

polygalacturonases also participate in coordinated wall loosening by acting on hemicellulose, cellulose, and pectin networks (Zhai et al., 2021; Su et al., 2023).

Softening during storage is also driven by respiration, water loss, and membrane deterioration. Sweet cherries have a high respiration rate, and postharvest dehydration contributes directly to softening and senescence (Correia et al., 2017; Çolak et al., 2025). Weight loss rises substantially during cold storage as tissue moisture declines, and this mass loss reflects the combined effects of water loss and respiration (Çolak et al., 2025). Water loss is aggravated by the fruit's thin peel and depends partly on cuticle integrity, since the cuticle limits permeability, infections, and firmness loss (Wang et al., 2025; Çolak et al., 2025). Reduced turgor further accelerates texture loss, and membrane deterioration during storage is reflected by higher malondialdehyde and relative conductivity, both of which are reduced by calcium treatments (Wu et al., 2023; Wang et al., 2025).

2.3 Nutrient-dependent processes

Among nutrients, calcium has the clearest physiological role in maintaining firmness. Calcium cross-links de-esterified homogalacturonan to form calcium-pectate gels, increasing wall stiffness and strengthening cell-to-cell adhesion in the middle lamella (Guo et al., 2023). More broadly, calcium influences cell wall properties, membrane stability, water relations, and ripening-related signaling, so low fruit calcium can promote leaky membranes, irregular softening, and poorer storage behavior (Hocking et al., 2016). In sweet cherry, calcium-treated fruit were firmer and showed lower weight loss and decay incidence during storage, while foliar calcium also improved tissue rheological properties and reduced respiration (Belge et al., 2017; Matteo et al., 2022; Michailidis et al., 2022). Calcium effects are partly explained by reduced wall degradation, since calcium can inhibit pectin degradation and suppress the activity or expression of softening-related enzymes and genes (Matteo et al., 2022). Calcium import into cherry fruit declines as development progresses because xylem functionality is progressively lost, which helps explain why early-season calcium supply is often more effective than late applications (Winkler et al., 2020; Matteo et al., 2022).

Potassium and carbohydrate status also shape fruit texture, but their effects are more conditional than those of calcium. Carbohydrate availability during fruit development is required for high-quality sweet cherry, and altered phloem transport can produce larger and sweeter fruit that are nevertheless softer when calcium concentration declines and K:Ca and N:Ca ratios rise (Quiroz et al., 2023). Fruit firmness is positively related to calcium concentration and negatively related to K:Ca and N:Ca ratios, indicating that nutrient balance matters as much as absolute potassium supply. This is consistent with production studies showing that fruit grown under high tunnels had lower calcium, higher K:Ca ratios, and lower firmness. At the same time, potassium fertilization can improve firmness and nutrient content, and potassium is widely associated with fruit quality traits such as size, soluble solids, and maturity (Winkler et al., 2020).

3 Key Nutrients Affecting Cherry Fruit Firmness

3.1 Calcium management for firmness enhancement

Calcium management is central to firmness enhancement because calcium accumulation in fruit is closely tied to water delivery, apoplastic transport, and cell wall binding. Fruit calcium distribution depends strongly on water flow and apoplasmic interactions, and localized deficiencies can arise from differences in xylem structure, water relations, and pectin composition (Hocking et al., 2016). In sweet cherry, natural calcium concentration tends to decline during fruit development, indicating that calcium import slows while ongoing fruit enlargement dilutes accumulated calcium (Matteo et al., 2022). Foliar uptake remains possible after fruit set, but timing matters: early applications are generally more effective because young fruit stomata are functional, whereas later uptake increasingly occurs through the epidermis and the pedicel–fruit junction. Evidence from ‘Santina’ also suggests that firmness increases as calcium mass per fruit rises to about 1.3 mg, after which additional calcium shows little further firmness benefit, implying a threshold rather than a linear response (Blanco et al., 2021).