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Regulation of Sugar-Acid Balance During Kiwifruit Fruit Development and Ripening

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Abstract Kiwifruit flavor and commercial quality are largely determined by sugar–acid balance, the formation of which involves complex regulation of carbon metabolism throughout fruit development, ripening, and postharvest stages. This study examines the dynamic changes in sugars and organic acids in kiwifruit and their metabolic, molecular, and environmental regulatory mechanisms. The results indicate that starch accumulation and organic acid formation are prominent during fruit development, whereas during ripening and post-ripening, starch is rapidly degraded and converted into sucrose, glucose, and fructose, while the decline in total acidity is mainly associated with citrate degradation. AGPase, BAM, SUS, SPS, INV, and genes involved in citrate synthesis, degradation, and vacuolar transport jointly participate in sugar and acid metabolism. Regulatory modules such as AcNAC1–AcALMT1 and AcPUB11–AcCTS1–AcBAM3 further elucidate the molecular basis of sugar–acid balance. Ethylene, ABA, temperature, light, water and fertilizer management, crop load, and postharvest treatments can regulate fruit flavor by affecting carbon allocation, starch degradation, and organic acid metabolism. Future studies should strengthen multi-omics analyses, spatiotemporal regulation, and germplasm-specific differences to provide a theoretical basis for flavor quality evaluation, molecular breeding, and precision cultivation of kiwifruit.
Keywords Kiwifruit; Sugar–acid balance; Sugar metabolism; Organic acid metabolism; Quality regulation

1 Introduction

Kiwifruit flavor and market quality are strongly shaped by sugar–acid balance, because soluble sugars, organic acids, and their ratio determine sweetness, sourness, overall flavor intensity, and consumer preference. Soluble sugars and organic acids are repeatedly identified as the principal contributors to kiwifruit flavor and palatability (Titeli et al., 2023). In kiwifruit, sweetness is especially important for overall eating quality, yet it is not perceived independently, because the sensory expression of sweetness is modified by concurrent acidity and volatile composition (Nardozza et al., 2013). Consumer studies further show that acceptance rises with improved ripe soluble solids and an appropriate acid background, whereas fruit with insufficient sweetness or unfavorable acid balance are judged less acceptable or more sour (Wang et al., 2025). Consistent with this, fruit differing in carbohydrate supply, orchard origin, cultivar, or storage condition show measurable differences in acidity, sugar accumulation, flavor perception, and eating quality, indicating that sugar–acid balance is not only a biochemical trait but also a practical determinant of commercial value (Lievre et al., 2021).

The sugar–acid ratio therefore serves as a key indicator of fruit maturity and market quality in kiwifruit. Studies on commercial and postharvest fruit show that soluble solids concentration is a primary ripening criterion, while the interaction between soluble solids and titratable acidity is closely linked to taste quality and consumer acceptance (Titeli et al., 2023). Early-harvest experiments in ‘Hayward’ demonstrated that fruit with higher ripe soluble solids were consistently preferred, and that acidity became especially important when sweetness remained low. At the same time, orchard comparisons showed that sugar/acid ratios differ during maturation and are associated with acceptable versus unacceptable eating quality, with poorly matured fruit showing weak flavor intensity and off-flavors. Recent sensory-metabolomic work also identifies sugar-acid ratio as a major driver of consumer preference among flesh-color types and as a metabolite-derived index elevated during post-ripening