Therefore, in facility-based production, priority should be given to strains with stable genetic traits, strong stress resistance, good adaptability to facility environments, high yield, and superior quality. Comparative studies have shown that different *G. lucidum* strains cultivated on the same woody substrates differ significantly in fruiting probability, yield, and β-glucan content, indicating a clear compatibility relationship between strains and substrates (Cortina-Escribano et al., 2020). Meanwhile, strain origin and genetic background also affect the nutritional quality and metabolic characteristics of fruiting bodies. For example, strains from different sources may vary in protein, carbohydrates, fatty acids, mineral elements, and antioxidant components (Sadiq et al., 2021). Therefore, *G. lucidum* strain selection should focus not only on mycelial vigor and yield, but also on active component profiles, contamination resistance, and regional adaptability.

Substrate is an important nutritional basis for *G. lucidum* growth. Its standardization focuses on establishing stable and reproducible raw material formulations, and controlling particle size, moisture content, carbon-to-nitrogen ratio, and mineral element levels. *G. lucidum* prefers substrates rich in cellulose and lignin, with low nitrogen content, a high C/N ratio, and a relatively high cellulose/lignin ratio. Yield is generally positively correlated with cellulose and lignin contents, but negatively correlated with excessive nitrogen content. At present, sawdust, cottonseed hulls, wheat bran, corn flour, and gypsum are commonly used as basic raw materials in production. Sawdust provides the main carbon source, while wheat bran and oilseed meal supplements provide nitrogen and mineral elements. Meanwhile, wheat straw, bean straw, corn cobs, peanut stems, cottonseed hulls, and other agricultural residues can also partially replace wood resources, reducing production costs while maintaining or improving biological efficiency, protein content, and mineral content (Roy et al., 2015; Mahmoud et al., 2026). For example, adding 40% corn cobs to sawdust can increase fruiting body protein and key mineral contents without reducing yield or biological efficiency; a 1:1 mixture of wheat straw and sawdust supplemented with 20% wheat bran can achieve favorable biological efficiency in seasonal cultivation.

Moisture content and pH are also key indicators that need to be controlled in standardized substrate production. In general, maintaining substrate moisture content at 60%~65% is suitable. Excessive moisture reduces aeration and increases the risk of contamination, whereas insufficient moisture affects mycelial expansion and substrate conversion efficiency. Substrate pH is usually maintained in the slightly acidic to near-neutral range, which is conducive to normal mycelial growth of *G. lucidum*. In actual production, standardized procedures should be established for raw material inspection, crushing and screening, formula weighing, water addition and mixing, and pH adjustment, so as to avoid batch-to-batch differences caused by moldy or contaminated raw materials, unstable proportions, or moisture fluctuations. Overall, substrate standardization should comprehensively consider raw material availability, cost control, nutritional balance, strain compatibility, and product quality targets, and should be validated through production practice to form stable formulation systems (Roy et al., 2015; Mahmoud et al., 2026).

4.2 *Ganoderma lucidum* cultivation bag preparation, sterilization, and inoculation management

Cultivation bag preparation is a core operational step in standardized *G. lucidum* production and serves as the basic unit linking substrate standardization with facility-based environmental control. A typical cultivation bag preparation process includes raw material drying, crushing, screening, proportional mixing, moisture adjustment, pre-fermentation when necessary, bag filling, and compaction. In production, raw materials such as sawdust, cottonseed hulls, peanut stems, bean stalks, wheat bran, gypsum, lime, and $MgSO_4$ are commonly used to prepare substrates, which are then filled into polypropylene or plastic cultivation bags to form bags with uniform specifications and density (Roy et al., 2015; Atila, 2020). During bag filling, the tightness should be reasonably controlled according to substrate characteristics. The substrate should have good aeration while maintaining an appropriate degree of compactness to facilitate uniform mycelial expansion. If the bag is too loose, the substrate may collapse and moisture distribution may become uneven; if it is too compact, gas exchange will be restricted and mycelial growth rate will decrease.

Sterilization is an important technical measure for preventing contamination and improving the qualified rate of cultivation bags. Bagged substrates are usually sterilized by high-pressure moist heat or atmospheric-pressure