from less than 1 g to approximately 10 g, closely associated with cell division and expansion before and after flowering as well as pericarp tissue development. Therefore, the performance of berry uniformity among cultivars has a strong genetic basis.

In table grape breeding, genetic selection plays a decisive role in improving berry size and uniformity standards. Breeding programs represented by ‘Kyoho’ and its derivatives have significantly increased berry size, while ‘Shine Muscat’ has further achieved a combination of large berries, excellent flavor, and good resistance. This cultivar has an average berry weight of approximately 10-12 g and can achieve seedless production through gibberellic acid (GA_3) treatments at full bloom and post-bloom stages, resulting in high berry consistency through the synergistic effects of genetic potential and cultivation practices. This demonstrates that the selection of superior cultivars is one of the core approaches to improving berry uniformity.

In addition to varietal differences, clonal variation is also an important genetic source of uniformity. Studies have shown that different clones may exhibit stable differences in seed number, fruit set rate, berry size, and cluster density, with seedless or low-seed types often displaying distinct berry developmental patterns and structural characteristics (Alañón-Sánchez et al., 2026). Overall, berry uniformity is a typical quantitative trait controlled by multiple genes and influenced by genotype-environment interactions, requiring multi-trait selection and long-term breeding efforts to achieve stable improvement.

4.2 Physiological factors

Berry uniformity largely depends on key physiological processes from flowering to early fruit development, among which the adequacy and synchrony of pollination and fertilization are fundamental for uniform berry development. Insufficient pollen viability or uneven pollination conditions may result in poor fertilization of some flowers, leading to the formation of underdeveloped small berries and increased variability within clusters. Sabir et al. (2020) demonstrated that supplementary or cross-pollination can significantly improve fruit set and berry development, indicating a direct effect of pollination quality on uniformity.

Pollination and fertilization further influence berry enlargement by regulating hormonal signaling and cellular development processes. Dauelsberg et al. (2011) reported that successfully pollinated berries exhibit larger diameters and faster flesh expansion, whereas berries formed from unpollinated flowers remain smaller and developmentally restricted. These differences are closely associated with the expression of genes related to gibberellins, auxins, and cytokinins, indicating that fertilization activates hormone-mediated regulation and cell division required for early fruit development. In addition, differences in pollen source and viability can influence berry size and uniformity through metaxenia effects (Dhakad et al., 2024).

During the berry enlargement stage, developmental synchrony becomes a key determinant of uniformity. Berry growth depends on assimilate supply, water transport, and hormonal regulation, and differences among berries in seed number, hormone levels, and competitive ability for resources can lead to asynchronous development, resulting in size variability. Therefore, berry uniformity is the cumulative outcome of multiple developmental stages, including pollination, fertilization, seed development, and berry enlargement, and is fundamentally determined by the synchrony of berry development.

4.3 Cultivation and environmental factors

In production practice, cultivation management is the most direct and controllable factor affecting berry uniformity. Practices such as flower thinning, cluster thinning, and berry thinning reduce berry number, optimize the source-sink relationship, and decrease competition among berries, thereby promoting balanced development of the remaining berries. Khalil et al. (2023) reported that cluster thinning can significantly increase berry weight and diameter in certain cultivars, although responses vary among genotypes, indicating that cultivation practices must be adapted to genetic background. For compact clusters, thinning also improves spatial distribution, reduces compactness, and enhances visual quality (Alshallash et al., 2023; Choi et al., 2023).