5.2 The impact of cultivation modes (protected vs. open-field) on quality

Comparisons of strawberries grown in high tunnels versus open-field systems indicate that protection modifies microclimate and can alter acidity and phytochemical profiles. In coastal Virginia, ten cultivars grown simultaneously in high tunnels and open field showed no significant environmental effect on total soluble solids, but titratable acidity and anthocyanin content were higher under high tunnels, implying a slightly tarter flavor with more intense color in protected systems (Osatuke and Pritts, 2021). A separate metabolite-focused study likewise found that titratable acidity was highest in high-tunnel 'Albion', while soluble solids and pH did not differ significantly between cultivation modes, suggesting that tunnels mainly enhance organic acid and phenolic accumulation rather than basic sweetness (Šimková et al., 2024).

Light-filtering structures such as colored shade nets provide a more targeted approach to modifying flavor-related traits under protection. Under beige and blue photoselective nets, total soluble sugars increased by about 42% compared with unshaded controls, and beige nets also raised titratable acidity by 24%, resulting in fruit with both higher sweetness and more pronounced sourness (Devi et al., 2024). In contrast, greenhouse LED supplemental lighting with controlled color temperature increased soluble solids and titratable acidity concurrently but reduced fruit firmness and single-fruit weight, highlighting trade-offs between sweetness-acidity enhancement and certain physical quality attributes in protected cultivation (Patel et al., 2023).

5.3 The impact of fertilization and post-harvest treatments on sugar and acid accumulation

Nutrient management significantly affects basic taste components, although effects can differ among fertilizer types and rates. Under protected fertigation, supplying 100% of the recommended NPK dose produced the highest total soluble solids, total sugars, and TSS:acidity ratio, while simultaneously minimizing titratable acidity, thus clearly shifting flavor toward greater sweetness and milder sourness (Aragón-Ramírez et al., 2025). In contrast, a comparison of organic, chemical, and combined fertilization showed that organic fertilizer generated fruit with higher soluble solids and glucose but lower firmness and vitamin C, and did not significantly alter citric acid content, suggesting that organic inputs may enhance sweetness primarily via increased sugars without strongly changing major organic acids (Cvelbar Weber et al., 2021).

More detailed work on nitrogen, calcium, and nano-fertilizers indicates that conventional N and Ca fertilization can markedly modify sugars, organic acids, and volatiles, often with negative consequences for overall flavor. Higher N and Ca doses increased certain aldehydes associated with grassy notes, while nano-fertilizer treatment improved phenolic content and fruity esters, illustrating that some innovative inputs can improve flavor-related metabolite profiles even when basic sugars and acids are only moderately affected (Ikegaya, 2023). Postharvest light and signaling treatments further modulate sugar-acid traits: red LED storage increased total soluble solids, whereas combined blue light and salicylic acid maintained low but stable TSS and titratable acidity, helping preserve an acceptable sugar-acid ratio while extending shelf life (Kilic et al., 2021; Xu et al., 2023).

6 Breeding Strategies for Improving Strawberry Sweetness and Acidity Quality

6.1 Traditional breeding methods and the selection of superior varieties

Conventional strawberry breeding has historically relied on controlled hybridization among elite cultivars followed by multi-year field selection for yield, disease resistance, appearance, and organoleptic quality, including sweetness and acidity balance. Long-term evaluations show that recurrent selection can generate cumulative genetic gain for soluble solids content (SSC) and titratable acidity (TA), confirming that both traits possess exploitable heritable variation and can be shifted upward or downward according to breeding goals (Pedrozo et al., 2023).

Selection of superior varieties increasingly integrates sensory panels and detailed physicochemical measurements. Studies comparing cultivars under commercial-like conditions demonstrate wide variability in SSC, TA, SSC/TA ratio, and volatile composition, with certain cultivars such as 'Flavorfest', 'Albion', and FL 00-51 consistently achieving higher sweetness, better flavor ratings, and more favorable SSC-TA combinations across harvests and environments (Liu et al., 2023). Multivariate approaches combining yield, SSC, TA, color, and bioactive compounds further support simultaneous selection for production and taste traits, enabling identification of hybrids suited to both fresh consumption and processing markets.