Scientific Papers. Series B, Horticulture. Vol. LXVII, No. 2, 2023
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

SWEET CHERRY FRUIT CRACKING - A CHRONIC PROBLEM IN THE ERA OF CLIMATE CHANGE

Mihai CHIVU[1, 2], Mădălina BUTAC [1], Adrian ASĂNICĂ[2]

[1]Research Institute for Fruit Growing Pitesti-Mărăcineni, 402 Mărului, Mărăcineni, 117450, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: mihai_chivu7915@yahoo.com

Abstract.

Scientific and practical interest in sweet cherry fruit cracking has steadily increased in the last decades, due to the higher incidence caused by climate changes. The problem is still less understood and the management strategies to prevent the incidence of the disorder in susceptible cultivars as well. Hailstorms and heavy rainfall after a long period of drought which are associated with new manifestations of climate changes might increase fruit cracking phenomenon. Other factors related to fruit characteristics or some cultural practices are also influencing fruit cracking. The responses of the trees to the application of some compounds (minerals, anti-transpirants and growth regulators) just before harvesting, vary according to the cultivar, application time, concentration and their type, which makes it difficult to generalize their effects. Moreover, their effectiveness it is not high and sometimes even counterproductive. Protecting crops with macrotunnels or covering orchards with polyethylene films, the use of seaweed-based biostimulants or the mechanical removal of rainwater have proven to be quite effective in many situations, but the need to develop new strategies to mitigate fruit cracking requires extra information on the mechanisms leading to skin cracking. Many studies have shown that some varieties manifest a high resistance to cracking, and phenotyping for selection the most resistant genotypes can be correlated with new molecular research and findings of molecular markers associated with fruit cracking, and also of the genes involved in the formation of the cuticle and cell wall. Current review explores the factors which are contributing to fruit cracking in sweet cherry, report advances recommended measures to reduce this disorder, and indicate directions for future research.

Key words: *climate changes, fruit cracking, rainfall, sweet cherry.*

INTRODUCTION

Sweet cherries are extremely sensitive to cracking, most of the time with severe effects on commercial production. Chrinstensen (1996) showed that if only 25% of the fruits are affected, the harvest becomes uneconomical, moreover even in a smaller percentage the fruits are quickly attacked by microbial agents, which makes them undesirable for marketing, becoming at the same time a source of infection in the orchard.

Considering that the phenomenon occurs before or after rain shortly before harvest, it is considered that fruit cracking occurs due to the water uptake (either osmotic, through the epidermis, or vascular, through the pedicel), which results in increase fruit turgor, volume and area surface, up to a critical value that causes the fruit to crack - "*critical turgor pressure concept*" (Considine and Kriedemann, 1972; Measham et al., 2009; Sekse, 1995; Sekse et al., 2005).

The difference in the osmotic potential of the water inside the parenchyma cells of the mesocarp and the water on the surface of the fruit's skin (usually close to zero) sets in motion the necessary force for absorption by osmosis of water from the outside into the inside of the fruit (Grimm et al., 2020).

In short, the theoretical model for sweet cherry fruit cracking agreed most of the time implies the acceptance of several aspects:

- plasmolysis of the epidermal cells exposed to mesocarp juice due to the potential difference between them (Grimm et al., 2015);
- in phase of rapid growth, most of the water and nutrients reach through the phloem in the vascular system of the fruit (Brüggenwirth et al., 2016) oriented primarily to the mesocarp and the ovules and less to the epidermis (Grimm et al., 2017).

Microcracks, usually detectable under a light microscope, affect the cuticle and usually do not assume damage to the mechanical properties of the fruit skin (Brüggenwirth et al., 2014), while **macrocracks** can reach the epidermal and hypodermal cell layers (Correia et al., 2018).

The skin (exocarp) of the sweet cherry fruit consists of a cuticular membrane and several dermal cell layers which forms the epidermis (single layer of collenchyma cells) and the hypodermis (up to 7 cell of collenchyma subepidermal layers) having an insignificant number of stomata and which are non-functional at fruit maturity (Peschel et al., 2003).

The cuticle. Minimization of water loss, water proofing, protection against biotic and abiotic factors, fruit appearance, and textural properties are just some of the attributes of the cuticle.

The cuticular membrane is synthesized by the epidermis of fruits and all above-ground plant organs, and must be seen as a lipidized cell wall region (Guzman et al., 2014) whose properties in terms of water permeability are the focus of most theories regarding cherries cracking susceptibility.

The basic element of the sweet cherry cuticular membrane is cutin (whose synthesis is done exclusively by epidermal cells), a series of esterified fatty acids C16:0 or C18:1 (reported mainly for sweet cherries), synthesized in the plastids, to which a series of waxes (epicuticular and intracuticular waxes with triterpenoid acids-ursolic acid- as the main component) are added (Lara et al., 2015).

In phase of rapid increase in fruit mass (stage III of fruit development), the mass of the cuticular membrane and wax per unit fruit surface area decreases, this is due not only to the fact that fruit surface increased by about 311% (while e.g. mass of the cuticular membrane increased by 50% in this phase), but also resulted from changes in the compositional structure of the two elements (Figure 1), which may affect some wetting characteristics and mechanical properties of the cuticular membrane (Peschel S. et al., 2007).

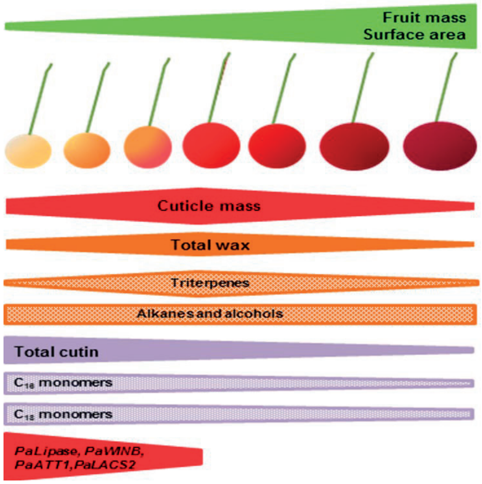

Figure 1. Changes in cuticle deposition and composition during the development of sweet cherry (Lara I. et al., 2015)

CURRENT STRATEGIES IN SWEET CHERRY FRUIT CRACKING MANAGEMENT

Gibberellic acid, a chemical compounds, that act as plant regulators, naturally synthesized in the plant, from the family of phytohormones (which can be both regulators and retarders or inhibitors of various plant traits or physiological processes), was most often associated with the idea of increasing plant resistance to biotic and abiotic factors, promotes growth and elongation of cells (Rothwell and Pochubay, 2014) increase fruit size and firmness, delays peel senescence, theoretically making it more difficult for fruit flies to infest the fruit (Birke et al., 2006), decrease mechanical injury and delay maturation for the late-maturing genotypes (Proebsting et al., 1973; Looney and Lidster, 1980) and delay exocarp coloration.

The signals regarding its use as a main pawn in the fight against fruit skin cracking have been mostly contradictory, due to a very high heterogeneity in terms of environmental conditions (Rothwell and Pochubay showed that the optimum is above 20°C), application doses, genetic diversity, application time and sometimes it depends on the use of surfactants (Rothwell and Pochubay, 2014).

Some studies showed that the application of gibberellic acid (GA_3) in the mandarin orange cultivar 'Nova' increases fruit splitting when applied at flowering, but reduces it when applied a little later, shortly after the end of the June drop (García-Luis et al., 1994). The results of the experiments initiated by Cline and Trought also showed in the same direction. They concluded that GA_3 sprays had positive effects on sweet cherry fruit quality parameters (weight, moisture content, firmness, soluble solids), but very unfavorable in terms of fruit cracking (amount of fruit splitting and size cracks) exceptionally wet weather at harvest (Cline and Trought, 2011). Completely different were the results obtained by Yildirim and Koyuncu (2010), who, in addition to an improvement in some parameters related to quality, their study showed that the GA_3 applications (straw colour) at the rate of 20 ppm decreased the cracking index in the fruit.

In terms of achieving satisfactory results on cherry fruit, most users agree that the timing of gibberellic acid application is crucial. This can vary from the end of the pit hardening phase, before the rapid period of fruit cell enlargement to straw colour, but always in the morning or evening, on windless days.

Facteau et al. (1989) suggest that if dose is increased, the result is reduction on flowering of sweet cherry ('Bing' and 'Lambert' cultivars in their experiment) for the next year, especially on 1-year-old wood. The reduction of transpiration on the surface of the fruit is the reason for using gibberellin, but in case of prolonged rains, the application of gibberellin can have opposite effects (Kaiser et al., 2019).

The latest innovations involve the use of **biofilms** (Figure 2) with a role in cuticle supplementation. Developed and patented by Oregon State University, the biofilm Parka (Cultiva, Las Vegas, NV) is a wax-based product, made from food grade, elastic and hydrophobic biopolymers, applied to supplement the fruit's surface cuticle and allow for increased elasticity and reduced cracking (Vance and Strik, 2018).

Although the product guarantees a reduction in the incidence of fruit cracking, not all experiments carried out with this product have shown this meaning (Vance and Strik, 2018).

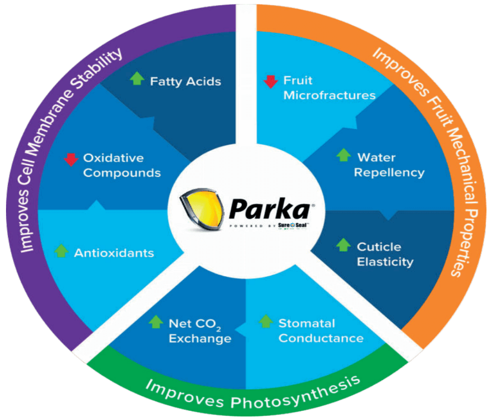

Figure 2. New biofilm with a role in cuticle supplementation, Parka (source https://www.cultiva.com)

Calcium physiology. As the fruit develops, the xylem (the only pathway through which calcium is transported) breaks the connection with the fruit, and the fruit's needs will be provided by the phloem, which leads to a continuous decrease of calcium in the fruit (Brüggenwirth et al., 2016).

Even if the results are contradictory, the use of calcium-based foliar products is used as a method to reduce sweet cherry fruit cracking.

Regarding the rationale for using calcium salts, it is based on two mechanisms: calcium salts are responsible for decreasing the osmotic potential for water uptake, and a decrease in the swelling of the cell wall simultaneously with the increase in adhesion between cells. The change in the osmotic potential following the application of calcium salts, some studies (at least at the theoretical level) have shown that it would be quite small (a reduction in the absorption of water through the skin with values between 8.3 and 16.2%) and which would be rather less visible under field conditions (Knoche et al., 2014; Moing et al., 2004). Schumann et al. (2022) demonstrated the effectiveness of Ca salts in reducing the swelling of cell walls (under laboratory conditions, by incubating epidermal segments in $CaCl_2$), the only impediment being the ability of these salts to penetrate through the intact cuticle, which implies their application immediately after rainfall when they will enter in contact with the emerging cracks.

In addition, Winkler and Knoche (2021) showed that the absorption of calcium is proportionally influenced by temperature and humidity on the surface of the skin, the pedicel cavity being the most important way for the calcium salts penetration into the fruit.

Genetics. As early as 1985, Cuartero et al. showed that fruit cracking has a strong genetic determinism involving several genes, and this character can be easily transmitted in the offspring. Encouraged by the good results obtained in tomato by Capel et al. (2015), Quero-Garcia et al. (2021), in an extensive study carried out between 2008-2016 which involved the multi-year analysis of a population of cherry hybrids (*Prunus avium*) - 3 hybrid combinations resulting from the crossing of 4 genotypes, 2 known to be very sensitive to cracking ‘Lapins’ and ‘Garnet’ and 2 that showed reduced susceptibility - ‘Regina’ and ‘Fercer’ - managed to identify three stable quantitative trait loci (QTL) for each type of cracking (in the area of the peduncular cavity, pistil and on the faces the fruit), which confirms the complexity of this phenomenon. From the breeder's perspective, locating quantitative trait loci (QTL) with different agronomic traits is very important for the implementation of marker-assisted selection strategies. But, as the authors go on to show, despite using multiyear values and analyses, the smallest confidence intervals for the most significant quantitative trait loci (QTL) spanned 4-5 cM (centimorgans), meaning that at least 100 genes are present in these ranges, which affected a realistic search for functional candidate genes responsible for cracking tolerance/susceptibility.

And in cherry, as in other species, increasing the genetic base through the selection of genotypes resistant to cracking and their introduction into breeding programs, remains an important direction to follow. Analyzing more than 200 cherry genotypes in the collection of Nikita Botanical Gardens in Crimea, Gorina et al. (2021) identified four genotypes that showed a high tolerance to cracking (‘Znatnaya’, ‘Zagadka’, ‘Kutuzovka’, ‘Zemfira’) and which can be used in programs to improve this character in cherry. At SCDP Iași, Corneanu et al. (2021) showed that through the hybridizations carried out in cherry breeding works, the new varieties obtained showed a much lower rate of fruit cracking than the parents used. Thus the new varieties ‘Cătălina’ (6.0%), ‘Margonia’ (1.3%), ‘Maria’ (9.3%), ‘Andreiaş’ (5.5%) and ‘George’ (5.8%) showed superior resistance to face cracking comparing to the varieties ‘Van’, ‘Boambe de Cotnari’, ‘Stella’, or ‘Fromm’ used as parents (between 10.0% and 70.3%).

On the other hand, experiences with focus on rootstocks have shown that they also influence the susceptibility to fruit cracking. Some trials conducted in The Dalles, Oregon, determined that ‘Mahaleb’ is generally the most susceptible rootstock, followed by ‘Mazzard’,‘Gisela 5’,‘Gisela 6’,‘MaxMa 14’,‘Krymsk 5’, and ‘Krymsk 6’ (Long et al. 2021).

Covers. The reduction in tree vigor has made possible the increasing use of tree cover systems to control fruit cracking. The high marketable value of the sweet cherry fruit could offset the rather high costs involved in installing such systems. In conditions of high precipitation, under Voen covering system, high valuable marketable yield can reach 85% and only 53% without cover due to high precipitation (Rubauskis et al., 2013).

Taking into account some less favorable aspects related to their use - high costs of establishment and maintenance, additional labor for installing them, problems related to dormancy (Quero-García et al., 2017), the negative balance of some quality parameters (Blanke and Balmer, 2008), the use of these systems in areas with high vulnerability is absolutely necessary.

In order to avoid such problems, some practices have been imposed as necessary - cover installation after bloom time (for example in Norway) or, most of the times, much later, near the fruit ripening (the third stage of fruit development), various colors covers for early ripening, retractable covers, etc. The complexity of these systems has increased - from the well-known the three-wire design system to the much more efficient and versatile Voen system Figure 3).


Figure 3. Three-wire design system (left side) and new Voen system (right side)

CONCLUSIONS

The phenomenon of cherry fruit cracking strongly affects the commercial value of production in many areas of the world, especially in the recent years with an evident climate change environment. Understanding the mechanisms underlying this phenomenon and choosing the best agrotechnical decisions. These are highlighted as follows: proper choice of the area to set up the plantation, the most suitable varieties and rootstocks, a good irrigation and fertilization programme and application of phytosanitary treatments and other special measures - like protective covers, and mineral supplements in areas with high climate vulnerability. All of these decisively influence the quality of production and the health of the plantation and make the difference between a successful or uneconomic plantation.

REFERENCES

Birke A., Aluja M., Bigurra E., Perez-Staples D., McDonald R., 2006. Long aculeus and behavior of Anastrepha ludens render gibberellic acid ineffective as an agent to reduce 'Rudy Red' grapefruit susceptibility to the attack of this pestiferous fruit fly in commercial groves. *J Econ Entomol*, 99(4): 1184-1193.

Blanke M.M., Balmer M., 2008. Cultivation of sweet cherry under rain covers. Acta Hortic. (795), 479–484.

Brüggenwirth M., Fricke H., Knoche M., 2014. Biaxial tensile tests identify epidermis and hypodermis as the main structural elements of sweet cherry skin. AoB Plants 6: plu019.

Brüggenwirth M., Winkler A., Knoche M., 2016. Xylem, phloem, and transpiration flows in developing sweet cherry fruit. *Trees*, 30, 1821–1830.

Capel C., Yuste-Lisbona F. J., López-Casado G., Angosto T., Cuartero J., Lozano R., Capel J., 2016. Multi-environment QTL mapping reveals genetic architecture of fruit cracking in a tomato RIL S. lycopersicum × S.pimpinellifolium population. *Theor Appl Genet.*, 2017 Jan; 130(1):213-222.

Christensen J.V., 1996. Rain-induced cracking of sweet cherries. Its causes and prevention. In: Webster AD, Looney NE (eds), *Cherries*. CAB International, Wallingford, pp 297–327.

Cline J. A., Trought M., 2011. Effect of gibberellic acid on fruit cracking and quality of Bing and Sam sweet cherries. *Canadian Journal of Plant Science*, 87(3): 545-550.

Considine J.A., Kriedemann P.E., 1972. Fruit splitting in grapes. Determination of the critical turgor pressure. *Aust J Agric Res*, 23:17–24.

Corneanu M., Iurea E., Sirbu S., 2021. Comparison of five new sweet cherry cultivars bred in Romania, with their parental forms. *Journal of Horticultural Research*, vol. 29(1): 1–8.

Correia S., Schouten R., Silva A.P., Gonçalves B., 2018. Sweet cherry fruit cracking mechanisms and prevention strategies: A review. *Sci. Hortic*., 240, 369–377.

Facteau T.J., Rowe K.E., Chestnut N.E., 1989. Flowering in sweet cherry in response to applications of gibberellic acid. *Scientia Hortic*., 38: 239-245.

García-Luis A., Duarte A.M.M., Porras I., García-Lidón A., Guardiola J.L., 1994. Fruit splitting in 'Nova' hybrid mandarin in relation to the anatomy of the fruit and fruit set treatments. *Scientia Horticulturae*, 5, 215-231.

Gorina V., Lukicheva L., Grigoriev A., Chernen'ky L., Sokolovskaya J., 2021. Genetic resources are the base for improving the assortment of sweet cherry and large fruit cherry plum. E3S Web of Conferences 254, 01023, Farba, 2021.

Grimm E., Knoche M., 2015. Sweet cherry skin has a less negative osmotic potential than the flesh. *J. Am. Soc. Hortic*. Sci. 140, 472–479.

Grimm E., Pflugfelder D., Hahn J., Schmidt M.J, Dieckmann H., Knoche M., 2020. Spatial heterogeneity of flesh-cell osmotic potential in sweet cherry affects partitioning of absorbed water. *Horticulture Research*, 7:51.

Grimm E., Pflugfelder D., van Dusschoten D., Winkler A., Knoche M., 2017. Physical rupture of the xylem in developing sweet cherry fruit causes progressive decline in xylem sap inflow rate. Planta, 246, 659–672.

Guzmán P., Fernández V., Graça J., Cabral V., Kayali N., Khayet M., Gil, L., 2014. Chemical and structural analysis of Eucalyptus globulus and E. camaldulensis leaf cuticles: a lipidized cell wall region. *Front. Plant Sci.*, 5, 481.

Kaiser C., Long L., Brewer L., 2019. Understanding and preventing sweet cherry fruit cracking. EM 9227.

Knoche M., 2005. Water uptake through the surface of fleshy soft fruit: Barriers. Mechanism, factors, and potential role in cracking. Chapter: Abiotic Stress Biology in Horticultural Plants.

Knoche M., Grimm E., Schlegel H.J., 2014. Mature sweet cherries have low turgor. *J.Am. Soc. Hortic. Sci*. 139, 3–12.

Lara I., Belge B., Goulao L.F., 2015. A Focus on the biosynthesis and composition of cuticle in fruits. *J. Agric. Food Chem.*, 63, 4005−4019.

Long L., Kaiser C., Thompson A., 2021. Sweet Cherry Rootstocks for the Pacific Northwest. PNW 619 |September 2021.

Looney N.E., Lidster P.D., 1980. Some growth regulator effects on fruit quality, mesocarp composition, and susceptibility to postharvest surface marking of sweet cherry. *J. Am. Soc. Hortic. Sci.*, 105: 130-134.

Marschner H., 1995. Mineral Nutrition of Higher Plants 2nd edn. Academic Press.

Measham P.F., Bound S.A., Gracie A.J., Wilson S.J., 2009. Incidence and type of cracking in sweet cherry (*Prunus avium* L.) are affected by genotype and season. *Crop Pasture Sci*, 60:1002–1008.

Moing A., Renaud C., Christmann H., Fouilhaux L., Tauzin Y., Zanetto A., Gaudillére M., Laigret F., Claverie J., 2004. Is there a relation between changes in osmolarity of cherry fruit flesh or skin and fruit cracking susceptibility? J. Am. Soc. Hortic. Sci., 129, 635–641.

Peschel S., Beyer M., Knoche M., 2003. Surface characteristics of sweet cherry fruit: Stomata number, distribution, functionality and surface wetting. Scientia Horticulturae, 97, 265-278.

Peschel S., Franke R., Schreiber L., Knoche M., 2007. Composition of the cuticle of developing sweet cherry fruit. *Phytochemistry*, 68 (2007), 1017–1025.

Proebsting E.L.Jr., Carter G.H., Mills H.H., 1973. Quality improvement in canned 'Rainier' cherries (*P. avium* L.) with gibberellic acid. *J. Am. Soc. Hortic. Sci*., 98: 334-336.

Quero-García J., Letourmy P., Campoy J.A., Branchereau C., Malchev S., Barreneche T., Dirlewanger E., 2021. Multi-year analyses on three populations reveal the first stable QTLs for tolerance to rain-induced fruit cracking in sweet cherry (*Prunus avium* L.). *Horticulture Research*, 8:136.

Quero-García J., Lezzoni A., Pulawska J., Lang G., 2017. *Cherries botany, production and uses*. CABI Int.

Rothwell N., Pochubay E., 2014. Gibberellic acid applications in cherries. Michigan State University Extension.

Rubauskis E., Skrīvele M., Ruisa S., Feldmane D., 2013. Effects of Voen cover on the growth and yield of two sweet cherry cultivars. *Proceedings of the Latvian Academy of Sciences. Section B. Natural, Exact and Applied Sciences*, 67. 10.2478/prolas-2013-0024.

Schumann C., Winkler A., Knoche M., 2022. Calcium decreases cell wall swelling in sweet cherry fruit. *Scientific Reports*, 12:16496.

Sekse L., 1995. Fruit cracking in sweet cherries (*Prunus avium* L.). Some physiological aspects: a mini review. Sci Hortic 63:135–141 11 .

Sekse L., Bjerke K.L., Vangdal E., 2005. Fruit cracking in sweet cherries: an integrated approach. *Acta Hortic*, 667:471–474.

Vance A., Strik B., 2018. New foliar-applied biofilm had no impact on splitting or fruit quality in 'Elliott' and 'Legacy' blueberry in Oregon. *HortTehnology*, 28(6).

Winkler A., Brüggenwirth M., Ngo N. S., Knoche M., 2016. Fruit apoplast tension draws xylem water into mature sweet cherries. *Sci. Hortic*., 209, 270–278.

Winkler A., Knoche M., 2021. Penetration of sweet cherry skin by ^{45}Ca-salts: pathways and factors. *Sci Rep.* 27; 11(1):11142.

Yildirim A.N., Koyuncu F., 2010. The effect of gibberellic acid applications on the cracking rate and fruit quality in the '0900 Ziraat' sweet cherry cultivar. *African Journal of Biotechnology*, Vol. 9(38), pp. 6307-6311. *Academic Journals.*