

These metabolic responses arise through both concentration effects and true biosynthetic regulation, and fertilizer status modifies them further. In Shiraz grape, water deficit reduced berry size, increased the skin-to-pulp ratio, and thereby increased phenolic concentration indirectly, but it also exerted a direct effect on biosynthesis that varied with stress timing and severity. In white grape, prolonged drought altered 4 889 genes, increased phenylpropanoids, monoterpenes, and tocopherols, and modulated 18 phenylpropanoid, 16 flavonoid, 9 carotenoid, and 16 terpenoid structural genes, showing that drought broadly reprograms secondary metabolism beyond anthocyanins alone (Savoi et al., 2016). Nutrient status interacts with these pathways because potassium improved anthocyanin, ellagic acid, and vitamin C accumulation in blackberry under ammonium nutrition, and strategic nutrient supply is recognized as a tool for modifying anthocyanin biosynthesis and fruit quality (Duan et al., 2023). For *R. chingii*, this supports a mechanism in which moderate water regulation and balanced fertilization not only maintain yield, but also reshape phenylpropanoid, flavonoid, terpenoid, and related pathways to determine the accumulation of medicinally active compounds and the final quality of the fruit.

6 Current Research Problems in *Rubus chingii* Water-Fertilizer Management

6.1 Insufficient understanding of water and fertilizer requirements at different growth stages

A primary problem in current *Rubus chingii* research is the lack of precise knowledge about water and fertilizer requirements across different growth stages, even though evidence from other fruit crops shows that the sensitivity of yield and quality traits changes sharply with phenology. In mango, irrigation amount and fertilizer rates at flowering, fruit expansion, and ripening contributed differently to yield, WUE, sugar, vitamin C, and carotenoids, and the recommended schedule required different fertilizer inputs at each stage rather than a single fixed regime (Sun et al., 2022). Tomato studies likewise show that irrigation amount is the primary determinant of yield and WUE, but fruit quality traits are affected differently by fertilizer applications in early, middle, and late reproductive stages, indicating that static fertilizer ratios cannot fully meet dynamic crop demand. Kiwifruit provides especially direct evidence that water-fertilizer deficit thresholds vary by stage: stage II and III deficits mainly changed physical quality, whereas stage III and IV deficits more strongly improved chemical quality, with different optimal deficit thresholds for water and fertilizer (Zha et al., 2023).

This gap is important for *Rubus chingii* because stage-specific regulation likely determines not only fruit yield but also medicinal-quality formation, yet current evidence is still too sparse to define critical windows for irrigation and fertilization. Melon experiments show that fertilization significantly affected net photosynthesis during flowering and fruiting, while growth then became the strongest direct driver of yield and quality, indicating that stage-specific water-fertilizer effects operate through changing physiological bottlenecks over time (Yang et al., 2023). Raspberry production research also shows that fruiting responses differ by fertilization system, and biologically supported mineral systems increased fruiting laterals, fruits per lateral, fruit weight, and soluble solids, suggesting that reproductive-stage nutrient demand is not captured well by conventional uniform fertilization schemes (Pešaković et al., 2026). Even in controlled strawberry systems, most water management strategies still rely on rigid schedules rather than variable plant requirements over time, and comprehensive comparisons remain limited, which underscores how underdeveloped dynamic demand-based management remains across berry crops (Hutchinson et al., 2025).

6.2 Need for improvement in water and fertilizer management systems and production standards

A second major problem is that water-fertilizer management systems and production standards for *Rubus chingii* are still insufficiently standardized, especially for precise irrigation, fertigation, and sustainability-oriented input control. Kiwifruit research states this problem explicitly: orchard water and fertilizer management lacked quantitative standards, and this seriously affected yield and quality, making regulated drip irrigation and fertilization necessary for green and efficient production (Zha et al., 2023). The broader fruit-crop literature shows that drip fertigation can synchronize water and nutrient delivery with crop demand and often serves as the basis for benchmark management schedules, yet its performance depends strongly on local climate, soil, and managerial conditions (Han et al., 2023). In China-wide meta-analysis, drip fertigation increased crop yield by 12.0%, water