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# Parthenocarpic vegetables: Importance and approaches: 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 or their enhanced endogenous level. Parthenocarpy improves the yield, quality and processing attributes of vegetable crops like cucumber, eggplant and watermelon, where seed is a limiting factor during consumption. Parthenocarpic vegetables increase profitability for processing industries. It may occur naturally or can be induced artificially by exogenous application of hormones or their enhanced endogenous level. This 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. In the ever-changing global scenario of the world, security for the nutrition in the country is the important issue for agricultural sector. Vegetables occupy an important place in diversification of agriculture and have played a vital role in food and nutritional security of ever-growing population of our large vegetarian society. Vegetable consumption per capita in India is very low and that is only around 230.4 g per day against minimum of about 300 g recommended by dieticians so there is a great demand for production of more quantities of vegetables with high quality and reduces postharvest loss by increase a storage life as well as processing. The absence of seed is usually appreciated by consumers and producers because it increases fruit quality and fruit shelf life. It is an established fact that phytohormones play important role in fruit setting and their genetic manipulation can lead to seedlessness. Therefore, present review is focused on importance, approaches and potential of parthenocarpy in vegetable crops.

**Keywords:** Parthenocarpic vegetables, seedless fruit, cucumber

## Introduction
Parthenocarpy (literally meaning a virgin fruit) is the natural or artificially induced production of fruit without fertilization of ovules. Seedlessness is a desirable trait in edible fruits with hard seeds (pineapple, banana, orange, grapefruit) also desirable in fruit crops that may be difficult to pollinize or fertilize. In dioecious species (*e.g.*, Persimmon), pathenocarpy increases fruit production as staminate trees do not need to be planted to provide pollen. Increases shelf life due to reduced ethylene generated by seeds. Improves processing quality & ultimately increases profitability.

The biological function of the fruit is the protection of embryos and seeds during their development and the facilitation of seed dispersal after maturation. The onset of fruit development from the ovary, the so-called fruit set, occurs after fertilization of the ovules. Fertilization of the ovule generally triggers the ovary development into fruit (Nancy, 2015) [35]. The processes of seed and fruit development are intimately connected, synchronized and controlled by phytohormone (Pandolfini, 2009) [38]. Thus, the signaling processes are required for the development of the fertilization products necessary for the initiation of seed and fruit development (Raghavan, 2003) [41]. Various phytohormone, especially gibberellins, cytokinins and auxins, are involved in the signalling processes that follow pollination and fertilization and these are the main requirements for further growth and development of seeds and the fruit (Fos *et al.*, 2001) [14]. Developing seeds are source of phytohormone and stimulate the fruit growth and development (Ozga *et al.*, 2002) [37]. However, in some vegetables presence of seeds in fruit are undesirable due to hard or leathery texture, bitter taste and presence of toxic compounds, allergens and effect on the palatability (Dalal *et al.*, 2006) [10]. 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 (Denna, 1973; Varoquaux *et al.*, 2000; Yin *et al.*, 2006) [12, 65, 72]. 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. The separation of fruit growth from fertilization and seed development resulted into a seedless parthenocarpic fruit (Fos, *et al.* 2001; Varoquaux, *et al.* 2000) [14, 65]. Parthenocarpy is genetically controlled and commercially exploited for production of seedless fruit (Sykes and Lewis, 1996; De Menezes, *et al.* 2005; Goetz, *et al.* 2006) [55, 11, 17]. Therefore, present review is focused on artificial and genetic causes of Parthenocarpy and its utilization in vegetable crops.

In absence of natural or genetic Parthenocarpy, alternate method should be adopted to have seedless fruit. Parthenocarpy can be induced in many crops (cucumber, tomato, bottle gourd, brinjal, *Cucurbita*, watermelon, etc.) by applying exogenous auxin (Homan, 1964; Elassar *et al*., 1974; Takashima and Hatta, 1955; Miyazaki, 1965; Terada and Masuda, 1941) [23, 13, 56, 33, 60], gibberellins and cytokines (Choudhury and Pathak, 1959; Elassar *et al*., 1974; Kulkarni and Rameshwar, 1978; Hayata *et al*., 2000) [9, 13, 26, 22] and also auxin transport inhibitors (Robinson *et al*., 1971; Cantliffe, 1977; Beyer and Quebedeaux, 1974) [46, 8, 4].

**Types of Parthenocarpy**

**Natural or genetic Parthenocarpy:** Genetic Parthenocarpy is called obligatory, when expression of the Parthenocarpic trait is not influenced by external factors and is facultative, if occurs only under adverse conditions for pollination and fertilization. Elevated level of endogenous hormones in the ovary in the absence of pollination and fertilization causes the natural Parthenocarpy (Nitsch, 1970; Gillaspy *et al.,* 1993) [36, 16]. It has been reported in various crops like grape (Wong, 1941) [68], tomato (Groot *et al*., 1987) [19], mandarins (Talon *et al*., 1992) [57], banana (Gustafson, 1939) [20], pointier (Weiss *et al.,* 1993) [67], Pepion (Prohens *et al.*, 1998) [40], eggplant (Yoshida *et al.,* 1998) [73], cucumber (Yan *et al.,* 2010) [71] and capsicum (Tiwari *et al.,* 2011) [63]. Genetic parthenocarpy can solve the problem of low pollen viability and poor pollen release, which often occurs under low light, low or high temperatures under open and greenhouse conditions.

**Artificial parthenocarpy:** 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 (Schwabe and Mills, 1981) [48]. The exogenous use of irradiated pollen, natural or synthetic auxins and gibberellins increased IAA content during ovary development (Tsao, 1980) [64]. This resulted in elevated levels of endogenous phytohormones during parthenocarpic fruit set and development from sources other than seeds (Talon *et al.,* 1992) [57]. Therefore, in Arabidopsis and a variety of agricultural species the parthenocarpy can be induced with exogenous application of auxin, cytokinins, or GAs (Smith and Koltunow, 1999; Ramin, 2003; Serrani *et al.,* 2007) [42, 49]. Nitsch (1970) [36] defined that a plant is Parthenocarpic, 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 an thesis, while a major peak of IAA appears at 20 days after an thesis in both pollinated and auxin treated flowers (Lee *et al.,* 1997) [29].

**Exploitation of parthenocarpy in vegetable crops**

Parthenocarpy is an economically valuable trait in number of horticultural crops. Consumers often prefer seedless fruit for aesthetic and quality reasons, because many such fruit have more attractive appearance, added convenience in terms of preparation, consumption and processing. Parthenocarpic cucumber does not require pollination, even though, it is a cross-pollinated crop. Combination of parthenocarpy and gynoecism gave added advantage of yield and palatability of cucumber (Denna, 1973) [12]. In eggplant, parthenocarpy improves fruit quality and reduces the labour needed for its out-of-season cultivation. Since the commercial ripeness of eggplant fruits precedes its physiological maturity, the presence of seeds considerably depreciates the value of fruits for both fresh and processed market. The negative effects associated with the presence of seeds have a faster and more intense browning of the fruit flesh upon cutting, increased saponin and solasonin compounds causing bitter taste and hard flesh. The absence of seeds increased the shelf life of the fruits for better conservation (Aubert *et al.,* 1989) [3]. This effect was also observed in watermelon, where seeds are the origin of fruit deterioration (Varoquaux *et al.,* 2000) [65]. Further, in tomato seedless fruits are tastier than the seeded variety. The Parthenocarpic tomato does not require removal of seed during processing. Seedless tomatoes have 1% more dry matter, more sugars, less acidity, less cellulose and more soluble solids than seeded cultivars (Lukyanenko, 1991) [30]. An important advantage of Parthenocarpic plants is that they set and develop fruits under environmental conditions that are unfavourable for successful pollination and fertilization, particularly greenhouse cultivation (Yin *et al.,* 2006; Gorguet *et al.,* 2008) [72, 18].

**Tomato**

It is well established that fruit set and development is triggered, after pollination and fertilisation, by the coordinated action of growth hormones provided and/or regulated by the pollen grains, the pollen tubes and, ultimately, the developing seeds (Nitsch, 1970; Gillaspy *et al*., 1993) [36, 16]. The expression of genetic parthenocarpy is correlated with the accumulation of auxin and gibberellins in the ovaries, which is autonomous and precocious compared to the respective wild-types (George *et al*., 1984) [15]. In consequence, genes for parthenocarpy are thought to affect the pattern of hormone production, transport and/or metabolism, and to overcome a growth substances concentration threshold during the critical period of a thesis, to promote ovary growth in such a way that pollination and fertilisation are no longer needed or possible (Nitsch, 1970) [36]. The *sha* mutant obtained by mutagenesis with ethyl methane suffocate (EMS) is characterised by a high tendency to parthenocarpy and abnormalities which concurrently affect anther development (Bianchi and Soressi, 1969) [6]. The expression of parthenocarpy in *pat* plants is based on an enhanced ovary growth rate during the first 10 days after an thesis, which correlates with a precocious onset of cell divisions in the pericarp and higher auxin, gibberellin and DNA contents in ovaries (Mapelli *et al*., 1978) [31]. Although parthenocarpy expression can be affected by environmental conditions and genetic background (Bianchi and Soressi, 1969) [6]. Andrea *et al.* (1998) [2] conducted experiment on *pat* and WT line of tomato and they revealed that all the WT fruits from the HTR and LTR regimens had more than 5 seeds, while a small percentage of low-seeded fruits were also produced in the NTR environment. In *pat* plants, the degree of

parthenocarpy, detected as percentage of seedless fruits at maturity. On average, WT fruits contained more than 30 seeds in all the environments, while seeded *pat* fruits yielded less than two seeds in LTR and NTR and about six in HTR. Rotino *et al.* (2005) [47] studied on mean values of percentage of fruits with seeds and number of seeds per fruit in the transgenic Parthenocarpic lines (Ri4 and Ri5), the untransformed control (UC 82) and the commercial $F_1$ cv. All flesh. They observed in transgenic Parthenocarpic lines Ri5 and Ri4 have minimum fruits with seeds.

**Cucumber**

Cucumber is a predominant greenhouse crop, which can be grown throughout the year, especially during offseason under protected condition that fetches higher price in very short span (Panghal *et al*. 2016) [39]. There is a constant demand throughout the year for cucumber, especially the smooth skinned seedless fruit because of its popular use in salad dish, sandwich, pizza and other preparations (Bisht *et al*., 2011) [7]. In fact, gynoecious and Parthenocarpic cucumber hybrids have revolutionized greenhouse industry throughout the world. However, the popularity of each hybrid has its own specificity depending on adaptability to particular growing conditions such as stability regarding pistillate flowering (More 2002), and local market demands for specialized fruits. The precocity or earliness for fruit bearing and harvest is the desired characters for early summer production that fetches high price. Additionally, the cultivar may have high yield potential and good commercial quality that relates to consumers preference. Special emphasis is to be laid for commercial exploitation of greenhouse for off-season cultivation of selected vegetables such as Parthenocarpic cucumber (*Cucumis sativus* L.), as this despite providing good yield and quality, is more remunerative (Yadav *et al*. 2014) [70]. Parthenocarpy has long been known to occur within the species of (*Cucumis sativus* L.) and parthenocarpic fruit development has long been recognized as an important characteristic for greenhouse cucumbers (Sturtevant 1890). Most greenhouse cultivars of slicing cucumbers grown today can set Parthenocarpic fruit, and Parthenocarpic pickling cultivars are of major importance in Europe (Tatlioglu, 1992) [58]. Response of fertilizers and training systems on Parthenocarpic cucumber var. Dinamik under NVPH. They reported that combination of 150% RDF (where, RDF *i.e*., 90 kg N, 75 kg $P_2O_5$ & 75 $K_2O$) through fertigation and single stem training in Parthenocarpic cucumber gives higher yield as well as more LAI after 30 and 60 days respectively Kumar *et al.* (2014). Kumar *et al*. (2015) observed hybrid KPCH-1 was best in term of days to harvest, no. of fruits per plant, yield per plant, yield/100 $m^2$ and parthenocarpy.

**Brinjal**

Brinjal (*Solanum melongena* L.) is very popular vegetable in India and grown as a warm season vegetable crop. It is rich source of antioxidants, minerals and vitamins. The presence of seeds in brinjal fruit is undesirable to consumers and seedless fruits are therefore in demand due to improved flesh quality and suitability for processing. Phytohormone play important role in fruit development through genetic manipulation, leading to seedlessness. With the development of Parthenocarpic brinjal, it can now be possible to grow under the protected conditions which ensure safer production of brinjal without using harmful chemicals. This trait is very useful to develop fruits in a particular environment (greenhouse cultivation) which are unfavorable for successful pollination and fertilization. The Parthenocarpic trait has been transferred to desirable varieties through crossing that had high yield with favourable fruit quality. A few lines have been developed through interspecific crossing. The exploitation of molecular markers and transgenic technology have been utilized in developing Parthenocarpic brinjal with enhanced fruit quality. Therefore, present review is focused on development and potentiality of Parthenocarpic brinjal. Acciarri *et al*. (2002) [1] conducted experiment on genetically modified Parthenocarpic eggplant production and their respective control. They found effective result of transgenic Parthenocarpic hybrids as compare to control. Transgenic Parthenocarpic accreted higher in yield/plant as well as higher in fruit weight.

**Watermelon**

Watermelon (Citrullus lanatus Thunb.) is a member of cucurbitaceous family, which contains more than 800 different species. It is originated from Southern Africa. Watermelon is a major cucurbit in India covering an area of 0.91 million hectares, with an annual production of 21, 82, 000 MT (NHB, 2017). In the distant past, seedless watermelon (*Citrullus lanatus* (Thunb.) Matsum and Nakai) fruits were produced using plant growth regulators (Wong, 1938; Terada and Masuda, 1940, 1941; Hayata and Niimi, 1995) [69]. The application of plant growth regulators has positive effect on watermelon. The application of growth regulators is reported to increased fruit size, yield and parthenocapic fruit development. Growth regulators are also reported to improve yield of many horticultural crops those in which involved in production of Parthenocarpic development. Now, almost all seedless watermelons are produced by a triploid technique by which diploid pollen is used to pollinate pistil late flowers (Kihara, 1951; Terada and Masuda, 1943) [24, 61]. We have developed a new method for producing seedless watermelon in diploid plants using soft-X-irradiated pollen (Sugiyama and Morishita, 2000) [53]. Sugiyama *et al*. (2014) [54] observed highest fruit set in watermelon with bottle gourd (Kachidoki 2) as pollen source. Sravani *et al*. (2018) [51] reported that parthenocarpy was completely achieved with CPPU @ 200 ppm and NAA @ 150 ppm in watermelon cv. Arka muthu.

**Summer squash**

Summer squash (*Cucurbita pepo* L.) cultivars were compared for ability to set Parthenocarpic fruit. Some cultivars set no Parthenocarpic fruit and others varied in the amount of fruit set when not pollinated. The degree of parthenocarpy varied with season, but the relative ranking of cultivars for parthenocarpy was generally similar. Cultivars with the best Parthenocarpic fruit set were of the dark green, zucchini type, but some cultivars of other fruit types also set Parthenocarpic fruit. A summer squash cultivar was developed that combines a high rate of natural parthenocarpy with multiple disease resistance. Yield of summer squash plants grown under row covers that excluded pollinating insects was as much as 83% of that of insect-pollinated plants in the open (Robinson and Reiners, 1999) [45]. Robinson and Stephen (1999) [45] conducted experiment to check the ability of summer squash cultivars to set fruit without pollination in 1992. He observed the cultivar ‘Chefini Hybrid’ with the most Parthenocarpic

fruit set.

**Spine gourd**

Spine gourd (*Momordica dioica* Roxb.) belongs to the genus Momordica in Cucurbitaceous. It is also known as kakrol or spine gourd. It shows dioecious, annual and viny habits, and propagated vegetative through tuberous root. It is rich in carotene, protein, carbohydrate (Rashid, 1993) [43] and vitamin C (154.7mg/100 g of edible portion) (Bhuiya *et al*., 1977) [5]. Teasle gourd has a number of problems relating to its yield and fruit quality. Among the problems, presence of a large number of seeds in the fruits (decrease palatability) and regular cumbersome hand pollination (increase cost of production) are noticeable. Besides, early fruit development and seed formation restrict the development of additional fruits in cucumber (Denna, 1973; Tiedjens, 1928) [12, 62]. This may be due to competition for metabolites by early developing fruit over later fruits or to the production of plant hormones by developing seeds, which inhibit further development (McCollum, 1934) [32]. Development of seedless fruit and unnecessary hand pollination can be achieved by genetically (natural parthenocarpy) or by chemically induced parthenocarpy.

Regarding fruit set, the treatments a day before a thesis and at a thesis were statistically similar. This indicated that the exogenous signal (PGR's, auxin analogues) triggered an increase in endogenous IAA and enhanced its activity in the ovary, which was responsible for promoting the highest fruit set and development at an thesis. This interpretation was consistent with that of Gustafson (1939) [20] and Kim *et al*. (1992) [2]. In spine gourd, higher percent (88.9%) of fruit set was also observed by applying 2, 4–D against NAA and IAA (Vijay and Jalikop, 1980) [66]. 2, 4–D showed better effect on growth and fruit set in teasel gourd than Fulmet and CPPU (cytokinins). Fruit size and weight were mostly increased with increase of concentration of PGR's. The results revealed that PGR's showed the possibility of developing parthenocarpy or seedless fruit in spine gourd (Rasul *et al*. 2008) [44].

**Conclusion**

Parthenocarpy is an important trait for improving the yield, quality and processing traits of vegetable crops. This trait proved highly useful in green house cultivation, particularly cross-pollinated vegetable crops. This is established fact that phytohormone play important role in fruit setting, however, their genetic manipulation can lead in development of seedlessness. Further, exploitation of biotechnological tools can enhance the efficiency and identification of Parthenocarpic genes across the crops for the benefit of mankind.

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