

The timing of fertilization is also very important. Giving the right nutrients during flowering, fruit setting, and fruit expansion helps pears grow bigger and build up more sugar (Liu et al., 2019; Jiang et al., 2020). For example, nitrogen fertilizer added in spring mostly goes to the young fruits. Fertilizers used in summer and autumn are stored in the roots, and later moved through the plant (Colpaert et al., 2021). During fruit setting and expansion, spraying regulators and trace elements can improve both the quality, and the yield of the pears (Gilani et al., 2021; Li et al., 2023).

5.3 Use of organic and biological inputs

Organic fertilizers, like compost, farmyard manure, and biogas slurry, can make the soil better by improving its structure, helping it hold water, and boosting microbial activity. This helps pears grow bigger, get sweeter, and store longer (Wang et al., 2022a; Ye et al., 2020; 2022; Butcaru et al., 2024). Bio-organic fertilizers with helpful microbes can go even further—they help pears make more sucrose, balance sugar and acid better, and improve overall fruit quality by affecting the genes that control sugar and acid metabolism (Kang et al., 2021; Wang et al., 2022a; b). Using organic fertilizers for many years, also builds up organic matter in the soil and makes nutrients easier for the trees to use, helping orchards keep producing in the long run (Butcaru et al., 2024).

Soil microbial inoculants like *Bacillus subtilis* and *Trichoderma* can help pear trees take in more nutrients. They boost enzyme activity, improve soil health, raise fruit yield, and keep the sugar-acid balance better (Kang et al., 2021; Shi et al., 2023; Yanwei et al., 2025). These biofertilizers change the microbes around the roots, encouraging good bacteria and fungi to grow. This helps nutrients move through the soil and supports plant growth (Wang et al., 2022b; Yanwei et al., 2025). When organic matter is used together with these inoculants, the effect is even stronger. It can stop leaves from dropping too early, raise yields even in bad weather, and make the fruit better in quality.

6 Variety Differences and Nutrient Regulation Adaptability in Pear

6.1 Nutrient response characteristics of different pear varieties

Different pear species take in nutrients and store minerals in their own ways. This changes how big and how sweet the fruit becomes. *Pyrus bretschneideri*, *P. pyrifolia*, and *P. ussuriensis* each have different patterns of sugar buildup, organic acid levels, and mineral content. For example, *P. ussuriensis* fruits have more potassium, calcium, and magnesium than *P. pyrifolia* or *P. bretschneideri*. Wild pears also usually hold more minerals than the pears grown in orchards (Liu et al., 2023).

Metabolomic studies, further elucidate these differences, revealing distinct patterns in phenylalanine metabolism, and other pathways related to fruit quality between white pears and sand pears (Zheng et al., 2022). Northeast pears exhibit higher potassium efficiency and greater tolerance to potassium-deficient environments, which is associated with the regulation of genes like *PbNRT2.4*, that is upregulated under potassium deficiency or exogenous sugar conditions (Yang et al., 2025).

The sensitivity of different varieties to nutrient management also varies. The high sugar type "Fengshui" upregulates sucrose synthesis related genes under nutrient supply, while the low sugar type "Korla Fragrant Pear" shows another expression pattern (Lü et al., 2020). Some varieties with larger fruits and higher sugar to acid ratios, like "Niitaka" and "Hanareum", have stronger nutrient absorption and accumulation abilities for sugars, amino acids, and minerals, making them suitable for both fresh and processed consumption. Some varieties can exhibit stronger tolerance or metabolic compensation ability, when they are deficient in potassium or iron (Melaouhi et al., 2022; Liu et al., 2025).

6.2 Breeding basis of traits related to nutrient regulation

Modern breeding increasingly values high-sugar and large-fruit traits, which are underpinned by both genetic and metabolic factors. QTL mapping and transcriptome analysis have identified a number of important loci and candidate genes, related to sugar accumulation and fruit enlargement, including *PpSUT*, *PpSDH*, *SPS*, *SUS*, etc. (Lu et al., 2020; Zhang et al., 2021; Jiang et al., 2023). Metabolomics studies supplemented more information, to