

4.2 Effects of water and fertilizer regulation on sugar-acid composition and nutritional quality of fruits

Sugar-acid composition is one of the main determinants of fruit flavor and eating quality, and water-fertilizer management consistently changes soluble solids, soluble sugars, titratable acidity, and sugar-acid ratio across fruit crops (Kılıç et al., 2021; Yang et al., 2023). In mango, irrigation amount was the strongest factor affecting soluble solids and total sugar content, and the treatment with 75% ETc plus stage-specific fertilization produced the highest total sugar content and the lowest titratable acid content, while a different full-irrigation treatment gave the best soluble solids, vitamin C, and carotenoid contents (Sun et al., 2022). In wine grape, moderate irrigation reduced titratable acid by 3.3% and increased sugar-acid ratio by 12.2%, while lower irrigation reduced acid further and increased sugar-acid ratio by 20.0%, showing that water deficit often improves flavor balance up to a point (Han et al., 2023). Strawberry responds similarly: as soil moisture decreases, soluble sugar rises, titratable acidity falls, and the sugar-acid ratio increases markedly, although stronger stress also reduces yield, so the recommended irrigation level is about 70~80% of field capacity when balancing flavor and production (Yang et al., 2025).

Fertilizer strategy also affects nutritional quality beyond sugars and acids. In strawberry, fertilizer application significantly changed soluble solids, total acidity, vitamin C, and individual sugars, and organic fertilizer increased SSC and glucose but reduced vitamin C relative to conventional chemical fertilizer (Kılıç et al., 2021). In loquat, humic-acid water-soluble fertilizer increased single-fruit weight, raised total soluble sugar by 18.58~21.25%, reduced total organic acid by 13.73~21.50%, and increased sweetness value and sugar/acid ratio, although vitamin C declined at one concentration and total phenols and carotenoids were unchanged (Xing et al., 2026). In melon and tomato, irrigation amount remained the primary determinant of fruit quality indices, including soluble solids, vitamin C, soluble sugars, lycopene, and titratable acidity, while fertilizer timing at later reproductive stages contributed strongly to quality optimization (Yang et al., 2023). For *R. chingii*, whose ripe fruit is consumed directly and processed into multiple food products, these results indicate that regulating water deficit within a moderate range and coordinating fertilizer supply by developmental stage should help improve sweetness, acid balance, and nutritional value, but excessive stress or overfertilization could impair stability of quality formation (Yu et al., 2019; He et al., 2023; Wu et al., 2024).

4.3 Effects of water and fertilizer management on the accumulation of medicinal active compounds

For *Rubus chingii*, fruit quality is not defined only by sensory quality but also by the accumulation of medicinally active compounds, especially ellagic acid, kaempferol-3-O-rutinoside, flavonoids, terpenoids, phenolic acids, and related metabolites (Sheng et al., 2020; Wu et al., 2024). The Chinese Pharmacopoeia uses ellagic acid and kaempferol-3-O-rutinoside as index components, with minimum contents specified for quality control, which makes agronomic regulation of these compounds directly relevant to medicinal raw-material quality (Figure 2) (He et al., 2023). Evidence from broader fruit and medicinal-plant research shows that plant nutrient status strongly affects anthocyanins and other polyphenols, and finely tuned fertilization in amount and timing can improve fruit quality by regulating anthocyanin accumulation (Jezek et al., 2018). A general review of fertilization and plant polyphenols further shows that lower fertilization levels can increase flavonols and ellagic acid in strawberry, that high nitrogen often lowers polyphenol accumulation, and that the effect of NPK depends strongly on combination and crop context (Heimler et al., 2017).

The interaction between water stress and fertilization is especially important for secondary-metabolite formation because moderate stress can stimulate protective metabolism, whereas severe stress tends to damage protein status and membrane integrity. In medicinal plants, mild to moderate drought increased phenolics, flavonoids, and anthocyanins, while organic fertilizers such as vermicompost and azocompost stabilized antioxidant activity, reduced oxidative damage, and produced the strongest biochemical enhancement under moderate stress. Meta-analysis of medicinal plants shows that both organic and inorganic fertilizers can increase active constituents, while combined fertilization often gives the best balance between compound accumulation and soil sustainability. In blackberry, $\text{NH}_4^+\text{-N}$ promoted anthocyanin, ellagic acid, and vitamin C accumulation, and polyphenols, ellagic acid, and anthocyanins were positively correlated with sugar content and fruit weight,