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Physiological and biochemical mechanisms of fruit cracking: A review

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ABSTRACT

Fruit cracking is a serious physiological disorder that affects fruit quality and productivity. It is a pre-harvest disorder that results in poor quality of fruits; these are not marketable and cause economic losses to growers. Generally, fruit cracking occurs during the second phase of fruit growth when expanding pulp induces pressure to peel and peel becomes thinner and microcracks appear, ultimately fruit splits and drops off from tree. Several factors that contribute to fruit cracking are irregular water supply, heavy crop load, warm-humid climatic conditions, nutrient mis-management and hormonal imbalance. Cultivars having thinner peels and deficiency of Ca, K, B and P in soils are more prone to fruit cracking. This review provides the physiological and biochemical basis of fruit cracking along with recommended control measures to reduce this disorder. Foliar application of synthetic auxins, gibberellins and minerals (Ca, Zn, P and B) at different time intervals for different species to significantly reduce fruit cracking is included in this review. Further molecular studies need to be proposed to study the actual mechanism of cracking through function of genes and biotechnological approaches can be followed so that cracking resistant varieties are produced.

Keywords: Citrus, Cracking, Fruits, Minerals, Nutrients

Fruit cracking is a physiological disorder in many citrus cultivars throughout the world. Citrus species mostly prone to fruit splitting are Hamalin orange, Valancia orange, Navelina orange, Lime and Lemons. Besides the citrus species, it is also observed in other fruits such as litchi, mango, pomegranate, cherry, apple, guava etc. (Cronje 2013, Bala *et al.* 2014). Losses due to fruit cracking lead to heavy marketable as well as financial loss to the growers. Cracked fruits also attract insects and pathogens that cause considerable decay in the neighbouring trees of the orchard. To sanitize the whole orchard, intense labour is imperative to pick up diseased fruits from the tree and also dropped ones from the orchard (Li and Chen 2017). Fruit cracking and fruit splitting are defined as major physiopathies that have been observed in grapes, figs, litchi, citrus, pome fruits, stone fruits etc. The terms, fruit cracking and fruit splitting are both separate terms, some studies use the term cracking to describe superficial cracks that expose the flesh, hence, the terminology is widely misunderstood (Mesejo *et al.* 2016). Thus, it's critical to emphasize that the meanings of the two words are vastly different. Fruit cracking is defined as the physical failure of the fruit peel in the form of cracks in the cuticle or peel that does not penetrate into the pulp tissues. On the other hand, Splitting is a severe form of cracking that penetrates the pulp. These both physiological pre-harvest disorders are mainly due to changes in fruit water relations and fruit peel properties (Rodríguez *et al.* 2018).

Fruit cracking develops due to disruption between peel and pulp irrespective to its origin (Sandhu and Bal 2014). It is a major pre-harvest disorder indicated as a peel meridian fissure which starts from the stylar end and extends till the equatorial zone of the fruit or beyond it (Kaur *et al.* 2022a). Studies done so far for the control of fruit cracking include pre-harvest mineral nutrient applications and foliar application of plant growth promoters to manage hormonal imbalance (Sandhu and Bal 2014). The control of the expansion of pulp using irrigation management during the period of initiation of split was reported by Ikram *et al.* (2020) and significant reduction in cracking was seen in pomegranate.

Fruit cracking is major pre-harvest disorder that negatively affects the crop quality, productivity and marketing. Till now, several research studies have been carried out to study the fruit cracking incidence with relation to plant growth development, associated physiology and different meteorological conditions responsible for cracking in different fruit crops. Further, to control this disorder various researchers tested different mineral nutrients and plant growth regulator treatments in field conditions at different time intervals with different successful rates. But the actual mechanism underlying the fruit cracking has not been reviewed yet. So, the present study has been

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conducted to understand the physiological, biochemical and anatomical mechanism associated with fruit cracking. Along with this, different remedial measures during fruit growth and development to control this disorder are discussed in this review. Further, this review also provides the future perspectives to unravel this disorder through understanding the fruit cracking mechanism via studying the gene function and biotechnological approaches to produce cracking resistant varieties.

Patterns of fruit cracking

In different fruiting plants, different types of cracking have been observed. The pattern of fruit cracking varies among citrus species due to variation in the fruit developmental stages. Earlier, two different types of fruit cracking have been observed in lemon i.e. radial and transverse type and in one study, out of all the cracked fruits, 90% showed radial cracking and 105% showed transverse type of cracking. Recently, Kaur *et al.* (2022b) studied fruit cracking in lemon cv. Punjab Baramasi and recorded different patterns of fruit cracking, viz. radial, transverse, oblique, irregular and combination of two radial transverse cracking, depending upon the direction of fissure origin. Cracking that initiated at the stylar end of the fruit and extended to the equatorial zone was regarded as radial type of cracking. In transverse cracking, fissure originated between the two ends of fruits. The various kinds of cracking that followed no set pattern were regarded as irregular (Kaur 2018). In the citrus species, three different cracking patterns are observed i.e. flavedo splitting, albedo splitting and inner cracking. Among these, flavedo-splitting was reported in Jincheng oranges that starts with the cuticle cracking of flavedo, followed by the gradual distortion and breakdown of cells from outside towards the flavedo cells that ends up with the disruption of albedo (Cronje *et al.* 2011). The second type of fruit cracking is albedo splitting (fruit creasing and fruit pitting), reported in Hongjiang sweet oranges. In these cultivars, fruit splitting begins from the cracking of albedo, followed by flavedo pitting, and ultimately fruit gets cracked (Li *et al.* 2006). Third type of citrus fruit splitting is inner cracking, i.e. the cracking of pomelo cv. Duwei starts from central axis of fruit, then the fruit top, and ultimately the fracture (crack) appears (Li and Chen 2011).

When does fruit cracking occur?

Fruit cracking in almost all citrus cultivars occurs during the phase of cell enlargement and fruit maturity, while in some citrus cultivars, it occurs throughout the fruit growth and developmental period (Li and Chen 2017). The intensive period of cracking generally coincides with the aril exponential growth. The rapidly expanding aril enhances the internal turgor pressure which directly acts upon the pericarp. This situation was conceptualized as "Bladder vs Ballskin effect" by Huang and Xu (1983). Liebisch *et al.* (2009) in tomato observed mechanism of fruit cracking and suggested that prematurely strengthened cells are unable to react the sudden supply of large threshold of water after a period of dry spell; pulp expands in volume and large tension exerted on peel causes eventual breakdown of tissue that later induces microcracks on upper surface ultimately inducing cracking. Khera and Bal (2014) studied fruit cracking in lemon cv. Baramasi and observed that fruit cracking started from second week of June when some of fruits showed initial symptoms of cracking which continued till harvest. The cracking recorded during the first week of July was significantly higher than other dates of observation.

Factors contributing fruit cracking

Fruit cracking is a major physiological disorder and a single factor cannot be constitutively responsible for it. Different factors that cause fruit cracking have been observed among different fruit crops and these are tree factors, environmental and cultural factors (Fig 1). Tree factors responsible for fruit cracking include type of fruit size, shape of fruit cracking susceptible varieties and crop load (Cronje 2013). Some cultivars with specific growth habit and a resulting tree shape as well as ineffective pruning stimulate fluctuations in microclimate within tree canopy of citrus are known to be more susceptible to breakdown

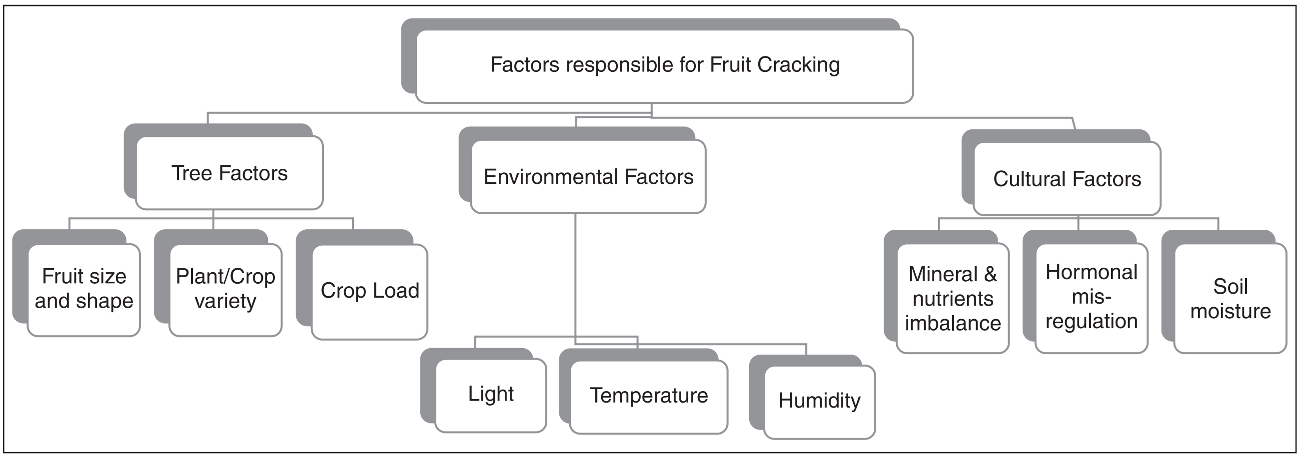

Fig 1 Several factors responsible for fruit cracking.

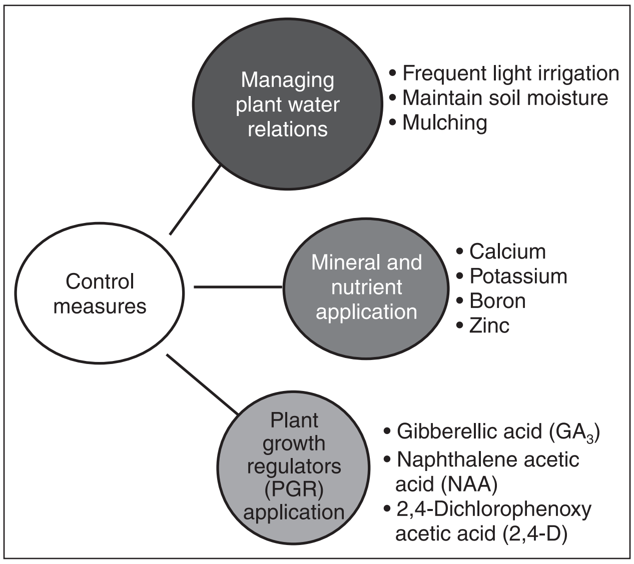

Fig 2 Control measures of fruit cracking.

of rind and ultimately lead to fruit cracking in Mandarin (Cronje *et al.* 2011). Fruit cracking also depends on flower number, percentage of fruit set as well as final crop load. Higher crop load results into higher fruit cracking percent, whereas little or no fruit cracking has been observed during the years of less crop load (Ikram *et al.* 2020).

Environmental factors that negatively affect fruit cracking are light, temperature and humidity. Fluctuation in light and temperature could cause succession period of high growth and development, and fruit shrinkage leading, to cuticle cracking (Li *et al.* 2011). Along with this, daily variation in light exposure intensity was directly correlated with daily fruit cracking rate (Li 2006). High temperature is also responsible for fruit cracking, because with increase in fruit temperature, gas pressure inside the fruit is also increased, that causes the fruit to expand in volume, thus fruit skin is stretched and the crack appears (Galindo *et al.* 2014). Li *et al.* (2006) reported that low relative humidity/ high temperature, hot dry winds and drought or excessive rainfall are the major cultural factors that increase the incidence of fruit cracking in Litchi. Similarly, Kaur *et al.* (2022b) reported highest fruit cracking per cent when dry spell was followed by sudden rainfall during stage II and III of fruit development.

Cultural factors that contribute to fruit cracking are imbalance in mineral and nutrition content, hormonal regulation, irregular irrigation and soil moisture content. Insufficient minerals and nutrients in the citrus fruit peel leads to developmental and metabolic disorders in peel, thus stimulation in external adverse environmental condition results in fruit cracking (Sharma 2007). Thus, imbalance in calcium (Ca), potassium (K) and phosphorous (P) indirectly cause cracking in citrus fruit type (Li and Chen 2017). During the phase of cell enlargement, spraying of potassium (K), Calcium (Ca), boron (B), zinc (Zn) could significantly reduce the fruit cracking percentage (Kaur 2018). Fruit cracking also depends on endogenous hormonal content of fruits during its growth and development to a greater extent. Gibberellins (GA_3) can promote the cell wall growth and extension, which could inhibit the incidence of fruit cracking (Devi *et al.* 2018). During the young fruit development period, foliar application of GA_3 could increase fruit size, peel thickness and fruit quality, along with this GA_3 could reduce the pectin methylesterase activity, thus decrease the occurrence of fruit cracking (Sandhu and Bal 2014). Higher endogenous gibberellin and cytokinin are responsible for excessive growth of citrus fruit rind, thus developed rind would have more thickness and roughness, less susceptible to crack.

Soil-water relation gets affected by rainfall and irrigation. Mostly fruit cracking is likely to occur shortly before maturity when high soil water ratio follows a drought period. The influx of water into pulp of fruit during stage II and III of fruit development develop pressure on developing rind and leads to initiation of cracks (Kaur *et al.* 2022b). Thus, maintaining soil water content by avoiding its fluctuation and depletion of water from deeper soil layers reduces susceptibility to fruit cracking. Hence, nutrient imbalance and hormonal mis-regulation cause erratic growing conditions that result into fruit cracking incident. Thus, optimal growing conditions with reasonable cultural practices along with mineral nutrition can reduce malady of splitting.

Mechanism of fruit cracking

The process of fruit cracking is not sudden one, but is gradual. The process of fruit cracking has been divided into five different phases; these are designated as period of normal fruit development, critical period, initial cracking, middle stage and the later stage of fruit cracking (Kaur *et al.* 2022b). During normal fruit development, fruit peel develops at a normal pace. During the initial fruit cracking, the peel cracking gets aggravated and the oil glands start to get ruptured. Due to further cell injury, tissues at surface get damaged and a larger space develops between the cells of the broken albedo. During the later period of cracking, the tissue structure of albedo and flavedo cannot be distinguished (Li 2006). The citrus fruit growth occurs in a sigmoid curve, the rind development occurs during stage I and II and the pulp growth occurs during stage II (Cronje 2013). There is however, very little increase in fruit size in stage III. Physically, splitting of fruit occurs during stage II on those cultivars which are prone to fruit splitting (Li and Chen 2017). It is thought that due to cell expansion caused by increase in turgor pressure, there is a corresponding increase in pulp volume during stage II which results in change in fruit shape. Fruit shape is dependent on ratio between diameter of fruit and height of fruit. During stage II, fruit gets transformed from globose to oblate as suggested by Kaur *et al.* (2022b). The pressure exerted by pulp forces the rind to adjust to increase in volume due to pulp cell growth as well as albedo cell growth. There is also an increase of internal stress exerted on calyx and stylar end. During IInd and IIIrd stages of fruit growth and development, when dry spell was followed by wet period, highest level of fruit cracking was recorded by Kaur *et al.*(2019).

The mechanism of fruit cracking in citrus species described by various researchers is summarized below:

Cracking as related to rind characteristics

a. Mechanical properties of peel: The utmost indicators of fruit cracking are peel thickness and peel hardness of fruit. During the later period of development of citrus fruit, the changes in mechanical property of fruit peel are related to occurrence of fruit cracking. The thin flavedo (peel) of the cultivars are more prone to splitting and are unable to accommodate the increase in pulp volume. This leads to fruit splitting at stylar end wherever rind is thinner and weaker (Khadivi 2019).

   Li and Chen (2011) observed cultivars Newhall navel oranges to have significantly higher peel thickness and are less susceptible to fruit cracking as compared to Cara Cara navel orange cultivar with relatively thin peel, high susceptibility to fruit creasing and splitting. Ali *et al.* (2000) reported that fruit peel thickness was negatively correlated with fruit creasing rate. The effect of uniformity of fruit peel thickness on fruit cracking was more than that of the fruit shape index on fruit cracking rate (Zhu *et al.* 2006). Hence, it may be concluded that when the citrus fruit peel is thicker, the possibility of peel to get stretched and deformed is lower and the crack resistance is also stronger. Besides peel thickness, peel hardness is also an important factor that influences the fruit cracking in citrus species. Li (2006) showed that during the late period of citrus fruit development, the fruit peel hardness of Anliu sweet orange is significantly more than that of Hongjiang sweet orange and its fruit cracking rate was also less than that of Hongjiang sweet orange. The peel acts as a barrier between external environment and the fruit, thus protects the fruit from external injury while also bearing internal pressure. As a result, the structure of peel as well as its degree of age are the key variables in fruit cracking. Among various peel characteristics, peel thickness is a dynamic factor that prevents rain water penetration to the internal tissues and reduces the cracking in cherry (Rehman *et al.* 2015) and tomato (Singh *et al.* 2020).

b. Ultra-structure of citrus fruit peel: Fruit cracking occurrence is correlated with the number of cell layers, structure of flavedo (Li and Chen 2011). Abundance of oil glands maintains the strength of peel and allows the surrounding cells to bear the high pressure that's why less fruit cracking has been observed in fruits having high density oil glands (Li 2006). Kaur *et al.* (2019) studied the anatomy of fruit peel of lemon and reported significant difference in peel thickness, epidermal thickness, arrangement of oil glands and vascular tissues between healthy and cracked fruit peels. It has been reported that fruit cracking in lemon is due to the irregularity in water influx that creates tension in xylem vessels, resulting in disorganization of vascular tissues of pedicel which disrupts the regular transport of water and nutrient to developing albedo and flavedo and cause fruit cracking.

c. Modification in cell wall hydrolases of peel: The cell wall metabolism is also an important factor that contributes to fruit cracking occurrence (Huang *et al.* 2006). Enzymes such as cell wall hydrolases and oxidoreductase have a crucial role to induce fruit cracking (Kaur *et al.* 2022a). Several researchers reported the role of cell wall hydrolases in Navel orange, Hongjiang sweet orange, Shatangju mandarin (Li *et al.* 2006). Cell wall hydrolases catalyses the degradation of cellular polysaccharides and lowers the strength of fruit peel, while cell wall oxidoreductases like peroxidase could catalyse the lignin deposition and formation of phenolic cross-linking among structural proteins, hemicelluloses and pectin that lead to cell wall hardening and reduce the extensibility of cell wall (Li and Chen 2011).

   Cellulase and Polygalacturonase activity: Cellulose is one of the main constituents of plant cell walls and this macromolecule can be degraded by the plant enzyme cellulase. Jiang *et al.* (2019) reported that activity of cellulase increases during the process of abscission. Cellulase and polygalacturonase enzymes are thought to function in the degradation of adhesive cell wall components that link abscission zone cells together and this increase in enzyme activities is highly correlated with reduction in fruit break-strength (Cronje 2013).

   Galacturonic acid is the important component of pectin in flavedo of citrus fruit. The higher enzymatic activity of peel of citrus fruit in cracked fruits revealed that flavedo was effectively degraded by the activity of enzyme that acts on polygalacturonic acid (Pretel *et al.* 2005), the upraised activities of cell wall degrading enzymes like cellulase polygalacturonase in the albedo and flavedo of creased compared with healthy fruit appear to be associated with the enhanced loss of pectins. This loss of pectin is accompanied by accumulation of starch in the cell walls of the albedo and alteration in mechanical properties of rind that cause cell wall loosening and possibly induces splitting (Saleem *et al.* 2014).

d. Cracking induced due to plant-water relations: Fruit cracking occurs primarily when fruits have thinner peels and higher osmotic content in pulp. The whole fruit development is regulated by internal turgor pressure established in pulp tissues; it gets increased with increase in soil moisture content. Mesejo *et al.* (2016) reported that irregular water supply and altered climatic conditions affect the soil moisture content that induces fruit growth rate changes and increases the fruit cracking incidence. Besides the soil conditions and species characteristics, other factors responsible for fruit cracking are the size of xylem vessels of fruit pedicel. Larger the xylem vessels, higher the fluctuation in plant water status, resulting in more severe daily fruit shrinkage expansion and higher fruit cracking (Rodríguez *et al.* 2018). Galindo *et al.* (2014) reported that when water deficient trees were irrigated suddenly after a long dry spell, it results in asymmetric rise in turgor pressure of fruit. The rise in turgor pressure induce pulp expansion that puts pressure on peel, it becomes thinner and increases the susceptibility of fruit cracking in it.

Control measures of fruit cracking

There are various methods that have been employed to control fruit cracking in different fruit species (Fig 2) and they are discussed as:

a. Managing plant water relations: To control fruit splitting in citrus, there should be careful and detailed management of irrigation practices during the development of fruit by avoiding fluctuations in soil water content. When normal irrigation was reduced during late summer in stage II, reduction in fruit cracking was observed by Ikram *et al.* (2020). Harrera and Fischer (2012) recorded differences in cracking among different irrigation levels in cape grossberry. With an irrigation frequency of 14 days, the cracking was 18%, while with irrigation every 4th day, cracking was 45.6%. The percentage of cracking decreased when irrigation was applied after a longer time. Vishwakarma *et al.* (2020) reported that irrigation at 20% and 40% depletion of available soil moisture reduced fruit cracking in litchi. Irrigation management decreased fruit cracking and enhanced quality in litchi.

b. Nutrients applications: Fruit cracking rate decreased significantly with spraying treatments of K, Ca, B and Zn fertilizer during the phase of fruit enlargement (Table 1). K has been reported to promote cell division in fruit peel and pulp. Application of K fertilizer in spring or during the early development period increases peel thickness and enhances the fruit cracking resistance (Ali *et al.* 2000). The additional application of K fertilizers during late fruit development period had little effect on reduction of pre-harvest fruit cracking. Calcium plays an important role in process of cell division and growth, transport of Ca is a passive process, weakly transported through transpiration pull. Any deficiency to Ca in fruit leads to physiological disorders as rind breakdown of Nules Clementine (Cronje *et al.* 2011). Further, Cronje (2013) suggested that single foliar application of $Ca(NO_3)_2$ reduced the cracking in Nova mandarin. Foliar application of combinations of boron and calcium was effective to reduce fruit cracks in tomato (Liebisch *et al.* 2009). Boron is responsible for increasing cell elasticity and prevents breakdown of vegetative tissues. Thus, reduction in fruit cracking with B application has also been reported in pomegranate

Table 1 Foliar application of minerals and plant growth regulators to reduce incidence of fruit cracking in different fruit crops (Sharma 2007)

Fruit crop	Foliar application	Recommended concentration	Time of foliar application
Citrus species	$CuSO_4$	0.3%	Three times during fruit development
	K_2SO_4	4.0%	Three times during fruit development
	$CaCl_2$	0.5%	One time at half grown stage of fruit development
	$Ca(NO_3)_2$	1.0%	Three times after fruit set at monthly interval
	$Na_2B_4O_7$	0.2%	Three times during fruit development
	NAA	10 ppm	Three times after fruit set at monthly intervals
	NAA	20 ppm	Two times after fruit set at monthly intervals
	GA_3	10 ppm	One time before harvesting stage
Apple	$CuSO_4$	500 ppm	One time during fruit development
	$Na_2B_4O_7$	1000 ppm	One time during fruit development
	Paclobutrazol	250 ppm	One time foliar or soil application
Litchi	$ZnSO_4$	1.5%	Foliar application at weekly interval from first stage of fruit development
	NAA	10 ppm	One time after fruit set
	GA_3	40 ppm	One time after fruit set
	2,4,5-T	10 ppm	One time after fruit set
	2,4-D	10 ppm	One time after fruit set, others after month
Pomegranate	$Na_2B_4O_7$	0.1%	One time in June
	GA_3	120 ppm	One time at second stage of fruit development
Pear	$Na_2B_4O_7$	0.5%	Two times after flowering stage
Cherry	$CaCl_2$	0.3%	Four times at weekly interval
	Paclobutrazol	750 ppm	One time after fruit set or soil application

by Bashira *et al.* (2019). Khadivi (2019) recommended foliar spray of boron fertilizers 3–4 times during flowering and early fruit development period to reduce fruit cracking in pomelo.

c. Plant Growth Regulator (PGR) applications: The exogenous application of plant growth regulators have been used to modulate the growth response of plant, which actively govern growth and development through regulating endogenous processes (Bons *et al.* 2015). PGR are commercially exploited in the field of horticulture because of the wide range of potential roles they play to increase productivity. Their application in citrus industry during different phases of growth and development is currently in practice as is evident from the present literature (Kaur *et al.* 2000). The advantage of plant growth regulators is their use at very low concentration because of which they do not lay any health hazards (Kaur *et al.* 2007). However, it is important to understand the basic mechanisms underlying the citrus growth and development in order to manipulate the key physiological processes and make use of the plant growth regulators at the appropriate stage of development and at the optimum dose.

These regulators have been employed to increase total soluble solids and alter fruit quality characteristics such as peel thickness, colour, fruit size and juice quality in several citrus species (Kaur *et al.* 2000). Citrus cultivars in which natural endogenous hormonal synthesizing mechanism is lacking are more prone to split. Application of GA_3 to split prone species reduces the senescence of rind and makes the fruit less susceptible to cracking in Eureka lemon (Devi *et al.* 2018). In citrus, GA_3 increases rind resistance to avoid pressure and reduces chlorophyll breakdown that indicates delay of senescence. GA_3 when applied after physiological fruit drop has been considered to be more successful than foliar spray during bloom to reduce cracking (Li and Chen 2017). During fruit enlargement stage, NAA was reported to regulate peel development. Thus, application of NAA significantly improved fruit set rate and increased peel hardness that is beneficial to reduce fruit cracking in citrus species (Greenberg *et al.* 2010).

Conclusion

Fruit cracking is a major disorder of important horticultural crops, viz. citrus, pomegranate, cherry, litchi, limes and lemons. Fruit cracking generally starts from stylar or navel end of fruit and begins where the peel is thin or weak than the other areas of fruit peel. Major factors that determine the incidence of fruit cracking in most of fruit crops are nutrient imbalance (low K, Ca, B and P), warm and humid climatic conditions, irregular water supply and heavy crop loads. Current horticultural practices should be applied to reduce the incidence of fruit cracking, such as manipulation in crop load by thinning and application of GA_3 as well as sufficient Ca, K, and P nutrition with consistent irrigation. Recent research on mandarin species reported significant reduction in fruit splitting through the application of 2,4-D. With reduction of fruit cracking, foliar application of 2,4-D causes the negative impact in fruit quality i.e. increased rind coarseness and reduced juice content. To reduce the fruit cracking, there is a need to study the molecular basis of cell wall metabolism and to investigate the genes that are responsible for rind properties so that biotechnological approaches and genetic engineering could be adopted to study the actual mechanism of fruit cracking and to reduce the fruit cracking incidence.

REFERENCES

Ali A, Summers L L, Klein G J and Lovatt C J. 2000. Albedo breakdown in California. (*In*) *Proceeding of International Society Citriculture Congress* **2**: 1090–93.

Bala A, Kaur N and Kumar A. 2014. Reaction of pomegranate cultivars to black rot and fruit cracking in pomegranate (*Punica granatum* L.) cultivars. (*In) Agriculture Diversification for Sustainable Livelihood and Environmental Security*, Ludhiana, Punjab, November 18–20, p. 453.

Bashira M, Noreen A, Ikhlaq M, Shabir K, Altaf F and Akhtar N. 2019. Effect of boric acid, potassium nitrate and magnesium sulphate on managing fruit cracking and improving fruit yield and quality of Pomegranate. *Journal of Horticultural Science and Technology* **2**: 49–53.

Bons H K, Kaur N and Rattanpal H S. 2015. Quality and quantity improvement in citrus : Role of plant growth regulators. *International Journal of Agriculture, Environment and Biotechnology* **8**(2): 433–37.

Cronje P J R, Barry G H and Huysamer M. 2011. Fruit position during development of 'Nules Clementine' mandarin affects the concentration of K, Mg and Ca in the flavedo. *Scientia Horticulturae* **130**: 829–37.

Cronje P J R. 2013. Postharvest rind disorders of 'Nadorcott' mandarin are affected by rootstock in addition to postharvest treatments. *Acta Horticulturae* **1007**: 111–17.

Devi K, Kumar R, Wali V K, Bakshi P, Sharma N and Arya V M. 2018. Effect of foliar nutrition and growth regulators on nutrient status and fruit quality of Eureka lemon (Citrus limon). *Indian Journal of Agricultural Sciences* **88**(5): 704–08.

Galindo A, Rodriguez P, Collado-Gonzalez J, Cruz Z N, Torrecillas E, Ondono S, Corell M, Moriana A and Torrecillas A. 2014. Rainfall intensifies fruit peel cracking in water stressed pomegranate trees. *Agricultural and Forest Meteorology* **194**: 29–35.

Greenberg J, Holtzman S, Fainzack M, Egozi Y, Giladi B, Oren Y and Kaplan I. 2010. Effects of NAA and GA_3 sprays on fruit size and the incidence of creasing of 'Washington' navel orange. *Acta Horticulturae* **884**: 273–79.

Harrera J A and Fischer B L G. 2012. Effect of irrigation and nutrition with calcium on fruit cracking of the cape gooseberry (*Physalis peruviana* L.) in the three strata of the plant. *Acta Horticulturae* **928**: 163–70.

Huang H B and Xu J K. 1983. The developmental pattern of fruits tissues and their correlative relationships in Litchi chinensis Sonn. *Scientia Horticulturae* **19**: 335–42.

Huang X M, Wang H C, Li J G, Yuan W Q, Lu J M, Huang H B, Luo S and Yin J H. 2006. The presence of oxalate in the pericarp and fruit pedicel is not linked to a shortage of fruit calcium and increase in cracking incidence in litchi. *Journal of horticultural science and biotechnology* **81**: 225–30.

Ikram S, Shafqat W, Qureshi M A, Din S, Rehman S, Mehmood

A, Sajjad Y and Nafees M. 2020. Causes and control of fruit cracking in pomegranate: A review. *Journal of Global Innovations in Agricultural and Social Sciences* **8**(4): 183–90.

Jiang F, Lopez A, Jeon S, de Freitas S T, Yu Q, Wu Z and Mitcham E. 2019. Disassembly of the fruit cell wall by the ripening-associated polygalacturonase and expansin influences tomato cracking. *Horticulture research* **6**: 17.

Kaur N, Monga P K, Thatai S K and Vij V K. 2007. Physiological fruit drop check in Kinnow mandarin. *Environment and Ecology* **25S**(4A): 1297–99.

Kaur N, Monga P K, Thind S K, Thatai S K and Vij V K. 2000. Effect of growth regulators on periodical fruit drop in Kinnow mandarin. *Haryana Journal of Horticultural Science* **29**(1&2): 39–41

Kaur R, Kaur N and Singh H. 2019. Pericarp and pedicel anatomy in relation to fruit cracking in lemon (*Citrus limon* L Burm). *Scientia Horticulturae* **246**: 462–68

Kaur R, Kaur N and Singh H. 2022b. Fruit cracking in lemon cv. Punjab Baramasi in relation to developmental physiology. (*In*) *Proceeding of National Academy of Sciences, India, Section B: Biological Sciences* https://doi.org/10.1007/s40011-021-01331-1

Kaur R, Kaur N, Singh H and Sangha M K. 2022a. Compositional differences in peel and juice of cracked and normal fruits of lemon (*Citrus limon* L. Burm). *Journal of agricultural science and technology* **24**(4): https://jast.modares.ac.ir/article-23-48548-en.html

Kaur R. 2018. 'Physiological, biochemical and anatomical basis of fruit cracking in lemon cv. Punjab Baramasi'. MSc Thesis, Punjab Agricultural University, Ludhiana, India.

Khadivi A. 2019. Cracking in Fruits and Vegetables. *Postharvest Physiological Disorders in Fruits and Vegetables,* pp. 127–62. De Freitas S T and Pareek S (Eds). CRC Press, Florida.

Khehra S and Bal J S. 2014. Influence of foliar sprays on fruit cracking in lemon. *International journal of plant and environmental science* **4**: 124–28.

Li C Y, Zhang G L, Zeng X, Luo N and Hu Q. 2006. Studies on cell wall enzymes of navel orange (*Citrus sinensis*) fruit. *Journal of Sichuan Agricultural University* **24**: 73–76.

Li J and Chen J Z. 2011. The style, process and control of cracking fruit in citrus. *Journal of agricultural sciences* **11**: 32–37.

Li J and Chen J. 2017. Citrus fruit cracking: Causes and Occurrence. *Horticultural plant journal* **3**: 255–60.

Li J. 2006. 'Creasing fruit and related research of the cell-wall metabolism in citrus'. MD Thesis, South China Agricultural University, Guangzhou, China.

Liebisch F, Max J F J, Walter G and Horst J. 2009. Blossom-end rot and fruit cracking of tomato grown in net-covered greenhouses in Central Thailand can partly be corrected by calcium and boron sprays. *Journal of Plant Nutrition and Soil Science* **172**(1): 140–50.

Mesejo C, Reiga C, Martinez-Fuentesa A, Gambetta G, Gravina A and Agusti M. 2016. Tree water status in fluences fruit splitting in Citrus. *Scientia Horticulturae* **209**: 96–104.

Pretel M T, Amoros A, Botella M A, Serrano M and Romojaro F. 2005. Study of albedo and carpelar membrane degradation for further application in enzymatic peeling of citrus fruits. *Journal of the science of food and agriculture* **85**: 86–90.

Rehman M U, Rather G H, Dar N A, Mir M M, Iqbal U, Mir M R, Fayaz S and Hakeem K R. 2015. Causes and Prevention of Cherry Cracking: A Review. *Crop Production and Global Environmental Issues*. Hakeem K (Eds). Springer Cham, Denmark. https://doi.org/10.1007/978-3-319-23162-4_19

Rodriguez P, Galindo A, Collado-Gonzalez J, Medina S and Corell M. 2018. Fruit response to water-scarcity scenarios: water relations and biochemical changes. *Water Scarcity and Sustainable Agriculture in Semi-Arid Environment*, pp. 349–75. Tejero I F G and Zuazo V H D (Eds). Academic press, Cambridge.

Saleem B A, Hassan I, Singh Z, Malik A M and Prevez M A. 2014. Comparative changes in the rheological properties and cell wall metabolism in rind of healthy and creased fruit of Washington Navel and Navelina sweet orange (*Citrus sinensis* L.). *Australian Journal of Crop Science* **8**: 62–70.

Sandhu S and Bal J S. 2014. Response of lemon (*Citrus limon* (L.) Burm.) cv. Baramasi to irrigation scheduling and mulching. *Progressive Horticulture* **46**(2): 232–35.

Sharma R R. 2007. Fruit cracking: causes and control. *Fruit production: Problems and solutions*, pp. 37–52. International Book Distributing Co, India.

Singh A, Shukla A K and Meghwal P R. 2020. Fruit Cracking in Pomegranate: Extent, Cause, and Management – A Review. *International Journal of Fruit Science* **20**: 1234–53.

Vishwakarma G, Kumari B, Zaman F, Goutam E and Singh K K. 2020. Prevention strategies for fruit drop and fruit cracking in Litchi (*Litchi chinensis*). *Biotica Research Today* **2**(7): 553–55.

Zhu Q J, Li H and Liao W P. 2006. The fruit development and cracking and control of 'Hong jiang' sweet orange. *China south pomology science* **35**: 6–7.