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Sweet cherry fruit cracking mechanisms and prevention strategies: A review

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ABSTRACT

Sweet cherry (*Prunus avium* L.) is highly perishable and is greatly affected by orchard management and environmental conditions, such as excess rainfall before harvest. Rain-induced cracking is the major cause of crop loss in sweet cherry in most production areas of the world. Advances in understanding the physiological and molecular mechanisms involved in cracking physiology in combination with orchard management strategies to limit cherry cracking are discussed. The current opinions to explain fruit cracking is that the process initiates with water uptake by the fruit surface that results in localised bursting of cells that release malic acid into the apoplast. This results in swelling of the epidermis and weakening of the epidermal and hypodermal cells until macroscopic fruit cracking. This review focusses on management strategies such as rain cover protection, mineral sprays, anti-transpirants and growth regulators. Tree responses to growth regulators and biostimulants vary with cultivar, application frequency, concentration and type, making it hard to generalize their effects. New approaches to limit cracking are presented, including the development of tolerant cultivars, candidate mineral sprays, biostimulants and technologies for rainwater removal such as orchard air-blast sprayers or creating downwash by helicopters.

1. Introduction

Fruit cracking is a disorder commonly found in several fruit species such as pomegranate, plum, citrus, grape, sweet cherry, tomato and apple. Fruit cracking causes significant economic losses (Simon, 2006; Khadivi-Khub, 2015). Climate change predictions (IPCC, 2013) point to an increasing frequency of excessive rainfall that likely increases the incidence of cherry cracking. Very few current cultivars are tolerant to cracking. ‘Regina’ is one of the most cracking-tolerant while ‘Kordia’, ‘Lapins’and ‘Hedelfingen’ have some tolerance. ‘Bing’, ‘Brooks’, ‘Skeena’ are very susceptible to cracking (Balbontín et al., 2013; Quero-García et al., 2017). Sweet cherry cracking has been the focus of research (Kertesz and Nebel, 1935; Christensen, 1973; Sekse, 1995; Measham et al., 2009; Balbontín et al., 2014; Koumanov, 2015) and has been compiled in reviews (Sekse et al., 2005; Simon, 2006; Balbontín et al., 2013; Khadivi-Khub, 2015; Rehman et al., 2015; Knoche and Winkler, 2017). However, the mechanisms involved in cracking are not completely elucidated. Physiological, biochemical, environmental, cultural, anatomical and genetic factors are not well understood, including the management strategies to mitigate rain-induced cherry cracking. This review provides an overview of the mechanisms involved in cherry cracking. The review focusses on management strategies to mitigate rain-induced cherry cracking such as the application of candidate mineral sprays, growth regulators, biostimulants and rain water removal. This review also highlights recent advances to find genetic markers for cherry cracking. Breeding for more resistant cultivars is likely, in combination with management strategies, the best way forward in the mitigation of cherry cracking.

2. Types of cracks: by size and position

The cherry skin can be divided in three parts: cuticle, epidermis and hypodermal cell layers. Cracking of sweet cherry is characterized by cuticular splitting and can be distinguished by the size of the cracks and position of cracks on the fruit surface. Microcracks are described as cracks in the cuticle without affecting the epidermal and hypodermal cell layers (Peschel and Knoche, 2005; Knoche and Peschel, 2006). Microcracks can be induced by water on the fruit surface (Knoche and Peschel, 2006) and are generally not detected by visual inspection. However, microcracks compromise the barrier function of the cuticle which might allow fungal infection to occur during shelf life (Børve et al., 2000). In addition, during the packing, microcracks increase the permeability of the skin, water uptake rate and transpiration. This may lead to loss of fruit firmness and increases fruit decay (Knoche and Peschel, 2006). Cracks visible to the naked eye are designated as macrocracks that compromise the cuticle and extend into the epidermal

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Fig. 1. Macroscopic cracks by position: in the cheek region (A), in the apical end region (B) and in the stem cavity region (C).

and hypodermal cell layers (Fig. 1). Macrocracking affects all cell layers and the crack occurs when the strain is released by the elastic skin of the mature fruit (Grimm et al., 2012). Macrocracks may originate from microcracks. Microcracking increases water uptake that may transform into a macrocrack at the site of water uptake (Glenn and Poovaiah, 1989; Knoche and Peschel, 2006). Three types of macrocracks may occur (Christensen, 1996): in the cheek- (Fig. 1A), in the apical end- (Fig. 1B) and in the stem cavity region (Fig. 1C). The apical end and stem cavity may be the first positions where cracks appear (Peschel and Knoche, 2005), and later affect the cheek region by elongation of pre-existing cracks (Verner and Blodgett, 1931; Glenn and Poovaiah, 1989). The type of cracking can be the consequence of the water uptake pathway. Apical end and stem cavity regions have been mentioned as the sites of preferential water uptake (Glenn and Poovaiah, 1989; Beyer et al., 2002). Measham et al. (2010) described that water deposited by overhead sprinklers caused small cracks in apical end and stem cavity regions.

3. Cracking quantification

Cracking quantification is best carried out just after rainfall, expressed as the percentage of cracked fruits in the orchard (Quero-García et al., 2014). The level, distribution and duration of rainfall, fruit maturity stage, orchard factors and environmental conditions are not standardized. This means that quantification of cracking is difficult to reproduce (Measham et al., 2012). Ideally, a standardized protocol for cracking susceptibility in vitro that reproduces in vivo observations in the field should be used (Knoche and Winkler, 2017). Currently, two laboratory-based assessments of cracking susceptibility exist by immersing detached fruit in water: (1) the cracking index (CI) and (2) the intrinsic cracking susceptibility. (1) The original CI test was introduced by Verner and Blodgett (1931) and modified by Christensen (1972a). Briefly, 50 fruits without defects, are immersed in 2 L containers filled with distilled water (20 ± 1 °C) for 6 h. Cracked fruits are removed, counted and fruits without cracks are re-incubated. After 2, 4 and 6 h, the fruits are observed for macroscopic cracks, with the CI calculated according to:

$$CI = \frac{(5a + 3b + c)^{*}\, 100}{250}$$

where a, b and c represent the number of cracked fruit after 2, 4 and 6 h, respectively. (2) Intrinsic cracking susceptibility was introduced by Weichert et al. (2004) and is determined by a combination of skin fruit mechanical properties and fruit water uptake characteristics (Winkler et al., 2015) that combine into WU50, the water uptake (in mg) at 50% fruit cracking. WU50 is an indirect measurement of the extensibility of the skin fruit and inversely related to the cracking susceptibility according to:

$$WU_{50} = R^{*}T_{50}$$

with R the mean rate of water uptake (mg h-1) and T50 (h) the time to 50% cracking.

4. Factors involved in cherry cracking

4.1. Climatic and agronomic factors

Climatic and agronomic factors play an important role in the occurrence and intensity of cracking. Rainfall and high humidity during harvest time increases the prevalence of fruit cracking (Simon, 2006). High temperature increases the incidence of fruit cracking since it increases the rate of water uptake and fruit transpiration (Richardson, 1998; Yamaguchi et al., 2002; Simon, 2006). Rootstock selection is one of the most relevant factors in tree size control and cherry management but can also interfere with the uptake of water (Simon et al., 2004). In compact trees, fruits are more protected against rain (Edin et al., 1997). Hence, fruits of heavy crop-loaded trees crack less than light cropping trees for the same sweet cherry cultivar (Way, 1967). Pruning promotes increased fruit size, but can also increase cracking susceptibility (Sekse, 1987). A negative correlation between crop load and incidence of fruit cracking was mentioned by Measham et al. (2012). Therefore, crop load should be a major consideration in orchard practices to limit fruit cracking. Soil moisture levels and irrigation have a role in cracking management. Irrigation management and the use of soil covers helps to decrease fruit cracking, because of lower water uptake by the roots (Edin et al., 1997).

4.2. Fruit characteristics

Fruit characteristics such as size, shape, firmness, sugar content and skin characteristics are important factors involved in fruit cracking. Bigger fruits (Christensen, 1975; Yamaguchi et al., 2002) and firmer fruits (Yamaguchi et al., 2002) are more affected by cracking than small and soft-fleshed ones. However, some studies found no correlation between fruit firmness and cracking susceptibility (Christensen, 1975). Kidney or heart fruit shape have deeper stem cavities that keeps the skin moist for longer after rain, increasing the rate of water absorption (Beyer et al., 2002; Sekse, 2008). Simon et al. (2004) reported a positive correlation between the soluble solid content (SSC) and fruit cracking in sweet cherry cultivars. These results were consistent with the findings of Huang et al. (1999) and Considine and Kriedemann (2000) in litchi and grape, respectively. No clear differences were shown between susceptible and tolerant cultivars in flesh or skin osmolarity, suggesting that cuticle properties may play an important role in cracking susceptibility (Moing et al., 2004). Kertesz and Nebel (1935) showed a positive correlation between thickness of the inner wall of the epidermis and cracking. However, Demirsoy and Demirsoy (2004) showed no correlation between epidermal characteristics, although a negative correlation was found between cuticle thickness and fruit cracking in eight sweet cherry cultivars. Further research on evaluating the size, shape, firmness and sugar content with regard to cracking resistance, taking into account consumer preference, is required as relations are sometimes contradictory.