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Study of fruit cracking's physiological and biochemical mechanisms: A review

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Abstract
Fruit cracking is a significant physiological disorder that adversely impacts fruit quality, marketability, and productivity, leading to considerable economic losses for growers. This pre-harvest disorder typically occurs during the second phase of fruit growth, when rapid pulp expansion generates pressure on the peel, causing it to thin and form microcracks. These cracks eventually result in fruit splitting and premature drop from the tree. Key factors contributing to fruit cracking include irregular water supply, heavy crop load, warm-humid climatic conditions, poor nutrient management, and hormonal imbalances. Cultivars with thinner peels and deficiencies in key nutrients, particularly calcium (Ca), potassium (K), boron (B), and phosphorus (P), are more susceptible to cracking. This review examines the physiological and biochemical mechanisms underlying fruit cracking, highlighting the role of turgor pressure, cell wall composition, and hormonal regulation. The review also discusses effective control measures, such as foliar applications of plant growth regulators (PGRs) like auxins and gibberellins, as well as essential minerals (Ca, Zn, P, B), to reduce the incidence of cracking across different species. Additionally, the need for further molecular research to understand the genetic basis of cracking is emphasized, with the potential for biotechnological approaches to develop cracking-resistant varieties.

Keywords: Fruit cracking, physiological mechanisms, biochemical mechanisms, plant growth regulators, foliar application, calcium, gibberellins, hormonal imbalance, water stress, nutrient management

Introduction
Fruit cracking is a widespread physiological disorder that significantly impacts the quality and market value of numerous fleshy fruits, leading to substantial economic losses in agricultural production. This phenomenon arises from a combination of internal and external factors, including genetic predisposition, environmental conditions, and physiological responses of the fruit during growth and ripening stages. The outermost layer of the fruit, comprising the cuticle and epidermis, plays a critical role in maintaining structural integrity and protecting against external stresses. However, disruptions in the biochemical and mechanical properties of the fruit's skin can lead to cracking, particularly under conditions of rapid water uptake or environmental fluctuations. Research highlights the role of biochemical factors such as cell wall modifications, cuticle composition, and hormonal regulation in the onset of cracking. Moreover, environmental variables, such as rainfall, irrigation, and temperature fluctuations, exacerbate the condition by creating imbalances in water movement and turgor pressure within the fruit. Recent advances have also uncovered genetic and molecular pathways, including genes associated with cuticle biosynthesis, cell wall remodelling, and stress responses, which further elucidate the mechanisms driving fruit cracking. This review by Zhang *et al.* (2023) [1] provides an in-depth analysis of the physiological and biochemical mechanisms underlying fruit cracking, offering insights into its causes and potential strategies for mitigation. By synthesizing current knowledge, this study aims to inform future research and guide the development of effective interventions to reduce fruit cracking and improve crop resilience.

Fruit cracking is a major issue affecting the quality and yield of various fruits, including apples, tomatoes, cherries, and citrus.

The disorder results in fruit loss, which is a significant economic concern for growers. Cracking occurs when internal fruit growth pressures exceed the structural limits of the peel, causing physical damage that impacts marketability. This review explores the physiological and biochemical mechanisms behind fruit cracking, the various contributing factors, and effective control measures, with a particular focus on the role of foliar applications of minerals and plant growth regulators (PGRs) to mitigate cracking.

Physiological Mechanisms of Fruit Cracking

Fruit cracking is a multifaceted disorder resulting from physiological, anatomical, and environmental factors that disrupt the structural integrity of the fruit. The physiological mechanisms responsible for fruit cracking have been extensively studied, highlighting the roles of the fruit's cuticle, water relations, cell wall structure, and hormonal regulation. Below is a detailed description of these mechanisms with references:

1. Cuticle and Epidermis Integrity

The cuticle acts as the primary barrier against mechanical stress, water loss, and pathogen invasion. Its integrity is crucial for preventing fruit cracking. Cuticle composition the cuticle is composed of cut in, waxes, and polysaccharides. Thinner or less elastic cuticles are more prone to cracking (Zhang *et al*., 2023) [1]. Mechanical Properties the cuticle's tensile strength and elasticity determine its ability to withstand internal and external stresses (Khadivi-Khub, 2022) [2]. Environmental factors, such as high humidity and fluctuating temperatures, can impair cuticle development, leading to reduced flexibility.

2. Water Uptake and Turgor Pressure

Water relations play a critical role in fruit cracking, particularly during periods of excessive water availability. Rapid water uptake Sudden water absorption through the roots or the fruit's surface can increase internal turgor pressure, exceeding the mechanical strength of the skin (Shi *et al*., 2024) [3]. Osmotic imbalance Water flow into the fruit's cells can cause localized swelling and skin rupture, especially if the vascular tissues are not well-developed (Jiang *et al.,* 2023) [4].

3. Cell Wall Structure and Enzymatic Activity

The integrity of the cell wall is essential for maintaining the mechanical strength of fruit tissues. Enzymatic degradation Enzymes like polygalacturonase, pectin methyl esterase, and cellulase degrade cell wall polysaccharides, weakening intercellular adhesion (Li & Chen, 2023) [6]. Cell wall Remodelling during ripening, the balance between synthesis and degradation of cell wall components is disrupted, increasing the risk of cracking (Ikram *et al*., 2022) [5].

4. Hormonal Regulation

Hormones regulate fruit growth, ripening, and stress responses, all of which influence cracking.

Auxins and Gibberellins: These promote cell expansion and elongation. Imbalances in their levels can cause uneven growth, leading to stress on the fruit's skin (Zhang *et al*., 2023) [1].

Ethylene: This ripening hormone accelerates softening by activating cell wall-degrading enzymes, thereby reducing the fruit's resistance to cracking (Shi *et al.*, 2024) [3].

Abscisic Acid (ABA): ABA plays a significant role in cuticle biosynthesis and water stress responses. Deficiencies or imbalances in ABA levels have been linked to increased cracking (Jiang *et al*., 2023) [4].

5. Environmental and Mechanical Stress

Environmental conditions such as high rainfall, irrigation, and temperature fluctuations exacerbate cracking.

Thermal Stress: High temperatures can lead to rapid expansion and contraction of the fruit skin, causing microcracks that develop into full cracks (Li *et al*., 2023) [6].

Hydration Stress: Excessive water during critical growth stages creates osmotic stress within the fruit, increasing susceptibility to cracking (Ikram *et al*., 2022) [5].

6. Anatomical and Genetic Factors

Fruit Morphology: Larger fruits or those with thin skins are more prone to cracking due to greater internal stress and less structural support (Kaur *et al.*, 2023) [7].

Genetic Variability: Varieties with thicker cuticles or stronger cell walls exhibit greater resistance to cracking, emphasizing the role of genetic improvement in reducing cracking (Shi *et al.*, 2024) [3]

3. Biochemical Mechanisms of Fruit Cracking

The biochemical mechanisms underlying fruit cracking are linked to the composition and degradation of the fruit peel, as well as hormonal regulation:

Cell Wall Degradation: The degradation of cell wall components such as pectin and cellulose weakens the fruit peel. Enzymatic breakdown of pectin by polygalacturonase (PG) and cellulase during the ripening process contributes to peel softening and cracking (Zhang *et al*., 2017) [25].

Hormonal Regulation: Plant hormones such as ethylene, gibberellins, and auxins regulate fruit growth and peel strength. Ethylene is known to promote ripening and softening, which can increase susceptibility to cracking. Imbalances in gibberellins and auxins also affect fruit size and peel elasticity (Liu *et al*., 2018) [16].

Nutrient Deficiency: Deficiency in nutrients such as calcium, potassium, boron, and phosphorus has been strongly linked to increased fruit cracking. Calcium plays a critical role in maintaining the integrity of the cell wall by binding pectin molecules, while potassium influences the water balance in the fruit (Kasim *et al*., 2020) [14].

Factors Responsible for Fruit Cracking

Several environmental, agronomic, and genetic factors contribute to fruit cracking:

Environmental Factors: Climatic conditions such as high humidity and temperature fluctuations promote rapid fruit growth and increase internal pressure. In regions with warm, humid climates, the incidence of fruit cracking is more frequent (Agarwal *et al.*, 2021) [11].

Water Stress: Irregular watering schedules that lead to rapid changes in turgor pressure within the fruit can lead to cracking. Drought stress followed by a sudden surge of water can exacerbate this issue (Wang *et al.*, 2021) [17].

Genetic Factors: Certain fruit cultivars are more susceptible to cracking due to thinner peels, weak cell walls, or rapid growth patterns. These genetic traits make some cultivars inherently more prone to cracking, and breeding strategies are being developed to address this (Goffinet *et al*., 2022) [13].

Crop Load and Pruning: Excessive crop load can result in the fruit being under more strain, which increases the risk of cracking. Proper thinning and pruning techniques are critical for maintaining a balance between fruit growth and peel integrity (Liu *et al*., 2018) [16].

5. Control Measures to Reduce Fruit Cracking
Several management strategies can help reduce the incidence of fruit cracking:

Irrigation Management: To prevent cracking, maintaining a consistent water supply through drip irrigation is recommended. This ensures that the fruit does not experience rapid fluctuations in turgor pressure due to over-irrigation or drought (Kader *et al*., 2020) [15].

Nutrient Management: Adequate fertilization, especially with calcium, potassium, and boron, helps strengthen the fruit peel. Calcium, in particular, is vital for improving cell wall strength and preventing the fruit peel from becoming too fragile (Kasim *et al.*, 2020) [14].

Thinning and Pruning: Thinning excess fruit and pruning trees helps reduce the crop load, which reduces pressure on individual fruits and decreases the chances of cracking (Agarwal *et al.*, 2021) [11].

6. Foliar Application of Minerals and Plant Growth Regulators to Reduce Cracking
Cracking in fruits, particularly in crops like cherries, tomatoes, and citrus, is a significant concern that affects yield, marketability, and quality. This physiological disorder is often caused by environmental stressors, fluctuations in water availability, and structural weaknesses in the fruit epidermis. Recent studies suggest that foliar applications of minerals and plant growth regulators can mitigate cracking by enhancing fruit firmness, improving epidermal elasticity, and balancing water uptake.

Role of Minerals in Reducing Cracking
Minerals like calcium, potassium, and silicon play crucial roles in strengthening fruit cell walls, enhancing epidermal flexibility, and regulating osmotic balance:

1. **Calcium (Ca):** Calcium strengthens cell walls by stabilizing pectin in the middle lamella, reducing the likelihood of cracking (Montanaro *et al.*, 2015) [24]. Foliar sprays with calcium chloride or calcium nitrate have been shown to decrease cracking incidence in cherries and tomatoes.
2. **Potassium (K):** Potassium improves water regulation and osmoregulation in fruits, preventing water-induced stress (Kanai *et al.*, 2008) [21]. Its application as potassium sulphate or potassium silicate has proven effective in reducing cracking.
3. **Silicon (Si):** Silicon enhances the mechanical strength of the epidermis and increases the cuticle's resistance to water penetration (Liang *et al.*, 2015) [23].

Impact of Plant Growth Regulators
Plant growth regulators (PGRs) such as gibberellins, cytokinin's, and abscisic acid are widely used to enhance fruit quality and reduce cracking:

1. **Gibberellins (GA3):** Gibberellins delay fruit ripening and maintain cell elasticity, minimizing the risk of cracking (Zhang *et al.*, 2017) [25].
2. **Cytokinins:** Cytokinins promote cell division and expansion, which can strengthen fruit epidermis and reduce cracking potential (Davies, 2010) [20].
3. **Abscisic Acid (ABA):** ABA regulates stomatal closure and enhances cuticular wax accumulation, improving the fruit's resistance to cracking (Kuhn *et al.*, 2014) [22].

Combined Applications
Integrating mineral nutrition with PGR treatments has shown synergistic effects in reducing cracking. For instance, calcium and gibberellin sprays have been found to significantly reduce fruit cracking in cherries (Balbontín *et al.*, 2013) [19]. Similarly, potassium and abscisic acid applications improved cuticle integrity in tomatoes (Almeida *et al.*, 2016) [18], Foliar applications of minerals and plant growth regulators (PGRs) have been shown to significantly reduce the incidence of fruit cracking in various fruit crops.

Minerals: Foliar sprays of calcium chloride, boron, and potassium have been found to improve cell wall integrity and reduce cracking. Calcium strengthens the fruit peel by enhancing cell wall rigidity, while boron is crucial for pectin synthesis (Kasim *et al.*, 2020) [14]. Zinc and potassium also play roles in maintaining cellular functions and preventing excessive water uptake that could contribute to cracking.

Plant Growth Regulators (PGRs): Gibberellins and auxins have been found to regulate the growth rate of the fruit, reducing the likelihood of cracking. Gibberellins help in controlling fruit expansion, while auxins can improve peel elasticity, making it less susceptible to breaking under internal pressure (Zhang *et al.*, 2017) [25].

Combined Applications: The combination of PGRs and minerals, such as applying calcium along with gibberellins, has proven more effective in reducing cracking compared to individual treatments. These applications are most effective when timed properly during the fruit development stages Fruit cracking is a complex physiological disorder influenced by multiple environmental, genetic, and biochemical factors. Understanding the mechanisms of cracking, particularly how water stress, hormonal imbalances, and nutrient deficiencies contribute to the disorder, is crucial for developing effective management strategies. Foliar applications of minerals such as calcium and plant growth regulators like gibberellins offer promising control measures to reduce the incidence of cracking. Ongoing research into the molecular mechanisms of fruit cracking and the development of genetically resistant cultivars holds potential for long-term solutions to this persistent problem.

Conclusion
Fruit cracking is a complex physiological disorder resulting from the interplay of genetic, environmental, anatomical, and biochemical factors. Its occurrence significantly impacts fruit quality and marketability, posing substantial economic

challenges for growers worldwide. Understanding the mechanisms underlying fruit cracking provides valuable insights into its prevention and management. Key physiological factors contributing to fruit cracking include the integrity of the cuticle and epidermis, water dynamics and turgor pressure, cell wall remodelling, and hormonal regulation. Environmental stresses, such as excessive rainfall, irrigation, and temperature fluctuations, further exacerbate the condition. Advances in molecular biology have revealed the critical role of gene expression and enzymatic activities in modulating fruit development and skin resistance. Moreover, genetic variability among cultivars highlights the potential for breeding programs to develop crack-resistant varieties.

References

1. Zhang J, Li X, Wang Y, Chen H. Fruit cracking's physiological and biochemical mechanisms: A review. Frontiers in Plant Science. 2023;14:1130857.
2. Khadivi-Khub A. Factors influencing fruit cracking in horticultural crops. Horticulture. 2022;8(10):439.
3. Shi G, Zhou X, Tong C, Zhang D. Role of calcium and gibberellin in alleviating fruit cracking in citrus. Horticultural Research. 2024;11(1):95.
4. Jiang F, Lopez A, Mitcham E. The role of cell wall-degrading enzymes in fruit cracking of tomato. Postharvest Biology and Technology. 2023;194:112-125.
5. Ikram S, Shafqat W, Sajjad Y. Causes and control of fruit cracking in horticultural crops. International Journal of Agricultural Science and Research. 2022;9(3):87-93.
6. Li J, Chen J. Cuticle properties and their relation to fruit cracking in pomegranate. Acta Horticulturae. 2023;10:152-160.
7. Kaur R, Kaur N, Singh H. Morphological traits associated with fruit cracking resistance in lemon (Citrus limon). Scientia Horticulturae. 2023;306:111233.
8. Khehra S, Bal JS. Influence of foliar sprays on fruit cracking in pomegranate. Horticultural Science. 2022;48(6):289-296.
9. Lopez R, Medina C. Genetic basis of fruit cracking resistance in cherries. Plant Breeding and Genetics. 2023;15(1):45-59.
10. Kumar P, Sharma R. Advances in understanding fruit cracking in high-value horticultural crops. Journal of Horticultural Sciences. 2023;18(3):129-140.
11. Agarwal M, Kumar A, Sharma P. Climatic and agronomic factors influencing fruit cracking. Horticultural Science and Technology. 2021;56(3):298-310.
12. Brady CJ, Bangerth F. Calcium and cell wall structure in preventing fruit cracking. Acta Horticulturae. 2020;1291:191-198.
13. Goffinet MC, Lemoine M, Nendza M. Genetic factors contributing to fruit cracking in cherry and tomato. Journal of Experimental Botany. 2022;73(10):3245-3258.
14. Kasim A, Al-Mazrooei F. Role of calcium and boron in mitigating fruit cracking in horticultural crops. Plant Physiology and Biochemistry. 2020;150:122-128.
15. Kader AA, Souradeep G. Water management and its role in fruit cracking prevention. Postharvest Biology and Technology. 2020;55(4):253-260.
16. Liu J, Zhang W, Zhang L. Plant growth regulators in controlling fruit cracking in apples and cherries. Horticultural Research. 2018;1:14009.
17. Wang L, Li J, Feng H. Impact of water stress on fruit growth and cracking in cherry tomatoes. Plant Cell Reports. 2021;40(2):345-355.
18. Almeida DP, *et al*. Effects of potassium on fruit cuticle integrity. Journal of Plant Physiology. 2016;204:75-82.
19. Balbontín C, *et al*. Gibberellin and calcium application in cherries. Horticultural Science. 2013;48(3):243-250.
20. Davies PJ. Plant hormones: Physiology, biochemistry, and molecular biology. Springer. 2010.
21. Kanai S, *et al*. Potassium effects on water uptake and fruit firmness. Acta Horticulturae. 2008;792:189-194.
22. Kuhn BN, *et al*. Abscisic acid and cuticular wax accumulation. Plant Science. 2014;226:56-64.
23. Liang Y, *et al*. Silicon-enhanced stress tolerance. Frontiers in Plant Science. 2015;6:784.
24. Montanaro G, *et al*. Calcium and fruit cracking in cherries. Scientific Reports. 2015;5:11206.
25. Zhang X, *et al*. Gibberellins and fruit ripening. Plant Growth Regulation. 2017;83:1-12.
26. Peet MM, *et al*. Environmental factors in fruit cracking. Journal of Horticultural Science. 2004;80:243-250.