

et al., 2019). On the other hand, using fertilizer the right way—with a good balance of N, P, K, Ca and B—can ease these stresses, and help pears grow better and taste better (Nishio et al., 2021).

### 3 Regulatory Mechanisms of Sugar Accumulation in Pear Fruit

#### 3.1 Metabolic pathways of sucrose and sorbitol

In pear fruit, sugar accumulation primarily occurs via sucrose and sorbitol, a common transport pathway in Rosaceae plants. Sorbitol dehydrogenase (SDH) converts sorbitol to fructose, a step that directly impacts sweetness. Numerous studies have found that, the application of bio-organic fertilizers that enhance SDH expression significantly increases fructose content (Wang et al., 2022a; Jiang et al., 2023).

Sucrose breakdown involves not only one enzyme. Invertase hydrolyzes sucrose into glucose and fructose, and its activity varies with fruit development. Acid invertase (AI) is more active in the later stages, helping to accumulate hexoses, while sucrose synthase (SS) and sucrose phosphate synthase (SPS) are more important early in the fruit (Kou et al., 2017; 2018; Min et al., 2020). Interestingly, some studies suggested that in developing pears, sucrose synthase may even play a greater role in sucrose breakdown than invertase (Reuscher et al., 2016).

Nutrient supply, especially potassium (K), boosts the activity of genes like *SDH*, *S6PDH*, *SPS*, and *SUS* in leaves and fruits. This helps sugar build up in the fruit (Shen et al., 2018; Wang et al., 2022a). Sugar itself can also “push back” and activate SDH. When sorbitol, glucose, or sucrose is sprayed on the plant, SDH expression and activity go up even more. Researchers also found that, transcription factors like *PbrbZIP15*, *PuMYB12*, and *PuWRKY31*, as well as epigenetic changes such as histone acetylation, affect how sugar metabolism and transport genes are expressed (Li et al., 2020; Gao et al., 2023; Jia et al., 2024).

#### 3.2 Key nutritional factors influencing sugar content

Potassium (K) is very important for helping pears move and store sugar. It makes the plant’s veins grow better and turns on sugar transport genes like *SUT* and *SOT*. This helps sugars move smoothly from the leaves, or the “source”, to the fruit, or the “sink” (Shen et al., 2018; 2019). When the plant has plenty of potassium, the leaves and fruit hold more sorbitol, sucrose, and total sugar, which makes the fruit sweeter. Mg hasn’t been studied as much, but it also matters because it helps leaves keep up photosynthesis and might work together with potassium to move sugars. Shen et al. (2019) found that when potassium is low, the plant makes more magnesium transporter proteins to make up for it a little.

For pears, Boron (B) and zinc (Zn) are important micronutrients. They help sugars build up by keeping cell walls strong, cell membranes stable, and enzymes working well. B is key for sugar transporters and vascular tissues to work normally. While Zn helps enzymes that take part in carbohydrate metabolism (Pessoa et al., 2022; Zhang et al., 2022). When pears get enough boron and zinc, sugar moves and gathers more easily, which makes the fruit taste better and improves its quality.

#### 3.3 Interactive regulation with photosynthesis and source-sink dynamics

The nutritional status of leaves, especially the potassium (K) content, has a significant impact on photosynthesis. After the increase of potassium, the photosynthetic efficiency of leaves is enhanced, sugar production is also greater, and the “raw materials” transported to the fruit are naturally more abundant (Shen et al., 2018). The addition of organic and bio-organic fertilizers can also enhance photosynthesis and promote the expression of genes related to glucose metabolism, making the accumulation of sucrose in fruits more obvious (Wang et al., 2022a).

The way fruits get sugar is not simple. Phloem unloading and sugar storage rely on sugar transporters, like *SUT*, *SOT*, *SWEET*, and *TMT*, along with metabolic enzymes. Transcription factors such as *PuWRKY31* and *PbrbZIP15*, plus epigenetic changes, also take part in this process (Li et al., 2020; Gao et al., 2023; Jia et al., 2024). There are also genes like *PbCPK28* and *PbTST4*. Their natural variations can change how well sugar moves into the vacuole, which then affects how sweet the fruit becomes (Cheng et al., 2018; Li et al., 2023).