

dormant applications reached flower buds and phloem but not vegetative buds, and postharvest hydrocooling increased tissue Ca while reducing pectin solubilization, splitting, decay, and firmness loss (Wang and Long, 2015; Michailidis et al., 2021).

Another limitation is strong variation among cultivars, seasons, and regions. Calcium effects are not always consistent across studies, and cultivar-specific responses are common (Winkler et al., 2020). In one cherry study, calcium improved firmness in Sweetheart and Regina but not in Bing, and fruit Ca concentration responded significantly only in Regina. Seasonal and regional conditions also reshape nutrient outcomes: year effects strongly altered fruit size and quality in Mg/K fertilization trials, and temperature and rainfall were identified as major influences on cherry quality responses (Santos et al., 2024). Even orchards under similar management can differ because of soil texture, pH, age, and rootstock effects, which complicates the transfer of fertilizer recommendations across regions (Karampatzakis et al., 2025).

7.3 Future development trends

Future development will likely center on precision nutrient management based on fruit demand rather than fixed fertilizer schedules. Precision approaches aim to supply the right nutrient amount at the right time and place using real-time information on soil conditions, plant health, and nutrient status (Singh et al., 2024). In cherry, this direction is supported by yield-based nutrient-removal models, where fresh fruit yield showed strong relationships with uptake of N, P, K, Mg, B, and Cu, enabling prediction of orchard nutrient losses (Karampatzakis et al., 2025). Because large fractions of N, P, K, and Mg remain in leaves and prunings, future programs should integrate nutrient recycling with external inputs rather than treating annual fertilization as one-way replacement. Sustainable organic options may also contribute, since compost tea plus compost improved tree water status, photosynthetic performance, yield, and fruit quality in an organic cherry orchard (Gaeta et al., 2025).

A second major trend is the integration of sensors, prediction models, and quality analytics to connect orchard nutrition with firmness and shelf-life outcomes. Reviews of precision nutrient management in fruit crops emphasize remote sensing, variable-rate technology, fertigation, and data-driven decision tools, but also note that validation for specific fruit crops remains limited (Singh et al., 2024). New sensing studies in other fruit systems show that hyperspectral imaging and machine learning can non-destructively predict soluble solids, nutrients, vitamin C, and protein across varieties and seasons, while soil-sensor networks can estimate harvest quality traits from field measurements (Elashmawy and Uysal, 2023; Zhai et al., 2025). Broader Agriculture 4.0 reviews similarly argue that multimodal sensors and AI can improve real-time fruit quality evaluation, although interpreting interacting effects of nutrient imbalance, stress, and disease remains technically complex (Colaco and Kamat, 2025). For cherry, the next step is to combine these tools with nutrient-uptake models and postharvest indicators so that fertilization decisions can be evaluated not only by yield, but by predicted firmness retention, cracking risk, and storage performance.

8 Conclusions and Perspectives

Nutrient regulation is an important approach for improving cherry fruit firmness and storability. Among the relevant nutrients, calcium is most directly associated with fruit firmness and storage performance. Calcium strengthens cell wall structure, maintains membrane system stability, and is closely related to reduced fruit cracking and decay, as well as higher firmness at harvest and during storage. However, the regulatory effect of calcium is strongly constrained by fruit developmental physiology. As fruit enlarge and xylem function declines, calcium influx into the fruit gradually weakens, and fruit calcium concentration is also likely to decrease because of dilution effects. Potassium plays a positive role in promoting fruit enlargement, sugar accumulation, and ripening, and some studies have also shown that it helps maintain firmness. Nevertheless, excessive potassium supply may increase the K:Ca ratio, disrupt calcium and magnesium balance, and consequently weaken fruit storage performance. Magnesium mainly acts indirectly by supporting photosynthesis, carbon assimilation, and quality formation, and its contribution to firmness improvement usually depends on an appropriate