cell wall disassembly processes (Khalaj et al., 2016; Álvarez-Herrera et al., 2025). In apple, postharvest calcium treatment and combined calcium-boron treatment both delayed fruit softening, primarily through reduced pectin solubilization and decreased activities of pectin lyase, β-galactosidase, and α-L-arabinofuranosidase, although calcium treatment showed a stronger effect than boron application alone (Mohebbi et al., 2020). In tomato, Haleema et al. (2024) found that combined Ca+B treatment improved fruit firmness more effectively than either nutrient applied separately, which was attributed to boron-mediated enhancement of calcium metabolism and reinforcement of cell wall cross-linked polymer networks. Liu et al. (2022) reported that calcium treatment increased apricot fruit firmness by 41.53% while reducing the activities of polygalacturonase, β-galactosidase, and pectin methylesterase. Strawberry studies have also shown that foliar boron application can increase fruit firmness and delay firmness loss during storage (Zhang et al., 2024). For blueberry, this synergistic mechanism has strong physiological relevance. During blueberry ripening and storage, continuous pectin solubilization contributes to fruit softening and firmness loss. However, responses under commercial production conditions remain strongly influenced by cultivar characteristics and application timing, and consistent improvements are not observed under all circumstances.

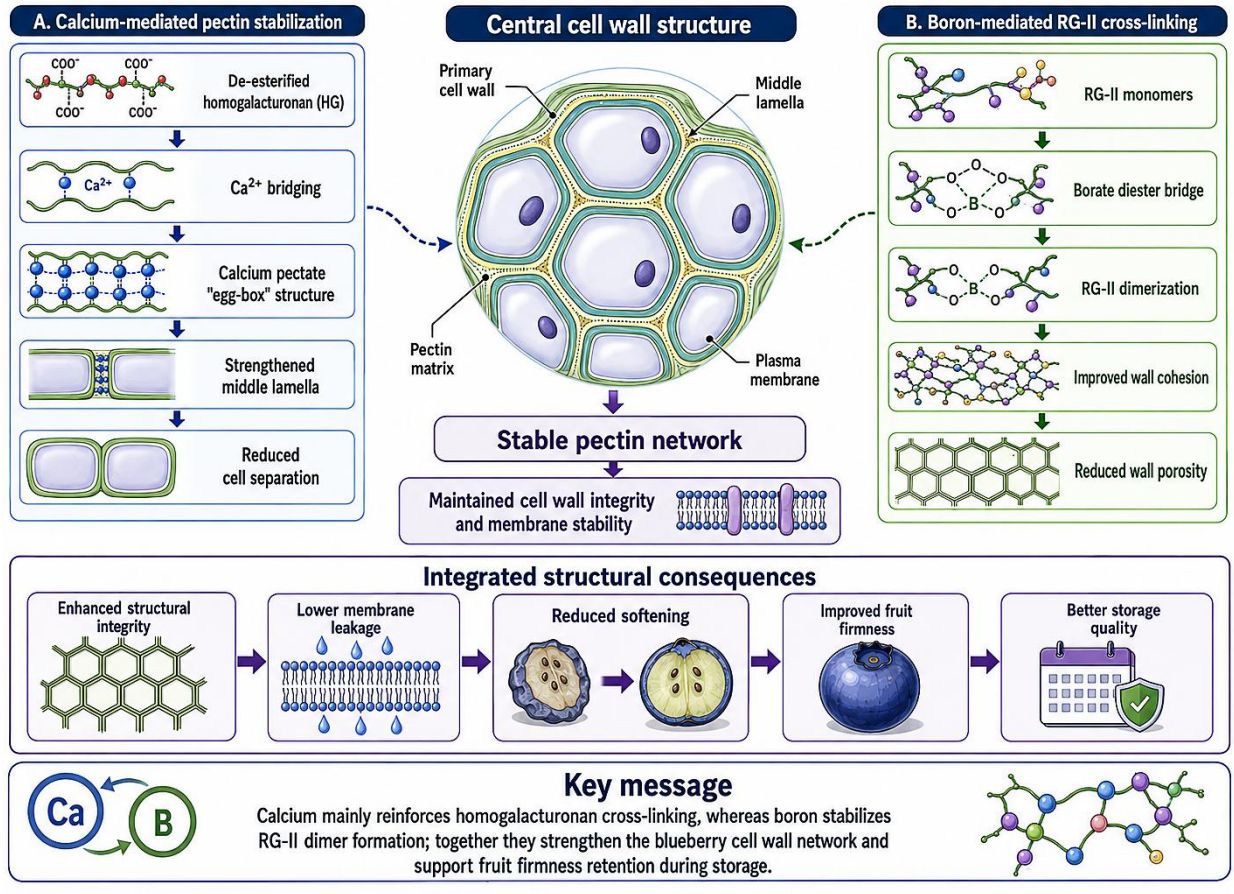


Figure 3 Complementary roles of calcium and boron in maintaining blueberry cell wall integrity

Image caption: Calcium and boron maintain blueberry fruit cell wall stability through complementary functions. Calcium primarily binds to de-esterified homogalacturonan (HG) to form calcium pectate cross-linked structures, thereby enhancing middle lamella stability. Boron promotes RG-II dimerization and borate ester bridge formation, improving pectin network integrity. The synergistic effects of calcium and boron reduce cell wall degradation and membrane damage, thereby delaying fruit softening and improving fruit firmness and storage stability

5.2 Combined effects on fruit development and storage performance

Calcium–boron combined nutrition can improve fruit size and quality components in some fruit crops; however, compared with other fruit trees, blueberry exhibits a more complex response to this combined treatment. El-Motaium et al. (2025) found that combined application of nano-calcium and boron resulted in the highest