Evidence on volatile compounds and aroma characteristics is more limited, but fertilizer regime clearly affects berry aroma composition. General berry-development studies by Yılmaz et al. (2024) show that aroma synthesis becomes prominent during ripening, after sugar accumulation and pigmentation intensify. In Hanxiangmi table grape, nutrient-related K treatments increased volatile free aroma compounds, especially terpenes such as linalool, nerol, and citronellol, alongside higher TSS and lower acidity under the combined treatment (Chen et al., 2022). More broadly, vineyard management studies conclude that fertilization can substantially alter sugar content, polyphenolic profiles, and therefore sensory attributes of grapes and wines (Jiang et al., 2024).

6.3 Effects on external and nutritional quality

Organic fertilization can improve berry size, firmness, color, and overall appearance, but these traits respond strongly to fertilizer formulation. In Shine Muscat, organic fertilizer substitution improved berry morphology, and path analysis identified vertical diameter and single-berry weight as major contributors to yield gains (Huang et al., 2026). In greenhouse grapes, commercial organic fertilizers increased early yield, whereas sheep manure and corn-stover treatments reduced it, implying that amendment maturity and nutrient balance affect berry development and marketable appearance (Wu et al., 2024). Increased organic fertilizer with reduced chemical fertilizer also improved flesh firmness in arid-area grapes (Wu et al., 2021). Evidence from related preharvest organic stimulants is consistent with these traits being nutritionally sensitive: molasses-based treatments improved berry coloration, firmness, and TSS while lowering acidity in Crimson Seedless (Samaan et al., 2026). Berry color is especially important in red cultivars because it directly affects consumer appeal and price, and improvements in anthocyanin accumulation generally translate into better external appearance (Salama et al., 2023).

The strongest consensus concerns nutritional quality and antioxidant capacity. Koureh et al. (2019) reported that organic fertilization produced the highest antioxidant activity, total phenolics, and valuable flavonoids in white seedless grapes. In Shine Muscat, organic substitution increased vitamin C content (Huang et al., 2026). Royal grape studies of Kaya et al. (2025) further showed that organic fertilization altered berry mineral composition, hormone levels, and antioxidant enzyme activities, indicating that nutritional improvement extends beyond sugars and phenolics alone.

7 Integrated Organic Nutrient Management in Vineyard Production

7.1 Combined use of organic and mineral fertilizers

Partial substitution of chemical fertilizers with organic fertilizers is the most consistently supported strategy. In Shine Muscat, reducing N by 20%-30% and adding organic fertilizer increased yield, improved sugar–acid balance, and produced the highest economic return, whereas substitution above 40% reduced economic benefit (Huang et al., 2026). In Superior grapevines, mineral N at 60% with 20% organic and 20% biofertilizer improved growth, yield, and berry quality, and replacing 40% of mineral fertilizer was recommended as a practical reduction target (Muhammed et al., 2023). Similar results were reported by Alsalhy et al. (2021) in Flame Seedless, where using 25%-50% of N requirement as mineral fertilizer plus organic and biofertilizer improved vine nutrient status, yield, fruit quality, and packable yield while lowering production costs and pollution risk. Humic- and fulvic-acid substitution also fit this pattern, with 75% of N requirement plus humic or fulvic acid improving vine nutrient status, yield, fruit quality, and some soil properties while reducing environmental costs from excess mineral N (El-Salhy et al., 2023).

The agronomic rationale is that mineral fertilizers provide immediate nutrient availability, whereas organic fertilizers strengthen long-term soil fertility. Combined organic–inorganic fertilization increased soil available N, P, and K, shoot growth, photosynthesis, yield, and fruit quality under drip irrigation in an arid vineyard, with 50% organic plus 50% inorganic fertilizer recommended at 720 mm irrigation (Chen et al., 2023). Commercial organic fertilizers combined with inorganic basal fertilization also improved early Shine Muscat yield and provided more comprehensive nutrient supply than chemical fertilizer alone (Wu et al., 2024). More generally, Luo et al. (2024) reported that joint organic–mineral fertilization improves soil P activation better than mineral fertilizer alone, which helps explain its value in low-fertility soils. However, balance is essential: sewage-sludge compost increased N