Berry uniformity not only affects appearance but also leads to spatial heterogeneity in fruit quality. Differences in berry size and structure can alter the ratio of pulp to skin, thereby influencing sugar-acid composition, coloration, and antioxidant capacity, ultimately resulting in uneven eating quality within the same cluster. This heterogeneity increases the difficulty of grading, reduces packaging and transportation efficiency, and may diminish commercial value and cause economic losses. Although grape germplasm exhibits abundant genetic diversity in berry size, shape, and cluster structure (Gharate et al., 2025), most existing studies focus on individual traits such as berry diameter or cluster compactness, while systematic quantitative evaluation of "uniformity" as an integrated trait remains limited. Moreover, inconsistencies in evaluation methods among studies restrict the comparability and practical application of research findings.

This study focuses on berry uniformity as a key trait in grapevine, systematically reviewing its conceptual framework, evaluation methods, and influencing factors, and further exploring its application in cultivar selection and cultivation management strategies. The aim is to provide theoretical foundations and technical references for improving table grape quality and promoting standardized production. In recent years, advances in phenomics and quantitative genetics have provided new approaches for the precise assessment and genetic improvement of berry uniformity. High-throughput quantification of berry size distribution and cluster architecture can be achieved through digital image analysis and two- and three-dimensional segmentation techniques. Meanwhile, QTL mapping and genome-wide association studies have identified multiple genetic loci associated with berry size and cluster structure. Combined with marker-assisted selection and optimized cultivation practices, these approaches offer promising opportunities for the coordinated improvement of berry uniformity.

2 Conceptual Framework of Grape Berry Uniformity

2.1 Conceptual components of berry uniformity

Grape berry uniformity is a comprehensive visual trait that not only reflects the consistency of individual berry size but also involves the coordination of spatial distribution within a cluster. At the intra-cluster scale, uniformity mainly refers to the low variability in berry length, width or diameter, weight, and shape, resulting in high visual consistency among berries located at different positions within the cluster. At the whole-cluster scale, uniformity also encompasses the spatial arrangement of berries along the rachis and its branches, including whether the distribution is balanced and whether local overcrowding, sparsity, or berry deformation due to compression occurs (Torres-Lomas et al., 2024).

In practical production, berry uniformity is the result of the combined effects of genetic background, reproductive development, and cultivation environment. Factors such as pollination quality, fruit set rate, seed development, berry growth rate, and the balance of assimilate distribution all influence berry size and the synchronization of ripening. Studies have shown that berries from different genotypes or with different seed numbers exhibit significant differences in size and uniformity, indicating that uniformity has a strong genetic dependency and developmental basis (De Oliveira et al., 2026). When berry development is synchronized and spatial distribution is well balanced, clusters typically display a full, orderly, and marketable appearance; otherwise, problems such as mixed berry sizes, local crowding, or excessive gaps may occur.

In addition, different grape cultivars exhibit substantial variation in cluster structure and berry development patterns. Some cultivars naturally produce compact clusters, which may enhance visual fullness but excessive compactness can lead to berry compression and deformation. In contrast, loosely structured clusters may reduce compression but can result in uneven spatial distribution and reduced visual coordination (Torres-Lomas et al., 2024). Therefore, berry uniformity should not be simply interpreted as "larger berries are better" or "more compact clusters are better," but rather as a comprehensive expression of size consistency, shape uniformity, and coordinated cluster architecture.

2.2 Key phenotypic traits of berry uniformity

Among the factors contributing to berry uniformity, berry size traits represent the most direct and fundamental basis for evaluation. Berry length, width (or diameter), and single-berry weight are commonly used descriptors of berry size, and these traits are often positively correlated, meaning that a berry large in one dimension is typically