can improve canopy light interception and CO_2 assimilation efficiency, thereby increasing female flower number, fruit dry matter accumulation, and total yield (Koo et al., 2024).

4.2 Hormonal regulatory mechanisms

Plant hormones are important endogenous signals regulating cucumber yield formation. By coordinating vegetative growth, reproductive development, and fruit formation processes, hormones directly influence cucumber fruiting ability and yield level. Cucumber is a typical monoecious crop with separate male and female flowers, and its female flower formation, fruit set stability, and fruit enlargement processes are highly dependent on hormonal balance. Hormones such as auxin, gibberellins (GA), ethylene, cytokinins, and abscisic acid (ABA) not only participate in sex differentiation and floral organ development but also influence fruit formation by regulating cell division, cell expansion, and assimilate transport (Baral et al., 2025). Therefore, hormonal regulation essentially constitutes an important physiological basis for "sink formation" and yield establishment in cucumber.

Ethylene is an important regulator of sex expression in cucumber and generally promotes female flower formation and increases the proportion of female flowers. Materials with stronger ethylene synthesis capacity often exhibit lower node positions of the first female flower and higher fruit-setting ability, thereby showing stronger early fruiting potential. Meanwhile, auxin and GA play key roles during fruit development. Auxin mainly participates in ovary development, cell division, and cell expansion, whereas GA regulates vine elongation, floral organ formation, and early fruit growth. Studies have shown that hormone signaling pathways mediated by Aux/IAA, ARF, and GA signaling components regulate cell proliferation and expansion during the early stages of fruit development, whereas ABA and ethylene levels gradually increase during fruit maturation (Baral et al., 2025). Dynamic changes in these hormonal signals collectively determine fruit formation efficiency and final yield performance.

Studies on cucumber parthenocarpy further demonstrate the important role of hormonal balance in maintaining stable fruit set and continuous fruiting. Materials with strong parthenocarpic ability generally exhibit higher cytokinin and GA levels but relatively lower ABA levels. Exogenous application of cytokinins, auxin, or GA_{4+7} can induce parthenocarpic fruit formation in weakly parthenocarpic materials. These processes are accompanied by enhanced expression of cytokinin synthesis and response genes and reduced expression of ABA signaling receptors, indicating that higher levels of promotive hormones are beneficial for maintaining stable fruit set. In addition, hormones such as brassinosteroids, melatonin, and ethylene also participate in fruit formation regulation, while synergistic and antagonistic interactions among different hormonal pathways further increase the complexity of cucumber yield formation mechanisms.

4.3 Environmental regulatory mechanisms

Cucumber yield formation is highly sensitive to environmental conditions. Factors such as temperature, light, CO_2 concentration, water availability, and root-zone environment can regulate yield formation by influencing photosynthesis, hormone metabolism, and reproductive development. Environmental factors not only determine plant assimilate production capacity but also affect female flower differentiation, fruit set, and fruit enlargement by regulating hormonal signaling pathways involving ethylene, auxin, GA, and ABA (Aparna et al., 2023). Under the background of climate change, stresses such as high temperature, drought, low light, and waterlogging often lead to reduced photosynthetic efficiency, imbalance between source and sink relationships, and restricted fruit development, thereby decreasing cucumber yield stability.

Temperature and light are key environmental factors affecting cucumber yield formation. Low-temperature conditions inhibit photosynthesis and root absorption capacity, impair floral organ development, and cause flower and fruit abortion, whereas high temperatures increase transpiration, reduce photosynthetic efficiency, and negatively affect gamete viability and fruit set rate (Aparna et al., 2023). Meanwhile, prolonged low-light conditions easily induce excessive elongation growth, reduce leaf functional capacity, and inhibit female flower differentiation, thereby restricting yield formation in greenhouse cucumber production. Supplemental lighting combined with CO_2 fertilization can effectively enhance photosynthetic source strength and increase female