active-component accumulation. Taken together, the evidence indicates that elite strains+optimized cultivation+controlled collection and processing are the core technical basis for raising yield, lowering risk, and strengthening the industrial competitiveness of *G. lucidum* spore powder.

Quality control systems are the key guarantee for product value because *G. lucidum* spore powder shows large variability in composition, authenticity, and source-dependent quality, and these differences directly affect identity, efficacy, and safety evaluation. Existing regulatory frameworks already define important anchors, including Chinese Pharmacopoeia requirements for identification, microbial limits, and minimum contents of 0.90% polysaccharides and 0.50% triterpenes/sterols, as well as USP indicators for appearance, heavy metals, and active ingredients. However, single-index control is not sufficient: HPLC-DAD fingerprinting identified 11 ganoderma acids as useful chemical markers, multidimensional fingerprinting distinguished samples from different sources, and HPLC fingerprints combined with chemometrics successfully grouped *Ganoderma* by cultivated origin. Authenticity monitoring is equally essential, because commercial spore powder is often adulterated with dyed starch, NIR-chemometric models can quantify that adulteration with calibration and validation correlations>0.99, and combined HS-GC-IMS plus DNA mini-barcode approaches detected that some marketed products may contain non-*G. lucidum* species. Therefore, future quality control should integrate appearance and physicochemical indices, multi-component fingerprinting, authenticity testing, and contaminant limits into one coordinated value-guarantee system.

Standardization and digitalization are now the main drivers of industrial upgrading in *G. lucidum* spore powder production, because they convert dispersed empirical experience into traceable, controllable, and continuously optimized process systems. On the standardization side, China has already formed a relatively complete framework spanning the Pharmacopoeia, GB/T 29344-2023, food-safety standards, wall-breaking-rate testing, ganoderic-acid determination, and total triterpenoid determination, while ISO standardization for *Ganoderma* has also advanced internationally . On the digital side, industrial data-mining strategies for sporoderm-removal spore powder have already been used to identify process-parameter intervals that keep critical quality attributes such as moisture, fineness, crude polysaccharides, and total triterpenes at Ppk ≥1.33, showing that data-driven optimization has direct manufacturing value. More broadly, IoT, fuzzy logic, cloud dashboards, and TinyML systems in mushroom cultivation enable real-time sensing, autonomous control, remote visualization, disease support, and local low-latency decision-making, and related cultivation studies reported ~49% and ~28% yield gains under digital control as well as improved quality consistency and reduced labor dependence. Digital analytics are also extending into downstream process monitoring, as UV-Vis combined with CNN predicted nine ganoderic acids during extraction with $R^2 > 0.88$, indicating that digital tools can support not only cultivation management but also processing and release control.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Adebayo S., Aworinde H.O., Olufemi O.O., Osueke C.O., Adeniyi A.E., and Aroba O.J., 2025, Understanding mushroom farm environment using TinyML-based monitoring devices, Environmental Research Communications, 7(4): 045014.
https://doi.org/10.1088/2515-7620/adc5cd

Ahmad M.F., Alsayegh A.A., Ahmad F., Akhtar M.S., Alavudeen S., Bantun F., Wahab S., Ahmed A., Ali M., Elbendary E.Y., Raposo A., Kambal N., and Abdelrahman M.H., 2024, *Ganoderma lucidum*: Insight into antimicrobial and antioxidant properties with development of secondary metabolites, Heliyon, 10(3): e25607.
https://doi.org/10.1016/j.heliyon.2024.e25607

Akçay Ç., Arslan R., and Ceylan F., 2025, Valorization of various lignocellulosic wastes to *Ganoderma lucidum* (Curtis) P. Karst (*Reishi Mushroom*) cultivation and their FT-IR assessments, PLOS ONE, 20(7): e0328732.
https://doi.org/10.1371/journal.pone.0328732

Al-Kaabi A.S.A., and Hussien A.M., 2025, The environmental requirements of three species of Reishi mushroom, *Ganoderma* spp., IOP Conference Series: Earth and Environmental Science, 1487(1): 012020.
https://doi.org/10.1088/1755-1315/1487/1/012020