Ganoderma powder processing technologies already demonstrate routes for fine powder manufacture, puffing, ultramicro-grinding, and digestibility improvement, which support development of standardized food-grade powders and compounded products. Overall, the industrial future of *G. lucidum* spore powder lies in linking standardized upstream production with digital management and downstream value-added product matrices, so that raw spores, extracted actives, oil-extracted residues, and food-formulation ingredients can all be incorporated into an integrated modern industrial chain (Araque et al., 2020).

6 Current Challenges and Future Development Directions

6.1 Further improvement of breeding technologies for high-yield and high-quality strains

A central challenge in *Ganoderma lucidum* spore powder production is that breeding for high spore yield, stable quality, and microbial resistance still lags behind breeding for fruiting bodies. Current industrial reliance on a very limited spore-oriented germplasm base remains a bottleneck, because "Longzhi No.1" has been widely used for spore production but shows weak resistance to competing microorganisms, and stable yield and batch quality remain difficult to control (Tang et al., 2023). Recent mutation breeding shows clear promise but also underscores that improvement is still incremental rather than complete: UV mutagenesis produced strain UV119 with 19.27% higher basidiospore yield than its parent and 20.56% higher yield than "Longzhi No.1," while atmospheric room-temperature plasma mutation identified strains with faster growth, 17.85~26.33% greater biomass, 15.72~32.10% higher triterpenoid production, and stability across five generations (Feng et al., 2024). Even outside established production regions, cultivation studies found large strain-to-strain differences in time to maturity and biological efficiency, but also very low overall productivity where substrates and cultivation conditions were poorly optimized, indicating that breeding gains cannot be separated from production context (Poyeri and Ohimain, 2024).

Future breeding should therefore move from empirical screening toward integrated molecular and physiological breeding systems. Synthetic biology reviews identify robust regulatory networks and low homologous recombination frequency as major obstacles to precise gene targeting in *G. lucidum*, but they also argue that modern molecular tools can accelerate pathway engineering and marker development (Azi et al., 2024). This direction is already supported by breeding studies showing that mono-mono crossing can create hybrids with both elevated polysaccharides and triterpenes, such as hybrid H-23 with 16.63 mg/g polysaccharides, 10.50 mg/g triterpenes, and satisfactory biological efficiency, and that genetic engineering combined with mating can raise individual ganoderic acids 1.75- to 2.69-fold in new dikaryons (Liu et al., 2017; Zhou et al., 2024). At the same time, future programs should widen the breeding target beyond nuclear genotype alone, because mitochondrial background affected basidiospore yield and polysaccharide and triterpenoid content, and local population studies found meaningful phenotypic diversity even where phylogenetic divergence was limited, supporting region-specific germplasm mining and multi-trait selection (Ye et al., 2022; Cortina-Escribano, 2024).

6.2 Enhancement of precision regulation levels in the production process

A second major challenge is that production control is still not precise enough across spawn preparation, environmental regulation, contamination management, and scale-up. Reviews consistently note that successful cultivation depends on meticulous substrate selection, efficient spawn production, and precise management of cultivation parameters, yet contamination remains a major barrier and genetic variability further complicates uniform production (Karunarathna et al., 2025). This is especially important for spore powder because strict growth requirements and unstable batch performance continue to restrict industrial development (Tang et al., 2023). Liquid spawn work shows that apparently minor upstream variables, including plate broth volume, mycelium picking position, and carbon-nitrogen concentration, significantly affect biomass and metabolic activity, while fermentor-prepared liquid spawn had better activity than smaller-scale preparations (Guo et al., 2023). Likewise, semi-industrial submerged culture studies found that controlled pH 5.5 markedly improved exopolysaccharide production, underscoring how strongly product output depends on tightly managed process variables.