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Induction of parthenocarpy through intergeneric pollen and growth regulators in horticultural crops: A review

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Abstract
Parthenocarpy is the growth of ovary into seedless fruit in the absence of pollination and fertilization. It may occur naturally or can be induced artificially by exogenous application of hormones, intergeneric pollen and irradiated pollen in some crops. Parthenocarpy improves the yield, quality and processing attributes of horticultural crops, where seed is a limiting factor during consumption. But because of seediness in those fruits, peoples are not interested to buy the product. Excessive seed number in fruit is fast becoming unacceptable in international markets. To cover this problem, different methods are used for getting seedless fruits showed in this review. Therefore, present review is focused on factors and potential of parthenocarpy in some fruit and cucurbitaceous crops.

Keywords: parthenocarpy, seedlessness, plant growth hormones, intergeneric pollen *etc*

Introduction

Fruits and some of gourds like watermelon, muskmelon, cucumber and teasel gourd are more nutritive and good for health. Seedless fruits provide an opportunity to satisfy our sense of taste without fear of swallowing the seeds. The seedless cultivars are in high demand by consumers not only because of seedlessness but also because they are sweeter than fruits from the seeded cultivars (Marr and Gast, 1991) [20].

Terada and Masuda (1938) [34] showed that seedless watermelon could be produced by artificially induced parthenocarpy. In the distant past, seedless watermelons are produced by a triploid technique by which diploid pollen (male parent) is used to pollinate pistillate flowers of tetraploid watermelon (Kihara, 1951) [16]. Sugiyama and Morishita (2000) [29] developed a method for producing seedless watermelon in diploid plants using soft-X-irradiated pollen. Along with this, plant growth regulators called as magic chemicals have been shown to be one of the means to induce parthenocarpy. A newly developed plant growth regulator forchlorofenuron (CPPU), 2, 4-D, NAA were also proved to promote parthenocarpy and increasing fruit set in different fruits and vegetables.

Impact of intergeneric pollen in inducing parthenocarpy in watermelon

Hai-yong *et al.* (2016) [9] reported that pollination with soft X-ray irradiated pollen produced the seedless watermelon by inhibiting embryotic developmental processes leading to abortion of the embryo and degeneration of endosperm. As well as the watermelon percent fruit set after pollination with *Lagenaria siceraria* var. *hispida* pollen was higher than that of *Lagenaria scieceraria* var. *gourda* pollen and the seedless fruits were oblong with hollow hearts having higher brix compared to normal fruit (Sugiyama *et al.*, 2015) [31]. But, in contrast Sugiyama *et al.* (2014) [30] developed seedless watermelon by pollinating the female flowers of watermelon with bottle gourd pollen (*Lagenaria siceraria* (Molina) Standl.) with fruit set of 57.1%. Moussa and Salem (2010) reported that the diploid seedless watermelon can be produced by pollinating the flowers with partially functional pollen, *i.e.*, pollen irradiated with γ-rays at the doses of 600 and 800 Gy. Further, Sugiyama and Morishita (2000) [29] developed seedless watermelon (*Citrullus lanatus*) in diploid plants by using soft X- irradiated pollen in which soft- X- irradiated doses of 800-1000 Gy resulted small empty seeds in c.v. 'Fujihikari TR' whereas, 400-1000 Gy resulted seedlessness in cv. Benikodama without effect on fruit weight, shape, rind thickness, days to maturation. Sugiyama *et al.* (2002) [32] observed that that double fertilization occurred after pollination with the irradiated pollen and that the abortion of the embryo results parthenocarpy or seedlessness in Watermelon. Before that, Kihara (1951) [16] proved that seedless watermelon (*Citrullus lanatus)* is produced by a triploid technique by which diploid pollen of male parent is used to pollinate pistillate flowers of tetraploid (female parent) watermelon.

Effect of growth regulators in inducing parthenocarpy in different crops

Hayashida *et al.* (2016) [10] proved that parthenocarpic fruits were produced by ferrous sulfate ($FeSo_4$) solution or a Bordeaux mixture, which, restricted pollen tube growth and empty seeds were observed during fruit development. Subsequently, bordeaux mixture-induced fruit was improved by GA paste and GA paste mixed with CPPU treatment of the fruit stalk; which resulted 100 g heavier fruit than the untreated fruit. In contrast, Sharif Hossain (2015) [27] also studied the effect of GA_3 @ 150 ppm on pumpkin (*Cucurbita moschata*) to induce seedlessness and observed 96.9% seedless pumpkin with increasing fruit weight, sugars, potassium and calcium than in control. Whereas, gibberellic acid at 1,500 ppm is efficient in producing seedless fruits in custard apple cv. Gefner (Rayane *et al.*, 2016) [24]. Aslmoshtaghi and Shahsavar (2013) [1] reported that the application of 250 and 300 ppm GA_3 induces parthenocarpy in loquat fruits. The seedless loquats were longer and narrower as compared with the untreated seeded fruits. The total soluble solids content of seedless fruits at harvest were similar with seeded fruits. Similarly, application of 2, 4-D @ 5 ppm is responsible for development of seedless parthenocarpic fruit with increased size but unfilled cavities at higher concentrations. While, GA_3 at lower concentration *i.e.*, 10 ppm results seed development but increased concentration results in the development of more number of smaller fruits per plant (Gelmesa, 2013) [8]. Further, Susila *et al.* (2013) [33] studied the effect of exogenous application of CPPU @ 200 ppm decreases the number of seeds per fruit, whereas application of CPPU @ 100 ppm in combination with GA_3 @ 100 ppm increases the number of fruits, fruit weight and lycopene pigment.

Mohammad *et al.* (2008) [21] observed PGR's *viz*., 2, 4–D, Fulmet and CPPU were effective in developing the parthenocarpic fruits in teasle gourd (kakrol, *Momodrica dioica* Roxb.). Fruit size and weight were increased with these growth regulators except 2, 4–D. Similarly, the pistillate flowers were applied with CPPU 50 mg/kg, NAA 100 mg/kg, and 2, 4-D 50 mg/kg in various combinations induced the parthenocarpic fruit set (Ji young *et al.*, 2008) [15]. The GA_4, GA_7 and CPPU are very effective in inducing parthenocarpic fruit growth and fruit expansion of Japanese pear cv. 'Akibae' (self-compatible) and cv. 'Iwate yamanashi' (a seedless cultivar). The percentage of parthenocarpic fruits were smaller in size, higher in flesh hardness, and showed advanced fruit ripening in comparison to pollinated fruit and to parthenocarpic fruits induced by CPPU (Zhang *et al*., 2008) [39]. Application of 2, 4-D at 50 ppm at the time of anthesis showed better performance in inducing parthenocarpy (Chowdhury *et al.*, 2007) [6].

Huitron *et al.* (2007) [13] reported that parthenocarpy in watermelon induced by using CPPU and 2, 4-D with maximum seedlessness at concentrations of CPPU @ 100 and 200 ppm compared to 2, 4-D with high sugars and good fruit quality. In same way application of GA_3 and 2, 4-D produced parthenocarpic fruits which were similar to naturally pollinated fruits in tomato (*Solanum lycopersicum* L.) cv. Micro-Tom. Combined application of X-ray (800 Gy) pollen and CPPU (50 ppm) results more fruit set (90%), seedlessness (95%) and TSS (11.8 Brix) in diploid seedless watermelon (Kwon *et al*., 2006) [18]. Prabhu and Natarajan (2006) [23] studied that GA_3 @ 100 ppm and NAA @ 400 ppm produced lesser amount of seeds and better individual fruit weight. Similarly, synthetic cytokinin CPPU and 2, 4-D at the concentrations of 200 ppm and 50 ppm applied at flower opening were effective in setting parthenocarpic fruits in the triploid watermelon cultivar 'Reina de Corazones' with increased yield per unit area (Maroto *et al*., 2005) [19]. Tolentino and Cadiz (2005) [35] also observed that exogenous application of NAA and GA_3 @ 20 ppm and 100 ppm at 5-leaf stage resulted in parthenocarpy, with reduced fruit size when compared to normal fruits in bitter gourd.

Camacho Ferre *et al.* (2003) [4] found for chlorfenuron @ 200 ppm, 100 and 50 ppm induced highest proportion of seedless fruits in diploid watermelon cv. Sweet Marvel. Further, NAA and GA_3 were ineffective in inducing parthenocarpy, whereas CPPU induced parthenocarpic fruit larger than the fruits obtained from pollination due to reactivation of cell division and expansion in *Lagenaria leucantha*. Hayata *et al*. (2000) [12] studied the effect of CPPU and BA on growth and quality of muskmelon (*Cucumis melo*) fruits and found that CPPU and BA applied at lower concentrations resulted a strong effect on fruit set in the seeded melons whereas, CPPU applied at 10 mg/lt increases parthenocarpic fruit set in seedless melons. Hayata *et al*. (1995) [11] reported that application of CPPU @ 200 ppm and kinetin @ 500 ppm to the ovary at the time of anthesis dramatically increased the fruit set and induced parthenocarpy with increased sugar content. Whereas, application of BA @ 500 ppm remarkably promoted fruit set of pollinated flowers but did not induced parthenocarpy in watermelon (*Citrullus lanatus* Mastum). In the same way Brent and Peter (1996) used a paste made up of BA @ 200 ppm and CPPU @ 200 ppm mixed in a lanolin-water paste was applied separately to the base of ovaries with a disposable syringe (minus needle) increased fruit set in watermelon from 26.9% and 95% whereas, CPPU induced parthenocarpy of 89.5% in cv. Delicious 51 of Muskmelon.

Kiyotoshi Takeno and Hiroyuki Ise (1992) [17] correlated the parthenocarpic fruit set and IAA content in ovaries of the cucumber varieties Chojitsu-Ochiai No. 2, a strongly parthenocarpic cultivar, and PMR-142, a weakly parthenocarpic cultivar and found that the ovaries which are reaching 6 cm in length and 3.5 times contains high amount of IAA which leads to set parthenocarpic fruits. The Chojitsu-Ochiai No. 2 on 3rd day after anthesis showed that ovaries longer than 6 cm were predicted to set parthenocarpic fruits contained 1.7 times more IAA than those shorter ovaries. In PMR-142, more female flowers at higher nodes with longer ovaries set parthenocarpic fruits than flowers at lower nodes bearing shorter ovaries. The GA_3 applied at 0.15 mM concentration before and after anthesis resulted in highest percentage of seedless berries in Swenson red seeded grape. However no difference was observed in percent seedlessness, number of berries per cluster and number of seeds per berry between clusters dipped or sprayed with 0.3 mM GA_3 (Fellman *et al.*, 1991) [7]. As well as Yamada *et al.* (1991) [37] studied the self and cross compatibility of pollen and the effect of pollination and gibberellins on fruit set, physiological drop, growth, and maturation in 'Le Lectier' pear. Treatments with 200 ppm GA_3 sprays one day before pollination and GA_{3+4+7} paste applications, 5 weeks after pollination increased fruit set (30.3%) in both self and nonpollinated flowers as GA induced the setting of parthenocarpic fruit and stimulates fruit maturation possibly by advancing the time of ethylene evolution. Gibberellic acid not only induce seedless fruits but also increase the length of fruit panicles (up to 50%) and fruit set and concluded that seedless fruits were smaller, elongated and matured 4-5 weeks earlier than seeded fruits. Saini *et al.* (1981) [25] conducted an experiment to induce parthenocarpy in grape varieties *i.e.*, Flordasum and Sharbathi by using GA_3 application found that higher concentration of GA_3 @ 600, 800 and 1000 ppm induced parthenocarpy in cv. Flordasun whereas in cv. Sharbati parthenocarpy was recorded only with GA_3 @ 400 ppm. In contrast to GA_3, the maximum fruit set of 88.8 percent was obtained at 100 ppm 2, 4-D and 2, 4, 5-T in Kakrol (*Momordica cochinchinensis* Spreng. The hand pollinated fruits contained 18 bold seeds while no seed coat was developed in the induced parthenocarpic fruit and the fruits were completely seedless (Vijay and Jalikop, 1980) [36]. Sarma and Barman (1977) [26] revealed that application of NOXA (B-naphthoxy acetic acid) in lanolin paste promotes higher percentage of fruit set as compared to the control in brinjal. The percentage of seedlessness increased with the rise in concentration up to 15 ppm of NOXA. Parthenocarpic fruits were smaller in size and resulted in reduction in weight but, the fruits were richer in carbohydrate and vitamin contents. Cantliffe (1972) [5] reported that the morphactin formulation, lT 3456 (methyl-2-chlor6-9-hydroxyfl uorene-(9)-carboxylate) @ 50 ppm, and TIBA 100 ppm were the most effective in stimulating parthenocarpic fruit-set and development in pickling cucumbers (*Cucumis sativus* L., cult Pioneer). Whereas, Isao Kiyokawa and Shoichi Nagakawa (1972) [14] studied various growth regulator concentrations were applied to the cut surfaces of the emasculated flowers at their bloom stage, GA_3 @ 500 ppm induced parthenocarpic fruit set whereas, other growth regulators failed to produce parthenocarpic fruit set in peach. Bhupal singh *et al.* (1971) [2] studied the different concentrations of (GA_3 and GA_{4+7}) and kinetin on fruit set, parthenocarpy and quality in kyoho grapes. They were applied by dipping clusters before four days of anthesis and B-nine @ 0.5% sprayed at seventh node stage of new shoots, all GA treatments induced complete seedlessness except GA_{4+7} @ 50 ppm was 95% whereas B-nine was used to increase the berry size. Similarly, the growth regulators IAA and NAA on tomato activated growth, increased the fruit set, size and yield of fruit and induces parthenocarpic fruits. They reported that chemicals could be applied on seeds, roots, whole plants or flowers, but foliar application was very effective for increasing the size of fruit and the yield (Singh and Upadhaya, 1967) [28].

Conclusion

By using soft X- ray irradiated pollen we can induce parthenocarpy in watermelon. Not only irradiated pollen, it is also possible to produce seedless watermelons by intergeneric pollen *i.e.*, bottle gourd pollen. In contrast, application of different plant growth regulators viz., CPPU. NAA, GA_3 induced parthenocarpy in different crops. Whereas, other growth regulators such as BA, TIBA, 2, 4-D were used to increase the fruit size, growth, development, TSS and sugars. More research is needed to find the mechanism involved in the parthenocarpic fruits.

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