

4 Nutrient Metabolic Regulatory Network in Pear Fruit

4.1 Signal transduction and transcription factor regulation

In the metabolic regulation of pears, transcription factors (TFs), like members of the bZIP, WRKY, and MYB families, all play a role. Take PpbZIP44 as an example, it can directly regulate the genes involved in the biosynthesis of carbohydrates, amino acids and flavonoids, redistribute the metabolic flow direction, and allow more fructose and phenylalanine to accumulate in the fruit (Wang et al., 2023). Members of the WRKY family, such as PbWRKY26, regulate organic acid metabolism by activating malate dehydrogenase-related genes, and ultimately affect malic acid levels and fruit acidity (Yang et al., 2023). MYB is more involved in the regulation of secondary metabolites and structural components, and has an impact on both flavor and quality (Xue et al., 2023).

Nutrient signals and hormone signals are closely linked in pears. For example, MeJA treatment can start changes in carbohydrate and amino acid metabolism. This process involves ceRNAs, miRNAs, and transcription factors (Yuan et al., 2024). ABA signaling has its own chain of control. It is shaped by DNA methylation, and transcription factors like PbZFP1. These signals affect how metabolic genes work, which then sets the pace for fruit ripening and the overall metabolic state (Gu et al., 2024).

4.2 Mechanisms of carbon-nitrogen balance regulation

Nitrogen supply not only determines the growth of leaves, but also affects the expression of genes related to sugar metabolism, thereby influencing the balance between carbon and nitrogen compounds. Transcriptome analysis revealed that, nitrogen-responsive transcription factors and metabolic genes were co-expressed with sucrose biosynthesis genes, suggesting that there was not an indirect relationship between nitrogen status and sugar accumulation, but a direct regulatory connection (Lu et al., 2020; Wang et al., 2023).

Lü et al. (2020) conducted a comparative transcriptome analysis of three developmental stages of the low-sucrose cultivar ‘Korla’ and the high-sucrose cultivar ‘Fengshui’, identifying seven key genes closely related to sucrose synthesis (*SPS*, *SUS*, *FRK*, and *PGI*, etc.) along with 42 transcription factors. They constructed a regulatory model linking signals, transcription factors, and target genes to explain how gene regulation and metabolic flux jointly drive differences in sweetness (Figure 1). This provides a valuable reference for understanding the molecular basis of sugar accumulation under nitrogen influence and also demonstrates that by regulating the expression of relevant genes, carbon–nitrogen metabolism can be coordinated to optimize fruit quality.

The balance of nutrients, especially the carbon-to-nitrogen ratio, also affects how pear trees work inside. Studies using different “omics” methods show that when this ratio changes, it can turn certain genes on or off. These genes are linked to how the plant handles sugars and amino acids. As a result, the amount of sugar, organic acids, and amino acids in the fruit also changes (Wang et al., 2023; Yuan et al., 2024).

5 Fertilization Strategies for Improving Fruit Quality

5.1 Balanced fertilization schemes for coordinated trait improvement

Studies have shown that moderate application of nitrogen fertilizer can increase fruit quantity and yield. However, excessive application not only fails to further improve fruit quality, but may also lead to nutrient excess and environmental risks (Chen et al., 2018; Sete et al., 2019; Liang et al., 2022). Especially, the role of potassium fertilizer is more prominent. It can not only enhance fruit hardness, soluble solid content and storability, but also promote sugar accumulation, thereby comprehensively improving fruit quality (Brunetto et al., 2015; Shen et al., 2016; Sete et al., 2020).

The optimal NPK ratio should be adjusted based on local soil conditions and tree needs. For example, studies have shown that in North China, moderate irrigation combined with high nitrogen application yields the best results (Liu et al., 2023; Li et al., 2024). Balanced fertilization can also increase the mineral and vitamin C content of fruit, improving flavor and nutritional value (Gill et al., 2017).

Slow-release and controlled-release fertilizers give the trees a steady flow of nutrients through the whole growing season. This cuts down on nutrient loss and helps the plant use the fertilizer better. These fertilizers can make