showed that these indicators were jointly affected by irrigation level and plant growth regulator treatment. Research on the genetic basis of appearance traits has also shown that peel anthocyanin composition, surface texture, and fruit surface appearance directly affect the commercial value of eggplant. This suggests that so-called "uniformity" is not an abstract concept, but one that is ultimately reflected in grading standards and market price.

Among these traits, peel color is especially critical under protected winter production conditions. Weak light environments easily lead to problems such as uneven pigmentation, whitening, and blotchy coloration. Luo et al. (2023) reported that low light reduces the visual quality and commercial value of eggplant peel, whereas materials that can maintain good coloration under low-light conditions are particularly valuable for commercial production. Further studies have shown that peel color at different developmental stages is jointly determined by a series of metabolites and regulatory genes. In other words, if plant growth regulators can stabilize the overall physiological status of the plant, or maintain anthocyanin accumulation during the later stages of fruit development in combination with cultivar characteristics, then improved uniformity may ultimately be expressed as more consistent fruit coloration and more stable appearance quality.

5 Physiological and Molecular Mechanisms

5.1 Hormonal signaling pathways

Plant growth regulators (PGRs) influence eggplant yield and uniformity by reshaping hormonal networks, carbon allocation, and stress responses that control fruit set, growth, and stability. Auxin and gibberellin (GA) act as primary drivers of fruit initiation, cell division and expansion, often sufficient to induce parthenocarpy when applied exogenously (Fenn and Giovannoni, 2020; He and Yamamuro, 2022; Su et al., 2025). Crosstalk occurs through direct interaction between auxin-responsive ARF/IAA proteins and GA repressor DELLA proteins, which co-regulate genes for hormone metabolism and fruit growth, integrating auxin and GA signals into a unified control of fruit set and early enlargement (Hu et al., 2018; He and Yamamuro, 2022). Cytokinin cooperates with auxin and GA to enhance parthenocarpic fruit set in cucumber, with high cytokinin and GA but low abscisic acid (ABA) characterizing highly parthenocarpic genotypes (Su et al., 2021; 2025; Zhao et al., 2025).

These hormones coordinate transcriptional programs: auxin–GA complexes modulate feedback genes in their own pathways and activate fruit growth-related genes, while cytokinin-responsive type-B response regulators and auxin-regulated ARFs mediate broad transcriptional reprogramming during fruit development (Fenn and Giovannoni, 2020). Shifts in ABA and ethylene further remodel gene expression at maturation and under stress, influencing fruit size and development patterns (Fenn and Giovannoni, 2020; Waadt et al., 2022; Thilakarathne et al., 2025).

5.2 Metabolic and cellular processes

PGRs indirectly govern carbohydrate allocation by altering sink strength in developing fruits. Sugar transporters and sugar–hormone integration ensure that sink organs such as fruits receive sufficient carbohydrates, with sugars acting as both substrates and signals that interact with auxin and cytokinin pathways (Wingler and Henriques, 2022; Guo et al., 2023). Under carbon restriction, marked declines in cytokinins and downregulation of cytokinin biosynthesis genes coincide with reduced expansin expression and fruit weight, showing that cytokinins drive not only cell division but also cell wall loosening and expansion (Nardozza et al., 2020).

At the cellular level, auxin and GA jointly promote cell division and subsequent expansion in early fruit development across multiple species, while cytokinins modulate both proliferation and elongation through expansin-linked cell wall relaxation (He and Yamamuro, 2022). Sugar-auxin crosstalk further integrates metabolic status with cell cycle activity, chromatin state and auxin-regulated gene expression, ensuring that cell division and differentiation proceed only when carbohydrate supply is adequate (Sabagh et al., 2022).

5.3 Stress responses and hormonal regulation

Abiotic stresses such as drought, salinity, heat and flooding disrupt endogenous hormone balances, compromising reproductive development and yield stability (Waadt et al., 2022; Baral et al., 2025). PGRs—endogenous or