Increasing fruit calcium concentration can also reduce pectin solubilization and degradation. Doyle et al. (2021) found that soil calcium application increased cell wall-bound Ca^{2+} concentration in blueberry fruits by approximately 10% at harvest, while increasing the proportion of tightly bound pectin and decreasing loosely bound pectin fractions. These results suggest that calcium can slow down cell wall disassembly processes. Related studies in blueberry have further shown that lower fruit calcium concentrations are often accompanied by higher polygalacturonase activity during storage (Lobos et al., 2021a). During cold storage, Ca^{2+} signaling can suppress the activities of pectin methylesterase and polygalacturonase, thereby delaying the conversion of protopectin and chelator-soluble pectin into water-soluble pectin (Wang et al., 2024).

Multiple blueberry studies have demonstrated that preharvest calcium supplementation can reduce the rate of fruit softening and maintain tissue structural stability during storage. For instance, in 'Liberty' blueberry, early-season foliar calcium application increased fruit firmness by approximately 10% compared with the control, and the effect was greater than that of later applications, indicating that the early fruit developmental stage may represent a critical period for calcium-mediated firmness regulation (Lobos et al., 2021a). Doyle et al. (2021) reported that soil calcium application during the autumn of the previous year also reduced postharvest softening and improved shelf-life performance in the cultivars 'O'Neal' and 'Bluecrop'. From a physiological perspective, calcium mainly maintains fruit firmness by preserving cell wall adhesion, reducing cell separation, and delaying structural deterioration of fruit tissues.

3.3 Calcium effects on postharvest quality preservation

The role of calcium in maintaining postharvest quality depends on its ability to enhance cell wall structural stability, while also being closely associated with the preservation of cell membrane integrity and regulation of water balance. Lobos et al. (2021a) reported that early preharvest calcium sprays reduced weight loss of blueberry fruits during cold storage. The water loss rate was approximately 1% lower than that of the control, and fruit calcium concentration showed a negative correlation with weight loss during storage. Another study also demonstrated that soil calcium application could reduce fruit weight loss after cold storage (Doyle et al., 2021).

Calcium can also reduce decay risk and maintain overall postharvest fruit condition. In 'Liberty' blueberry, early calcium application increased the proportion of healthy fruits after storage while decreasing the proportions of dehydrated and decayed fruits (Lobos et al., 2021a). This protective effect is consistent with the findings of Hocking et al. (2016), who suggested that calcium deficiency increases fruit susceptibility to pathogen infection and promotes abnormal softening, whereas sufficient calcium supply enhances apoplastic barrier function and reduces the risk of quality deterioration.

Calcium nutrition contributes to improvements in blueberry fruit firmness and storage quality; however, its effectiveness depends largely on whether calcium can reach the fruit during early developmental stages and participate in the establishment of stable cell wall and membrane structures. In addition, the response to calcium fertilization is influenced by application timing, transport efficiency, and the intrinsic calcium accumulation capacity of different cultivars (Doyle et al., 2021; Larocca et al., 2025).

4 Effects of Boron Nutrition on Blueberry Fruit Quality

4.1 Boron regulation of fruit development and structural integrity

Boron is an essential nutrient for normal plant growth and development and participates in multiple physiological processes, including cell wall formation, cell membrane maintenance, cell division, cell elongation, and carbohydrate transport. In blueberry, physiological processes such as pollen germination, fertilization, and cell expansion directly influence subsequent fruit set and fruit enlargement, and boron has been shown to be particularly important during flowering and early fruit development stages (De Silva et al., 2022). Studies in other fruit crops also support the promotive role of boron during early fruit development. Michailidis et al. (2023) reported that pre-bloom boron application in sweet cherry increased early fruit set, fruit fresh weight, and mesocarp cell expansion, indicating that adequate boron supply facilitates sink organ establishment and early fruit growth. Similar effects have been observed in pitaya, where boron application improved pollen germination