Reviews

Pre- and Postharvest Muskmelon Fruit Cracking: Causes and Potential Remedies

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SUMMARY. **Fruit cracking is an important disorder that can cause severe loss of marketable yield and revenue in the muskmelon (*Cucumis melo*) fruit industry. The physiological and environmental factors causing cracking are poorly understood. Although generally considered a physiological disorder caused by fluctuating environmental conditions, current evidence indicates that this disorder also has a genetic as well as a genotype × environment component. Certain cultivars are more susceptible than others, but wide fluctuations in irrigation, temperature, and nutrition during late fruit maturation stages appear to predispose fruit to cracking. This article summarizes the current state of our understanding of the causes of fruit splitting in muskmelons.**

Fruit cracking (also known as growth cracks or fruit splitting) is a major physiological disorder that can cause significant economic losses in a wide variety of fruit including tomato (*Solanum lycopersicon*), cherry (*Prunus avium*), apple (*Malus domestica*), atemoya (*Annona* ×*atemoya)*, peach and nectarines (*Prunus persica*), mango (*Mangifera indica*), pepper (*Capsicum* sp.), watermelon (*Citrullus lanatus*), muskmelon, citrus (*Citrus* sp.), and many other fruit (Matas et al., 2004; Opara, 1997; Paull, 1996; Peet, 1992; Savvas et al., 2008).

Fruit cracking is characterized by rupturing of the outer protective fruit tissues (rind), rendering the fruit nonmarketable (Matas et al., 2004). This disorder is usually associated with rapid absorption of large amounts of water, and the consequential development of abnormally higher turgor pressures than the rind can withstand, resulting in rind rupture. Even if fruit rupture does not ensue, excessive water intake can dilute solutes, reduce quality, and delay harvest maturity.

Although cracking has been documented commercially for many decades, the physiology of fruit cracking is still poorly understood. This is in part because of the difficulty in replicating the causal environmental conditions in any consistent fashion in controlled studies. This is supported by the fact that fruit cracking tends to be sporadic, being more prevalent in some years than others (Peet, 1992). However, transcriptomic events during the development of cracks between the pedicel and the fruit in melons during abscission have recently been characterized (Corbacho et al., 2013).

Certain environmental conditions such as irregular rainfall or irrigation, high temperatures, rapid fruit growth, high humidity, thin-skinned cultivars, and wide day–night temperature differences seem to precede fruit cracking (Peet, 1992). Among vegetables, fruit cracking has been investigated extensively in tomato (Matas et al., 2004; Moctezuma et al., 2003; Peet, 1992; Peet and Willits, 1995; Savvas et al., 2008). Matas et al. (2004) have reported correlations between cracking in cherry tomatoes and membrane integrity, and presented data indicating that cell membrane thickness can be a useful indicator of crack susceptibility among cherry tomato cultivars. Antisense suppression of a β-galactosidase gene (TBG6*)* in tomato has also been shown to increase fruit cracking and reduce fruit firmness during the early fruit development (Moctezuma et al., 2003). However, the problem in muskmelons has received little attention especially in the United States.

In the United States, preharvest cracking among netted melon (*C. melo* Reticulatus Group) and honeydew melon (*C. melo* Inodorus Group) fruit is not as widespread as with thin-rind melon types. This is in part because of their thicker rinds, which can be up to 1-cm thick (Lester, 1988). However, cracking is becoming more prevalent in the United States, especially with smooth-skinned specialty melon cultivars (Fig. 1A and B) that are sweeter (soluble solids of 11% to 15%) and seen as replacements for the netted cultivars that have frequently been linked to microbial (enteric bacteria) contamination.

Cracking is also prevalent among small-scale growers and home gardeners who typically harvest fruit at much later maturity stages; such vine-ripe fruit have been reported to be more susceptible to cracking than fruit harvested at breaker stage. Thin-rind specialty-melons of different types

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

such as Hami (*C. melo* Reticulatus Group), Charentais (*C. melo* Cantalupensis Group), Canary (*C. melo* Inodorus Group), snapmelons (*C. melo* Momordica Group), etc., or green melons with relatively smooth skin such as the Piel de Sapo [PS; (*C. melo* Inodorus Group)] commonly grown in Spain, India, and East Asian countries, regularly suffer this anomaly (Dhillon et al., 2007, 2009; Fernández-Trujillo et al., 2007; Gómez-Guillamón et al., 1997; Wu et al., 2008). As a result, considerable research effort has been deployed to better understand the causes and potential remedies for preharvest cracking of thinner-rind melon fruit.

Phipps (2012) noted that the main causes of melon splitting or cracking include: temperature extremes between day and night, extreme soil moisture levels during ripening, high concentrations of fruit sugars during ripening, close plant spacing, and high or low fertility rates since these factors regulate fruit texture and other quality attributes (Arpaia, 1994; Lester et al., 2010; Sams, 1999).

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Symptoms of melon cracking and splitting

Cracking is a general term that has been applied to certain physical disorders in fruit that are expressed as fractures in the cuticle or skin (Opara, 1997). Splitting is an extreme form of cracking in which the cracks penetrate deep into the flesh (Opara, 1997). Melon fruit cracking or splitting around the distal (blossom-end) or at the peduncle (stem-end) has been visually documented in historical paintings (Janick and Paris, 2006), where fruit cracking at blossom- and stem-ends is apparently associated with postclimacteric senescence, as a seed dispersal mechanism (Corbacho et al., 2013; Fernández-Trujillo et al., 2008; Martínez et al., 2009; Vrebalov et al., 2009). Usually moderate to severe symptoms of blossom-end breakdown (Fig. 2) are associated with internal cladosporium rot (*Cladosporium herbarum*) after cutting melons longitudinally.

Fruit splitting or cracking in maturing or recently harvested fruit can happen immediately after cutting the stem from the fruit, particularly if the cut is exceptionally close to the fruit and/or the crop has been irrigated within days of harvest, or has experienced a soil-saturating rainfall 48–72 h before harvest (Lester et al., 1994; Llanos, 1998; Pomares et al., 1995). Observations of "explosive" fruit cracking during harvest, in-field transportation (Fig. 1C), or at the packing house (Fig. 1D) have been reported. This "explosive" cracking behavior is more common in some cultivars and melon types; for example, some PS-type cultivars with about 0.7-mm-rind thickness (Fig. 1E). Splitting is typified by a straight longitudinal crack from the stem-end to the blossom-end (Fig. 1F). In melon cultivars with high ethylene production rates, such as the Charentais-type cultivar Vedrantais (Flores et al., 2001), cracking can occur around the stem-end because of the abrupt transitions in physiology between the nonclimacteric stem and onset of the climacteric peak in fruit ready to harvest (Fig. 1G and H). This stem-end splitting can occur within as little as 2 h after the peak in ethylene, and is also found in senescent, overripe fruit in the field in 'Vedrantais' and snapmelon accession PI 124112 (Fig. 1G–I). This phenomenon is associated with seed dissemination and has also been observed in other species such as *Ecballium elaterium* (Fernández-Trujillo, 2011).

In some melon cultivars (e.g., snapmelons), fruit maturity or harvest readiness is indicated by incipient rind splitting or abscission (Figs. 1J and 3A) (Dhillon et al., 2007, 2009; Stepansky et al., 1999). In other cultivars, nonsenescent cracking symptoms may include longitudinal fruit cracking (Fig. 1E, F, and J), random cracking close to the peduncle or blossom-end area that is associated with ripening (Fig. 1K and L), or cracking of the lenticular (netting) tissue in fruit that have not attained harvest maturity (Fig. 3B–E).

Factors affecting melon splitting

Cultivar effect. Melon cultivars with very thin rinds such as the Korean accession, PI 161375 [*C. melo* Conomon Group cultivar Shongwan Charmi (SC)], are generally very susceptible to cracking. The cracking disorder in thin-rind cultivars is even more damaging when cracks develop after harvest and during transportation or retail display. Such cultivars therefore require special handling during transportation, in the laboratory, and during retail. Cultivars with deep sutures or pronounced sutures are also highly susceptible to fruit cracking during transportation particularly if cracks were evident at harvest (Fig. 3C–E). The Korean SC accession when introgressed into PS-type melon background resulted in deep furrowing (Fernández-Trujillo et al., 2007), netting expression, and susceptibility to longitudinal cracking in some near-isogenic lines regardless of the season of production (Fig. 3C, F, or G). Closely-related Hami-type melons, now grown in some regions of the United States (Fig. 1A and B) and widely grown in China (Wu et al., 2008), probably have similar levels of susceptibility. The Hami-type melon is thought to be a member of the Acidulous-type melons [*C. melo* Acidulous Group (A.J. Monforte, personal communication)].

Near-isogenic lines (NILs) of melons containing introgressions of SC into PS-type melons are typically

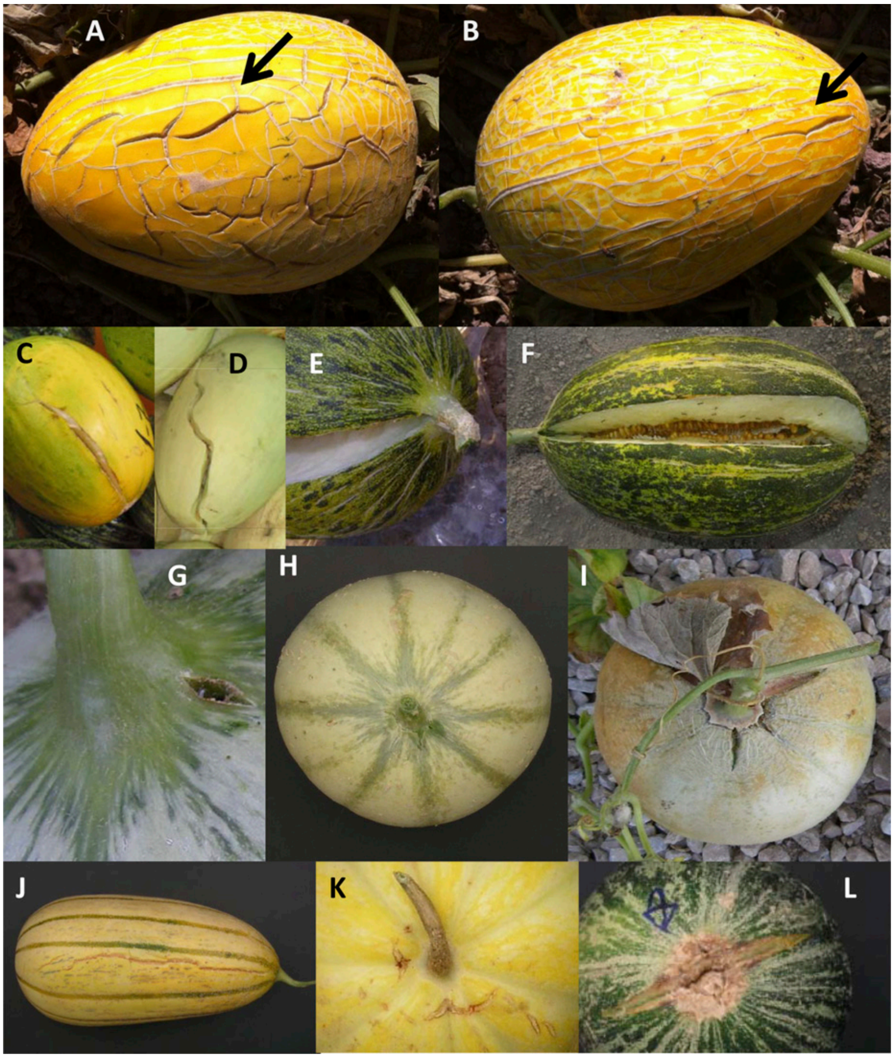

Fig. 1. Melon splitting symptoms. (A, B) Splitting in Hami-type melon [Imperial, AZ in season 2012 (courtesy of M. Russell)]. The black arrow is the typical net cracking with deep furrow as seen in Cartagena, Spain. (C) Near-isogenic line SC3–5-1 suffering transportation splitting. (D) Cultivar Branco Do Ribatejo suffering splitting in packinghouse. (E) Splitting following in part the netting cracks in Piel de Sapo-type cultivar T111. (F) Splitting in near-isogenic line SC7–2 with signs of direct sun exposure. (G) Start of cracking in Charentais-type cultivar Vedrantais. (H) Cracking around the peduncle immediately after harvest in 'Vedrantais'. (I) Splitting in senescent 'Vedrantais' fruit. (J) Cracking associated to full maturity in snapmelon accession PI 124112. (K) Cracking in cultivar Ginsen Makuwa. (L) Blossom-end of near-isogenic line SC10–2.

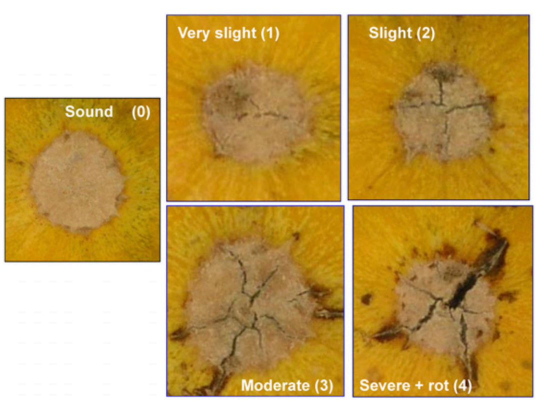

Fig. 2. Severity level of blossom-end breakdown (0 to 4 scale) in the near-isogenic melon line SC3–5-9 after 30 d of storage at 7 °C (44.6 °F). The black color in the cracks is due to cladosporium rot.

netted, with deep sutures (Eduardo et al., 2005). They also tend to be very susceptible to fruit cracking that frequently facilitates development of fungal or bacterial soft rots (Fig. 4A) (Fernández-Trujillo et al., 2007). Deep suturing is a heritable trait in melons and is frequently expressed in progeny when sutured cultivars are crossed with nonsuturing cultivars (Martínez et al., 2009). Ample field observations have shown that some NILs for suturing tend to be more susceptible to splitting compared with the parental controls such as the PS-types, SC7–2 (Figs. 1D, 3C, and 4B), SC7–3 (Fig. 4C), SC10–1, or SC10–2 (Figs. 1L and 3G) containing introgressions in linkage groups (LG) VII or X of melon. Round-shaped melons also tend to be less susceptible to splitting than the oblong-types (Martínez et al., 2009).

Some melon NILs containing two introgression of SC into LG III and VI such as SC3–5 (Fernández-Trujillo

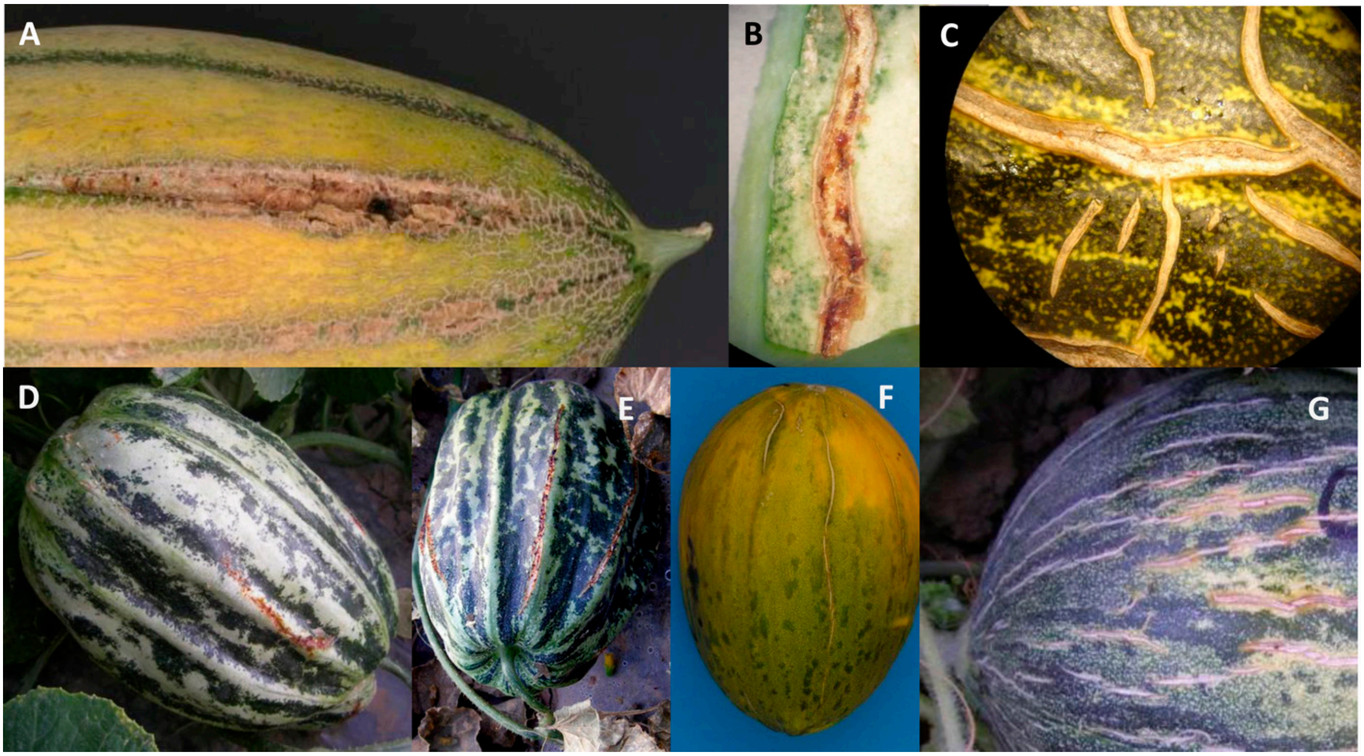

Fig. 3. Cracking in netted areas in different melon cultivars. (A) Partial healing in preharvest splitting of snapmelon accession PI 124112. (B) Gummosis exudates in accession PI 161375 as a response to fusarium rot infection. (C) Initial cracking in near-isogenic line SC7–2 with hyphae of *Cladosporium* species and *Fusarium* species. (D) PI 161375 with the typical gum as a response to the start of cracking. (E) Severe deep furrow in the Korean accession PI 161375. (F) Longitudinal peeling (skin netting) in climacteric near-isogenic line 5M8 after 30 d at 8 °C (47.6 °F). (G) Net cracking in near-isogenic line SC10–2 (moderately susceptible to cracking).

et al., 2008; Moreno et al., 2008; Vegas et al., 2013) have been shown to be less susceptible to net cracking or skin "wartiness" than the parental control PS-type cultivar T111, except when splitting was associated with sunscald (Fig. 4D–F). Some climacteric NILs such as SC3–5 or SC3–5–1 (Fig. 4H) are more susceptible to blossom-end cracking (Fig. 5F and G) due in part to dehiscence (Martínez et al., 2009). Also, the former NILs contained quantitative trait loci (QTLs) in LG III and VI that induce climacteric ripening and also interact epistatically to induce advance in ethylene biosynthesis (Vegas et al., 2013). The effect of net cracking on transient, but small bursts of ethylene production [increases about 1–4 $\text{pmol·kg}^{-1}\text{·s}^{-1}$ of ethylene (data not shown)] can be a sign of healing in netted or stem-end areas; however, when levels increase continuously in nonclimacteric melons, this is a sign of splitting or other disorders such as mechanical damage or microbial infection.

Snapmelons are native to India, where they are commonly known as phut or phoont, which means to split (Dhillon et al., 2009). Dhillon et al., (2007) found genetic polymorphism for the pattern of fruit cracking reported above. In snapmelons, a variety of cracking patterns have been identified (Figs. 3A, 4D, and I; Dhillon et al., 2007). These include longitudinal as well as random cracking patterns that start around the equatorial region of the fruit. Some of the climacteric melon NILs with the PS genetic background can also develop longitudinal peeling similar to early splitting symptoms (Fig. 3F).

Splitting in bitter melon (*Momordica charantia*) has been observed during postharvest ripening in air at 15 °C (Zong et al., 1995). However, when fruit were stored for up to 3 weeks in 2.5% or 5% carbon dioxide, in combination with 2.5% oxygen, bitter melons had a reduced tendency to split than air-stored fruit due, at least in part, to a delay in ripening symptoms (Zong et al., 1995). For such split-sensitive cultivars, a general recommendation is to minimize vibrations during transportation, especially with thinner-rind melon types, as this can cause cracking and splitting similar to those observed in tomatoes during simulated export and marketing (Park et al., 1999).

Other melon cultivars have also been shown to be susceptible to splitting (Corbacho et al., 2013; Martínez et al., 2009; Schultheis and Jester, 2005). These include: 'Arava' [*C. melo* Reticulatus Group (Syngenta/Zeraim Gedera, Revadim, Israel)], Charentais-type melons (Fig. 1G and I), the climacteric accession 'Rochet' B15 (*C. melo* Inodourus Group) from Instituto Universitario de Conservación y Mejora de la Agrodiversidad Valenciana, Valencia, Spain (Fig. 4J), or certain Hami-type cultivars such as Xuelihong, New Queen, or Xianguo (Corbacho et al., 2013; Martínez et al., 2009; Schultheis and Jester, 2005; Wu et al., 2008). The Galia-type (*C. melo* Reticulatus Group) cultivar Solar King stored at ripening temperatures also develops high levels of cracking (Lima et al., 2004). Martínez et al. (2009) have reported

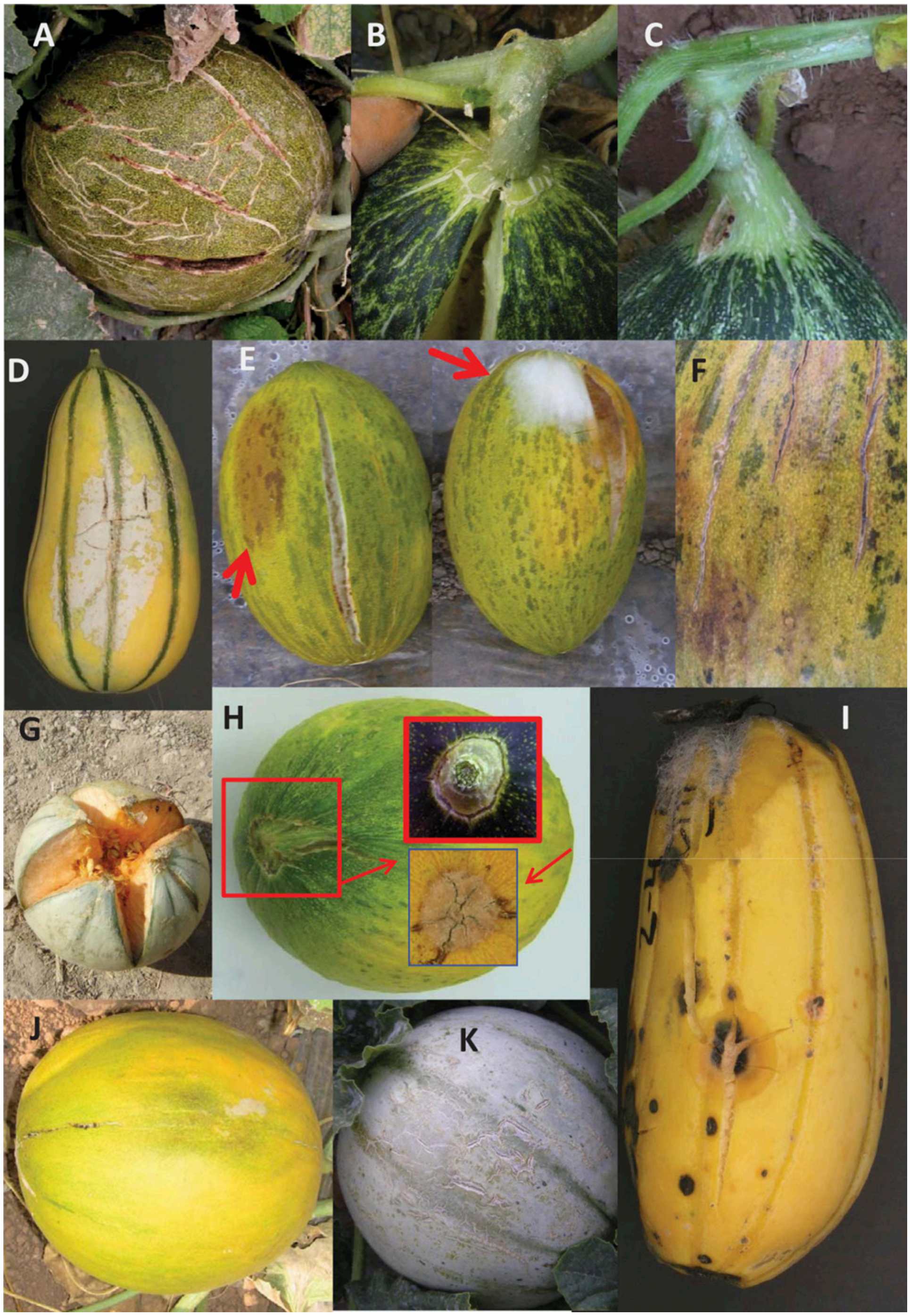

Fig. 4. Cracking symptoms in different near-isogenic melon lines. (A) SC2–3d. (B) SC7–2. (C) SC7–3. (D) Splitting in sunscalded skin in melon accession PI 124112. (E) SC3–5-12 (climacteric). The red arrow indicates sunburn. (F) Parental Piel de Sapo-type cultivar T111 with sunscald affected by cladosporium rot. (G) Blossom-end splitting in Charentais-type cultivar Vedrantais. (H) Premature dehiscence and splitting in SC3–5-1 with details of dehiscence and moderate stem-end cracking. (I) Random and longitudinal cracking with cladosporium and rhizopus rot in full maturity snapmelon accession PI 124112 after 4 weeks of storage at 7.5 °C (45.5 °F). (J) Accession 'Rochet' B15 with signs of lignification. (K) 'Vedrantais' with cracking.

cracking in 14% of fruit of the Galia-type cultivar Fado F1 before harvest.

Fruit cracking after harvest has also been observed in some studies. The Galia-type cultivar Fado developed 85% fruit with blossom-end cracking 30 d after storage at 8 °C that did not affect PS, whereas other nonclimacteric or climacteric NILs developed blossom-end cracking in only 1% to 3% fruit. For cultivar Vedrantais, 21% of the total losses occurred in the field, which is 3.6 times more than what was observed in PS-types, and 6.4 times the average losses of climacteric NILs (Martínez et al., 2009). Fruit cracking has been reported as a serious obstacle for releasing tetraploid melon cultivars vs. the common diploid cultivars (Dumas de Vaulx, 1974).

Some of the problems of cracking could be associated with the difficulties in developing cultivars with adequate synchrony between internal and external ripening processes especially in cultivars bred for specific traits and markets (e.g., skin color, netting, whole fruit hardness, peduncle lignifications, etc.). Hence, cracking or splitting disorders seem to be random and to result from specific genotype × environment combinations. Systematic studies comparing different melon types are scarce.

Developmental, environmental, and management factors

Susceptibility to splitting increases during fruit development in the field, particularly in the last stages of ripening when day time temperatures are relatively high and night time temperatures are relatively low (Opara, 1997). Such wide diurnal temperature fluctuations are common in Mediterranean production regions such as southeastern Spain where night temperatures of 18 to 22 °C and day temperatures of 26 to 30 °C are common.

Excessive nitrogen (N) fertilization, especially with inadequate potassium (K) and/or calcium (Ca) particularly in the later stages of fruit ripening has also been reported to promote cracking and splitting (Baixauli, 1995; Baixauli et al., 1997; Cabello et al., 2011; Serrano, 1996).

Intense solar radiation incident on the fruit can also exacerbate cracking especially when plants have suffered defoliation either because of herbivory, mechanical damage, or diseases that typically reduce leaf area, canopy size, and fruit shading. Intense radiation and the associated rise in fruit temperature can significantly increase internal turgor pressure exerted by the pulp on the rind, thereby increasing the incidence of splitting (Lang and During, 1990). Fruit surfaces affected by sunscald (sunburn) and cracking are followed by infection with microbes such as cladosporium rot (Fig. 4D–F, and K). The problem of excess solar radiation resulting in sunscald and cracking can be minimized with shade nets, bagging individual fruit, or spraying the entire crop with particle films such as a processed kaolin clay or calcium carbonate (Glenn et al., 2001; Jifon and Syvertsen, 2002, 2003).

Moderate shade and particle films can reduce radiation stress in crops by protecting the foliage and fruit from damaging ultraviolet and infrared radiations, while still allowing photosynthesis to occur. Particle films based on aluminosilicate clays, calcium carbonate, and other formulations are now commercially available for crop stress and disease protection (Glenn et al., 2000; Puterka et al., 2000; Sekutowski et al., 2002).

Cracking-susceptible cultivars are also commonly susceptible to opportunistic bacterial and fungal diseases, as pathogens can gain easy access through developing cracks (Fig. 4F and I). It is common to find small hyphae and microconidia of *Fusarium* species and short hyphae and conidia of *Cladosporium* species inside cracks of susceptible cultivars such as SC. Fruit of SC with enhanced production of lignin or suberin in fruit rind tissues, as well as rapid deposition of a gummy protective layer on surfaces of the cracks (gummosis) seem to have fewer post cracking disease problems (Fig. 3B, C, and E). Some resistance has been observed in the field even in split fruit (Figs. 3A, 4A, and F).

Gummosis is external and particularly associated with the presence of *Fusarium* species and *Cladosporium* species and always appears on lignified wounds. Internal cladosporium rot, probably entering by sunscald-related microcracks, has been reported in melons (Martínez et al., 2009) and cucumber [*Cucumis sativus* (Martínez and Fernández-Trujillo, 2007)]. If net cracks develop from openings in the epidermis (skin), or by deep furrows, fungal colonization can occur with rhizopus rot [*Rhizopus oryzae* (Fig. 5A)] or bacteria causing soft rot [*Erwinia carotovora* (Fig. 5B–D)]. In NIL SC3–5-1 and other climacteric NILs, some fungi or bacteria can also grow in cracked areas associated with fruit abscission either at the blossom-end or the bottom-end (ground spot) of the fruit (Fig. 5E–H).

Even when cracks are microscopic and not readily discernible, there is still a high risk of internal mesocarp contamination in the field with pathogens such as *Escherichia coli* O157:H7, various *Salmonella* species such as *Salmonella poona*, and naturally occurring microflora (Richards and Beuchat, 2005a, 2005b). This is a critical issue especially for fruit destined for fresh-cut products. Susceptible cultivars should therefore be closely inspected before harvest and transportation off farms.

It has been postulated that melon splitting might be related to papaya ringspot virus infection; however, solid evidence for this conjecture is weak (Melgarejo et al., 2010).

Plant population density, together with irrigation management can influence water and nutrient acquisition by competing plants and subsequently predispose fruit on those plants to cracking. High-fruit yields associated with high-density plantings is a trend that growers in resource-limited regions are adopting to maximize resources. Melons grown under such management practices may be prone to cracking if uniform water supply is not maintained. This is most likely to occur when excessive irrigation or heavy precipitation precedes a period of pronounced drought (Abdel, 1975; Bertelsen et al., 1994; Foord and MacKenzie, 2009).

Deficit irrigation has recently been promoted as an on-farm strategy for conserving water. However, improper management of a deficit irrigation regime can lead to an increase in cracking incidence (Zapata et al., 1989). Irrigation and soil management practices such as mulching and use of subsurface drip irrigation can ensure uniform soil moisture supply to plants, even under intermittent stress periods, and help to minimize the prevalence of the cracking disorder (Ribas et al., 2001; Warriner and Henderson, 1989). Reduced incidence of cracking has been reported in protected production systems where the level of stress is minimized (San Bautista et al., 2004).

The growth regulator (accelerator), forchlorfenuron, is registered on watermelon in China and kiwifruit (*Actinidia deliciosa*) and grape (*Vitis vinifera*) in the United States. When applied at a relatively early stage of watermelon fruit growth, it does not cause cracking problems. However, when fruit are mature, this growth regulator causes melons to crack and burst when ripe, especially during wet weather and particularly with thinner-rind cultivars

Fig. 5. Rots affecting cracked melon fruit in the field. (A) Decay caused by rhizopus rot (black) and green colors because of cladosporium rot after splitting the fruit of near-isogenic line SC7–2. (B) Bacteria causing soft rot in cracked netting tissue in climacteric near-isogenic line SC3–5-11. (C) Splitting in the ground area (in contact with soil) in nonclimacteric near-isogenic line SC2–3d with bacterial soft rot. (D) Bacterial exudes through cracked skin in climacteric near-isogenic line SC3–5-11. (E) Dehiscent fruit peduncle affected by bacterial soft rot in climacteric near-isogenic line SC3–5-12. (F) Dehiscent fruit at the blossom-end (climacteric near-isogenic line SC3–5-5). (G) Cracking and gummosis in the bottom-end in climacteric near-isogenic line 6M1. (H) Intact bottom-end in fruit of climacteric near-isogenic line SC3–5-8.

Fig. 6. Variations in surface characteristics of muskmelons with implications for fruit cracking. (A) Typical "western-shipper"-type cantaloupe melons predominantly in the United States and Latin America. (B) Extremely lightly netted specialty casaba-type melon. (C) Typical netted/sutured cantaloupe-types grown in Europe. (D) Sutured, non-netted type. (E) Smooth-skinned honeydew-type muskmelons.

Fig. 7. Variations in severity and cracking patterns among smooth-skinned muskmelon types.

(Daily Mail Reporter, 2013). It has also been observed that Hami-type melons are less susceptible to cracking during development when plants were treated with benzothiadiazole (a plant growth regulator), azoxystrobin (a fungicide), or "kang du fen" (a biopesticide) (Xuewen et al., 2007).

Fruit netting, suturing, and irrigation management

Fruit surface characteristics such as sutures, netting, and the pattern/density of netting are cultivar-dependent traits that play a critical role in melon-fruit cracking. The netting character starts from fine skin cracks and is present in nonclimacteric and climacteric cultivars (Gerchikov et al., 2008). Five QTLs controlling this character in melons have been identified (Obando et al., 2008). Deeply sutured cultivars tend to be more susceptible to cracking than typical nonsutured, "western-shipper"-type cultivars (Fig. 6A–D). Smooth-skinned, sutured and thin-rind cultivars seem to be the most susceptible, based on surface characteristics (Fig. 7). For instance, in Amarillo-type melons (also known as Canary melons), dense netting is not common, but deep sutures are common, and these are prone to cracking, particularly when the rind is very thin. The problem can be even more complicated as cracking, and splitting has been associated with hard-flesh melons that have not reached a high level of soluble solids (i.e., 7% to 10% vs. 10% to 14%) and therefore are not at the proper stage of commercial maturity.

In netted melons, susceptibility to cracking seems to be more prevalent in sutured cultivars. Cracking seems to originate in the netted regions of the fruit. Melon netting originates from fissures (cracks) that appear at the surface of the fruit (Lester, 1988). Therefore, rind physical properties and ultrastructure seem to be essential in developing cracking. Thicker cuticle deposition enclosing most of the epidermis surrounding the netted regions may reduce the elasticity of the rind during rapid fruit expansion phases, during wide fruit temperature fluctuations, and during periods of rapid water intake, making the rind more susceptible to cracking (Keren-Keiserman et al., 2004). However, netting is not always associated with melon cracking or splitting.

Fertigation management has the strongest association with cracking of the many cultural and environmental factors involved. For instance, field studies in Campo de Cartagena, Spain with four types of melons: PS (green melons), Galia, Charentais, and Amarillo indicate that each cultivar required slightly different fertigation protocols (Botía et al., 2005).

During fruit maturity and fruit set, N absorption rate in the whole plant was linear, and similar for each melon type, suggesting that the entire melon crop could be fertilized with constant daily N amounts until 2 to 3 weeks before the last harvest regardless of melon type (Cabello et al., 2011). Lack of homogeneity in fruit maturity within the plot because of different maturity rates of each melon type resulted in excessive water supply or inadequate fertigation to some fruit types (particularly excess N without the right balance of K), causing premature cracking. Excessive fertigation after the fruit has attained maximum size (physiological maturity) can also increase the risk of fruit cracking (Gómez-Guillamón et al., 1997; Shimizu, 2005) by creating large gradients and fluctuations in osmotic potentials and electrical conductivity that eventually lead to cracking (Camacho, 2003).

Remedial management practices

Although melon fruit cracking in most cases is sporadic and unpredictable, certain management practices as discussed in the preceding sections can help reduce the incidence of this disorder especially as cracking-susceptible specialty cultivars become more prevalent. These remedial steps include, but are not limited to:

Maintaining uniform growing conditions especially with respect to irrigation timing during the critical last two weeks before harvest as well as mulching and composting can help maintain uniform moisture levels and reduce the incidence of fruit cracks.

Balanced nutrition, especially adequate K and Ca, can promote development of thicker rinds that are less susceptible to cracking. K and Ca are known to play crucial roles in membrane and cell wall integrity. For instance, Ca dips have been shown to improve fruit texture (Lester and Grusak, 1999). Similarly, foliar K applications during fruit development and maturation stages have also improved melon fruit texture through turgor maintenance (Jifon and Lester, 2009; Lester et al., 2006). In situations where soil-derived nutrients are inadequate, foliar sprays can be an effective supplement.

Monitoring weather conditions that are likely to induce cracking such as extended drought periods, and avoiding excessive irrigation after such periods can also help reduce the incidence of cracking.

Selecting and planting cultivars that are less susceptible to cracking. Cultivars with a history of cracking are not recommended for long-term storage or long-distance transport.

Grafting susceptible cultivars on resistant rootstocks that have vigorous root systems can help dampen fluctuations in water supply (Jifon et al., 2008) and hence, reduce the incidence of cracking. Besides disease resistance/tolerance, an added benefit of rootstock vigor is greater soil exploration and uptake of water and nutrients that should help the scion maintain a more uniform/positive water status and nutrient sufficiency.

Conclusions and future research

The physiological mechanisms that underlie preharvest melon fruit cracking and splitting need further investigation as the predictable cause is still uncertain. It is clear that there is a strong cultivar/genetic factor associated with thinner-rind phenotypes and a strong environmental/cultural factor associated with fertigation of thinner-rind fruit within days of harvest maturity. Further research on the interactions between cultivars, soil moisture and fruit cracking are also needed to better understand causal mechanisms and to prescribe improved management practices to avoid melon cracking and splitting.

As more growers transition into production of cracking-susceptible "specialty melons" that are otherwise preferred for a variety of reasons (Schultheis and Jester, 2005), new cultural practices will be needed in an effort to avoid pre- and postharvest fruit cracking and splitting. These would include cultivar-specific guidelines for irrigation as well as mineral nutrient management. Utilization of manure and compost for melons with a history of cracking is cautioned since cracks can serve as conduits for contamination with pathogenic microbes thereby posing a food safety risk.

A renewed focus on breeding for cracking resistance has the potential to also translate into fruit quality improvements such as firmness and resistance to contamination with food-borne pathogens. Improved production procedures, and a better understanding of the genetic component(s) of cracking resistance/susceptibility in melons are needed to efficiently manage this disorder.

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