transport of both elements into fruits is subject to certain limitations. Future sustainable management strategies should integrate leaf and soil testing results, implement precise fertigation or foliar fertilization according to phenological stages, and strengthen pH regulation and rhizosphere ecological management. Lopes et al. (2026) demonstrated that rhizosphere microbial inoculation and other preharvest regulation measures can promote nutrient uptake in blueberry and improve fruit size, yield, and firmness. Therefore, calcium and boron nutritional management should shift from a single fertilizer input model toward an integrated regulation system based on plant requirements, environmental conditions, and quality objectives, thereby achieving coordinated improvement of fruit quality and efficient resource utilization.

7 Concluding Remarks

Calcium and boron are important mineral nutrients affecting blueberry fruit firmness formation and postharvest quality maintenance. Their functions are mainly associated with cell wall structural stability, membrane system maintenance, and fruit development regulation. Calcium forms stable pectin cross-linked structures by binding with de-esterified pectin, thereby enhancing middle lamella stability, reducing pectin degradation and cell separation, and delaying fruit softening. Boron contributes to fruit structural formation through RG-II cross-linking, maintenance of cell wall integrity, and promotion of pollen germination and young fruit development. Both nutrients participate in the construction of cell wall networks, providing a physiological basis for maintaining blueberry fruit texture and storage stability.

Current studies indicate that preharvest calcium supplementation has relatively clear effects on improving blueberry fruit firmness and delaying postharvest quality deterioration; however, its effectiveness is highly dependent on application timing, cultivar characteristics, and calcium transport efficiency into fruits. For example, early preharvest calcium spraying in ‘Liberty’ blueberry increased fruit firmness and reduced weight loss and decay risk, whereas later applications showed relatively limited effects. This difference is mainly related to the fact that calcium transport into blueberry fruits relies predominantly on xylem movement, while fruit transpiration decreases and calcium accumulation capacity declines during ripening. In comparison, boron plays a more stable role in maintaining normal reproductive development and the formation of certain quality traits. However, increasing boron levels in plants or fruits does not necessarily directly translate into improvements in firmness and yield, as its effects are constrained by nutritional status and environmental conditions.

Combined calcium and boron regulation provides a new management approach for improving blueberry quality. Theoretically, calcium mainly enhances pectin network stability, whereas boron contributes to RG-II cross-linking and improves cell wall structure, indicating complementary functions between these two nutrients. However, the synergistic effects of calcium and boron in blueberry production remain highly variable. Some studies have demonstrated improvements in firmness, weight loss reduction, and storage performance, whereas others have not observed significant quality enhancement. These differences indicate that simply increasing calcium and boron inputs does not guarantee improved fruit quality. Instead, the efficiency of nutrient transport into fruits, the synchronization between application timing and critical developmental stages, and the intrinsic nutrient uptake and utilization capacity of cultivars may be more important than fertilizer input levels alone.

Calcium and boron management in blueberry production should shift from a traditional nutrient supplementation approach toward a precision regulation model based on cultivar characteristics, nutritional diagnosis, and fruit developmental stages. Currently, a more reasonable production strategy is to conduct targeted calcium supplementation during the early post-flowering period, evaluate boron deficiency risks according to soil and leaf nutrient status, and improve nutrient utilization efficiency through integrated measures such as drip irrigation, fertigation, and rhizosphere environment optimization. Future research should further investigate calcium and boron uptake and transport mechanisms in blueberry, optimal Ca:B ratios, and differences in cultivar responses, thereby establishing a more precise and efficient quality-oriented nutrient management system to achieve coordinated improvements in fruit firmness, storage life, and resource utilization efficiency.