distribution, a clean appearance, and strong market appeal, whereas clusters with obvious size variation, local overcrowding, or excessive sparsity are more likely to be downgraded.

Within scientific evaluation systems, the descriptors established by the International Organisation of Vine and Wine (OIV) provide a relatively standardized basis for visual grading of grape clusters and berries. For example, OIV 204 is used to evaluate cluster compactness, and OIV 221 is used for berry size classification. Evaluators typically assign compactness levels ranging from very loose to very compact based on cluster appearance and determine berry size grades according to berry diameter ranges. This method is simple to operate, low in cost, and requires minimal instrumentation, and thus remains widely used in field surveys, germplasm characterization, and production grading.

However, visual grading is inherently semi-quantitative and experience-based, making it susceptible to evaluator expertise, interpretation of scoring scales, and subjective bias. Particularly in populations with small phenotypic differences, different evaluators may assign different scores to the same cluster, leading to reduced reproducibility and comparability of data (Sharma et al., 2025). In addition, traditional berry size grading often employs relatively coarse classification scales, making it difficult to detect subtle differences in berry size distribution within clusters and unable to accurately reflect spatial distances among berries, internal void proportions, or local crowding within clusters. Therefore, although visual grading retains practical value in production, it is insufficient for detailed analysis of berry uniformity under the demands of modern grape production, which emphasizes standardization, precision, and efficient breeding selection.

3.2 Quantitative evaluation methods

To overcome the subjectivity of traditional visual grading, the evaluation of grape berry uniformity has gradually shifted from qualitative description to quantitative analysis based on continuous variables. This approach constructs a multi-indicator evaluation system by measuring individual berry traits such as length, width, diameter, weight, area, and volume, as well as structural traits including berry number per cluster, cluster length, width, and weight. Among these, berry size distribution serves as the foundation for assessing size consistency. By analyzing the mean, standard deviation, and range of berry size or weight, the degree of concentration and dispersion within a berry population can be directly quantified, providing a preliminary basis for evaluating uniformity.

Among various statistical indicators, the coefficient of variation (CV) is one of the most widely used parameters for uniformity evaluation. CV describes trait dispersion as the ratio of standard deviation to mean, effectively eliminating the influence of different measurement scales and mean values, thereby improving comparability among materials. For a given cluster, smaller CV values for berry diameter, weight, or volume indicate more concentrated distributions and higher uniformity, whereas larger CV values indicate greater variability. Somogyi et al. (2021), in a study on 'Italia' grapes, found significant differences in the CV of berry weight and circumference among berries with different seed numbers, with seedless berries showing higher variability and seeded berries generally exhibiting greater uniformity, highlighting the important biological role of seed number in determining berry uniformity.

Beyond berry size, cluster compactness provides a critical structural dimension for evaluating uniformity. Compactness reflects the integrated relationship among berry number, berry volume, and rachis structure, and can be quantified using metrics such as berry number per unit cluster length, the ratio of berry area to projected cluster area, or the ratio of total berry volume to cluster volume (Meneses et al., 2025). Compared with single size metrics, compactness better captures the spatial arrangement of berries. For instance, clusters with similar average berry size may exhibit different levels of uniformity due to differences in berry number or internal void space. Therefore, uniformity evaluation should be based on multi-indicator integration, considering both size consistency and spatial structural coordination.

3.3 Modern technological approaches

With the development of computer vision and intelligent agricultural technologies, high-throughput phenotyping methods based on digital image analysis have become important tools for evaluating berry uniformity.