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Effects of Calcium and Boron Nutrition on Fruit Firmness and Storage Quality of Blueberry

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Abstract Blueberry fruits are prone to softening, water loss, and decay after harvest, and fruit firmness and storage quality have become important factors affecting their commercial value. This study reviews the effects of calcium and boron nutrition on blueberry fruit firmness, storage performance, and quality formation, and analyzes the underlying mechanisms, synergistic effects, and production application strategies of these two nutrients. The results indicate that calcium improves fruit firmness and delays postharvest quality deterioration by promoting pectin cross-linking, enhancing cell wall stability, and reducing the activities of softening-related enzymes. Boron mainly influences fruit development and structural stability through its involvement in RG-II cross-linking, pollen germination, and cell expansion. Combined calcium and boron supply has the potential to synergistically improve fruit quality; however, its effectiveness is influenced by cultivar characteristics, application timing, nutrient transport efficiency, and environmental conditions. Future blueberry nutrient management should integrate nutrient diagnosis, phenological stages, and rhizosphere environment regulation to establish a precision calcium-boron management system, providing a theoretical basis for improving blueberry fruit quality and extending storage life.

Keywords Blueberry; Calcium nutrition; Boron nutrition; Fruit firmness; Storage quality; Precision nutrient management

1 Introduction

Blueberry is an economically and nutritionally important fruit crop worldwide, and its production has expanded rapidly in recent years. Doyle et al. (2021) reported that global blueberry production has increased approximately fourfold over the past two decades. With the growing demand for fresh blueberries, increasing attention has been directed toward postharvest quality maintenance and storage performance (Vance et al., 2017; Lopes et al., 2026). As fresh fruit supply chains continue to extend, blueberries must maintain desirable appearance, texture, and biochemical quality during postharvest transportation and storage (Vance et al., 2017; Manzi and Lado, 2019). Among these quality traits, fruit firmness is a critical indicator of blueberry market value, as it directly affects resistance to mechanical damage, transportation adaptability, and storage life (Olmedo et al., 2021; Hirzel, 2023). However, blueberry fruit is highly susceptible to softening, water loss, and decay after harvest, resulting in quality deterioration and economic losses.

The development of blueberry fruit firmness is closely associated with cell wall structure and mineral composition; therefore, calcium nutrition has become an important target for preharvest quality regulation. Calcium maintains the stability of cell walls and cell membranes, participates in pectin structural maintenance and cellular signaling regulation, and plays a crucial role in preserving fruit texture (Wang et al., 2024; Lopes et al., 2026). Previous studies have shown that higher concentrations of cell wall-bound calcium, together with specific structural characteristics of cell wall polysaccharides, including calcium-associated homogalacturonan domains and xyloglucans, are closely correlated with greater firmness during storage (Olmedo et al., 2021; Lopes et al., 2026). Calcium can also enhance pectin stability, restrict pectin degradation, and reduce the activities of softening-related enzymes, such as polygalacturonase and pectin methylesterase, thereby delaying fruit softening (Jaime-Guerrero et al., 2024; Wang et al., 2024).