(Figure 1). However, under field conditions, the effects of boron fertilization on fruit firmness and yield remain highly variable.

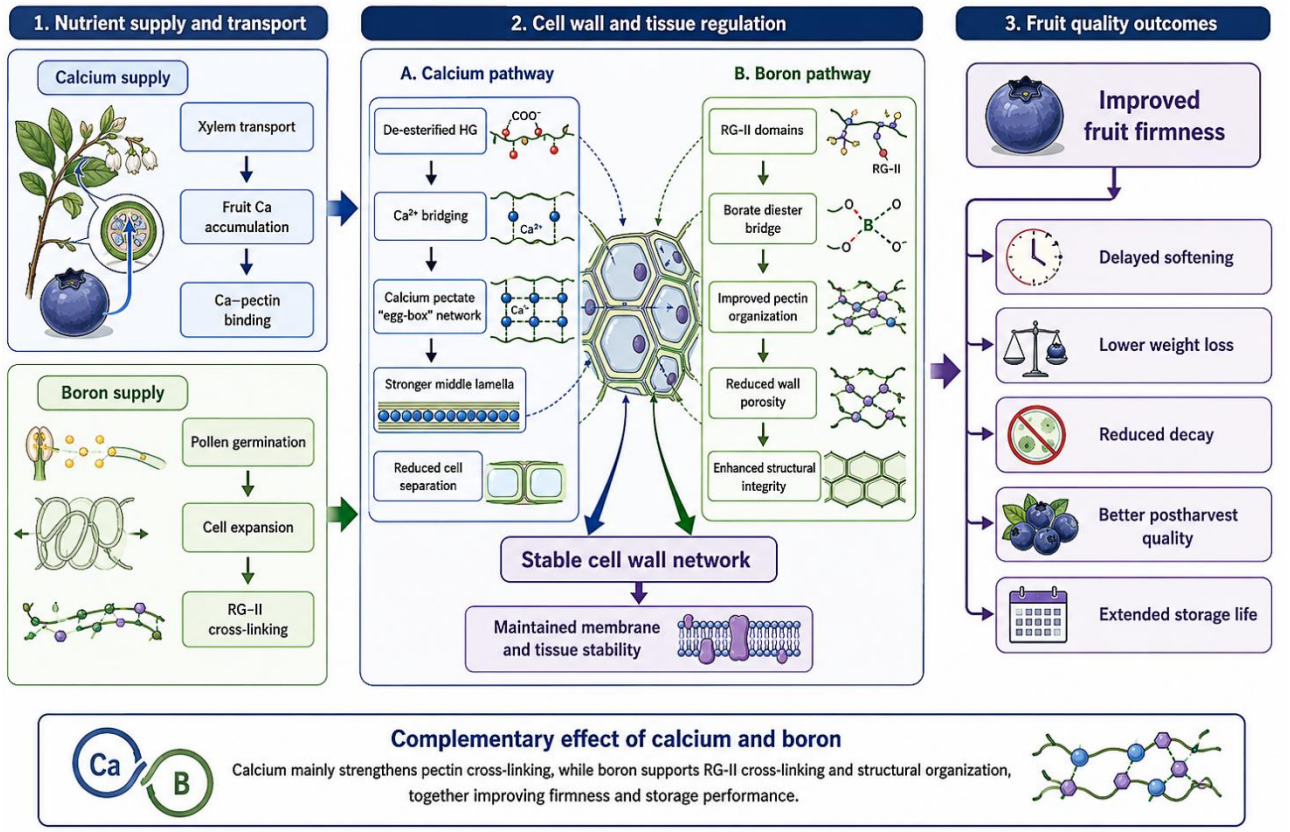



Figure 1 Integrated roles of calcium and boron in blueberry fruit firmness formation and quality regulation

## 3 Effects of Calcium Nutrition on Blueberry Fruit Firmness and Storage Quality

### 3.1 Calcium uptake, transport, and distribution in blueberry plants

Calcium uptake begins in the root system, and its continuous absorption depends on maintaining concentration gradients across root cell membranes and a low cytosolic $Ca^{2+}$ level. Calcium is subsequently transported mainly through the xylem into different plant tissues (Hocking et al., 2016; Jaime-Guerrero et al., 2024). In fruit trees and berry crops, the amount of calcium delivered to fruits is jointly determined by xylem water flow, fruit transpiration, and vascular structural characteristics, while membrane-associated transport systems regulate $Ca^{2+}$ allocation among different tissues (Hocking et al., 2016). Although calcium transport mechanisms in blueberry remain insufficiently characterized, existing studies suggest that fruit transpiration intensity, xylem functionality, and calcium transporter activity are key factors influencing $Ca^{2+}$ uptake and distribution in blueberry fruits, which require further investigation (Doyle et al., 2021).

Calcium accumulation in fruits mainly occurs during the early developmental stage, when cell division, rapid fruit expansion, and xylem transport activity are relatively high. During later developmental stages, the contribution of phloem transport to calcium supply remains limited because calcium has relatively low mobility within the phloem, resulting in reduced additional calcium input into fruits (Larocca et al., 2025; Rojas-Barros et al., 2025). In blueberry, fruit calcium concentration generally decreases progressively during fruit development and ripening (Figure 2). For example, Doyle et al. (2021) reported that calcium concentration in blueberry fruits declined from approximately 0.2% at early developmental stages to below 0.05% at maturity. Manzi and Lado (2019) also observed that calcium concentration in the cultivar 'O'Neal' decreased from 0.32% at 25 days after full bloom (25 DAFB) to 0.11% at harvest.