Agronomía Colombiana
ISSN: 0120-9965
ISSN: 2357-3732
Universidad Nacional de Colombia, Facultad de Agronomía

Fischer, Gerhard; Balaguera-López, Helber Enrique; Álvarez-Herrera, Javier
Causes of fruit cracking in the era of climate change. A review
Agronomía Colombiana, vol. 39, no. 2, 2021, May-August, pp. 196-207
Universidad Nacional de Colombia, Facultad de Agronomía

DOI: https://doi.org/10.15446/agron.colomb.v39n2.97071

Available in: https://www.redalyc.org/articulo.oa?id=180376061006

Causes of fruit cracking in the era of climate change. A review

Causas del rajado de frutos en la era del cambio climático. Una revisión

Gerhard Fischer[1], Helber Enrique Balaguera-López[1*], and Javier Álvarez-Herrera[2]

ABSTRACT

The objective of this review was to report on advances in environmental, cultural, and physiological aspects of fleshy fruit cracking to reduce or avoid this disorder, which affects many fruit species. Cracking is a physiological disorder that limits the production and quality of fleshy fruits because it affects the exocarp and mesocarp, especially with climate change and variability. Fruit cracking is generated by external factors (agronomic and environmental) and internal factors, several of which require exhaustive study. The incidence of cracking varies widely according to climatic characteristics during fruit development, different fruit species and varieties, growth sites, and crop management. This physiological disorder is aggravated by increases in rain intensity, especially after a dry season or in areas with increased temperatures. Knowledge on causes of cracking has generated management strategies that involve genetic improvement, ecophysiological conditions, agronomic practices such as pruning, irrigation, and fertilization (mainly with Ca, Mg, B, and K), applications of plant growth regulators, and use of plastic covers, etc. For several fruit trees, these strategies are effective, but in species such as the cape gooseberry, cracking remains without a full explanation or effective management.

Key words: mineral nutrition, climate, heavy rains, fleshy fruits, fruit growing, physiological disorders.

RESUMEN

El objetivo de esta revisión es informar sobre los avances en los aspectos ambientales, culturales y fisiológicos del rajado en los frutos carnosos más importantes para disminuir o evitar este desorden el cual afecta numerosas especies frutales. El rajado es una fisiopatía que limita la producción y la calidad de frutos carnosos porque afecta el exocarpio y el mesocarpio, especialmente en escenarios de cambio y variabilidad climática. El rajado del fruto es generado por factores externos (agronómicos y ambientales), e internos, varios de los cuales todavía son motivos de exhaustivo estudio. La incidencia del rajado varía ampliamente según las características climáticas durante el desarrollo del fruto, las diferentes especies frutales y variedades, además de los sitios de crecimiento y el manejo del cultivo. Esta fisiopatía se agrava por el aumento de la intensidad en las lluvias y especialmente cuando estas ocurren después de una época seca, igualmente en zonas donde ha aumentado la temperatura. El conocimiento de las causas del rajado ha permitido generar estrategias de manejo que involucran: mejoramiento genético y de condiciones ecofisiológicas, practicas agronómicas como podas, riego y fertilización (principalmente Ca, Mg, B y K), aplicación de fitorreguladores y uso de cubiertas plásticas, entre otros. En varios frutales estas estrategias son efectivas, pero en especies como la uchuva aún el problema del rajado permanece sin total explicación y manejo efectivo.

Palabras clave: nutrición mineral, clima, lluvias intensas, frutos carnosos, fruticultura, fisiopatías.

Introduction

Food security is strongly influenced by the threat of climate change (CC), not only through global warming but also by altered rain patterns, which generate more extreme weather events (IPCC, 2019). The effects on fruit trees will probably intensify for countries in the tropics and subtropics with higher initial temperatures, which will affect more marginal or degraded lands and underdeveloped regions with a low adaptation potential (Yohannes, 2016). Thus, global warming will affect small farmers more, who, for the most part, depend solely on rain (Sthapit *et al*., 2012). In addition, the Andean tropics will be greatly affected by CC, not only because it would increase precipitation by 20% to 25% but also because warming would increase more at altitude than in valleys (Marengo *et al*., 2011).

Zandalinas *et al*. (2021) highlighted that multifactorial stress, generated by CC, severely affects the growth and survival of crops, for which Dubey *et al*. (2021) pointed out that the intensity and frequency of abiotic stress are constantly increasing. Chmielewski *et al*. (2008) stated that adaptations of fruit plantations to CC require time and long-term research.

Received for publication: 4 July, 2020. Accepted for publication: 27 August, 2021. Doi: 10.15446/agron.colomb.v39n2.97071

[1] Departamento de Agronomía, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Bogota (Colombia).
[2] Grupo de Investigaciones Agrícolas (GIA), Facultad de Ciencias Agropecuarias, Universidad Pedagógica y Tecnológica de Colombia, Tunja (Colombia).
* Corresponding author: hebalagueral@unal.edu.co

One of the most important limitations for fruit growth is the presence of physiological disorders, especially fruit cracking (Fig. 1), which limits production and quality (Ramteke *et al*., 2017) both at harvest and post-harvest, mainly in berries and drupes. This disorder affects the appearance of fruits, increases water loss and susceptibility to infection by pathogens, and decreases storage and shelf-life, resulting in substantial commercial losses for growers (Ginzberg & Stern, 2016; Yu *et al*., 2020). The peel plays a crucial role in resistance to cracking, portability, storability, and quality during storage (shelf-life quality) (Wang *et al*., 2021).

Cracked fruits lose their commercial value for the fresh market and can only be sold locally or for the processing and transformation, as reported by Rojas Alfonso *et al*. (2012) for cape gooseberry producers in Cienaga (Boyaca, Colombia), where the exporting company returns at least 20% of the fruits because of cracking. Likewise, in times of heavy and prolonged rainfall, exporters can reject up to 50% of cape gooseberry fruits because of cracking (Fischer, 2005). Interestingly, cracked pomegranate fruits developed a higher oil content than intact fruits (Zaouay *et al*., 2020).

For the main causes of this physiological disorder, Yilmaz and Özgüven (2019) mentioned genetic factors, very ripe fruits, and fluctuating soil moisture, apart from nutritional deficiencies, sunburn, injuries, and pathogens on the skin of the fruits. Generally, fruit cracking occurs because of a physical failure of the cuticle or skin as the result of tensions (stresses) and heavy rains (Ramteke *et al*., 2017). Because of fruit cracking, water management and nutrition in crops have become a concern for many countries (Fischer & Orduz-Rodríguez, 2012).

In nature, fruit cracking manifests at the end of fruit development, that is, just after ripening and before seed dispersal (Lichter *et al*., 2002). It is a physiological disorder that affects the exocarp and the mesocarp (Yu *et al*., 2020) and can be distinguished from epidermis cracking, which is more superficial, including the cuticle and epidermal tissue. Deeper cracking can be characterized by an opening to the interior of the pulp, known as splitting (Opara *et al*., 1997; Fischer, 2005). In the cape gooseberry, Gordillo *et al*. (2004) found two types of cracking: superficial (cracking) and deep (splitting) (Fig. 1A). However, in most cases, cracking and splitting are used synonymously (Lopez-Zaplana *et al*., 2020).

In the case of cherries, microcracking results in deterioration of the barrier, involving only the cuticle, whereas macrocracking involves both the barrier and structure,

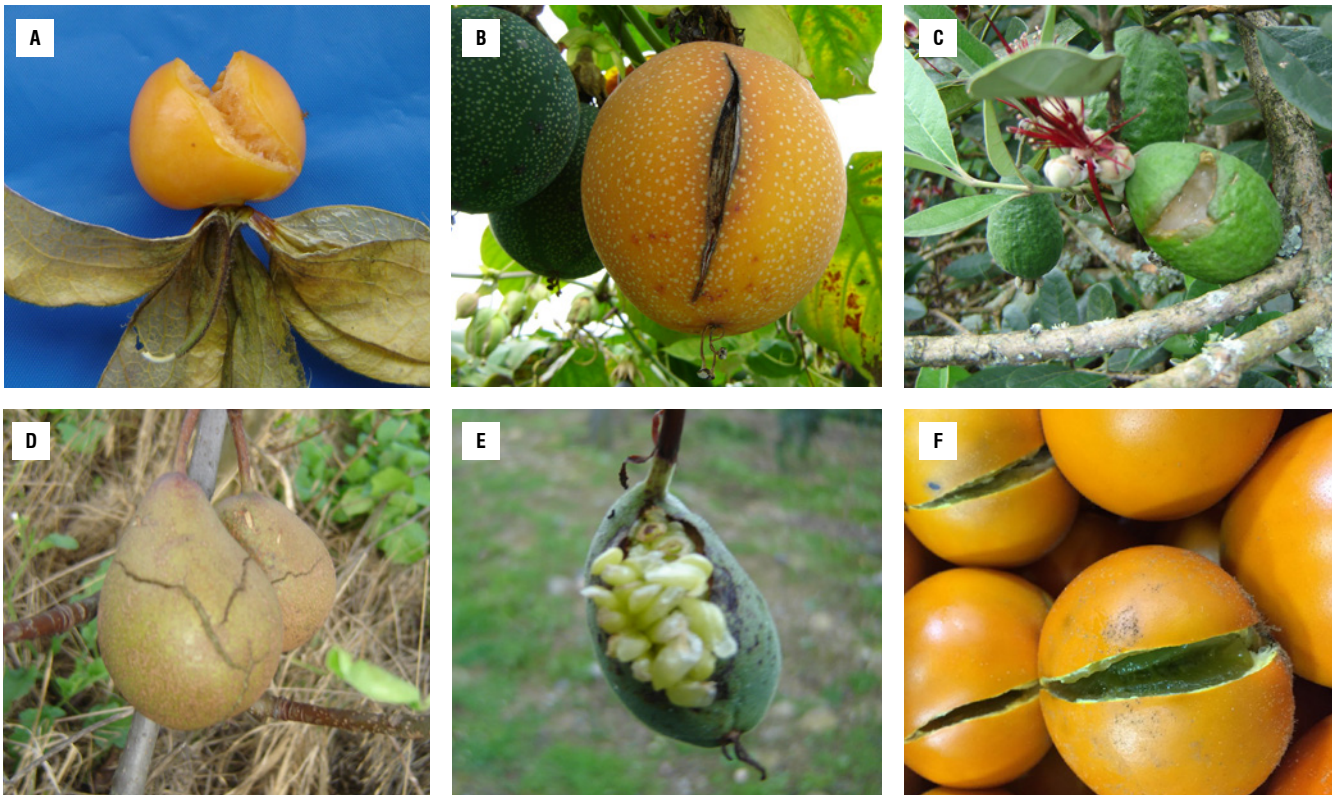

FIGURE 1. Fruit cracking in different fruit species. A) cape gooseberry; B) sweet granadilla; C) feijoa; D) pear; E) banana passion fruit; F) lulo.

deteriorating the cuticle and the internal cell layers (Knoche & Lang, 2017).

The objective of this literature review was to report on advances in environmental, cultural, and physiological aspects of fruit cracking, which are important for making management decisions, and plant breeding programs to reduce and avoid this disorder in many fruit crops, especially in the context of climate change and variability.

Factors causing fruit cracking

Figure 2 shows these factors for the cape gooseberry (*Physalis peruviana* L.), a fruit that shows high percentages of cracking and various causes. Fruit cracking is generated by external factors, including agronomic and environmental, and internal factors (Yu *et al*., 2020). It is a physiological disorder that involves the exocarp and mesocarp of the fruit and affects its appearance, intensifies the loss of water and predisposition to infection by pathogens, and decreases the postharvest shelf-life, generating considerable losses for fruit growers (Ginzberg & Stern, 2016; Ramteke *et al*., 2017). Wang *et al*. (2021) characterized fruit cracking as a common physiological disorder, in which the surface cracks because of uncoordinated internal growth and an external environment with high climatic variability.

The incidence of cracking varies widely according to the climatic characteristics during fruit development, the different fruit species and varieties, growth sites, and crop management (Fischer & Orduz-Rodríguez, 2012). As these authors report, fruit cracking can occur occasionally in any season, garden plant, branch, or cultivar.

Environmental factors

Water

Cracking because of rain, especially in fleshy fruit, (Fig. 1) imposes a severe problem in production and is related to huge commercial losses worldwide (Grimm *et al*., 2019). This situation greatly affects the cultivation of fruit trees in the Andes, where rainfall will increase as a result of climate change (Marengo *et al*., 2011).

High amounts of rain for several days or short heavy rains after a dry season can cause fruit cracking, such as in the cape gooseberry (Fischer & Melgarejo, 2020; Fischer *et al*., 2021). There is a disproportion between the amount of water that enters a fruit in a given time and the extensibility of its epidermis (Fischer & Orduz-Rodríguez, 2012). However, this turgor model (the critical turgor hypothesis), initially developed for grapes (*Vitis vinifera* L.) by Considine and Kriedemann (1972), was questioned by Winkler *et al*. (2016) in sweet cherries (*Prunus avium* L.) because its results indicated that rain cracking is a localized phenomenon, a local exposure of a fruit's skin to water that is not related to the net water balance. According to Grimm *et al*. (2019), rain and fruit cracking have a causal relationship, and cracking is related to a change in the water relations of fruits, associated with the humidity of its surface. Also, abundant rains can cause very watery fruits, as in guava (*Psidium guajava* L.), with a reduced content of sugars, ascorbic acid, and titratable acidity, making them more susceptible to cracking (Fischer & Melgarejo, 2021).

The water balance of fruits is associated with several factors that can generate cracks (Saei *et al*., 2014), where the

FIGURE 2. Diagram of possible factors of cracking in the cape gooseberry fruit.

water potential is the force that produces cracking, while the cell wall and other structures must withstand this pressure (Lichter *et al*., 2002). Thus, the biomechanical characteristics of the epidermis are crucial in maintaining internal pressure and resistance to fruit cracking (Saei *et al*., 2014). In the case of cherries, Knoche (2015) pointed out that an important cause of cracking is the rapid absorption of water by a fruit, which can be generated by direct absorption of the skin of the fruit or absorption by the vascular system of the plant.

In berries, such as the tomato and cape gooseberry, the high-water content and the high concentration of solutes exert high pressure on the epidermis of fruits, which cannot resist and cracks (Peet, 2009; Fischer & Melgarejo, 2020). This situation is accentuated if there are few fruits on the plant, such as the first fruits when the cape gooseberry production cycle begins (Gordillo *et al*., 2004). In postharvest, this problem is also accentuated when cape gooseberry fruits are subjected to immersion treatments in water, which limits the use of technologies such as pre-cooling with water and disinfection with products in liquid form.

In the case of high-water availability in the soil, cracking is very frequent in combination with two other factors, high relative humidity (RH) and low air temperature, conditions that reduce the transpiration of fruits (Fischer, 2005). For the pomegranate, Ikram *et al*. (2020) mentioned environmental factors, such as the imbalance of soil and air humidity, that contribute to intense cracking, that is, factors that have a high influence on fruit growth and development.

Relative humidity and temperature

In several studies in apple, Opara *et al*. (1997) reported greater cracking as the result of a lower formation potential or change in the composition of the cuticle, losing protective capacity, and a high RH that decreases the loss of water through the fruit. Deep splitting occurred when there was noticeable and depressed transpiration for 6 hours or more (Opara *et al*., 1997). On the other hand, Fischer (2005) reported a propitious effect of fruit cracking from low night temperatures in combination with a high RH.

A high RH prevents transpiration, which generates a high pressure inside the fruit, so that the epidermis can crack (Fischer & Orduz-Rodríguez, 2012), especially during prolonged periods of a RH between 99% and 100%, alone or in combination with rain (Fischer, 2005).

In tropical species such as passion fruit (*Passiflora ligularis* Juss, Fig. 1B), temperatures below 12-15°C are conducive not only to floral abortion and lower fertilization but also to fruit cracking (Fischer & Miranda, 2021). In addition, this species cracks more when sudden changes occur between day and night temperatures (Miranda Lasprilla, 2020). Cape gooseberries are susceptible to cracking from high amounts of water (Figs. 1A and 2) when the fruit grows completely inside the closed calyx, which dampens extreme temperatures by up to 5°C, especially with variations in day and night temperatures (Fischer *et al*., 2021).

In the cherry, apple, and peach, Bohlmann (1962) observed a tendency to crack when the temperature of the water on the epidermis increased. Reddy *et al*. (2017) also pointed out that physiological disorders are accentuated by global warming, such as the cracking of lychee fruits. Likewise, in hotter and more humid weather that follows a cold and dry period, there is danger of cracking, especially when young fruits begin to fill (Opara *et al*., 1997).

For the pomegranate, an excessive increase in temperature, hot dry winds, a downpour after a dry season, and large differences between day-night temperatures with temperatures greater than 38°C combined with a RH of 60%, favor fruit cracking in this species (Ikram *et al*., 2020).

Light

Regarding light, the side of the fruit exposed to direct sun can crack more because the epidermal cells on this exposed side become comparatively thicker and inelastic and do not adapt to the rapid increase of the tissues below (Opara *et al*., 1997). Ikram *et al.* (2020) reported that direct sun increases the temperature and evapotranspiration of the fruit surface, which results in a high moisture loss and a greater susceptibility to cracking.

Opara *et al*. (1997) pointed out that, in some apple varieties, cracking occurs preferably on the shady side of the apples, *i.e.,* the phenomenon is exclusively varietal. Fischer (2000) observed greater crack at 2,700 m a.s.l. in the department of Cundinamarca (Colombia) in 'Jonagold' apples exposed directly to the sun and affected by *Venturia inaequalis*.

Ulinnuha *et al*. (2020) found a lower incidence of cracking in tomatoes under shade and proposed further investigation of this phenomenon with associated crops that produce shade. Suzuki *et al*. (2007) harvested more fruits without cracking in this species when the foliage and fruits intercepted a lower amount of light than with other types of conduction (training).

Cultural factors

Mineral nutrition

The mineral nutrition of fruit is highly related to cracking (Yu *et al*., 2020). Ca deficiency has been reported as one of the main causes of cracking, such as in mandarin (Chabbal *et al*., 2020), lemon (Devi *et al*., 2018), grape (Yu *et al*., 2020), fig (Aydin & Kaptan, 2015), sweet cherry (Erogul, 2014), sour cherry (Simon *et al*., 2007), apricot (Nie *et al*., 2017), pomegranate (Davarpanah *et al*., 2018), litchi (Martínez Bolaños *et al*., 2017), loquat (Yilmaz, 2020), sweet granadilla (Fischer & Miranda, 2021; Fig. 1B), and cape gooseberry (Cooman *et al*., 2005; Fig. 1A).

As a macroelement and the most important element for fruit quality (Marschner, 2012), Ca is essential for multiple important functions in plant physiology, mainly because of its role in the structural integrity and stability of cell walls and the middle lamella, not only serving as a bridge between pectin molecules but also improving the integrity of cell membranes through the bonds with phospholipids. Additionally, it participates in stress signaling as a secondary messenger (Ranty *et al*., 2016; Yu *et al*., 2020).

Gordillo *et al*. (2004) observed that a deficient dose of potassium (K), as well as a lack of boron (B) in fertilization, induced greater cracking in cape gooseberry fruits. Cooman *et al*. (2005) also found an increase between 5.5% and 13.0% in the number of cracked fruits in this species when Ca or B was lacking in fertilization (Fig. 2). Fischer *et al*. (2020) reported cracking in banana passion fruit, known in the high tropics of Colombia as "the witch's laugh" (*risa de bruja* in Spanish) (Fig. 1E) because of the visibility of all seeds, attributed to Ca and/or B deficiency. Marschner (2012) underlined the role of B in the structure of cell walls.

On the other hand, Garzón-Acosta *et al*. (2014) recorded the highest cracking in mature and harvested cape gooseberry fruits in a greenhouse in plants that suffered from a magnesium (Mg) deficiency (Fig. 2), compared to plants deficient in Ca (11% and 1% cracked fruits, respectively). Problems with fruit cracking in feijoa (*Acca sellowiana;* Fig. 1C) have also been reported in Colombia with a Ca/Mg ratio ≥10 in the soil, where fruits crack and develop brown pigmentation (Fischer *et al*., 2021). Marschner (2012) stated that part of Mg is firmly bound to pectin in cell walls; therefore, deficiency of this element would contribute to cracking.

On the contrary, high concentrations of N in the soil from chemical or organic overfertilization, especially when the content of organic matter (OM) in the soil exceeded 20%, increased cracking in the cape gooseberry (Fig. 2) (Gordillo *et al*., 2004). Fischer and Orduz-Rodríguez (2012) suggested that the increase in the epidermis is not enough to keep up with the expansion of the fruit. Similarly, Yilmaz (2020) found an overconcentration of N in cracked loquat fruits.

Phytosanitary problems

Superficially or deeply cracked fruits not only exhibit open lesions that facilitate a loss of moisture and wrinkling but also are susceptible to infection by pathogens (Opara *et al*., 1997), which Fischer (2005) described in cracked cape gooseberries affected by Botrytis.

In apples cultivated in the high tropics, the epidermis of the fruit can be burned and cracked by high insolation (sun burning), especially by high amounts of UV light, which facilitates infection by *Venturia inaequalis* (Fischer, 2000). Casierra-Posada (2012) pointed out that B deficiencies can weaken the epidermis of young apples and pears, facilitating infection by *V. inaequalis* and *V. pyrina*, respectively, that later show lesions similar to cracking.

Ikram *et al.* (2020) and Singh *et al.* (2020) reported that attacks by insects, pathogens, and birds especially affect ripe, cracked fruits, which greatly reduces their commercial quality.

Another cause of cracking or aggravation in existing lesions may be the application of agrochemicals, especially mixtures with surfactants since they increase the penetration of water through the cuticle of the fruit (Opara *et al*., 1997).

Fruit factors

The relationships between fruit characteristics and susceptibility to cracking have also been evidenced (Fig. 2). Khadivi-Khub (2015) have reported a series of correlations between cracking and different aspects of the fruit, such as size, shape, and firmness, and the epidermis (resistance, stomata, and cuticular properties), in addition to the osmotic concentration, water capacity of the pulp, and the state of development of the fruit.

In the 'Terigas' mandarin, Hardiyanto and Nirmala (2019) found that fruit cracking increased with decreases in the thickness of the epidermis and, surprisingly, thinning of the peel of the mandarins was not influenced by nutrients (K, Ca, Mg).

In most species, the fruit suffers constant stress during development, because the volume is constantly increasing and, therefore, the surface of the fruit increases as well

(Knoche & Lang, 2017). These authors characterized the skin of fruits as a primary structure, consisting of a polymeric cuticle whose function is similar to that of a barrier that covers the epidermis and hypodermis, cell layers that are responsible for the skin's load-bearing functions.

Mishra *et al*. (2016) in pomegranate (*Punica granatum* L.) and Fischer (2005) in cape gooseberry reported that a prolonged drought hardens the skin (epidermis) prematurely, and the next heavy rain causes the pulp to expand. The same occurs during phases of rapid fruit growth, in which the skin cracks, especially in late harvests of mature fruits (Fig. 2) (Mishra *et al*., 2016). The parts of the fruit that are most susceptible to cracking are its weak parts, as is the case with lenticels (Fischer, 2005).

In the pomegranate, during water stress, the growth of the peel is limited, as in the aril; however, when the water enters the fruit again, the aril expands more than the peel, which results in fruit cracking (Ikram *et al*., 2020). This desynchronization when the pulp turgor exceeds a critical threshold causes the fruit skin to stretch beyond its extensibility limit and crack (Considine & Kriedemann, 1972).

In most studies, an increase in the incidence of cracking was found as fruit maturation advanced (Fig. 2). Jiang *et al*. (2019) and Wang *et al*. (2021) stated that, when the fruit is in an advanced state of maturity and a downpour occurs, the risk of cracking is much higher. In addition, fruits in a state of overmaturity are more susceptible to cracking because of the senescence of the epidermis (Fischer & Orduz-Rodríguez, 2012).

Gordillo *et al*. (2004) found in the cape gooseberry that this physiological disorder occurs especially in fruits with a large volume and weight and at the beginning of the harvest season (Figs. 1A and 2), considering that this species has indeterminate growth (Fischer *et al*., 2021), in which vegetative and reproductive development occur at the same time. This situation was described by Torres Azuero *et al*. (2016) as an imbalance between the source-demand relationship because of an excess of assimilates in the first stage of the harvest, which supposedly generates pressure from assimilates, propitiating an average of 15% of cracked fruits in the cultivation of the cape gooseberry in the Cundiboyacense highlands. Also, Alvarez-Herrera *et al*. (2012) found the highest cracking (81%) in large cape gooseberry fruits (Fig. 2) but only 33% in small fruits in the same greenhouse study; the highest percentage of cracked fruits was observed in the upper stratum (38%) (Fig. 2), as compared to only 25% in the lower stratum of the plant.

In different citrus cultivars, most of the cracking occurs during cell elongation or in the period of fruit maturation. However, in some cultivars, cracking can occur throughout the development of the fruit (Li & Chen, 2017).

In tomato studies, Jiang *et al*. (2019) concluded that ripe fruit is more resistant to cracking as it contains more intact pectins as a result of a good degree of binding between the pectins by Ca^{2+} and other cross-linkages. Additionally, the correlation analysis by these authors verified that tomato cracking is significantly more related to the level of protopectin and cellulose than to that of Ca^{2+}.

On the other hand, a transcriptome analysis of atemoya (*Annona cherimola* × *A. squamosa*) by Chen *et al*. (2019) found that the decomposition of starch into soluble sugars and the metabolism of polysaccharides of the cell wall are closely related to fruit cracking. The hydrolytic enzyme of the cell wall, polygalacturonase (PG), breaks the α-(1-4)-galacturonan bond in the pectin chain, so an increase in PG activity generates fruit softening (Lu & Lin, 2011). On the other hand, research on the non-enzymatic protein expansin (EXP), which is involved in the extension of cell walls, is essential for knowledge on causes of cracking (Balbontín *et al*., 2013) since varieties that are more resistant to cherry and lychee splitting have a level of EXP expression that was noticeably higher than in those most susceptible to this physiological disorder (Balbontín *et al*., 2014).

Brüggenwirth and Knoche (2017) and Jiang *et al*. (2019) noted that factors such as disassembly, modification, and composition of the cell wall can affect the mechanical characteristics of the pericarp; therefore, they become determining elements of susceptibility to fruit cracking.

Varietal and genetic factors

As described above, the causes of cracking can be diverse, and the reasons vary between different species (Lu & Lin, 2011) and, in many cases, also between varieties of the same species (Opara *et al*., 1997). Khadivi-Khub (2015) pointed out that fruit cracking is a quantitative trait that is controlled by several genes. Additionally, this author indicated that the cultivars most resistant to this problem and that show adequate fruit quality can be chosen for subsequent cultivation. Therefore, cultivars that exert greater skin break force and elasticity are more resistant to fruit cracking (Brüggenwirth & Knoche, 2016).

When evaluating 54 cape gooseberry materials from northeastern Colombia, Herrera *et al*. (2011) found large differences in the occurrence of cracking, which was higher

in feral cultivars with an average of 23.9%. However, within this group, there was an accession (06Uch0001) without broken fruits, as compared to accession 06Uch0073 with 50% cracked fruits. This result confirmed that cracking depends to a high degree on the genetics of the material (Fischer, 2005), as in other nightshade berries, such as the tomato (Peet, 2009). Criollo *et al.* (2014) compared cracking in three genotypes of cape gooseberry and found that the highest percentages of this disorder occurred in the materials 'Silvania' and 'Kenya' (8.9% and 8.1%, respectively), compared to 'Regional Nariño' with only 3.1%. These results confirmed that, under the same climatic conditions, fruits of different cultivars of the same species show differences in susceptibility to cracking (Khadivi-Khub, 2015). On the other hand, Lagos-Burbano *et al.* (2021) characterized the fruit of 36 hybrids obtained from double haploid lines, with cracking being one of the three parameters that explained the total variability through principal component analysis. They also reported that two of the six clusters registered a high seed content, a low maturity index, and a high percentage of cracking.

Berries are particularly susceptible to splitting (Fischer *et al.*, 2021). However, Medina *et al.* (2009) reported that improved material from 'Lulo de la Selva' was used to find materials more resistant to cracking in the cultivation of lulo (*Solanum quitoense* Lam.) (Fig. 1F), and, after a generation of open pollination, the Jalisco clone showed reduced cracking and large fruits. Fischer and Melgarejo (2020) pointed out that plant breeding programs should also include resistance to cracking, and not only the production of large fruits, because size is highly correlated with the number of seeds (Trevisani *et al.*, 2017; Balaguera-López *et al.*, 2020). This should always be considered in these programs because cracking is an attribute whose gene expression may also depend on environmental conditions.

It is worth mentioning that the development of high-quality varieties resistant to cracking and the identification of genes involved in this resistance should be an important objective in plant breeding programs in fruit trees (Balbontín *et al.*, 2013).

Examples for cracking handling

The best way to reduce fruit cracking today would be proper orchard management that tries to minimize water stress and considers nutrition and physiological factors that contribute to fruit cracking (Khadivi-Khub, 2015).

Table 1 shows examples of Ca applications in cultivation, alone or in combination with B or K, which resulted in a decrease in the incidence of cracking in grapes, citrus, and

TABLE 1. Examples of crop management to reduce the incidence of fruit cracking.

Management type	Species	Effect	Authors
Fertilization			
Cluster immersion with 5 g L^{-1} $CaCl_2$	Grape 'Xiangfei'	Ca inhibited the production of water-soluble proteins, delaying the degradation of protopectin in the cell wall	Yu *et al.* (2020)
Foliar applications of 1% $CaCl_2$, boric acid or a combination	Mandarin 'Shogun'	Significant reduction in the number of cracked fruits	Sdoodee and Chiarawipa (2005)
Application of K_2SO_4 (10%) and $CaCl_2$ (1%)	Lemon 'Eureka'	Reduction of cracking and improvement of fruit quality	Devi *et al.* (2018)
Application of Ca (0, 50, or 100 kg ha^{-1})	Cape gooseberry 'Colombia'	Cracking of 38% in fruits without Ca, decreased cracking to 27% when 100 kg ha^{-1} of Ca was applied	Alvarez-Herrera *et al.* (2012)
Application of B (0, 1, or 3 mg L^{-1}), K (3, 5, or 7 meq L^{-1})	Cape gooseberry 'Colombia'	The two levels of B decreased the number of cracked fruits, as did the application of 3.5 meq L^{-1} of K	Sabino-López *et al.* (2018)
Irrigation			
Irrigation levels with net coefficients of 0.7, 0.9, 1.1, and 1.3 evaporation from tank class A	Cape gooseberry 'Colombia'	The 1.3 and 1.1 irrigation levels produced the fruits with the lowest percentage of cracking	Álvarez-Herrera *et al.* (2021)
Plant hormones			
Application of 50 mg L^{-1} naphthaleneacetic acid (NAA)	Lemon 'Pant Lemon-1'	Lower number of cracked fruits	Bhatt *et al.* (2016)
Double application of 40 mg L^{-1} NAA	Lemon 'Eureka'	More effective treatment in minimizing cracking	Devi *et al.* (2018)
Application of 0, 5, 10, or 15 mg L^{-1} GA_3	Cape gooseberry 'Colombia'	Plants with 10 mg L^{-1} of GA_3 resulted in the lowest cracking percentage, and the highest was with 5 mg L^{-1}	Amézquita *et al.* (2008)
Covers			
Plastic film cover (Oroplus®), 5 m above the plants	Cherry 'Lapins'	The plastic cover reduced cracking from 20% to 2% in both seasons, without affecting fruit yield	Mika *et al.* (2019)

cape gooseberries. Cronjé *et al.* (2013) suggested an interaction of Ca with B, forming a stabilizing complex in the middle lamella of cells. For these effects, Yu *et al.* (2020) carried out applications of Ca during the maturation phase to prevent a localized deficiency of this element since it is necessary for fruit quality. Also, in the cape gooseberry, B or K alone (Tab. 1) reduced the percentage of fruit cracking (Sabino-López *et al.*, 2018). In the pomegranate fruits highly susceptible to cracking with losses of up to 40-60% (Ikram *et al.*, 2020), 0.2% B reduced the presence of this physiological disorder (Sharma & Belsare, 2011).

Applications of naphthaleneacetic acid have shown good results for controlling cracking in lemons (Tab. 1), which Devi *et al.* (2018) attributed to the significant role of this plant hormone in increasing resistance and plasticity of the peel, which determine the intensity of cracking. Furthermore, Amiri *et al.* (2012) specified that synthetic auxins decrease cracking in citrus fruits because of the increased thickness of the rind. In the pomegranate, an application of 5 mg L^{-1} of forchlorfenuron (CPPU), a cytokinin, significantly reduced cracking (Sahu & Sharma, 2019), as did applications with paclobutrazol (an anti-gibberellic compound) (Khalil & Aly, 2013). The results of the application of gibberellins in cultivation are not consistent (Amézquita *et al.*, 2008), possibly because this regulator can increase the size of fruits. However, Amézquita *et al.* (2008) found that applications of 10 mg L^{-1} of GA_3 generated the lowest percentage of cracking of cape gooseberry fruits (Tab. 1; Fig. 2).

Besides proper management with nutrition, irrigation, and growth regulators, Ikram *et al.* (2020) reported other practices to reduce cracking for the pomegranate, such as protecting the fruits from direct solar radiation by bagging or putting a shade net, as well as the application of antitranspirants based on kaolin.

Additionally, in different crops, specific management methods should be sought, such as the elimination of the first flowers at the beginning of the productive cycle in the cape gooseberry (Fischer & Miranda, 2012). Also, in the cape gooseberry 'Silvania', cracking was reduced by pruning (training) with an increase in primary branches, from three to four (Criollo *et al.*, 2014). By increasing the number of branches, the plants had a greater transpiratory volume, an increase in cell mass, and a better water distribution (Marsal *et al.*, 2006). Criollo *et al.* (2014) assumed that they reduced the risk of breaking the fruit surface because of a decrease in pressure exerted on the cell walls at the pericarp level.

Conclusions

Fruit cracking is a physiological disorder that seriously affects the quality and marketability of many fruit species.

Because of climate change, this physiological disorder is aggravated in areas where the intensity of rains is higher, but also in regions where there is an increase in temperatures and solar radiation and in the dry seasons that will be followed by rains, which is the main cause of this disorder. In general, fruit cracking is due to the stated climatic conditions, but also due to prolonged rains in combination with a high RH that suppress the transpiration of fruits.

High temperatures and/or sunburn age the epidermis of fruits, which cannot withstand the pressure when the fruit fills up with more turgor again. Likewise, sudden changes between daytime and nighttime temperatures or hot seasons after cold ones promote cracking in several species.

The deficiency of nutrients that are important for the stability of the cell wall, such as Ca, B, and Mg, is another important cause of this physiological disorder. Additionally, the lack of K that regulates the water rate in plants, influences cracking. Likewise, excess N can increase the pressure of the pulp on the epidermis of the fruit, causing it to crack.

Measures are proposed to control this disorder, such as the selection of more resistant varieties, adequate nutrition to strengthen the resistance of the cell wall, the avoidance of water stress in plantations, and the application of growth regulators such as NAA or GA_3, depending on the species. Additionally, plastic covers should be placed on species, such as cherries, that easily crack as a result of water absorption on the skin of the fruit. Specific tasks are important according to the species, such as eliminating the first flowers or increasing the number of primary branches in the cape gooseberry to reduce the pressure of water and solutes on a small number of fruits when the plant is in full growth and just beginning production.

Finally, since many fruit species lack successful research on fruit cracking, this literature review provides initiatives to lessen this problem with proper crop management and breeding programs for the affected species and varieties that consider the aforementioned traits.

Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Author's contribution

GF wrote the initial draft and carried out the final revision of the manuscript. HEB wrote, carried out the revision of the manuscript and translated the initial draft. JAH carried out the revision and complemented the manuscript.

Literature cited

Alvarez-Herrera, J., Balaguera-López, H., & Fischer, 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*, 163–170. https://doi.org/10.17660/ActaHortic.2012.928.19

Álvarez-Herrera, J., Fischer, G., & Vélez, J. E. (2021). Análisis de la producción de uchuva (*Physalis peruviana* L.) durante el ciclo de cosechas en invernadero con diferentes láminas de riego. *Revista de la Academia Colombiana de Ciencias Exactas Físicas y Naturales, 45*(174), 109–121. https://doi.org/10.18257/raccefyn.1239

Amézquita, N., Balaguera-López, H. E., & Álvarez-Herrera, J. G. (2008). Efecto de la aplicación precosecha de giberelinas y calcio en la producción, calidad y rajado del fruto de uchuva (*Physalis peruviana* L.). *Revista Colombiana de Ciencias Hortícolas*, *2*(2), 133–144. https://doi.org/10.17584/rcch.2008v2i2.1182

Amiri, N. A., Kangarshahi, A. A., & Arzani, K. (2012). Reducing of citrus losses by spraying of synthetic auxins. *International Journal of Agriculture and Crop Sciences*, *4*(22), 1720–1724.

Aydin, M., & Kaptan, M. A. (2015). Effect of nutritional status on fruit cracking of fig (*Ficus carica* L. cv. Sarilop) grown in high level boron contained soils. *Scientific Papers. Series A. Agronomy*, *58,* 20–25.

Balaguera-López, H. E., Fischer, G., & Magnitskiy, S. (2020). Seed-fruit relationships in fleshy fruits: role of hormones. A review. *Revista Colombiana de Ciencias Hortícolas*, *14*(1), 90–103. https://doi.org/10.17584/rcch.2020v14i1.10921

Balbontín, C., Ayala, H., Bastías, R. M., Tapia, G., Ellena, M., Torres, C., Yuri, J. A., Quero-García, J., Ríos, J. C., & Silva, H. (2013). Cracking in sweet cherries: a comprehensive review from a physiological, molecular, and genomic perspective. *Chilean Journal of Agricultural Research*, *73*(1), 66–72.

Balbontín, C., Ayala, H., Rubilar, J., Cote, J., & Figueroa, C. R. (2014). Transcriptional analysis of cell wall and cuticle related genes during fruit development of two sweet cherry cultivars with contrasting levels of cracking tolerance. *Chilean Journal of Agricultural Research*, *74*(2), 162–169. https://doi.org/10.4067/S0718-58392014000200006

Bhatt, B. B., Rawat, S. S., Naithani, D. C., Kumar, D., & Singh, K. K. (2016). Effect of foliar application of bio-regulators and nutrients on growth and yield characters of lemon (*Citrus limon* Burma.) cv. Pant Lemon-1 under subtropical condition of Garhwal region. *Plant Archives*, *16*(2), 821–825.

Bohlmann, T. E. (1962). Why does fruit crack? *Farming in South Africa, 38*, 12–13.

Brüggenwirth, M., & Knoche, M. (2016). Mechanical properties of skins of sweet cherry fruit of differing susceptibilities to cracking. *Journal of the American Society for Horticultural Science*, *141*(2), 162–168. https://doi.org/10.21273/JASHS.141.2.162

Brüggenwirth, M., & Knoche, M. (2017). Cell wall swelling, fracture mode, and the mechanical properties of cherry fruit skins are closely related. *Planta*, *245*, 765–777. https://doi.org/10.1007/s00425-016-2639-7

Casierra-Posada, F. (2012). Manzano y peral (*Malus domestica* Borkh. y *Pyrus communis* L.). In G. Fischer (Ed.), *Manual para el cultivo de frutales en el trópico* (pp. 657–681). Produmedios.

Chabbal, M. D., Yfran-Elvira, M. M., Giménez, L. I., Martínez, G. C., Llarens-Beyer, L. A., & Rodríguez, V. A. (2020). Control del rajado de los frutos en plantas de mandarino Clementino. *Cultivos Tropicales*, *41*(4), Article e06.

Chen, J., Duan, Y., Hu, Y., Li, W., Sun, D., Hu, H., & Xie, J. (2019). Transcriptome analysis of atemoya pericarp elucidates the role of polysaccharide metabolism in fruit ripening and cracking after harvest. *BMC Plant Biology, 19*, Article 219. https://doi.org/10.1186/s12870-019-1756-4

Chmielewski, F. M., Blümel, K., Henniges, Y., & Müller, A. (2008). Vulnerability of fruit growers to climate change observed impacts and assessments. *Italian Journal of Agronomy*, *3*(3), 605–606.

Considine, J. A., & Kriedemann, P. E. (1972). Fruit splitting in grapes: determination of the critical turgor pressure. *Australian Journal of Agricultural Research*, *23*(1),17–24. https://doi.org/10.1071/AR9720017

Cooman, A., Torres, C., & Fischer, G. (2005). Determinación de las causas del rajado del fruto de uchuva (*Physalis peruviana* L.) bajo cubierta: II. Efecto de la oferta de calcio, boro y cobre. *Agronomía Colombiana*, *23*(1), 74–82.

Criollo, H., Lagos, T. C., Fischer, G., Mora, L., & Zamudio, L. (2014). Comportamiento de tres genotipos de uchuva (*Physalis peruviana* L.) bajo diferentes sistemas de poda. *Revista Colombiana de Ciencias Hortícolas*, *8*(1), 34–43. https://doi.org/10.17584/rcch.2014v8i1.2798

Cronjé, P. J. R., Stander, O. P. J., & Theron, K. I. (2013). Fruit splitting in citrus. *Horticultural Reviews*, *41*, 177–200.

Davarpanah, S., Tehranifar, A., Abadía, J., Val, J., Davarynejad, G., Aran, M., & Khorassani, R. (2018). Foliar calcium fertilization reduces fruit cracking in pomegranate (*Punica granatum* cv. Ardestani). *Scientia Horticulturae*, *230*, 86–91. https://doi.org/10.1016/j.scienta.2017.11.023

Devi, K., Kumar, R., Wali, V. K., Bakshi, P., Sharma, N., & 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), 704–708.

Dubey, S., Kuruwanshi, V. B., Bhagat, K. P., & Ghodke, P. H. (2021). Impact of excess moisture in onion genotypes (*Allium cepa* L.) under climate change scenario. *International Journal of Current Microbiology and Applied Sciences*, *10*(03), 166–175.

Erogul, D. (2014). Effect of preharvest calcium treatments on sweet cherry fruit quality. *Notulae Botanicae Horti Agrobotanici*, *42*(1), 150–153.

Fischer, G. (2000). Ecophysiological aspects of fruit growing in tropical highlands. *Acta Horticulturae*, *531*, 91–98. https://doi.org/10.17660/ActaHortic.2000.531.13

Fischer, G. (2005). El problema del rajado del fruto de uchuva y su posible control. In G. Fischer, D. Miranda, W. Piedrahita, & J.

Romero (Eds.), *Avances en cultivo, poscosecha y exportacion de la uchuva (Physalis peruviana L.) en Colombia* (pp. 55–82). Unibiblos, Universidad Nacional de Colombia.

Fischer, G., Balaguera-López, H. E., & Magnitskiy, S. (2021). Review on the ecophysiology of important Andean fruits: Solanaceae. *Revista U.D.C.A Actualidad & Divulgación Científica*, *24*(1), Article e1701. http://doi.org/10.31910/rudca.v24.n1.2021.1701

Fischer, G., & Melgarejo, L. M. (2020). The ecophysiology of cape gooseberry (*Physalis peruviana* L.), an Andean fruit crop. A review. *Revista Colombiana de Ciencias Hortícolas*, *14*(1), 76–89. https://doi.org/10.17584/rcch.2020v14i1.10893

Fischer, G., & Melgarejo, L. M. (2021). Ecophysiological aspects of guava (*Psidium guajava* L.). A review. *Revista Colombiana de Ciencias Hortícolas*, *15*(2), Article e12355. https://doi.org/10.17584/rcch.2021v15i2.12355

Fischer, G., & Miranda, D. (2012). Uchuva (*Physalis peruviana* L.). In G. Fischer (Ed.), *Manual para el cultivo de frutales en el trópico* (pp. 851–873). Produmedios.

Fischer, G., & Miranda, D. (2021). Review on the ecophysiology of important Andean fruits: *Passiflora* L. *Revista Facultad Nacional de Agronomía Medellín*, *74*(2), 9471–9481. https://doi.org/10.15446/rfnam.v74n2.91828

Fischer, G., & Orduz-Rodríguez, J. O. (2012). Ecofisiología en frutales. In G. Fischer (Ed.), *Manual para el cultivo de frutales en el trópico* (pp. 54–72). Produmedios.

Fischer, G., Quintero, O. C., Tellez, C. P., & Melgarejo, L. M. (2020). Curuba: *Passiflora tripartita* var. *mollissim*a y *Passiflora tarminiana*. In A. Rodríguez Carlosama, F. G. Faleiro, M. Parra Morera, & A. M. Costa (Eds.), *Pasifloras - especies cultivadas en el mundo* (pp. 105–121). ProImpress & Cepass.

Garzón-Acosta, C. P., Villarreal-Garzón, D. M., Fischer, G., Herrera, A. O., & Sanjuanelo, D. W. (2014). La deficiencia de fósforo, calcio y magnesio afecta la calidad poscosecha del fruto de uchuva (*Physalis peruviana* L.). *Acta Horticulturae*, *1016*, 83–88. https://doi.org/10.17660/ActaHortic.2014.1016.9

Ginzberg, I., & Stern, R. A. (2016). Strengthening fruit-skin resistance to growth strain by application of plant growth regulators. *Scientia Horticulturae*, *198*, 150–153. https://doi.org/10.1016/j.scienta.2015.11.016

Gordillo, O. P., Fischer, G., & Guerrero, R. (2004). Efecto del riego y de la fertilización sobre la incidencia del rajado en frutos de uchuva (*Physalis peruviana* L.) en la zona de Silvania (Cundinamarca). *Agronomía Colombiana*, *22*(1), 53–62.

Grimm, E., Hahn, J., Pflugfelder, D., Schmidt, M. J., van Dusschoten, D., & Knoche, M. (2019). Localized bursting of mesocarp cells triggers catastrophic fruit cracking. *Horticulture Research*, *6*, Article 79. https://doi.org/10.1038/s41438-019-0161-3

Hardiyanto, & Nirmala, F. D. (2019). Application of K, Ca and Mg on peel thickness and fruit cracking incidence of citrus. *Russian Journal of Agricultural and Socioeconomic Sciences*, *3*(87), 45–56. https://doi.org/10.18551/rjoas.2019-03.07

Herrera, A. M., Ortiz, J. D., Fischer, G., & Chacón, M. I. (2011). Behavior in yield and quality of 54 cape gooseberry (*Physalis peruviana* L.) accessions from north-eastern Colombia. *Agronomía Colombiana*, *29*(2), 189–196.

Ikram, S., Shafqat, W., Qureshi, M. A., Din, S. U., Rehman, S. U., Mehmood, A., Sajjad, Y., & Nafees, M. (2020). Causes and control of fruit cracking in pomegranate: a review. *Journal of Global Innovations in Agricultural and Social Sciences*, *8*(4), 183–190. https://doi.org/10.22194/JGIASS/8.920

IPCC. (2019). Summary for policymakers. In *Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Intergovernmental Panel on Climate Change.

Jiang, F., Lopez, A., Jeon, S., Freitas, S. T., Yu, Q., Wu, Z., Labavitch, J. M., Tian, S., Powell, A. L. T., & Mitcham, E. (2019). Disassembly of the fruit cell wall by the ripening-associated polygalacturonase and expansin influences tomato cracking. *Horticulture Research*, *6*, Article 17. https://doi.org/10.1038/s41438-018-0105-3

Khadivi-Khub, A. (2015). Physiological and genetic factors influencing fruit cracking. *Acta Physiologiae Plantarum*, *37*, Article 1718. https://doi.org/10.1007/s11738-014-1718-2

Khalil, H. A., & Aly, H. S. H. (2013). Cracking and fruit quality of pomegranate (*Punica granatum* L.) as affected by pre-harvest sprays of some growth regulators and mineral nutrients. *Journal of Horticultural Science and Ornamental Plants*, *5*(2), 71–76.

Knoche, M. (2015). Water uptake through the surface of fleshy soft fruit: barriers, mechanism, factors, and potential role in cracking. In Y. Kanayama, & A. Kochetov (Eds.), *Abiotic stress biology in horticultural plants* (pp. 147–166). Springer. https://doi.org/10.1007/978-4-431-55251-2_11

Knoche, M., & Lang, A. (2017). Ongoing growth challenges fruit skin integrity. *Critical Reviews in Plant Sciences*, *36*(3), 190–215. https://doi.org/10.1080/07352689.2017.1369333

Lagos-Burbano, T. C., Mejía-España, D. F., Arango-Bedoya, O., Villaquirán-Samboni, Z. Y., Lagos-Santander, L. K., & Duarte-Alvarado, D. E. (2021). Fruit characterization of 36 cape gooseberry hybrids for identification of potential industrial or fresh consumption uses. *Revista Colombiana de Ciencias Hortícolas*, *15*(2), Article e12526. https://doi.org/10.17584/rcch.2021v15i2.12526

Li, J., & Chen, J. (2017). Citrus fruit-cracking: causes and occurrence. *Horticultural Plant Journal*, *3*(6), 255–260. https://doi.org/10.1016/j.hpj.2017.08.002

Lichter, A., Dvir, O., Fallik, E., Cohen, S., Golan, R., Shemer, Z., & Sagi, M. (2002). Cracking of cherry tomatoes in solution. *Postharvest Biology and Technology*, *26*, 305–312.

Lopez-Zaplana, A., Bárzana, G., Agudelo, A., & Carvajal, M. (2020). Foliar mineral treatments for the reduction of melon (*Cucumis melo* L.) fruit cracking. *Agronomy*, *10*, Article 1815. https://doi.org/10.3390/agronomy10111815

Lu, P. L., & Lin, C. H. (2011). Physiology of fruit cracking in wax apple (*Syzygium samarangense*). *Botanica Orientalis: Journal of Plant Science*, *8*, 70–76. https://doi.org/10.3126/botor.v8i0.5954

Marengo, J. A., Pabón, J. D., Díaz, A., Rosas, G., Ávalos, G., Montealegre, E., Villacis, M., Solman, S., & Rojas, M. (2011). Climate change: evidence and future scenarios for the Andean region. In S. K. Herzog, R. Martinez, P. M. Jørgensen, & H. Tiessen (Eds.), *Climate change and biodiversity in the tropical Andes* (pp. 110–127). IAI, SCOPE.

Marsal, J., Lopez, G., Mata, M., & Girona, J. (2006). Branch removal and defruiting for the amelioration of water stress effects on fruit growth during stage III of peach fruit development. *Scientia Horticulturae*, *108*(1), 55–60. https://doi.org/10.1016/j.scienta.2006.01.008

Marschner, P. (Ed.). (2012). *Marschner's mineral nutrition of higher plants* (3rd ed.). Elsevier.

Martínez Bolaños, M., Martínez Bolaños, L., Guzmán Deheza, A., Gómez Jaimes, R., & Reyes Reyes, A. L. (2017). Calcio y ácido giberélico en el bretado de frutos de litchi (*Litchi chinensis* Soon.) cultivar Mauritius. *Revista Mexicana de Ciencias Agrícolas*, *8*(4), 837–848.

Medina, C. I., Lobo, M., & Martínez, E. (2009). Revisión del estado del conocimiento sobre la función productiva del lulo (*Solanum quitoense* Lam.) en Colombia. *Corpoica Ciencia y Tecnología Agropecuaria*, *10*(2), 167–179.

Mika, A., Buler, Z., Wójcik, K., Konopacka, D. (2019). Influence of the plastic cover on the protection of sweet cherry fruit against cracking, on the microclimate under cover and fruit quality. *Journal of Horticultural Research*, *27*(2), 31–38. https://doi.org/10.2478/johr-2019-0018

Miranda Lasprilla, D. (2020). Granadilla: *Passiflora ligularis* Juss. In A. Rodríguez Carlosama, F. G. Faleiro, M. Parra Morera, & A. M. Costa (Eds.), *Pasifloras - especies cultivadas en el mundo* (pp. 65–103). ProImpress & Cepass.

Mishra, D. S., Tripathi, A., & Nimbolkar, P. K. (2016). Review on physiological disorders of tropical and subtropical fruits: causes and management approach. *International Journal of Agriculture, Environment and Biotechnology*, *9*(6), 925–935. https://doi.org/10.5958/2230-732X.2016.00120.0

Nie, G., Kai, L. I., Tian, Y., Dai, G., Yang, X., Song, Y., Jingjiang, L. I., Zhang, X., & Lyu, J. (2017). Correlation of fruit cracking and mineral nutrient content in apricot. *Journal of Agriculture*, *7*(5), 23–27.

Opara, L. U., Studman, C. J., & Banks, N. H. (1997). Fruit skin splitting and cracking. *Horticultural Reviews*, *19*, 217–262.

Peet, M. M. (2009). Physiological disorders in tomato fruit development. *Acta Horticulturae*, *821*, 151–159. https://doi.org/10.17660/ActaHortic.2009.821.16

Ramteke, S. D., Urkude, V., Parhe, S. D., & Bhagwat, S. R. (2017). Berry cracking; its causes and remedies in grapes - a review. *Trends in Biosciences*, *10*(2), 549–556.

Ranty, B., Aldon, D., Cotelle, V., Galaud, J. P., Thuleau, P., & Mazars, C. (2016). Calcium sensors as key hubs in plant responses to biotic and abiotic stresses. *Frontiers in Plant Science*, *7*, Article 327. https://doi.org/10.3389/fpls.2016.00327

Reddy, A. G. K., Kumar, J. S., Maruthi, V., Venkatasubbaiah, K., & Rao, S. (2017). Fruit production under climate changing scenario in India: a review. *Environment & Ecology*, *35*(2B), 1010–1017.

Rojas Alfonso, D., Velandia Torres, S. R., & Castro Sánchez, A. M. (2012). Aprovechamiento del fruto rajado de uchuva (*Physalis peruviana* L.) en la elaboración de mermeladas. *Revista de Investigación, Desarrollo e Innovación*, *3*(1), 18–24.

Sabino-López, J. E., Sandoval-Villa, M., Alcántar-González, G., Ortiz-Solorio, C., Vargas-Hernández, M., & Colinas-León, T. (2018). Fecha de trasplante, boro, potasio y poda en la producción de frutos de *Physalis peruviana* L. en hidroponía e invernadero. *Agrociencia*, *52*, 255–265.

Saei, H., Sharifani, M. M., Dehghani, A., Seifi, E., & Akbarpour, V. (2014). Description of biomechanical forces and physiological parameters of fruit cracking in pomegranate. *Scientia Horticulturae*, *178*, 224–230. https://doi.org/10.1016/j.scienta.2014.09.005

Sahu, P., & Sharma, N. (2019). Fruit cracking and quality of pomegranate (*Punica granatum* L.) cv. Kandhari as influenced by CPPU and boron. *Journal of Pharmacognosy and Phytochemistry*, *8*(1), 2644–2648.

Sdoodee, S., & Chiarawipa, R. (2005). Fruit splitting occurrence of Shogun mandarin (*Citrus reticulata* Blanco cv. Shogun) in southern Thailand and alleviation by calcium and boron sprays. *Songklanakarin Journal of Science and Technology*, *27*(4), 719–730.

Sharma, N., & Belsare, C. (2011). Effect of plant bio-regulators and nutrients on fruit cracking and quality in pomegranate (*Punica granatum* L.) 'G-137' in Himachal Pradesh. *Acta Horticulturae*, *890*, 347–352. https://doi.org/10.17660/ActaHortic.2011.890.48

Simon, G., Tóth, M., & Papp, J. (2007). Cracking susceptibility of sour cherry (*Prunus cerasus* L.) in Hungary and relation to calcium application. *International Journal of Horticultural Science*, *13*(3), 109–118. https://doi.org/10.31421/IJHS/13/3/757

Singh, A., Shukla, A. K., & Meghwal, P. R. (2020): Fruit cracking in pomegranate: extent, cause, and management - a review. *International Journal of Fruit Science*, *20*(Sup 3), S1234–S1253. https://doi.org/10.1080/15538362.2020.1784074

Sthapit, B., Rao, V. R., & Sthapit, S. (Eds.). (2012). *Tropical fruit tree species and climate change*. Bioversity International.

Suzuki, T., Yanase, S., Enya, T., Shimazu, T., & Tanaka, I. (2007). Effects of total integrated solar radiation on radial fruit cracking in tomato cultivation under rain shelter in cool uplands. *Horticultural Research*, *6*(3), 405–409.

Torres Azuero, C., Fischer, G., & Miranda, D. (2016). Principales fisiopatías del cultivo de uchuva (*Physalis peruviana* L.). In D. Miranda, C. Carranza, & G. Fischer (Eds.), *Problemas de campo asociados al cultivo de uchuva* (*Physalis peruviana* L.) (pp. 139–146). Universidad Nacional de Colombia.

Trevisani, N., Melo, R. C., Colli, M. P., Coimbra, J. L. M., & Guidolin, A. F. (2017). Associations between traits in fisális: a tool for indirect selection of superior plants. *Revista Brasileira de Fruticultura*, *39*(4), Article e-106. https://doi.org/10.1590/0100-29452017106

Ulinnuha, Z., Chozin, M. A., & Santosa, E. (2020). The growth, fruit set and fruit cracking incidents of tomato under shade. *Journal of Tropical Crop Science*, *7*(2), 92–101.

Wang, Y., Guo, L., Zhao, X., Zhao, Y., Hao, Z., Luo, H., & Yuan, Z. (2021). Advances in mechanisms and omics pertaining to fruit cracking in horticultural plants. *Agronomy, 11*(6), Article 1045. https://doi.org/10.3390/agronomy11061045

Winkler, A., Peschel, S., Kohrs, K., & Knoche, M. (2016). Rain cracking in sweet cherries is not due to excess water uptake but to localized skin phenomena. *Journal of the American Society for Horticultural Science*, *141*(6), 653–660. https://doi.org/10.21273/JASHS03937-16

Yilmaz, C. (2020, December 6–9). *The effect of mineral content on fruit cracking of loquat* [Conference presentation]. Eurasia Summit Congress on scientific researches and recent trends. Baku Eurasian University, Azerbaijan.

Yılmaz, C., & Özgüven, A. I. (2019). Physiology of pre-harvest fruit cracking in pomegranate: mineral contents. *Acta Horticulturae*, *1254*, 205–211. https://doi.org/10.17660/ActaHortic.2019.1254.31

Yohannes, H. (2016). A review on relationship between climate change and agriculture. *Journal of Earth Science and Climatic Change*, *7*(2), Article 335. https://doi.org/10.4172/2157-7617.1000335

Yu, J., Zhu, M., Bai, M., Xu, Y., Fan, S., & Yang, G. (2020). Effect of calcium on relieving berry cracking in grape (*Vitis vinifera* L.) 'Xiangfei'. *PeerJ*, *8*, Article e9896. https://doi.org/10.7717/peerj.9896

Zandalinas, S. I., Fritschi, F. B., & Mittler, R. (2021). Global warming, climate change, and environmental pollution: recipe for a multifactorial stress combination disaster. *Trends in Plant Science*, *26*(6), 588–599. https://doi.org/10.1016/j.tplants.2021.02.011

Zaouay, F., Marwa Brahem, M., Boussaa, F., Haddada, F. M., Tounsi, M. S., & Mars, M. (2020). Effects of fruit cracking and maturity stage on quality attributes and fatty acid composition of pomegranate seed oils. *International Journal of Fruit Science*, *20*(sup3), S1959–S1968. https://doi.org/10.1080/15538362.2020.1839625