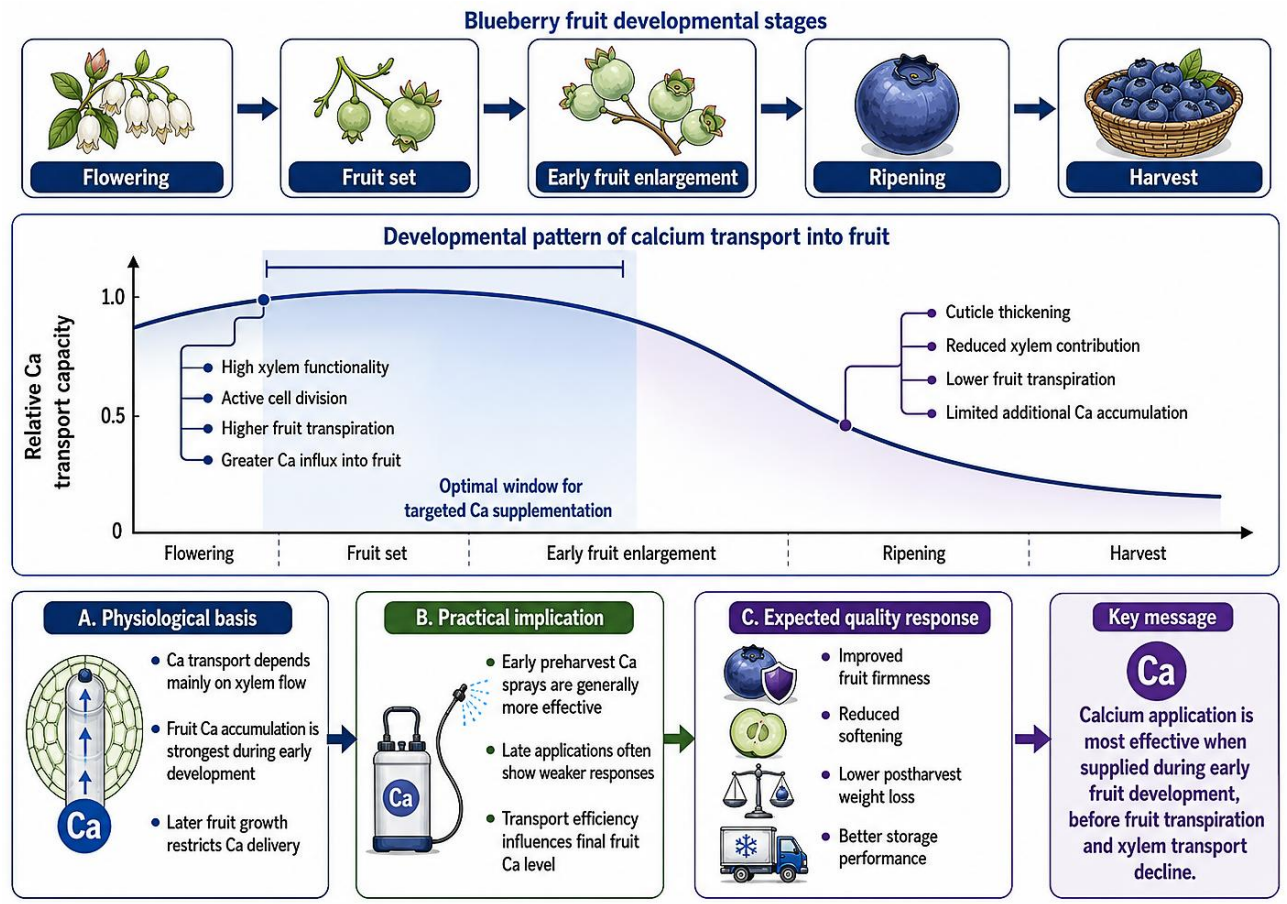


Figure 2 Developmental changes in calcium transport capacity and optimal timing of calcium application in blueberry

Recent hydroponic studies further indicated that calcium uptake in blueberry reaches its peak during periods of rapid vegetative growth, whereas calcium absorption becomes stable or even declines during later fruiting stages. This trend is particularly evident under high-temperature conditions and high vapor pressure deficit environments, which is consistent with the limitation of xylem-mediated calcium transport during late fruit development (Peñuelas-Montoya et al., 2026). Because fruit calcium accumulation is closely associated with transpiration and vascular continuity, calcium transport into fruits is further restricted in related berry crops as fruit development progresses, accompanied by cuticle thickening and reduced xylem functionality. These limitations ultimately affect the maintenance of postharvest quality (Rojas-Barros et al., 2025).

3.2 Effects of calcium application on fruit firmness

The primary mechanism by which calcium enhances fruit firmness is through its binding with de-esterified homogalacturonan in the cell wall, forming calcium pectate cross-linked structures that strengthen middle lamella stability and restrict cell wall degradation processes (Martins et al., 2020; Jaime-Guerrero et al., 2024). In blueberry, higher levels of cell wall-bound calcium are generally associated with greater fruit firmness. For example, Olmedo et al. (2021) compared the cell wall composition of the firm-fleshed cultivar ‘Emerald’ and the soft-fleshed cultivar ‘Jewel’ at harvest and after 30 days of storage at 0 °C. The results showed that ‘Emerald’ had higher concentrations of cell wall-bound calcium and stronger signals detected by the 2F4 antibody targeting calcium-binding HG domains. After 30 days of storage, ‘Emerald’ also exhibited increased glucose content and stronger LM15 antibody signals associated with xyloglucan structures. These findings indicate that firmness differences are not determined solely by total pectin content but are closely related to Ca^{2+}-mediated low-methylesterified HG cross-linking and the stability of xyloglucan networks.