are also closely associated with yield formation (Patidar et al., 2024). Correlation and path coefficient analyses have shown that fruit number, single fruit weight, and fruit size exert significant direct positive effects on yield per plant or yield per unit area, making them key factors influencing cucumber yield performance (Kaur et al., 2024; Lnu et al., 2025). In addition, the coordination between vegetative and reproductive growth directly affects yield formation. For example, plant height, leaf area, root activity, and photosynthetic capacity influence dry matter accumulation and assimilate transport, whereas female flower ratio, fruit set rate, and fruit enlargement rate determine yield formation capacity. Numerous studies have demonstrated that many cucumber yield-related traits possess high heritability and considerable genetic advance, indicating strong potential for genetic improvement and selection value (Negi et al., 2025).

However, cucumber yield-related traits also exhibit strong environmental sensitivity, with substantial differences observed among ecotypes, cultivation methods, and planting seasons (Lnu et al., 2025). Environmental factors such as temperature, light, water and fertilizer management, and cultivation conditions under protected or open-field systems can affect yield trait expression by regulating plant physiological and metabolic processes. Moreover, stresses such as high temperature, drought, salinity, and diseases interact complexly with genotypes, further influencing flowering, fruit set, and fruit development, thereby increasing the complexity of high-yield formation mechanisms in cucumber (Serhiienko et al., 2025). With the rapid development of molecular biology and omics technologies, studies on cucumber yield formation mechanisms have gradually expanded from traditional phenotypic observation and genetic analysis to genomics, transcriptomics, metabolomics, and epigenetic regulation. Studies have shown that cucumber yield formation is closely associated not only with physiological processes such as photosynthesis, hormonal regulation, carbon and nitrogen metabolism, and source-sink relationships, but also with the coordinated actions of multiple key genes and complex regulatory networks. For example, genes related to sex determination regulate female flower formation and fruit-setting ability, whereas fruit development-related genes directly affect fruit size, fruit shape, and single fruit weight (Dey et al., 2023). In recent years, technologies such as QTL mapping, candidate gene mining, genome-wide association studies (GWAS), genetic transformation, and CRISPR/Cas gene editing have been widely applied in studies of important agronomic traits in cucumber, providing new theoretical foundations and technical support for elucidating the genetic basis and molecular regulatory mechanisms of cucumber yield-related traits.

This study aims to explore cucumber yield-related traits and their variation and formation mechanisms by systematically reviewing research progress on genetic variation patterns, heritability, correlations, and gene effects of yield-related traits in different cucumber germplasm resources, landraces, breeding materials, and segregating populations. Due to differences in research materials, ecological environments, and evaluation criteria, systematic integration and unified understanding among different studies are still lacking. Considering the complexity of cucumber yield formation mechanisms and their importance in modern protected horticulture, this review focuses on summarizing the classification and characteristics of cucumber yield-related traits, patterns of genetic variation, physiological and molecular regulatory mechanisms, and the effects of cultivation techniques on yield formation. In addition, recent advances in multi-omics research and molecular breeding are discussed, and current research limitations and future development directions are analyzed and prospected. Through systematically summarizing relevant research achievements, this review aims to provide theoretical references for breeding new cucumber cultivars with high yield, superior quality, stable production, and stress resistance, as well as for optimizing efficient cultivation technologies, while also offering new insights into the genetic basis and regulatory mechanisms of complex quantitative traits in cucumber.

## 2 Yield-Related Traits in Cucumber

### 2.1 Vegetative growth traits

Vegetative growth traits in cucumber constitute an important foundation for determining plant vigor, canopy structure, and photosynthetic productivity. These traits mainly include vine length, internode length, branch number, leaf area, leaf number, root development, and photosynthetic capacity. Considerable phenotypic and genetic variation in these traits has been observed among different cucumber genotypes, landraces, and breeding materials, and some traits exhibit relatively high heritability, making them important indicators for high-yield