

Calcium enhances firmness primarily by strengthening the cell wall and limiting softening processes.  $\text{Ca}^{2+}$  cross-links pectic polymers, helps form cell wall networks, increases mechanical strength, and can restrict the access of wall-degrading hydrolases (Hocking et al., 2016; Wu et al., 2023). In cherry systems, calcium treatments consistently retard firmness loss and postharvest deterioration: calcium-treated ‘Celeste’ fruit were firmer and had lower weight loss and decay than controls, while calcium-treated sweet cherries in cold storage maintained firmness and showed lower respiration (Belge et al., 2017; Erbaş and Koyuncu, 2021). Mechanistically, exogenous calcium reduces the activity or expression of softening-related enzymes and genes, including pectin methylesterase, polygalacturonase, cellulase,  $\beta$ -galactosidase, and expansin-associated pathways (Jaime-Guerrero et al., 2024). Calcium also helps reduce cracking because stronger and less rupture-prone cell walls better withstand excessive water uptake, and preharvest or postharvest calcium applications have been associated with lower cracking incidence in cherries (Matteo et al., 2022; Varaldo and Giacalone, 2025).

### **3.2 Potassium and magnesium regulation**

Potassium and magnesium regulate cherry quality through complementary effects on growth, carbohydrate economy, and mineral balance. Potassium is the most abundant mineral element in sweet cherry fruit, often exceeding 4 500 mg/kg, and functions as a major osmotic solute that supports cell expansion, stomatal activity, photosynthesis, protein synthesis, and energy metabolism (Zhang et al., 2025). Because of these functions, potassium is closely linked to fruit size and sugar movement; recent work describes it as vital for increasing fruit size, soluble solids, color development, maturity advance, and yield (Erbaş and Koyuncu, 2021). Foliar potassium-based programs in sweet cherry have increased the proportion of marketable large fruit and improved storage firmness, while broader fertilizer studies associate potassium application with increased fruit length, fruit weight, and flesh firmness (Varaldo and Giacalone, 2025). However, potassium effects on firmness are not independent of calcium status. In ‘Santina’, fruit firmness was negatively correlated with the K:Ca ratio, and fruit grown under tunnels had both higher K:Ca and lower firmness, indicating that excessive potassium relative to calcium can weaken the firmness advantage otherwise gained from growth promotion (Blanco et al., 2021).

Magnesium supports firmness more indirectly through its role in photosynthesis and assimilate supply. Magnesium is a component of phytin, pectin, and many enzymes, and it contributes to the transport of both  $\text{K}^+$  and  $\text{Ca}^{2+}$  within plant tissues (Zhang et al., 2025). It is also one of the principal characteristic mineral elements identified in sweet cherry fruit and is required for secondary metabolism and overall plant function (Zhang et al., 2025). By sustaining chlorophyll function, carbon assimilation, and carbohydrate production, magnesium helps maintain the assimilate supply needed for fruit growth and compositional quality. Recent foliar nutrition studies reported that magnesium treatments, particularly moderate-to-high rates, produced sweeter cherries and enhanced color development, consistent with a role in supporting source activity and sugar accumulation (Sandilya et al., 2023; Usmani et al., 2025). Even so, magnesium balance matters: the Mg:Ca ratio was negatively related to firmness in ‘Santina’, which indicates that beneficial magnesium effects on plant physiology do not substitute for adequate calcium in firm fruit tissues (Blanco et al., 2021).

### **3.3 Micronutrients related to tissue strength**

Micronutrients contribute to tissue strength mainly through boron-mediated cell wall stabilization and through zinc- and manganese-dependent enzyme systems. Boron is particularly important because most plant boron is located in the cell wall, where it plays a major role in cell wall formation and mechanical strength (Thakur et al., 2023; Álvarez-Herrera et al., 2025). Boron is also functionally linked with calcium. It interacts with calcium and other nutrients, and boron deficiency can hinder calcium allocation to the tree canopy and edible fruit tissues (Vera-Maldonado et al., 2024). More broadly, boron influences uptake, absorption, and accumulation processes and is slightly mobile in the phloem, which helps explain why deficiency in rapidly growing tissues can disrupt fruit quality (Thakur et al., 2023). In sweet cherry, preflowering boron application increased endogenous boron content at early growth stages, improved fruit set, and promoted mesocarp cell enlargement, indicating that boron supports structural fruit development from the start of the season (Michailidis et al., 2023). Boron also delays