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Yield-Related Traits in Cucumber (*Cucumis sativus*) and Their Variation and Formation

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Abstract This study explored the yield-related traits of cucumber and their variation and formation mechanisms. The characteristics and interrelationships of major yield components, including vegetative growth traits, reproductive growth traits, population structure, and stress-resistance traits, were systematically analyzed. The effects of natural germplasm resources, artificial selection, and molecular-level genetic variation on the formation of cucumber yield traits were also discussed. Furthermore, the physiological mechanisms underlying yield formation, including photosynthesis and assimilate accumulation, hormonal regulation, and environmental factor regulation, were elucidated. Advances in functional genes related to fruit morphology, parthenocarpy, organ size, and stress resistance, as well as signal transduction networks and multi-omics studies, were summarized. In addition, the roles of cultivation technologies, such as greenhouse environmental regulation, water and fertilizer management, and cultivation pattern optimization, in cucumber yield formation were reviewed. Combined with recent advances in marker-assisted selection, genomic selection, CRISPR/Cas gene editing, high-throughput phenotyping, and artificial intelligence technologies, the current challenges and future breeding directions for high-yield cucumber research were further discussed. This review provides a theoretical reference for breeding new cucumber varieties with high yield, superior quality, stable production, and stress resistance, as well as for optimizing efficient cultivation techniques.
Keywords Cucumber; Yield traits; Genetic variation; Molecular regulation; High-yield breeding

1 Introduction

Cucumber (*Cucumis sativus* L.) is one of the most widely cultivated and economically important vegetable crops in the Cucurbitaceae family worldwide, particularly in Asia and Europe, and is also an important vegetable crop in both protected horticulture and open-field cultivation systems. Cucumber is characterized by a short growth cycle, strong adaptability, and high yield potential. Its fruits are crisp, juicy, and rich in nutrients, giving the crop high market demand and economic value. In recent years, with the rapid development of protected agriculture and the modern horticultural industry, cucumber has become one of the largest vegetable crops cultivated under protected conditions in China, and China accounts for a dominant proportion of global cucumber production. Meanwhile, consumers have placed higher demands on cucumber commodity quality, nutritional quality, and year-round stable supply, making high yield, superior quality, stress resistance, and adaptability to mechanized production important objectives in modern cucumber breeding (Dey et al., 2023). However, under the increasing pressures of global climate change and resource limitations, abiotic stresses such as drought, salinity, high temperature, and low temperature, as well as biotic stresses including downy mildew and viral diseases, significantly affect cucumber growth, development, and yield stability (Serhiienko et al., 2025). Therefore, in-depth studies on yield-related traits and their formation mechanisms are of great significance for improving cucumber productivity and promoting the sustainable development of protected horticulture.

Cucumber yield is a typical complex quantitative trait whose formation is jointly regulated by genetic background, physiological metabolism, environmental conditions, and cultivation management practices. In general, cucumber yield is mainly determined by fruit number per plant, single fruit weight, and effective plant number per unit area, while agronomic traits such as fruit length, fruit diameter, female flower number, branch number, and vine length