



E-ISSN: 2278-4136

P-ISSN: 2349-8234

JPP 2019; 8(6): 1053-1059

Received: 22-09-2019

Accepted: 24-10-2019

Amal PremachandranRegional Agriculture Research
Institute, Pilicode, Kasaragod,
Kerala, India**Dhayasree K**Msc Fruit Science, Dept Fruit
Science, College of Horticulture
Vellanikkara, Kerala Agriculture
University, Kerala, India**Dr. Sajan Kurien**Prof of Horticulture and Ex
Director of Research, Kerala
Agriculture University, Kerala,
India

Seedless fruits: fruits of future

Amal Premachandran, Dhayasree K and Dr. Sajan Kurien

Abstract

Seedlessness and the affection of consumers for it were profoundly pictured in current market. Evidence that seedless forms of *Vitis vinifera* grapes have been prized for many centuries' as dried fruit is provided by Greek philosophers such as Hippocrates, Platon and in the writings of ancient Egypt of 3000 BC. In most plants early fruit development can be divided into three phases. Phase I: Ovary development, Fertilization, and Fruit Set, Phase II: Cell division, Seed formation, and Early embryo development and Phase III: Cell expansion and Embryo maturation. For seedless fruits an entirely different scenario of chemical and genetical manipulation can be observed were hormonal and signal transduction alteration particularly growth regulators gibberellins, cytokinin synthetic auxin, and parthenocarpic gene. These hormonal changes mimic the normal fruit development and result into seedless fruit. Parthenocarp is the paragon of seedlessness, majorly 3 types of parthenocarp exist they are vegetative, stimulative and stenospemocarp. Further, seedlessness could also be due to environmental conditions, such as low or high temperatures, chemical treatments, chromosomal aberrations leading controlling meiosis and certain minor factors like self-incompatibility and age. The induction of seedlessness can be with growth regulator application, ploidy breeding, mutation breeding, and endosperm culture. Further, studies biotechnological and transgenic approaches like somatic hybridization, suicidal gene incorporation and manipulating hormonal gene which regulate the fruit set were some of the promising technique. Seedless fruit have many advantage over seeded, possibility of year-round production without the worry of pollen is profound. Moreover, it has gustatory and fruit quality advantage. Biochemical analysis also revealed that clear cut superiority of seedless fruit over seeded. Above all consumer preference and needs of processing industry also reveals the significance of seedless fruits.

Keywords: Seedless fruits, fruits, Seedlessness

1. Introduction

Seedlessness is appreciated by consumers both for fresh consumption (e.g., grape, citrus, and banana) as well as in conserved or processed form. This is of paramount importance in types that have strong, hard seed and impart off flavor and taste. Further, seeds can produce substances that accelerate the senescence.

The independence (whole or partial) of fruit development from pollination and subsequent fertilization is advantageous in horticulture crops in case where rate of fruit set is low. Pollen development, maturation and fertilization are affected by environmental factors such as light, temperature, relative humidity. Unfavorable environmental conditions can also drastically affect pollination and fruit development. These problems are occurring in crops/varieties where parthenocarpic fruit development is the norm. In horticulture, parthenocarp can be exploited both for winter and timing the production regarding the ready availability of fruits for the fresh horticultural produce in all seasons.

1.1 Mechanism of fruit development and seedless fruit formation

In most plants, early fruit development can be divided into three phases. Earliest phase involves the development of the ovary and the decision (signal, stimulus and process of development) to abort or to proceed with further cell division, differentiation and fruit development which is generally referred to as fruit set. In second phase, fruit growth is primarily due to cell division. The third phase begins after cell division ceases. During this phase, fruit growth continues, mostly by cell expansion, until the fruit reaches its final size. This growth phase is the most visible and physiologically most significant because of the strong sink activity exerted by the expanding cells.

1.2 Phase I: Ovary development, Fertilization, and Fruit Set

In normal development, the decision to set fruit is dependent on the successful completion of act of pollination and fertilization. The presence of fertilized ovules generally triggers the development of the ovary into a fruit. The germination and pollen tube growth occur during or after fusion of the nuclei.

Corresponding Author:**Amal Premachandran**Regional Agriculture Research
Institute, Pilicode, Kasaragod,
Kerala, India

Growth factors by which pollen influence fruit set most likely include the plant hormones auxins and gibberellins. Gibberellins stimulate pollen germination and pollen tube growth, and exogenous application of gibberellins to flowers can result in fruit set in the absence of fertilization ^[1]. Gibberellins produced by the pollen may thus play a role in increasing auxin production in the ovary, which in turn may act as a signal (or may amplify a signal) for fruit set and subsequent activation of cell division. Parthenocarpy, i.e., the development of fruit without fertilization leading to seedless fruits, has contributed much information about the role of hormones in early stages of fruit development ^[2]. Parthenocarpic fruit development can be genetically controlled or artificially induced by exogenous application of hormones. It usually results from lack of pollination, pollination that does not lead to fertilization (such as pollination with dead pollen degeneration or pollen from incompatible species), or successful fertilization that is followed by embryo abortion. Several lines of evidence suggest a correlation between increased auxin and gibberellin levels in the ovary before fertilization and parthenocarpic fruit development. This conclusion further implies that signal transduction pathways must exist during ovary development that control the temporal synthesis of auxin in the tissues surrounding the ovules to co-ordinate cell division activity with gametophyte development and fertilization.

Over all it appears that the sequential or co-operative action of gibberellins and auxin is a part of the signal transduction chain that leads to fruit set and subsequent activation of cell division. In ovaries that develop parthenocarpic fruits, this signal transduction pathway is altered such that one or more signals now act consecutively or independently of other regulatory factors to produce elevated hormone levels prior to or in the absence of, the normal fertilization event.

1.3 Phase II: Cell division, Seed formation, and early embryo development

Following fertilization, cell division is activated in the ovary as the cell division phase ends, individual cells enlarge, as does the entire fruit. Before the cell enlargement phase, dividing cells in the developing fruit are small, tightly compressed, and rich in cytoplasmic substances and have small vacuoles. It is generally concluded that during phase II, cell division activity is highest in outer pericarp and placental tissues. Cell division in the developing seeds occur at the peripheral integument layers rather than in the embryos.

It is generally accepted that in normal fruit development, the developing embryo or seed controls the rate and sustenance of cell division in the surrounding fruit tissue. This view is consistent with observations that the number of fertilized ovules generally determines the initial growth rate of the ovary, i.e., the rate of cell division. A positive correlation also exists between the number of developing seeds and sustained fruit growth ^[3]. Information on the biochemical and molecular interplay between the developing embryo- seed and fruit cells is sparse, but bioassays generally indicate a correlation between high cytokinin levels in developing seed and cell division activity in the surrounding tissue. Cytokinins are most probably transported into the seeds and not produced there and seeds are believed to control the rate of cytokinin transport. This suggestion is supported by the observation that parthenocarpic fruits, which lack seeds, contain low levels of cytokinin ^[4]. It is possible that an outward flow of cytokinin from the developing seed regulates cell division activity but that the hormone is rapidly degraded in the surrounding

tissues. Alternatively, cytokinin in the developing seed may control the synthesis of a positive regulator that diffuses into surrounding cells, which are developmentally programmed to divide. All together induction of cell proliferation and differentiation is mediated by a cascade of protein phosphorylation in response to a variety of growth factors or differentiation signals ^[5]. Therefore, cells enter the mitotic cycle, which results either in cellular proliferation or in specific differentiation events that are often coupled to gene activation.

1.4 Phase III: Cell expansion and Embryo maturation

After the period of cell division, fruit growth is mostly due to an increase in cell volume. The cell expansion in the fruit tissues is not paralleled by developmental events in the seed, which does not show a comparable increase in size. During this period of rapid fruit cell expansion, it is generally accepted that auxins are responsible for the increase in cell expansion in fruit tissues, although in most fruits, the auxin concentrations are higher in the seed than in the surrounding fruit cells. Auxins presumably cause an increase in the extensibility of cell walls and induce uptake and retention of water and solutes. Several observations indicate, however, that cell expansion may not be caused directly by seed-produced auxins alone but rather by an ill-defined sink activity exerted by the developing seeds. For example, cell expansion in parthenocarpic fruit with a small number of seeds is reduced, and auxins were found to be unable to replace developing seeds as stimulants of *in vitro* fruit growth by cell expansion.

The rapid and significant cell expansion that occurs during this period of fruit development could serve as a useful model system to dissect the mechanisms by which synthesis, transport, and integration of cell wall proteins and carbohydrates are regulated. Considering the large increase in cell volume during fruit development (10-fold or more), it is likely that this process cannot be accomplished by cell wall extension alone, but that synthesis of new cell wall material is necessary.

Further the role of gibberellins in fruit development is not well understood, but it is generally assumed that they are necessary to stimulate cell division and to maintain cell expansion. Parthenocarpic fruit show a similar temporal accumulation of gibberellins in phase II, although the level is several fold higher than in normal fruit. This correlates with an increase in the rate of cell expansion during early phase II, which does not occur in seeded fruit. The temporal accumulation of the hormone during phase III is less pronounced in parthenocarpic fruit than in normal fruit ^[3], which could explain the reduced growth rate of parthenocarpic fruit at this stage of development.

2. Types of Parthenocarpy

Parthenocarpy, literally means “virgin fruit” is the natural, artificially induced, or genetically modified production of fruit without fertilization. In the absence of pollination, parthenocarpic plants will set seedless fruit ^[1]. Thus, parthenocarpy can be regarded as a primary requirement to produce seedless fruit.

Various types of parthenocarpy have been recognized. A distinction is often made between obligatory parthenocarpy, which always results in seedless fruit, and facultative parthenocarpy, which results in seedless fruit only when pollination is prevented. A distinction is also often made between vegetative parthenocarpy, which allows fruit set

without pollination, and stimulative parthenocarpy, in which fruit set follows pollination, but subsequent fertilization is prevented, resulting in the production of seedless fruit. Seedlessness can also be obtained through stenospermocarpy, in which pollination and fertilization occur and embryo abortion is the cause of seedlessness. All three types of seedlessness are existing in grape, i.e. vegetative Parthenocarpy, stimulative Parthenocarpy and stenospermocarpy. The study [6] compared 8 diploid cultivars of grape by various method of induction of fruit by different pollination method such as 'Non pollination' with 'Sterile pollen (triploid)' and 'open pollination. The two cultivars *Italia* and *Rosario Bianco* show a good parthenocarpy behavior in Non-pollination suggesting that it have high vegetative Parthenocarpy and in case of pollination with sterile pollen cultivar '*Muscat Bailey A*' showed good percentage of parthenonocarpic berry set which showed stimulative Parthenocarpy. Another type is the stenospermocarpy in which pollination and fertilization occur, but the abortion of embryo occurs which is seen in the case of open pollination. Cultivar '*Muscat Bailey A*' which showed good percent of Parthenocarpy.

3. Factors affecting Seedlessness

Factors inducing Seedlessness include certain environmental conditions, such as low or high temperatures, chemical treatments, chromosomal aberrations, and genetic factors, such as genes controlling meiosis.

4. Techniques of seedless fruit production

4.1 Growth regulator application

A widespread agriculture practice for the production of seedless Parthenocarpic fruit consists in treating flowers with Phyto-hormones before pollination. Auxin, gibberellin and cytokinins or mixtures of these hormones have all been proven to be effective in inducing fruit development in the absence of fertilization in several crop species.

4.1.1 Gibberellins

Gibberellins stimulate pollen germination and pollen tube growth, and exogenous application of gibberellins to flowers can result in fruit set in the absence of fertilization [1]. Gibberellins produced by the pollen may thus play a role in increasing auxin production in the ovary, which in turn may act as a signal (or may amplify a signal) for fruit set and subsequent activation of cell division. Thus, exogenous application will result in parthenocarpic fruit

A study conducted in IARI by [7] on '*Bhokri*' variety of grape using GA application 10- 11 days at pre bloom with graded concentrations showed that there is an increase in seedless berry percentage with increase in concentration of GA₃ but study also showed there is a decrease in bunch weight, berry number per cluster and berry weight and concluded that the seedlessness is due to the damage caused by the action of GA. In another study conducted by [8] on two mandarin varieties, one of which is an obligate parthenocarpic variety *Satsuma* and other is a facultative parthenocarpic variety *Clementine*, to investigate reactivation of gibberellins in the ovary wall at the time of anthesis. It was observed that external application of GA₃ to the facultative parthenocarpic variety had an increase the activity of *CYCA 1* gene expression along with GA activity. Thus, it increased the cell division in the ovary and fruit set where as in *Satsuma* mandarin GA synthesis is autonomous with regulation of *CYCA 1* gene.

4.1.1.1 Effect of GA on Apple

[9] studied the morphological character of a gibberellin induced parthenocarpic apple variety '*Wealthy*' and reported a substantial increase in the fruit width and fruit length of apple across the weeks. Besides by the application of GA 300 ppm the quality of fruit was also improved with increase in fruit core and diameter.

4.1.1.2 Effect of GA on Rambutan

A study conducted on the yield and quality of rambutan fruits at harvest with the GA₃ application before bud break showed positive response to the induction of seedlessness. Application at other times did not significantly promote seedlessness. The number of fruits also significantly increased with the application of 0 to 50 ppm and from 100 to 200 ppm [10].

4.1.1.3 Effect of GA on loquat (*Eriobotrya japonica* Lindl.)

Studies of [8] on the effect of GA on application loquat 100 mg l⁻¹ to the flower panicle resulted in the production of parthenocarpic fruit and its application for three times at different stages of the panicle development resulted in good percentage of seedless fruits.

4.1.2 Cytokinin

The cytokinin is found in the developing seed, with very little in the pericarp and placental tissues. But how the cytokinin accumulates to high levels in the seed and also how it can regulate cell division in the surrounding tissues are still unknown. Cytokinins are most probably transported into the seeds and not produced there, but the seeds are believed to control the rate of cytokinin transport. This suggestion is supported by the observation that the parthenocarpic fruits, which lack seeds, contain low levels of cytokinin [3]. It is possible that an outward flow of cytokinin from the developing seed regulates cell division activity, but the hormone is also rapidly degraded in the surrounding tissues. Alternatively, cytokinin in the developing seed may control the synthesis of a positive regulator that diffuses into surrounding cells, which are developmentally programmed to divide. Cytokine resulted in induction of parthenocarpy in fruits like apple kiwi and pear have also been reported.

A hormonal regulation study conducted by [11] to elucidate the action of different growth regulators such as gibberellins (GAs), GA₁, GA₃, GA₄ and GA₇ with a cytokinin, N-(2-chloro-4-pyridyl)-N0-phenylurea (Forchlorfenuron) (CPPU), indole-3- acetic acid (IAA) and uniconazole (U) with the fruits in the Rosacea family revealed the profound effects of CPPU a derivative of cytokinin in development of parthenocarpic fruit. The combined treatment of GA₄ + Uniconazole, GA₃+ uniconazole and GA₄, GA₇ showed almost 100 per cent abortion where CPPU recorded 90 per cent abortion of seed. From the result it is clear that the cytokinin has positive effect to create the parthenocarpic effect in the Rosaceae family where a substantially amount of aborted seed is present and it also had good effect in fruit set.

4.1.3 Auxin

It is generally accepted that auxins are responsible for the increase in cell expansion in fruit tissues, although in most fruits, the auxin concentrations are higher in the seed than in the surrounding fruit cells. Auxins presumably cause an increase in the extensibility of cell walls and induce uptake and retention of water and solutes and auxin had less effect on induction of parthenocarpy in Rosaceae and Citrus families

[11, 12]. demonstrated that fruit set is inhibited by the negative regulator initiation *ARF8*, because loss-of-function *arf8* alleles allow Parthenocarp [12]. Proposed that the auxin signal induced by pollination leads to the phosphorylation and subsequent proteolytic degradation of the Auxin/indole-3-acetic acid (IAA) protein, which triggers the subsequent expression of fruit initiation genes. However, in the *arf8* mutant, the inhibitory complex cannot be formed and parthenocarpic fruit development occurs. Nonetheless, the molecular events directly involved in the initiation of fruit development and their link to plant hormone signal transduction processes remain unknown [12].

4.2 Ploidy breeding

Ploidy manipulation using crosses between diploids and tetraploids have yielded several valuable triploid cultivars in many of crops. Triploid plants are generally considered an evolutionary dead-end, since they generally give rise to aneuploid gametes with very low fertility. Predominantly trivalent associations and also a high number of bivalent and univalent associations are formed during meiosis in citrus triploid hybrids. Moreover, abortion of megasporogenesis during the period between the embryo-sac first divisions and the fecundated egg cell is common. For these reasons, citrus triploid hybrids are generally sterile, although they can occasionally produce fruits with very few seeds and induce seed formation in the fruit of other cultivars by cross-pollination [13]. The seeds produced through these crosses will be small or under developed and this could be extracted and rescued through embryo rescue technique.

4.2.1. Triploidy breeding in citrus

In a study conducted by [14] have used the two tetraploids clementine genotypes used as female parents are non-apomictic and were obtained by *in vitro* micrografting of shoot-tips, combined with treatment of shoot-tips with colchicine or oryzalin [15]. For tetraploids '*Clemenules*' clementine, 822 pollinations were done with '*Imperial*', '*Kara*', '*Kinnow*', '*Moncada*', '*Ponkan*', '*Primosole*' and '*Willow leaf*' mandarins, '*Murcott*' and '*Nadorcott*' tangors, '*Seedy*' navel sweet orange and '*Pink*' pummelo diploid male parents. For tetraploid '*Fina*' clementine, 557 pollinations were done with '*Fairchild*', '*Kara*', '*Kinnow*', '*N-27*', '*N-15*', '*N-6*', '*Page*', '*Ponkan*', '*Scarlet*' and '*Temple*' mandarins, '*Murcott*' tangor and '*SN*' sweet orange diploid male parents. They were pollinated in protected condition and fruits were harvested and seeds were studied. In 4x2x hybridizations, three seed types are obtained: undeveloped seeds, developed seeds (normal seeds) and developed small seeds. Generally, undeveloped seeds did not contain embryos (1/19), whereas the other two types contained one embryo per seed. Totally, 512 fruits were obtained from 1,379 pollinations and 2,524 developed seeds were recovered, of which 99.3 per cent (2,507/ 2,524) was of small size and only 0.7 per cent (17 / 2,524) was of normal size. Ninety-eight percent of the plants recovered from developed small seeds were triploid, whereas from normal seeds only 76 per cent was triploid. Although from normal seeds it is also possible to recover triploid plants, the efficiency is very low due to the very small number of normal seeds per fruit (on average 0.03 per fruit) [16]. Conducted histological studies demonstrating that in 4x2x hybridizations. Small seeds contained triploid embryos with pentaploid endosperms and indicated that triploid embryos originate from reduced megagametophytes and haploid pollen. In addition, these authors proposed that

the three to five ratios between the Ploidy level of embryos and endosperm was responsible for seed size reduction, since pentaploid endosperms grow more slowly and stop development prematurely. From this study it is very clear that crossing of tetraploids and diploid species in citrus will result in the seedless (Small sized) fruits.

4.2.2 Triploidy breeding in grape

Production of large seedless berries with high quality is one of the most important objectives in table grape breeding programs. Almost all the commercial seedless cultivars are stenospermocarpic ones, which sets berries through fertilization and subsequent embryo abortion. Although stenospermocarpic cultivars produced larger berries than diploid parthenocarpic cultivars up to, breeding of new cultivars that have high parthenocarpic ability might be useful to establish seedless grapes without stenospermocarpic. Recently, many researchers have been trying to breed new triploid seedless cultivars [17]. Because of very low fertility in the triploids, high parthenocarpic ability in the parental plants is a key for high fruit set and enlargement of seedless berries without exogenous gibberellins. In a study conducted [6] on eight diploids and four tetraploid cultivars of grapes pollination was done by three techniques, i.e., non-pollination (NP), pollination with dysfunctional pollen of a triploid (PT) and open pollination (OP). In this pollination with dysfunctional pollen of a triploid yielded 73.1 per cent of parthenocarpic berries in '*Muscat Bailey A*'.

4.3. Mutation Breeding

Irradiation is a valuable tool to obtain seedless cultivars from seeded ones. Mutation affects pollen viability. Female and male sterility seem to be directly related, In Citrus clones with a lower seed number present a lower pollen viability, and chromosomes aberration during meiosis caused by irradiation are responsible for sterility. Now a day's irradiation is largely used for induction of seedless fruit. A sequential and systematic study by [18] was done by using bud woods of irradiated '*Moncada*' Mandarin (Coat (50 ± 10) % Gys) and then grafted on *Carrizo* citrange rootstock again the bud wood was selected from 1st 7th and 12th bud from bottom and grafted on same rootstock to create mutation. The self-incompatible variety was planted with "Foster" but it was found that Clones of '*Moncada*' Mandarin variety yielded less seeds [19]. Studied the effect of mutation on eight cultivars of citrus and compared with the non-irradiated once. It was found that there was strict control on seed production. The irradiation was done at 2.75 - 6.5 krad of Cogamma irradiation at 13 Gy/min [20]. Confirms there are similarity in the *inner no outer (ino)* mutant of *Arabidopsis thaliana* and the Thai seedless variety of *Annona squamosa* in there integument development, in which latter shown an mutated INO gene which resulted in the seedlessness. These results shows the useful agronomic trait (seedless fruit) in a crop species through a molecular basis. This also showcase the role of regulator in the ovule development between eudicots and some of the early angiosperms The outer integument in the angiosperms were a group of cell separating them from other seed plants, further the evolution of this structure was in parallel with the derivation of *INO* from ancestral *YABBY* genes. This lateral structural might have evolved parallelly with the plants with the gene essential for the structural formation b. Propose that abortion of Seed Development Inhibitor (SDI) locus by mutation of the stenospermocarpic seedless grape varieties is the major cause of seedlessness. This was further envisaged

and stated that single-nucleotide variant (SNV) causing the Arg-197Leu substitution in *VviAGL11* as the seedlessness-responsible mutation basis for the grapevine *SDI* locus.

4.4 Endosperm culture

Endosperm is widely known as the fusion product of three haploid nuclei. Technically it is a triploid cell and having three nuclei. This is a good potential area to isolate triploid plants directly from the embryonic stage and cut short the lengthy process of growing and crossing which could develop into a possible seedless plant. This technique could be useful in occasions where embryo abortion is observed and in crops like citrus where apomixis is seen, although many speculations arise due to the culturing procedure and isolating stage in which viable plants are obtained.

4.5 Biotechnological and transgenic approaches

Parthenocarpy is an important agricultural trait and therefore, a target for biotechnological research. Auxin and GAs play important roles in parthenocarpic fruit development. Increased levels of these hormones in the ovary or ovule can substitute for pollination and can trigger fruit development, and this has been used for the induction of Parthenocarpy in genetic engineering studies. The *barnase* suicide gene, a cytotoxic ribonuclease of *Bacillus amyloliquefaciens* Fukumoto, was transformed into tobacco plants, producing transgenic plants with female sterility under the control of a stigma-specific promoter [22] and male sterility under the control of the tapetum-specific promoter. These approaches involve targeting the seedcoat or embryo could result in embryo abortion, and thus stenospermocarpy [23]. Reported on a transgenic 'Ponkan' mandarin transformed with the *barnase* suicide gene under the control of a tapetum-specific promoter (pTA29). These efforts may yield male-sterile mandarins, and therefore seedlessness. Another important technique is the somatic hybridization via protoplast fusion and development of cybrids. The first somatic hybrid of citrus was produced in 1985 and by now numerous inter and intrageneric somatic hybrids have been produced. This approach is now becoming the most important in the creation of triploids and novel germplasm for improving rootstock and scion varieties. Transgenic lime (*C. aurantifolia*) plants containing gene for decreased seed set were obtained from seedling hypocotyl and epicotyl segments using *Agrobacterium* mediated transformation. Putative transformants were identified by polymerase chain reaction, (PCR). If haploid lines are obtained and then crossed with diploid lines via protoplast fusion, triploids can also be produced. This allows the insertion of a haploid genome to the whole diploid genome of high organoleptic quality cultivars. It can be done via electro fusion of protoplasts.

5. Advantages of Seedlessness

5.1 Year-round production

Production of fruits is greatly influenced by the pollen and studies have shown that effective pollination is a prerequisite for the quality fruit production. An alarming situation is prevailing in the world that effective pollination is becoming a hindrance and due to many factors like pollinators environmental factors that affecting the fruit production. Malformed fruits are produced due to this reason. So, it will be an effective way to produce fruit without effective pollination. By breeding seedless varieties foremost production can be made year-round without worrying about the availability of pollen and pollinators.

5.2 Gustatory advantage

Seedless fruits have many gustatory advantages. Seeds are often hard, can have a bad taste and can be harmful; for example, grape seeds can bring about digestive problems. Furthermore seedlessness in citrus is gaining popularity among the consumers it could be mainly due to the tiresomeness to remove the seed from it. Studies have also shown that seedless tomato fruits are tastier than the seeded variety. Indeed, seedless tomato fruits exceed seeded fruits in dry-matter content by up to 1 per cent, contain more sugars, less acidity, less cellulose and have considerably more soluble solids than seeded cultivars.

5.3 Processing

Seedlessness will be a boon to the processing industry which removes many of the procedures in the fruit processing related to the seed and it is known that 80 per cent of the grapes cultivated in the world are seedless and there are mostly used for wine making and resin making.

5.4 Seed cavity can be filled with fruit tissue

The seeds and their cavities are replaced with edible fruit tissue; this is more attractive to the consumer. An illustration of this is the seedless pickled gherkin, which is more crunchy, firmer and fleshier than its seeded variety. It is possible to speculate that this advantage might be even greater for species with a large seed, such as peaches and mangos, or for those with a large cavity that is filled with numerous seeds, such as melons and papayas.

5.5 Improve shelf life

The shelf life of seedless fruit is expected to be longer than seeded fruit because seeds produce hormones that trigger senescence. This effect has been observed in watermelons, in which seeds are the origin of fruit deterioration. Seedless watermelons develop a meaty texture and become overripe significantly later than seeded varieties.

5.6 Fruit quality

Fruit weight, size, acidity, maturity index and harvest time, as well as chemical and nutritional composition are all important quality traits, consequently different fruit quality features have been evaluated in a study conducted by [18] with mandarin varieties to produce seedless clones by way of irradiation showed that there are some characters of fruit which are improved when it is being irradiated like fruit peel color, fruit diameter, fruit length, easiness in peeling. It is very evident that due to irradiation seed in the fruit are greatly reduced than the non-irradiated ones. Seed numbers and pollen germination (%) are less in several 'Moncada' clones, obtained in forced pollination, same result was shown by work conducted by [19].

5.7 Organic acids and Flavonoids

The content of vitamin C which is an important antioxidant and other organic acids in fruits and vegetables can be influenced by various factors such as genotypic differences, climatic conditions and cultural practices. Furthermore, their nature and concentration largely affect taste characteristics and organoleptic quality. A study was conducted by [18] on mandarin varieties to produce seedless clones by way of irradiation. It was observed that certain clones produced high amount of organic acids than control (seeded) which are ascorbic acid, malic acid and citric acid while succinic acid concentration did not significantly change in case of

flavonoids and hesperidin concentration was higher than control in most of the clones.

5.8 Carbohydrates, carotenoids and essential oils

The main portions of carbohydrates in citrus fruits are three simple sugars: fructose, glucose and sucrose, they represent the largest percentage of total soluble solids of citrus juice, and the ratios of fructose: glucose: sucrose are generally about 1:1:2. A study conducted by ^[18] with mandarin varieties to produce seedless clones by way of irradiation showed that the ratio was similar for the irradiated "Moncada" clones under study, and sucrose was present in the largest amounts for all clones. In case of carotenoids β -carotene increased significantly in clone's *limonene* was identified as profound essential oil present in the citrus and shown significant increase in irradiated clone than control.

5.9 Seedlessness in date palm

^[24] evaluated 3 types of date palm i.e. seeded, climacteric seedless, natural seedless, in which he found climacteric seedless is good among them and have good traits like high protein content, high moisture content which are all desirable characters for the consumption. Other factor like acidity was less in climacteric seedless fruits.

6. Limitation of seedless fruits

6.1 Lack of stability and uniformity in the expression of Parthenocarpy

The expression of Parthenocarpy in the fruit is highly variable and unstable. still in many fruit crops Parthenocarpy is reported but it is not stable in crops like mango, jamun, mangosteen. etc.

6.2 Small sized fruits

Parthenocarpic fruits are generally small in size. This could of various reasons such as hormonal changes inside the fruits due to the absence of seeds and the space of the seed will also be considered.

6.3 Malformed fruits

Parthenocarpic fruit sometimes will be resulted in a malformed fruit the reason pointing to the hormonal imbalance in the fruit development.

6.4 Hampers the production of commercial seeds

Seedlessness results in hampered seed production and there is no room for the commercial seed production.

7. Conclusion

Seedless fruits are a desirable commodity for consumers and have been produced using traditional farming and breeding methods for many centuries. Evidence that seedless forms of *Vitis vinifera* grapes have been prized for many centuries as dried fruit, provided by Greek philosophers such as Hippocrates, Plato and in the writings of ancient Egypt of 3000BC. Seedlessness fruit production is a age old practice, several technologies have been evolved but relevant one are discussed here, in that foremost is the plant growth regulator application among which gibberellin was found to be promising in certain major fruit crops. Further, technologies which have greatly improved seedless fruit production are, suicide gene and mutation.

Seedlessness is a boon to the processing industry and to a greater level to the consumers they can reduce the hardship regarding a crucial step in the fruit processing. Above all

preference in the market is the key success in fruit production to farmer. Nowadays trend is shifting, and urban culture is growing, and people are very busy and in this context, Seedless fruit: Fruits of future i.e. seedlessness is having great importance in the fruit production.

8. References

1. Gustafson F. Influence of gibberellic acid on setting and development of fruits in tomato. *Plant Physiol.* 1960; 35:521-523.
2. George W, Scott J, Splittstoesser W. Parthenocarpy in tomato. *Hort. Rev.* 1984; 6:65-84.
3. Gustafson F. The cause of natural parthenocarpy. *Am. J. Bot.* 1939; 26:135-138.
4. Gillaspay G, Ben-David H, Grissem W. Fruits: A Developmental Perspective. *Plant Cell.* 1993; 5:1439-1451.
5. Cohen P. Signal integration at the level of protein kinases, protein phosphatases and their substrates. *Trends Biochem. Sci.* 1992; 17:408-413.
6. Sarikhani H, Wakana A. Effect of Ploidy on Parthenocarpy in Grape Cultivars. *Acta Hort.* 2009, 827.
7. Dass HC, Randhawa GS. Effect of gibberellins on seeded *Vitis vinifera* with special reference to induction of seedlessness. *Vitis.* 1968; 7:10-21.
8. Mesejo C, Yuste R, Reig C, Fuentes AM, Iglesias DJ, Fambuenab NM *et al.* Gibberellin reactivates and maintains ovary-wall cell division causing fruit set in parthenocarpic Citrus species. *Plant Sci.* 2016; 247:13-24.
9. Nakagawai S, Bukovac MJ, Hiratai N, Kurokai H. Morphological studies of gibberellin-induced parthenocarpic and asymmetric growth in apple and Japanese pear fruits. *J. Japan Soc. Hort. Sci.* 1967, 37(1).
10. Romaquin ME, Eligio DT. [Powerpoint presentation] Effect of Gibberellic Acid (GA3) on Seedlessness of Rambutan (*Nephelium lappaceum*, Linn.). Presented in International Conference on Society and University (ICSU 2009), 2009, 5-6.
11. Zhang C, Lee U, Tanabe K. Hormonal regulation of fruit set, parthenogenesis induction and fruit expansion in Japanese pear. *Plant Growth Regul.* 2008; 55:231-240.
12. Goetz M, Vivian-Smith A, Johnson SD, Koltunow AM. AUXIN RESPONSE FACTOR 8 is a negative regulator of fruit initiation in Arabidopsis. *Plant Cell.* 2006; 18:1873-1886.
13. Fatta Del Bosco S, Matranga G, Geraci G. Micro and Macrosporogenesis of two triploid hybrids of Citrus. In: Proceedings of 7th International Citrus Congress. International Society of Citriculture, Acireale, Italy. 1992; 1:122-124.
14. Aleza P, Juárez J, Hernández M, Ollitrault P, Navarro L. Implementation of extensive citrus triploid breeding programs based on 4x×2x sexual hybridizations. *Tree Genet. Genomes.* 2012; 8:1293-1306.
15. Aleza P, Juárez J, Hernández M, Pina JA, Ollitrault P, Navarro L. Recovery and characterization of a Citrus clementina Hort. ex Tan.'Clemenules' haploid plant selected to establish the reference whole Citrus genome sequence. *BMC Plant Biol.* 2009; 9(1):110.
16. Esen A, Soost RK, Geraci G. Seed set, size and development after 4x–2x and 4x–4x crosses in Citrus. *Euphytica.* 1978; 27:283-293.
17. Hiramatsu M, Wakana A, Park SM, Fukudome I. Production of triploid plants from crosses between

- diploid and tetraploid grapes (*Vitis* complex) through immature seed culture and subsequent embryo culture. J Faculty Agri., Kyushu Univ. 2003; 48:51-57.
18. Bermejo A, Pardo J, Cano A. Influence of Gamma Irradiation on Seedless Citrus Production: Pollen Germination and Fruit Quality. Food Nutr. Sci. 2011; 2:169-180.
 19. Goldenberg L, Yaniv Y, Porat R, Carmi N. Effects of gamma-irradiation mutagenesis for induction of seedlessness, on the quality of Mandarin fruit. Food Nutr. Sci. 2014; 5:943-952.
 20. Lora J, José I Hormaza, Herrero M, Gasser CS. Seedless fruits and the disruption of a conserved genetic pathway in angiosperm ovule development Proceedings of national academy of science of the United States of America 29. 2011-2018; 108(13):5461-5465
 21. Royo C, Torres-Pérez R, Mauri N, Diestro N, Cabezas JA, Marchal C *et al.* the Major Origin of Seedless Grapes Is Associated with a Missense Mutation in the MADS-Box Gene VviAGL11 Plant Physiol. 2018; 177(3):1234-125.
 22. Goldman MH, Goldberg RB, Mariani C. Female sterile tobacco plants are produced by stigma-specific cell ablation. EMBO J. 1994; 13:2976-2984.
 23. Li DD, Shi W, Deng XX. Agrobacterium-mediated transformation of embryogenic calluses of Ponkan mandarin and the regeneration of plants containing the chimeric ribonuclease gene. Plant Cell Rpt. 2002; 21:153-156.
 24. Hamza H, Mrabet A, Araujo AJ. Date palm parthenocarpic fruits (*Phoenix dactylifera* L.) cv. DegletNour: chemical characterization, functional properties and antioxidant capacity in comparison with seeded fruits. Sci. Hortic. 2016; 211:352-357.