to the absence of fertilization in plants, pollination and embryo development. In botany, parthenocarpic fruit means "virgin fruit". These types of fruits are generally seedless. It is generally driven by genetic factors, nonetheless seedlessness can be also induced with the application of various plant hormones to young inflorescences.

Different types of parthenocarpy includes:

- **Natural parthenocarpy**: (Due to genetic sterility) e.g. Banana
- **Facultative parthenocarpy: (**Due to environmental stimulation) e.g. citrus, cucumber
- **Stimulative parthenocarpy**: e.g. grape var. Black Corianth, Watermelon.
- **Stenospermocarpy:** e.g. grape cv. Thompson seedless (all commercial cultivars).

Role of plant growth regulators in regulating parthenocarpy in horticultural crops:

a) Auxin

The treatment of unpollinated ovaries with auxin and its analogs can bypass fertilization and generate seedless (parthenocarpic) fruits in crops plants, such as tomato, cucumber, pear, and watermelon. The synthetic auxin 2,4-D was shown to successfully induce parthenocarpic fruits in tomato and pear, NAA in cucumber and strawberry by prompting the cell division process. More recently, an ovary injection method was used to produce seedless okra. The injection of IAA (100 mg L^{-1}) solution into ovaries at the anthesis stage resulted in 100% pod setting rate and produced seedless okra with better quality.

Fig. 1 Parthenocarpic fruits a) citrus fruit, b) cucumber, c) grape and d) watermelon

b) Cytokinin

CK has long been known to play a crucial role in organ development by inducing cell division. The participation of CK in influencing parthenocarpic fruit setting has been reported in many economically important horticultural crops. For instance, the application of t-zeatin (ZT), to unpollinated ovaries of tomato plants produced parthenocarpic tomato fruits with a fruit setting percentage of 80%. Application of CPPU (N-(2-chloro-4-pyridyl)-N-phenylurea) @10 ppm to Kiwi is also effective. CK-induced parthenocarpic fruit production has also been described in cucumber, fig and grapes.

Fruit crop species	Type of Plant Growth Regulators	Growth Regulators	Reference
Pear	Auxin	2,4-D	Cong *et al.*, 2019
Strawberry		NAA	Romero *et al.*, 2021
Sugar apple	Brassinosteroids	GA_3, Combination of GA_3 at 1000 mg L^{-1} and BRs at 0.5 mg L^{-1}	Mostafa *et al.*, 2018
Grapes	Cytokinin	BAP	Lu *et al.*, 2016
Kiwi		CPPU (N-(2-chloro-4-pyridyl)-N-phenylurea) @10 ppm	Murakami *et al.*, 2020
Persimmon	Gibberellic acid	GA_3	Reig *et al.*, 2018
Pear		GA_4	Zhang *et al.*, 2021
Watermelon	CPPU		Kawamura *et al.*, 2018
Pear	Melatonin	Melatonin	Liu *et al.*, 2018

c) Gibberellic acid

GA is a key hormone regulating the vegetative and reproductive stages of plants. It is involved in the positive modulation of many fruit-related traits and is vital for the successful production of fruits. To avoid this problem and produce parthenocarpic custard apples, the spraying of GA_3 (1500 ppm) has successfully induced seedless parthenocarpic fruit production. GA_3 treatment of the "Honeycrisp" apple cultivar also resulted in parthenocarpic fruit production. However, the GA_{4+7} combinations successfully induced parthenocarpy in cucumber. The, GA_{4+7}, instead of GA_3, may play an important role during the pear and cucumber fruit setting.

d) Brassinosteroid

BRs are a group of steroid hormones that play an essential role in the growth and development of plants. In cucumber, the BR analog 24-epibrassinolide (EBR) successfully induced parthenocarpic fruit production when applied at a rate of 0.2 µM. More recently, the application of GA_3, EZR (combination of GA_3 at 1000 mg L^{-1} and BRs at 0.5 mg L^{-1}) to sugar apple trees produced high-quality parthenocarpic fruits.

e) Ethylene

Ethylene plays well-documented role in postharvest biology and plant sexual determination. The negative role of ethylene in fruit set has been reported previously. For instance, the application of 1–Methylcyclopropene (1-MCP), an ethylene inhibitor, to unpollinated tomato ovaries significantly reduced the ethylene content and facilitated the parthenocarpic fruit setting). Aminoethoxyvinylglycine (AVG), the ethylene biosynthesis inhibitor, also increased parthenocarpic fruit production by suppressing ethylene production in unpollinated ovaries.

f) Melatonin

The function of melatonin in parthenocarpic fruit formation had been reported only in pear. Spraying exogenous melatonin (100 µM) on the unpollinated flowers of the pear cultivar "Starkrimson" induced parthenocarpic fruit of a similar size to pollinated fruits. Additionally, the melatonin-induced fruit displayed better nutritional values than the pollinated fruits.

Benefits of Parthenocarpy with the application of growth regulators

- It overcomes the risk of a low yield due to a disrupted fertilization process and produces seedless fruits, which is a highly preferred agronomic trait in horticultural crops.
- It increases profitability for processing industries (fruit beverages, jams, and sauces) for example, a seedless tomato.
- It helps to avoid browning and bitterness caused by seeds in some horticultural crops, such as avocado and eggplant.

Conclusion

It can be concluded from the above article that the plant growth regulators play a key role in inducing the Parthenocarpy in horticultural crops and thereby serves as a boon for inducing the parthenocarpy, especially in horticultural crops. Many recent

researches conducted across the world have also shown a positive result of PGRs in this field. Such fruits are favorable to growers because they are set independently of successful pollination and to producers and consumers because they are easier to deal with and to eat.

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