stable genetic loci and selection signals associated with fruit quality and morphology have been identified in grape germplasm, providing a foundation for targeted improvement. Collectively, these findings indicate that berry uniformity is a multidimensional trait with significant economic value that can be clearly defined, accurately measured, and genetically dissected.

Improving berry uniformity requires coordinated efforts in cultivar selection, molecular breeding, and field management. High-density genotyping, genome-wide association studies, and SNP array technologies, combined with high-throughput phenotyping, enable precise identification of genetic loci associated with berry size, cluster structure, and stress resistance, thereby supporting marker-assisted selection and future gene-editing approaches. Meanwhile, advanced breeding strategies such as genomic selection, clonal selection, and polyploidization, together with the integration of multi-omics data, can effectively accumulate favorable alleles and achieve the coordinated improvement of berry traits, fruit quality, and stress tolerance. In addition, digital phenotyping and remote sensing technologies can guide thinning practices, canopy management, and water-nutrient regulation, ensuring that cultivation practices are aligned with genetic potential and promoting synchronized berry development and stable fruit quality. Future progress in improving grape berry uniformity will depend on advancing standardized trait evaluation, precision management, and intelligent production systems. On the one hand, intelligent algorithms based on foundation models such as SAM and deep learning techniques (e.g., AS-SwinT and Mask R-CNN) have enabled automated berry segmentation, counting, and size measurement, laying the groundwork for standardized, machine-readable phenotypic data systems for uniformity and cluster compactness. On the other hand, integrating phenomics, genomics, and environmental monitoring data with machine learning models will enhance the prediction of yield and fruit quality, enabling precision management and selective harvesting based on spatial variability. Furthermore, combining variable-rate irrigation and fertilization technologies with optimization algorithms and IoT-based control systems can improve resource use efficiency and stabilize berry development. Overall, establishing unified data standards, shared trait ontologies, and integrated “perception-decision-execution” systems will be essential pathways for achieving stable improvements in grape berry uniformity and advancing intelligent production systems.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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