

GIES Case Study on Jiaohe *Ganoderma Lucidum* Facility Agriculture

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Abstract: Jiaohe City stands as one of the principal production areas of high-quality *Ganoderma lucidum* and sporoderm-broken *G. lucidum* spore powder in China. The case area covers a total area of 3,041 km², including 140 administrative villages and 6 communities. Situated in the transitional region from the Changbai Mountains to the Songliao Plain, it is mainly characterized by low mountains and hills. It features a temperate continental monsoon climate, with an annual average temperature of 4.38 °C and an average annual precipitation of 710 mm. The soil predominantly consists of black soil, which is rich in nutrients, and the heavy metal contents are below the national standard limits (GB 15618—2018 and HJ/T332—2006). The water environmental quality meets the Standards for drinking water quality (GB 5749—2022), rendering it suitable for *G. lucidum* irrigation. Jiaohe *G. lucidum* is cultivated using *Xylosma racemosum* wood segments as the substrate. The wood is dense and contains abundant nutrient elements, which can provide sufficient nutrients for mycelial growth and meet the requirements of fruiting body

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[2] Li, D. F., Hu, S., Yang, J. J., et al. GIES case dataset on Jiaohe *Ganoderma lucidum* Changbai Mountains [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2025. <https://doi.org/10.3974/geodb.2025.11.01.V1>.

development. The total triterpenoid and polysaccharide contents in *G. lucidum* slices exceed the limits stipulated in the 2020 edition of the Pharmacopoeia of China, and 11 pesticides, including deltamethrin, are not detected. The average sporoderm-broken rate of the spore powder is 99.2%. The average content of total triterpenoids is 9.16 g/100g and that of polysaccharides is 2.47 g/100g, all surpassing the limits set by the group standard *Ganoderma lucidum* spore powder from Changbai Mountain in Jilin (T/YYTC 008—2024). Meanwhile, the ash content, peroxide value, heavy metal contents, and microbial counts comply with the standard limits, and pesticides such as BHC and DDT, as well as pathogenic bacteria like *Salmonella* and *Staphylococcus aureus*, are not detected. Jiaohe City has a long-standing history of *G. lucidum* cultivation and has established a comprehensive industrial chain production model. This model encompasses spawn cultivation, technical guidance, corporate buy-back, and deep processing into high-value-added products. It has evolved from the traditional model of extensive production and low-price sales to new business formats, including e-commerce live streaming and culture-tourism integration. The case dataset is archived in .shp, .docx, .tif, .jpg, and .xlsx data formats, and consists of 111 data files with data size of 92.5 MB (Compressed into one file with 42.6 MB).

Keywords: Changbai Mountain; *Ganoderma lucidum*; sporoderm-broken *Ganoderma lucidum* spore powder; Jiaohe City; GIES; Case 28

DOI: <https://doi.org/10.3974/geodp.2026.03.02>

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: <https://doi.org/10.3974/geodb.2025.11.01.V1>.

1 Introduction

In the context of the rapid development of the social economy and the continuous improvement of better life, the public's demand for daily health preservation and wellness is on the rise. The “Quality Geographic Products” initiative, featuring agricultural modernization and intelligent agricultural monitoring and management, has emerged in line with this trend^[1,2]. Since 2016, the Chinese government has promulgated policies such as the “Healthy China 2030” planning outline, the National nutrition plan (2017–2030), and the “14th five-year plan” for national health to foster public health awareness and a prevention-oriented health concept, thereby implementing the Healthy China strategy. Enhancing immunity has become a core requirement for people of all age groups to maintain bodily functions. Anti-aging and antioxidant properties, regulation of blood glucose, lipids, and blood pressure, as well as liver protection and detoxification, represent major consumption trends among the young, middle-aged, and elderly populations for specialty agricultural products and health foods.

Ganoderma lucidum refers to the dried fruiting body of the Polyporaceae fungi *Ganoderma lucidum* (Leyss. ex Fr.) Karst. or *Ganoderma sinense* Zhao, Xu et Zhang (Figure 1)^[3]. Presently, a total of 137 species within the genus *Ganoderma* have been identified globally, among which the confirmed species in China constitute 88% of the overall count^[4]. Research findings suggest that polysaccharides, triterpenoids, sterols,



Figure 1 *Ganoderma lucidum* of Jiaohe City

small peptides, adenosine, and alkaloids are the principal active constituents of *G.*

lucidum, which demonstrate effects such as immune enhancement, anti-inflammatory and antioxidant activities, anti-tumor properties, neuroprotection, as well as anti-glycemic and hepatoprotective effects^[5,6]. The Pharmacopoeia of China (2000 Edition)^[3] has documented the medicinal value of *G. lucidum*. In 2001, the Ministry of Health incorporated *G. lucidum* (including *G. lucidum* and *G. sinense*) and *G. tsugae* into the List of fungal strains usable for health foods. In 2019, *G. lucidum* was included in the List of medicinal and edible substances by the National Health Commission. In 2021 and 2023, the State Administration for Market Regulation, the National Health Commission, and the National Administration of Traditional Chinese Medicine successively issued the Directory of health food ingredients: sporoderm-broken *G. lucidum* spore powder and the Directory of health food ingredients: *G. lucidum*. As the origin of *G. lucidum*, China holds a leading position globally in terms of both production volume and quality. Statistics from the China Edible Fungi Association indicated that in 2023, the total output of *G. lucidum* in China reached 159,800 tons, with *G. lucidum* accounting for over 50%, and the total national consumption amounted to 50,000 tons^[7]. According to data from the General Administration of Customs, China's exports of *G. lucidum* products reached 5,000 tons, with a value of 100 million USD in 2023, representing year-on-year increases of 10% and 15% respectively^[7]. The "14th five-year plan" for national agricultural modernization explicitly advocates for the support of the *G. lucidum* industry, and the National report on the development of characteristic rural industries also designates *G. lucidum* as a key support sector.

The production areas of *Ganoderma lucidum* in China are primarily concentrated in regions such as the Changbai Mt. in Jilin, Mount Tai and Guanxian in Shandong, the Dabie Mountains in Anhui, and Huangsongdian in Jilin. The quality of *Ganoderma lucidum* varies owing to differences in varieties, ecological environments, and cultivation techniques. The Huangsongdian production area in Jilin Province is part of Jiaohe City, situated at the western foot of the Changbai Mt. and beside Songhua Lake, within the transitional zone from the Changbai Mt. to the Songliao Plain, which is known as a "Three-dimensional Resource Treasure Trove of the Changbai Mt." In Jiaohe City, *Ganoderma lucidum* is cultivated using the locally prevalent *Xylosma congestum* wood as a substrate, recognized as the "golden substrate" for *Ganoderma lucidum* or the preferred material for "semi-wild" cultivation, giving rise to high-quality geographical specialty products represented by "Huangsongdian *Ganoderma lucidum*". To facilitate the orderly development of the Geographical Indications Environment & Sustainability (GIES)^[8], this paper developed and analyzed the dataset of the Jiaohe *Ganoderma lucidum* geo-ecological environment case study in the Changbai Mt. area, with the aim of providing scientific and technological support for the geo-ecological protection and sustainable development of Jiaohe *Ganoderma lucidum*.

2 Metadata of the Dataset

The author information, geographic region, year of the data, data format, data size, and other details of the GIES case dataset on Jiaohe *Ganoderma lucidum* Changbai Mountains^[9] are presented in Table 1.

3 Case Area

Jiaohe City (126°45'–127°56'E, 43°12'–44°09'N) is located at the western foot of the Changbai Mt., at the southern terminus of the Zhangguangcai Range, and on the shore of Songhua Lake. It shares boundaries with Dunhua City of Yanbian Korean Autonomous Prefecture to the east, separated by the Weihe Ridge, Huadian City to the south, the Longtan and Fengman Districts of Jilin City to the west, and Shulan City and Wuchang City of

Heilongjiang Province to the north (Figure 2). The topography is characterized by higher elevations in the northeast and lower elevations in the southwest, with an average altitude of 455 m.

Table 1 Metadata summary of the GIES case dataset on Jiaohe *Ganoderma lucidum* Changbai Mountains

Items	Description
Dataset full name	GIES case dataset on Jiaohe <i>Ganoderma lucidum</i> Changbai Mountains
Dataset short name	JiaoheGanodermalucidumCase28
Authors	Li, D. F., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, lidf@igsnrr.ac.cn Hu, S., People’s Government of Jiaohe City, Jilin Province, jhsj67002787@163.com Yang, J. J., Jiaohe Administration for Market Regulation, Jilin Province, 13944269981@163.com Liu, Y. Y., Jiaohe Administration for Market Regulation, Jilin Province, jhsj67002787@163.com Chen, W. M., Jiaohe Administration for Market Regulation, Jilin Province, 164737084@qq.com Xu, L. C., Jiaohe City Agricultural Characteristic Industry Development Center, Jilin Province, xlc2006@126.com Wu, J. X., Jilin City Ecological Environment Bureau Jiaohe City Branch, jhsj67002787@163.com Liu, Y. N., Jiaohe Water Resources Management Center, Jilin Province, jhszy851@163.com Li, L. P., Jiaohe Meteorological Bureau, Jilin Province, jhqx54181@163.com Xu, D. C., People’s Government of Huangsongdian Town, Jiaohe City, Jilin Province, 532772077@qq.com Chen, S. K., People’s Government of Xinzhan Town, Jiaohe City, Jilin Province, 179757274@qq.com Ma, F. W., People’s Government of Huangsongdian Town, Jiaohe City, Jilin Province, 532772077@qq.com Guo, L. S., Jiaohe City Huangsongdian Edible and Medicinal Fungi Association, Jilin Province, 799913051@qq.com Jia, J. G., Jilin Jinzhilou Biotechnology Co., Ltd., 284543841@qq.com Ji, X. B., Jiaohe City Chashuling Local Specialty Products Co., Ltd., ah2j@hotmail.com Liu, X., Fuzhidao (Jilin) Biotechnology Co., Ltd. Jiaohe Branch, 18686686027@qq.com Zhu, J. Q., Senzhifu (Jilin) Biotechnology Co., Ltd., 15886285999@qq.com Wang, D. Q., Jilin Zhiye Biotechnology Co., Ltd., 15981247800@qq.com Yan, F. F., Jilin Beizhi Biotechnology Co., Ltd., 172762701@qq.com Cao, W. S., Sanhe Village, Huangsongdian Town, Jiaohe City, Jilin Province, 799913051@qq.com Wang, Z. B., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, wangzb@igsnrr.ac.cn Wang, P. X., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 1092546064@qq.com Liu, J. Y., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, liujingyang251@mails.ucas.ac.cn Liu, S. P., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, liusp@igsnrr.ac.cn
Geographical region	Jiaohe City, Jilin Province, China
Data format	.shp, .docx, .tif, .jpg, .xlsx
Data size	92.5 MB
Data files	Case area boundary, physical geography data, product characteristic data, operation management, socioeconomic and historical cultural data, production process images
Foundation	Jilin Provincial Administration for Market Regulation (2025)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	(1) <i>Data</i> are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use <i>Data</i> subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute <i>Data</i> subject to written permission from the GCdataPR Editorial Office and the issuance of a <i>Data</i> redistribution license; and (4) If <i>Data</i> are used to compile new datasets, the “ten percent principle” should be followed such that <i>Data</i> records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset ^[10]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

Jiaohe City falls within the Songhua River system, boasting 89 rivers¹. The majority of these rivers flow from north to south or east to west, ultimately discharging into Songhua Lake. The river surface area is approximately 231.87 km², and the water area of Songhua Lake spans 330 km². The principal rivers include the Lafa River, with a total length of 65 km and a drainage area of 920 km², and the Gaya River, with a total length of 75 km and a drainage area of 1,121 km², along with the Jiaohe, Mangniu, and Piaohe Rivers, as well as the Hongxing, Longfeng, and Qingfeng Reservoirs. The total surface water resources of the city amount to 1.752 billion m³, and the exploitable groundwater resources reach 5.103 billion m³.

The cultivation of *Ganoderma lucidum* in Jiaohe City is predominantly concentrated in Huangsongdian Town, Xinzhan Town, Qianjin Township, Lafa Sub-district, Henan Sub-district, Wulin Korean Township, and Baishishan Town. These areas were chosen as the case area with a total area of 3,041 km², incorporating 140 administrative villages and 6 communities (Figure 2).



Figure 2 Geo-location map of Jiaohe City

4 Ecological and Environmental Data

4.1 Topography

The case area is characterized by a topography that is elevated in the east and lower in the west, with a central low-lying area encircled by higher terrains, exhibiting a composite landscape of hills, mountains, and valleys. An analysis grounded in Digital Elevation Model (DEM) data² revealed that the elevation spans from 248 to 1,283 m, with a mean elevation of 488 m (Figure 3). The slopes vary from 0 to 45.4°, with an average slope of 8.4° (Figure 4). The moderate elevation and gentle slopes, in conjunction with a suitable climate and adequate drainage conditions, are conducive to greenhouse construction, production management, and harvesting operations.

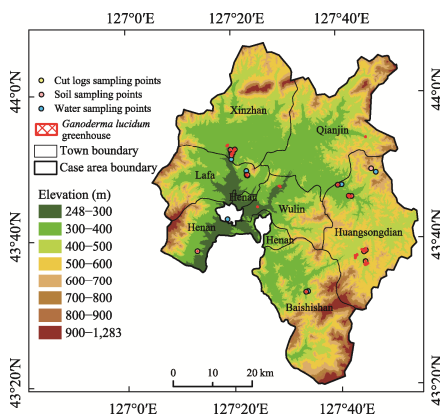
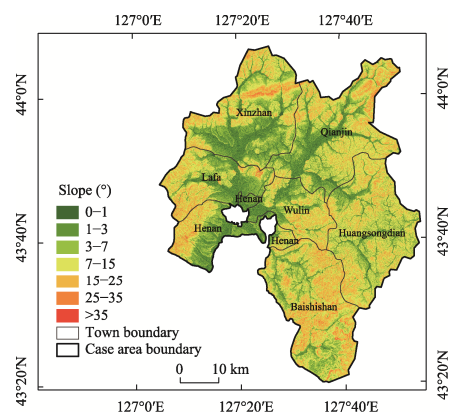


Figure 3 Distribution map of the sampling sites **Figure 4** Slope classification map of the case area and the elevation classification in the case area



¹ People's Government of Jiaohe City. <http://www.jiaohe.gov.cn/jhgk/>.

² NASA, NGA. <http://srtm.csi.cgiar.org/srtmdata/>.

4.2 Climatic Conditions

The case area features a temperate continental monsoon climate, which is characterized by the co-occurrence of rainfall and heat and distinct four seasons. A statistical analysis of meteorological data from 1980 to 2024³ reveals that the multi-year averages of the maximum, minimum, and mean temperatures were 10.68 °C, −1.17 °C, and 4.38 °C, respectively. The annual precipitation ranged from 455.0 to 1,033.2 mm, with a multi-year average precipitation of 710.8 mm (Figure 5). Temperature and precipitation exhibit significant seasonal differentiation. In summer (June–August), rainfall accounts for 62.7% of the annual precipitation, amounting to 455.7 mm. The highest temperature (27.16 °C) and maximum precipitation (178.9 mm) occur in July, with a daily mean precipitation of 5.77 mm and a daily mean temperature of 21.96 °C. In winter (December–February), precipitation accounts for only 3.59% of the annual total. The lowest temperature (−23.92 °C) and minimum precipitation (6.42 mm) occur in January, with a daily mean precipitation of 0.21 mm and a daily mean temperature of −17.85 °C (Figure 5). The annual effective accumulated temperature ≥10 °C ranges from 2,350 to 2,750 °C. The frost-free period is 105–115 d in mountainous areas and 120–130 d in hilly areas. The annual average relative humidity fluctuates between 65.9% and 76.5%, with a multi-year average of 70.1%. The coefficient of variation for the monthly average relative humidity is merely 11.77% (Figure 5). The case area enjoys abundant sunshine, with annual sunshine hours ranging from 1,975 to 2,574 h and a multi-year average of 2,242 h. The maximum (7.32 h/d) and minimum (4.29 h/d) sunshine hours occur in May and December, respectively (Figure 5). From 2013 to 2024, the overall air quality in the case area was of excellent quality. The average concentrations of PM₁₀, PM_{2.5}, SO₂, and NO₂ were 0.064 mg/m³, 0.029 mg/m³, 0.018 mg/m³, and 0.020 mg/m³, respectively, all of which were below the limits stipulated in China’s Ambient air quality standards (GB 3095—2026)^[11]. The proportion of days with excellent or good air quality exceeded 88%.

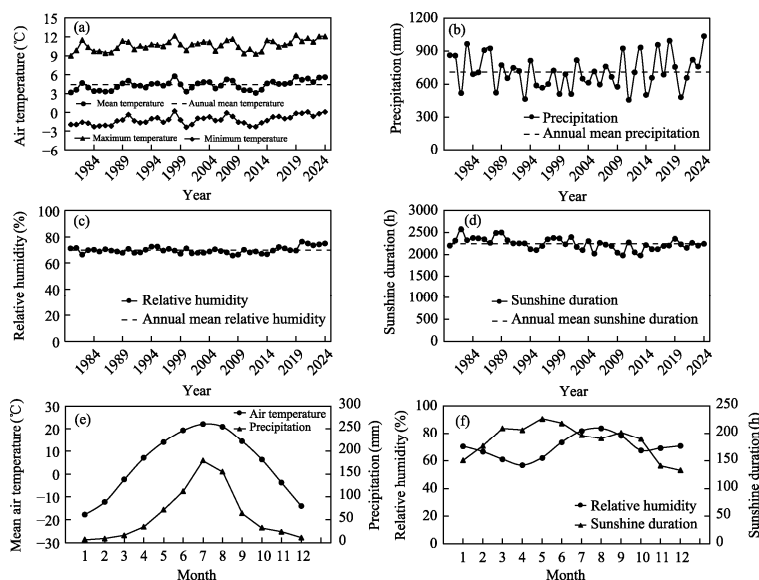


Figure 5 Statistical analysis chart of climatic characteristics for Jiaohe City (1980–2024)

The growth and development of *Ganoderma lucidum* are intricately associated with temperature, light, and moisture conditions. In Jiaohe City, the relatively high air humidity

³ China’s National Meteorological Administration. <http://data.cma.cn/>.

(ranging from 56.7% to 61.0%) from March to May facilitates mycelial colonization on the substrate and averts contamination by competitive fungi. From June to September, the temperatures are in accordance with the optimal temperatures for mycelial growth (20–25 °C) and fruiting body development (25–30 °C). The adequate diurnal temperature variations inside greenhouses, combined with sufficient ventilation, are conducive to dry matter accumulation, enhance disease resistance (by inhibiting pest egg incubation, larval development, and adult activity), and effectively prevent infection by competitive fungi. The short sunshine duration in late spring and early summer is beneficial for mycelial growth and primordium differentiation, whereas the long sunshine duration from midsummer to early autumn contributes to increasing greenhouse temperatures and promotes cap thickening.

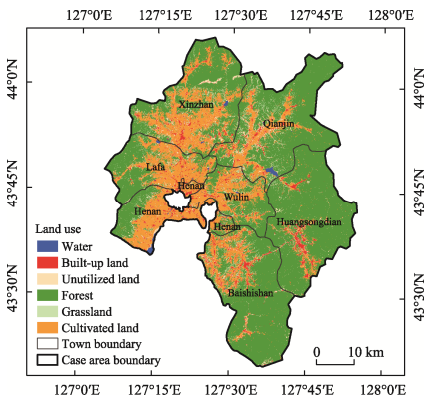


Figure 6 Land use map of the case area (2022)

4.3 Land Use and Vegetation Cover

The authors employed the maximum likelihood method for supervised classification on Landsat 9 imagery with a 30-m spatial resolution to acquire the land use types of the case area in 2022⁴. Forest and cropland emerge as the predominant land use types, constituting 66.5% and 25.0% of the total area respectively (Figure 6). Leveraging Landsat 5 TM imagery (2000) and Landsat 9 imagery (2022), the Normalized Difference Vegetation Index (NDVI) for both years was computed, and the trend of annual NDVI change from 2000 to 2022 was analyzed. In 2022, the NDVI in the case area spanned from -0.13 to 0.63, with a mean value of 0.36, suggesting a moderate degree of vegetation cover. Over the past two decades, the average annual rate of NDVI change in the case area was 0.15, and areas exhibiting an increasing NDVI trend accounted for 97.2% of the region, indicating an overall enhancement in vegetation cover (Figure 7, 8). The favorable land use and vegetation cover patterns offer ecological security, encompassing suitable terrain (agroforestry interlacing, gentle slopes), climate (temperature, humidity, light, etc.), and raw materials (substrate, soil), which are conducive to the cultivation of *Ganoderma lucidum*.

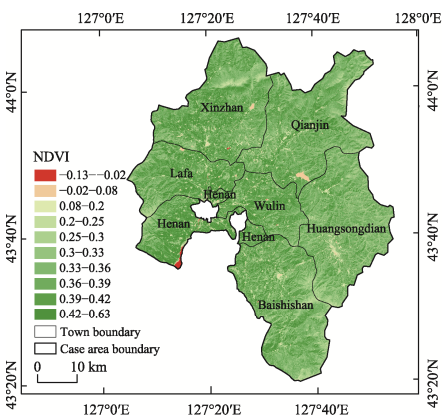


Figure 7 Distribution map of NDVI (2022)

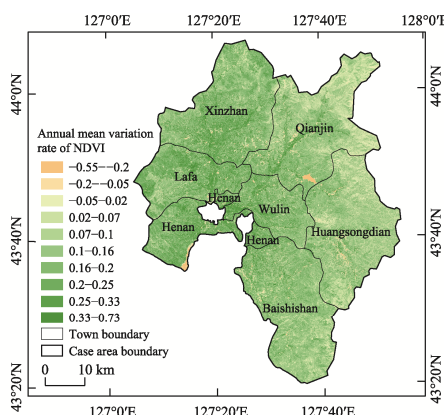


Figure 8 Distribution map of annual NDVI change rate (2000–2022)

⁴ USGS. <https://earthexplorer.usgs.gov/>.

4.4 Soil Conditions

In May 2025, the authors gathered a total of 107 soil samples from 0–1 m deep profiles (layers: 0–10, 10–20, 20–40, 40–60, 60–80, and 80–100 cm) at 19 *Ganoderma lucidum* cultivation sites within the case area (Figure 3). These samples were dispatched to the Center for Physical and Chemical Analysis, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (IGSNRR, CAS), for examination.

Soil texture, organic carbon, and macro-nutrient contents serve as core indicators that reflect the soil nutrient status under the combined influence of parent material sources, soil formation processes, and agricultural management practices. According to the international soil particle classification standard, the average contents of clay, silt, and sand in the 0–1 m deep soil profiles of the case area were 5.24%, 47.92%, and 46.84%, respectively. The soil texture was predominantly silty loam (accounting for 70.1%), followed by sandy loam (accounting for 24.3%) (Table 2). The soil pH ranged from 6.09 to 7.97, with a mean value of 6.70, generally presenting a neutral nature. The soil electrical conductivity (EC) ranged from 11 to 117.2 $\mu\text{S}/\text{cm}$, with a mean of 29.13 $\mu\text{S}/\text{cm}$, indicating soils with low salinity and moderate fertility. The average contents of soil organic carbon, ammonium nitrogen, nitrate nitrogen, total nitrogen, total phosphorus, and total potassium were 12.49 g/kg, 9.14 mg/kg, 6.64 mg/kg, 1.27 g/kg, 0.68 g/kg, and 21.04 g/kg, respectively (Table 2). Approximately 15.9% and 47.7% of the samples reached Grade 3 or above for soil organic carbon and total nitrogen content, respectively, based on the national standard of the Second national soil survey. The contents of cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), arsenic (As), and mercury (Hg) in all soil layers were below the risk screening values for soil contamination specified in the Soil environmental quality risk control standard for soil contamination of agricultural land (Trial) (GB 15618—2018)^[12] and the limits set in the Environmental quality evaluation standards for farmland of edible agricultural products (HJ/T 332—2006)^[13] (Table 3). Pesticide residues such as BHC and DDT were not detected in the soil, conforming to the requirements of GB 15618—2018^[12]. The 0–1 m deep soil profiles in the case area demonstrated high nutrient contents and were devoid of heavy metal and pesticide contamination.

4.5 Water Conditions

The water quality at the Jiaohekou section consistently met Class III of the Environmental quality standards for surface water (GB 3838—2002)^[14]. Meanwhile, the water quality at the

Table 2 Statistical testing results of soil routine physical and chemical property in the case area

Test item	Depth (cm)						Mean	CV (%)
	0–10	10–20	20–40	40–60	60–80	80–100		
Number of samples	19	19	19	18	17	15	–	–
Clay (%)	4.91	5.05	5.50	5.76	5.30	4.87	5.24	35.97
Silt (%)	45.94	48.04	50.81	50.25	47.81	43.91	47.92	26.14
Sand (%)	49.15	46.90	43.69	43.99	46.88	51.21	46.84	30.59
Texture	Silt loam	Silt loam	Silt loam	Silt loam	Silt loam	Silt loam	Silt loam	–
pH	6.68	6.62	6.61	6.68	6.77	6.86	6.70	5.80
Electrical conductivity ($\mu\text{S}/\text{cm}$)	46.78	33.95	25.69	23.11	21.30	23.98	29.13	76.48
Organic carbon (g/kg)	28.23	17.45	10.34	6.66	4.98	4.53	12.49	153.52
NH ₄ -N (mg/kg)	12.26	10.50	7.82	7.29	8.22	8.41	9.14	45.36
NO ₃ -N (mg/kg)	13.93	9.21	5.12	3.61	3.32	3.50	6.64	121.62
Total nitrogen (g/kg)	2.53	1.70	1.18	0.74	0.62	0.62	1.27	111.78
Total phosphorus (g/kg)	0.99	0.77	0.62	0.54	0.59	0.55	0.68	42.17
Total passium (g/kg)	20.28	20.22	21.06	20.99	21.88	22.13	21.04	10.15

Note: – indicates no corresponding data.

Table 3 Statistical testing results of soil heavy metal content in the case area

Test item	Depth (cm)						Mean	Limits ^[12]	Limits ^[13]
	0–10	10–20	20–40	40–60	60–80	80–100			
Number of samples	19	19	19	18	17	15	–	/	/
Cd (mg/kg)	0.17	0.16	0.16	0.13	0.17	0.16	0.16	≤0.3	≤0.3
Cr (mg/kg)	45.79	46.84	48.40	50.14	48.38	46.87	47.74	≤200	≤200
Cu (mg/kg)	10.75	10.04	8.57	9.03	9.77	9.26	9.59	≤100	≤100
Ni (mg/kg)	17.12	17.51	18.05	18.83	18.87	17.90	18.03	≤100	≤50
Pb (mg/kg)	13.23	9.61	9.42	8.94	11.35	7.76	10.15	≤120	≤80
Zn (mg/kg)	84.61	77.21	76.67	74.96	72.35	72.26	76.58	≤250	≤250
As (mg/kg)	9.17	9.09	9.48	10.81	11.48	11.51	10.18	≤30	≤30
Hg (mg/kg)	0.07	0.05	0.03	0.02	0.03	0.02	0.04	≤2.4	≤0.5

Note: – indicates no corresponding data; / indicates no corresponding standard limit.

Yangqiao and Xinzhao sections of the Lafa River maintained or surpassed Class II standards over the long-term. In May 2025, the authors collected 8 samples of surface water and groundwater from the case area (Figure 3). At the sampling sites, the pH, electrical conductivity, and total dissolved solids (TDS) were measured with a portable multi-parameter water quality meter. The concentrations of 8 heavy metals and 18 trace elements in the water samples were determined at the Center for Physical and Chemical Analysis, IGSNRR, CAS. Nitrate, chemical oxygen demand (COD), and five-day biochemical oxygen demand (BOD₅) were analyzed by Hangzhou Yanqu Information Technology Co., Ltd.

The pH of surface water and groundwater in the case area ranged from 6.79 to 7.84, with a mean of 7.12, indicating weak alkalinity. The mean values for total dissolved solids (TDS), permanganate index, chemical oxygen demand (COD), five-day biochemical oxygen demand (BOD₅), and nitrate in the water samples were 71.43 mg/L, 2.03 mg/L, 22.13 mg/L, 5.55 mg/L, and 7.10 mg/L, respectively (Table 4). The water quality not only conforms to the Standards for irrigation water quality (GB 5084—2021)^[15] and the Environmental quality evaluation standards for farmland of edible agricultural products (HJ/T 332—2006)^[13] but also meets the Standards for drinking water quality (GB 5749—2022)^[16],

Table 4 Statistical testing results of surface water and groundwater environmental quality

Test item	Sample No.								Limits ^[15]	Limits ^[13]	Limits ^[16]
	W1	W2	W3	W4	W5	W6	W7	W8			
pH	7.84	7.25	6.92	6.86	6.79	6.94	7.48	6.85	5.5–8.5	5.5–8.5	6.5–8.5
ORP (mV)	201.4	192.9	213.1	154.7	225.7	234.2	145.7	215	/	/	/
DO (mg/L)	0.02	0.01	0.07	0.05	0.03	0.02	0.01	0.06	/	/	/
EC (μS/cm)	10	19	228	158	85	64	26	194	/	/	/
TDS (mg/L)	ND	12	148	102	55	41	16	126	/	/	≤1,000
SAL (mg/L)	ND	10	70	50	30	20	10	60	≤1,000	≤1,000	/
Chlorophyll (mg/L)	14.8	14.1	12.5	12.3	15.7	20.2	0.8	19.9	/	/	/
COD _{Mn} (mg/L)	1.99	2.23	1.58	1.50	1.66	1.75	2.96	2.56	/	/	≤3
COD (mg/L)	15	26	26	18	21	22	25	24	≤200	/	/
BOD ₅ (mg/L)	3.88	6.48	6.53	4.63	5.15	5.47	6.21	6.03	≤100	≤80	/
NO ₃ -N (mg/L)	5.21	7.62	4.43	4.91	8.09	8.75	8.85	8.94	/	/	≤10
Cd (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	≤0.01	≤0.01	≤0.005
Cr (mg/L)	0.0004	0.0002	0.0002	ND	0.0005	0.0012	0.0008	0.0007	≤0.1	≤0.1	≤0.05
Cu (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	≤1	≤1	≤1
Ni (mg/L)	0.0005	0.0008	ND	ND	ND	ND	0.0010	ND	≤0.2	/	≤0.02
Pb (mg/L)	ND	0.0040	ND	ND	ND	ND	ND	ND	≤0.2	≤0.2	≤0.01
Zn (mg/L)	ND	ND	0.0078	0.2010	0.0016	0.0013	0.0001	ND	≤2	≤2	≤1
As (mg/L)	ND	ND	ND	0.0061	0.0072	0.0002	ND	0.0060	≤0.1	≤0.1	≤0.01
Hg (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	≤0.001	≤0.001	≤0.001

Note: ND indicates not detected; / indicates no corresponding standard limit.

rendering it suitable as irrigation water for *G. lucidum*.

4.6 *Ganoderma Lucidum* Cultivation Substrate Quality Data

The naturally distributed tree species in the case area are primarily from the temperate Changbai Mt. flora, with a few subtropical and cold-temperate relatives, encompassing over 40 species from 11 families. Major species include *Xylosma congestum*, elm, and Manchurian walnut. *Ganoderma lucidum* cultivation in the case area utilizes *Xylosma congestum* wood segments as the substrate (Figure 9). *Xylosma racemosum* (Sieb. & Zucc.) Miq., an evergreen shrub or small tree of the Salicaceae family, is lauded as the “golden substrate” for cultivating *Ganoderma lucidum* or the preferred material for “semi-wild” cultivation. In May 2025, the authors collected 4 samples of *X. congestum* wood segments from the case area (Figure 3) and sent them to the Center for Physical and Chemical Analysis, IGSNRR, CAS, for testing.



Figure 9 The material and packaging of *Xylosma congestum* wood segments, and the substrate after spawn-running

The results indicated that *X. congestum* wood is hard, dense, and decomposes slowly, providing a stable growth matrix for *Ganoderma lucidum*. Its fibrous structure facilitates the attachment and expansion of *Ganoderma lucidum* mycelia. The wood segments are rich in lignin and cellulose, and contain abundant macro-nutrients like nitrogen, phosphorus, and potassium; secondary nutrients like calcium, magnesium, and sulfur; and trace elements such as iron, sodium, and zinc, providing ample carbon and nitrogen sources for the mycelia. These can be converted into absorbable, readily available nutrients by the enzymatic system of the mycelia, fulfilling the growth requirements of the fruiting bodies. The contents of 8 heavy metals, including cadmium, mercury, and arsenic, were all below the limits stipulated in Green food-environmental quality for production area (NY/T 391—2021)^[17] and the Technical regulations for standardized production of *Ganoderma lucidum* (T/CACM 1374.83—2021)^[18] (Table 5). Using *X. congestum* as a natural substrate, without applying any chemical fertilizers or pesticides during the growth process, effectively reduces the risk of heavy metal and pesticide contamination in the products.

Table 5 Statistical testing results of elemental contents in *Xylosma congestum* wood segments used as *Ganoderma lucidum* cultivation substrate

Test item	Sample No.				Limits ^[17]	Limits ^[18]
	1	2	3	4		
Total nitrogen (g/kg)	5.74	4.22	4.26	4.11	/	/
Total phosphorus (g/kg)	0.48	0.13	0.21	0.30	/	/
Total potassium (g/kg)	2.80	1.60	1.62	2.21	/	/
Cd (mg/kg)	ND	0.0468	0.2407	0.0488	≤0.3	≤1
Pb (mg/kg)	3.9549	4.2859	3.4501	3.8831	≤35	≤5
Hg (mg/kg)	0.0062	0.0041	0.0055	0.0038	≤0.1	≤0.2
As (mg/kg)	0.7513	0.6611	0.7864	0.6275	≤0.8	≤2
Cr (mg/kg)	2.9613	1.1533	1.3800	1.8067	/	/
Cu (mg/kg)	4.3211	2.7898	3.7711	3.4344	/	/
Ni (mg/kg)	0.9670	0.8572	1.0752	2.3602	/	/
Zn (mg/kg)	16.7556	6.9198	25.5309	10.9381	/	/

Note: ND indicates not detected; / indicates no corresponding standard limit.

5 *Ganoderma Lucidum* Product Characteristics Data

Ganoderma lucidum generally pertains to *Ganoderma lucidum* (Red Reishi). *Ganoderma* spores are the reproductive cells discharged from the cap during the maturation phase of the fruiting body, containing all the genetic active substances of *Ganoderma lucidum*. The Shennong Bencao Jing recorded the effects of *Ganoderma lucidum* as “nourishing lung qi, nourishing liver qi, and nourishing spleen qi”. The 2020 edition of the Pharmacopoeia of China^[3] elaborated in detail on the properties and functions of *Ganoderma lucidum* and its spores. The *G. lucidum* in the case area is mainly *Ganoderma lucidum* (Red Reishi), featuring individual, non-clustered fruiting bodies with round and regular caps that are brownish-red, having a surface covered with spore powder and a pale yellow or milky-white ventral surface. The stipes are thick, dark brown, and lustrous. The sporoderm-broken spore powder is dark brown, emits a fungal fragrance, and has a delicate and smooth flavor. Polysaccharides, triterpenoids, and adenosine are the principal active components of *G. lucidum* and its spore powder, demonstrating effects such as immune enhancement, blood circulation promotion, spleen invigoration and lung nourishment, hypoglycemic and hepatoprotective effects, as well as anti-tumor and anti-cancer properties^[5,6,19,20].

5.1 *Ganoderma Lucidum* Slices Quality

Testing of *Ganoderma lucidum* slices conducted by the authors showed that polysaccharide, total triterpenoid, and adenosine contents ranged from 0.98 to 1.62 g/100g, 0.73 to 1.94 g/100g, and 104 to 152 mg/kg, respectively, with mean values of 1.32 g/100g, 1.23 g/100g, and 138.25 mg/kg (Table 6). These values surpassed the limits specified in the 2020 edition of the Pharmacopoeia of China^[3]. Pesticides including insecticides like deltamethrin, herbicides like 2,4-D, and fungicides like tebuconazole were not detected (Table 6), indicating no pesticide contamination.

Table 6 Statistical testing results of *Ganoderma lucidum* slice quality in the case area

Test item	Unit	Range	Mean	Limits ^[3]
Crude polysaccharides	g/100g	0.98–1.62	1.32	≥0.9
Triterpenes	g/100g	0.73–1.94	1.23	≥0.5
Adenosine	mg/kg	104–152	138.25	/
Deltamethrin	mg/kg	ND	ND	/
Cyfluthrin and beta-cyfluthrin	mg/kg	ND	ND	/
Cypermethrin and beta-cypermethrin	mg/kg	ND	ND	/
Tebuconazole	mg/kg	ND	ND	/
Dinotefuran	μg/kg	ND	ND	/
2,4-Dichlorophenoxyacetic acid	mg/kg	ND	ND	/
Ortho-phenylphenol	mg/kg	ND	ND	/
Acetamiprid	mg/kg	ND	ND	/
Prochloraz	mg/kg	ND	ND	/
Procymidone	mg/kg	ND	ND	/
Carbendazim	mg/kg	ND	ND	/

Note: ND indicates not detected; / indicates no corresponding standard limit.

5.2 Sporoderm-Broken *Ganoderma Lucidum* Spore Powder Quality

The test results demonstrated that the average sporoderm-broken rate of the spore powder from the case area reached 99.2%, with the average contents of total triterpenoids and polysaccharides being 9.16 g/100g and 2.47 g/100g respectively (Table 7). These values exceeded the limits stipulated by the enterprise standards of major manufacturers^[21–24] and the group standard *Ganoderma lucidum* spore powder from Changbai Mt. in Jilin (T/YYTC

008—2024)^[25]. The mean values of moisture, ash, and peroxide value were 4.83%, 0.80%, and 0.08 g/100g respectively. The contents of heavy metals such as lead, arsenic, and mercury, as well as the counts of aerobic plate, coliforms, and mold and yeast, were below the relevant limits. Pesticides such as BHC and DDT, and pathogenic bacteria such as *Salmonella* and *Staphylococcus aureus*, were not detected (Table 7). The contents of ash, lead, arsenic, and mercury in the sporoderm-broken spore powder from the case area were lower than those reported for products from Guanxian in Shandong, Jinzhai and Jingde in Anhui, and Pingnan in Fujian^[26,27]. Previous research has indicated that the ash content of sporoderm-broken spore powder is lower than that of unbroken spore powder, while the polysaccharide content is higher^[27,28]. The sporoderm-broken *Ganoderma lucidum* spore powder from the case area features a high sporoderm-broken rate, is safe, and has higher active component contents compared to products from other regions that use agricultural by-products as base materials.

Table 7 Statistical testing results of sporoderm-broken *Ganoderma lucidum* spore powder quality

Test item	Unit	Range	Mean	Limits 1 ^[21]	Limits 2 ^[22]	Limits 3 ^[23]	Limits 4 ^[24]	Limits 5 ^[25]
Cell wall breaking rate (%)	%	98.7–99.6	99.2	≥95	≥95	/	≥95	/
Triterpenes (as ursolic acid)	g/100g	3.5–14.4	9.16	≥2.2	≥2.0	≥2.6	/	≥7.5 (Calculated as oleanolic acid)
Crude polysaccharides (as anhydrous glucose)	g/100g	1.54–12.6	2.59	≥1.5	≥0.9	≥1.5	≥2.0	≥1.6
Moisture	%	1.68–6.6	4.83	≤9.0	≤9.0	≤9.0	≤9.0	≤9.0
Ash	%	0.31–1.3	0.80	≤3.0	≤3.0	≤3.0	≤3.0	≤3.0
Peroxide value	g/100g	0.01–0.18	0.08	≤0.2	≤0.2	≤0.2	≤0.20	/
Hexachlorocyclohexane	mg/kg	/	/	≤0.2	≤0.1	≤0.1	≤0.2	≤0.05
DDT	mg/kg	/	/	≤0.2	≤0.1	≤0.1	≤0.2	≤0.05
Pb	mg/kg	0.055~0.184	0.10	≤1.9	≤1.95	≤1.95	≤1.9	≤1.8
As	mg/kg	0.046–0.38	0.13	≤1.0	≤1.0	≤1.0	≤1.0	≤0.9
Hg	mg/kg	0.003–0.02	0.01	≤0.1	≤0.3	≤0.3	≤0.1	≤0.1
Cd	mg/kg	0.032–0.26	0.14	/	/	/	≤0.5	≤0.5
Cr	mg/kg	0.1–0.95	0.55	/	/	/	≤2.0	≤2.0
Ni	mg/kg	0.109–0.6	0.35	/	/	/	≤1.0	≤0.9
Total bacterial count	CFU/g	<10	<10	≤30,000	≤30,000	≤30,000	≤30,000	/
Coliform	MPN/g	<0.3	<0.3	≤0.92	≤0.92	≤0.92	≤0.92	/
Molds and yeasts	CFU/g	<10	<10	≤50	≤50	≤50	≤50	/
Salmonella	0/25g	–	/	≤0	≤0	≤0	≤0	/
Staphylococcus aureus	0/25g	–	/	≤0	≤0	≤0	≤0	/

Note: – indicates no corresponding data; / indicates no corresponding standard limit.

6 *Ganoderma Lucidum* Industry Management

6.1 Socioeconomic Overview of Jiaohe City

The statistical communiqués on the national economic and social development of Jiaohe City from 2013 to 2024⁵ indicate that the total population decreased from 445,700 to 392,000. Simultaneously, the rural population declined from 277,000 to 231,000, and the urbanization rate increased from 37.83% to 41.07%. The GDP decreased from 21.205 billion CNY to 10.660 billion CNY. Specifically, the added-value of the primary industry declined from 3.578 billion CNY to 2.980 billion CNY. The industrial structure ratio changed from 16.9:50.0:33.1 to 27.9:19.6:52.5, demonstrating a significant decline in the proportion of the secondary sector and a strong growth trend for the tertiary sector. The urban per capita

⁵ People’s Government of Jiaohe City. <http://www.jiaohe.gov.cn/xxgk/tjxx/>.

disposable income increased from 17,490 CNY to 31,619 CNY, with an average annual increment of 1,177 CNY. The rural per capita disposable income rose from 10,012 CNY to 21,280 CNY, with an average annual increment of 939 CNY.

6.2 Cultivation History and Industrial Development

The exploration and utilization of *Ganoderma lucidum* in China can be traced back 6,800 years. As per the earliest pharmacological treatise in China, the Shennong Bencao Jing, *Ganoderma* is categorized into 6 varieties: Zi Zhi (Purple Ganoderma), Chi Zhi (Red Ganoderma), Qing Zhi (Green Ganoderma), Huang Zhi (Yellow Ganoderma), Bai Zhi (White Ganoderma), and Hei Zhi (Black Ganoderma), characterized by a sweet taste and a neutral property. Medical records from the Han, Tang, and Song dynasties, including the Shang Han Lun and Jin Kui Yao Lue, contain relevant descriptions. During the Ming Dynasty, works such as the Bencao Gangmu, Weinan Bencao, and Bencao Yuanshi offered comprehensive accounts of the morphology and medicinal efficacy of *Ganoderma lucidum*.

Jiaohe City is rich in wild *G. lucidum* resources (Figure 10). Villagers have been collecting wild *G. lucidum* for nearly a century. In the spring of 1989, the first Changbai Mountain Red Reishi was cultivated in Huangsongdian Town, pioneering artificial cultivation. According to the Jiaohe City Annals (1998–2003), large-scale artificial cultivation in Jiaohe City began in 1995. In 2001, Huangsongdian Town, a primary production area for Jiaohe *G. lucidum*, was designated an Organic *Ganoderma lucidum* Production Base by the Food and Agriculture

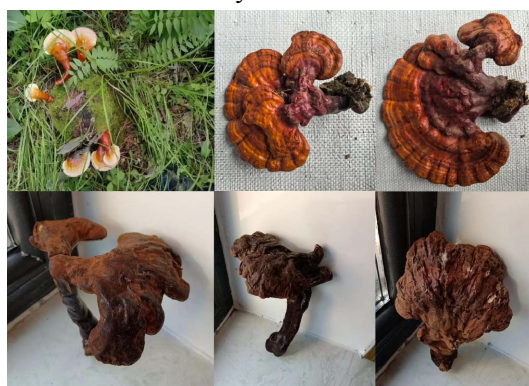


Figure 10 Wild *Ganoderma lucidum* in the case area

Organization of the United Nations (FAO). In 2005, Huangsongdian Town was recognized as a National Outstanding Base Township for the Edible (Medicinal) Fungi Industry by the China Edible Fungi Association. In 2009, Huangsongdian Town pioneered the introduction and optimization of axial flow fans combined with specially designed collection bags for spore powder harvesting, achieving low-loss, high-efficiency collection. In July 2015, the Ministry of Agriculture approved the registration of “Huangsongdian *Ganoderma lucidum*” as a National Agro-product Geographical Indication. In 2018, “Huangsongdian *G. lucidum*” was approved by the State Administration for Industry and Commerce as a China geographical indication certification trademark.

In the past two decades, the Huangsongdian Edible (Medicinal) Fungi Association has been founded, and enterprises specializing in the deep-processing of *Ganoderma lucidum*, such as “Beizhi”, “Fuzhidao”, and “Jinzhilou”, have emerged in succession. These enterprises integrate scientific research, cultivation, processing, sales, technical consultation, and training related to edible and medicinal fungi. They supply medicinal fungal raw materials to major domestic *Ganoderma lucidum* enterprises, pharmaceutical factories, health product manufacturers, and research institutions. In 2022, taking advantage of the “Huangsongdian *Ganoderma lucidum* Geographical Indication Protection Project” initiated by the Ministry of Agriculture and Rural Affairs, a 1,000-greenhouse *Ganoderma lucidum* cultivation base was established. By 2024, 7 workshops in Jiaohe City met the Good Manufacturing Practice (GMP) standards, and 17 health food registration and filing approvals were obtained.

Currently, the *Ganoderma lucidum* product categories in Jiaohe include *Ganoderma*

lucidum slices, *Ganoderma lucidum* cubes, sporoderm-broken *Ganoderma lucidum* spore powder, *Ganoderma lucidum* spore oil, *Ganoderma lucidum* pancakes, and *Ganoderma lucidum* bonsai. A comprehensive industrial chain production model has been established, which encompasses spawn cultivation, technical guidance, corporate buy-back, and deep processing into high-value-added products. The production model has transformed from an extensive production and low-price sales model to new business formats integrating e-commerce live streaming and culture-tourism integration. The products are sold to 31 countries and regions, including Japan, South Korea, and the United States.

From 2014 to 2025, the scale of *G. lucidum* cultivation in Jiaohe City expanded from 917 greenhouses (1.1 million segments) to 3,272 greenhouses (3.6 million segments). Total output, *G. lucidum* yield, and spore powder yield increased from 343.9 t, 229.3 t, and 114.6 t to 1,300 t, 850 t, and 450 t, respectively. The output value grew from 25.905 million CNY to 98 million CNY (Table 8), making it a significant industry for rural revitalization and farmers' income growth.

Table 8 Statistics of *Ganoderma lucidum* cultivation scale in Jiaohe City (2014–2025)⁶

Year	Cultivation quantity (10,000 segments)	Number of greenhouses	Total yield (t)	Fruiting body yield (t)	Spore powder yield (t)	Output value (10,000 CNY)
2014	110	917	343.9	229.3	114.6	2,590.5
2015	60	500	187.5	125.0	62.5	1,412.5
2016	100	833	312.4	208.3	104.1	2,665.6
2017	100	833	312.4	208.3	104.1	2,748.9
2018	140	1,167	437.6	291.8	145.9	3,851.1
2019	130	1,083	406.1	270.8	135.4	3,573.9
2020	140	1,167	437.7	291.8	145.9	3,851.8
2021	70	583	204.1	116.6	87.5	2,075.5
2022	178	1,483	519.1	296.6	222.5	4,389.7
2023	184	1,533	536.6	306.6	230.0	5,457.5
2024	310	2,800	981.8	420.8	561.0	7,237.0
2025	360	3,272	1,300.0	850.0	450.0	9,800.0

6.3 *Ganoderma Lucidum* Cultivation Management

Production bases are established in areas with altitudes exceeding 350 m, characterized by favorable ecological conditions, level terrain, convenient irrigation and drainage systems, and the absence of pollution sources within a 5-km radius and 20-km upwind area. Greenhouse cultivation is employed, with dedicated sites for spawn segment preparation, spawn running, and fruiting (Figure 11). The “Jiaohe Model”, which is adapted to the local climate, raw materials, soil, and water environment, has been developed:

(1) Cultivation techniques

Fresh wood of *Xylosma congestum* harvested during the period from the Winter Solstice to the Beginning of Spring is utilized. Straight trunks and branches are cut into segments with a length of 13–15 cm and evenly split. Segments with a diameter less than 7 cm and twigs do not necessitate splitting; segments with a diameter of 7–10 cm are split into 2 parts; segments with a diameter exceeding 10 cm are split into 4–6 pieces. The processed wood segments are bundled into circular bundles with a diameter of approximately 30 cm, placed in bags, and the bags are tightly sealed (Figure 9). The wood segments undergo sterilization, disinfection, inoculation, and spawn-running processes. Greenhouses are oriented in a north-south direction, with a length of 24 m, a width of 7 m, and a height of 2.2 m. Drainage ditches are dug at the ends and sides, 0.5 m away from the greenhouse. Approximately 1,200 segments are placed in each greenhouse, and they are given a 7-d resting period before being

⁶ The data is from Jiaohe City Bureau of Agriculture and Rural Affairs and Jiaohe Administration for Market Regulation.

transferred to the soil. When the temperature consistently exceeds 25 °C, the nursery beds are leveled. The plastic bags are removed, and the inoculated ends of the segments are placed facing upwards on the beds. The segments are positioned at a distance of 1–1.5 m from the greenhouse entrance, with an inter-segment distance of 3–5 cm and a row spacing of 8 cm, and then covered with 2 cm of soil. Water reservoirs, pumps, and water pipelines are configured in accordance with the base scale. An irrigation system is installed, which is connected to rotating in-ground misting sprinklers.

(2) Greenhouse management

The initial watering is carried out 10 days subsequent to soil covering. Germination is triggered when temperatures persistently surpass 28 °C. Throughout the germination phase, soil moisture is preserved while waterlogging is precluded, with due consideration given to ventilation and warming. When temperatures fall below 20 °C or during consecutive overcast days, supplementary scattered light is supplied to facilitate primordium formation.

During the bud stage, both soil and air humidity within the greenhouse are sustained, with watering conducted approximately 5 times per day. The frequency of watering is decreased or halted on rainy days and appropriately augmented on sunny days. When buds attain a height of approximately 7 cm, thinning is implemented, retaining 1–2 robust buds per segment.

During the cap expansion stage, frequent misting is employed to maintain a humid atmosphere inside the greenhouse. Light distribution is uniform, and adequate ventilation is ensured within 40 cm above the ground level to guarantee sufficient stipe length and flat cap expansion. If adjacent fruiting bodies are in close proximity, the segments are rotated and re-covered with soil in a timely fashion.

During the spore ejection stage, the temperature inside the greenhouse is regulated within the range of 28–35 °C. Appropriate misting is utilized to preserve soil moisture, while daytime air humidity is maintained at 50%–60%. The entrance area of the greenhouse is shaded to prevent direct sunlight from irradiating the fruiting bodies near the entrance, and adequate ventilation is provided to ensure normal sporulation.

Each greenhouse is equipped with two 350 W or 500 W spore collection fans. Ropes are tied from the greenhouse roof pipes to the fans, which are positioned 3 m from the entrance and 1 m above the ground. The fans are connected to collection bags suspended inside the greenhouse (19 m long, 0.5 m diameter). During the collection process, the fans operate continuously for 24 hours, the collection bags are tapped 3–4 times per day, and the spore powder is collected from the bags each morning.

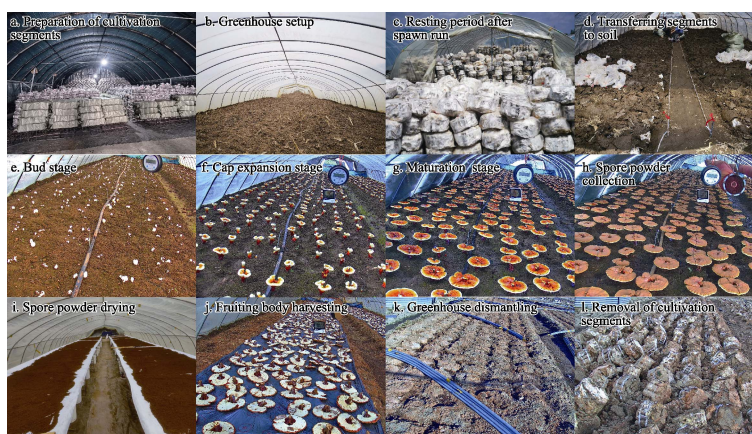


Figure 11 *Ganoderma lucidum* cultivation process in the case area

(3) Harvesting and drying

Collected spore powder must be spread out thinly and air-dried promptly or microwave-dried at 50–60 °C, then bagged and stored at low temperatures. Fruiting bodies

are harvested after the sporulation phase ends. The stipe is cut at the connection point with the wood segment, and any adhering soil is removed. The caps are placed face down, arranged individually, or the fresh *G. lucidum* is sliced and dried or air-dried. Once the moisture content falls below 11%, the product is graded and packaged.

6.4 Ecological Environment Traceability for Jiaohe *Ganoderma Lucidum*

To enable near-real-time monitoring of the *G. lucidum* habitat, a Jiaohe *Ganoderma lucidum* GIES ground station was established at the Sanhe Village cultivation base in Huangsongdian Town in May 2025 (Figure 12). This ground station is a low-power Internet of Things (IoT) sensing system. It dynamically monitors and records habitat factors such as air temperature, precipitation, wind speed, wind direction, relative humidity, atmospheric pressure, light intensity, negative oxygen ions, soil temperature at 0–10 cm, 10–20 cm, and 20–30 cm depths, soil moisture content, and soil electrical conductivity, as well as processes such as *G. lucidum* growth and spore powder collection, and transmits the data back in real time.

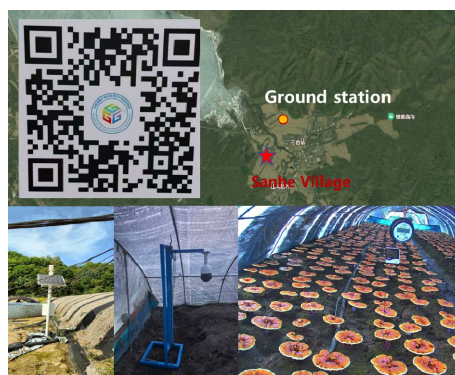


Figure 12 GIES ground station in the case area

7 Discussion and Conclusion

Ganoderma lucidum is a fungus of the genus *Ganoderma* with health-promoting properties and high economic value. Its industry possesses broad development prospects and requires integrated development in terms of government support, industry-academia-research collaboration, and marketing promotion.

7.1 Deepening Technological Innovation, Addressing Continuous Cropping Obstacles, and Enhancing Industrial Benefits

National and local laws and regulations on the conservation and utilization of *G. lucidum* are insufficient, leading to occasional illegal harvesting of wild germplasm resources. Research on the selection and breeding of high-quality varieties for artificial cultivation lags, or selected varieties are unsuitable for industrialized cultivation management. Except for a few leading enterprises, the *G. lucidum* industry focuses primarily on cultivation and primary product processing, signifying a need to strengthen large-scale, standardized cultivation and deep processing. Scientific and technological transformation in the *G. lucidum* industry is insufficient, with weak talent cultivation and technical reserves. Currently, many enterprises focus on developing spore powder product lines, while the development and marketing of *G. lucidum* products in the broader wellness sector are relatively lacking. In the future, there is a need to strengthen the protection of *G. lucidum* germplasm resources, breed new, high-quality varieties, develop standardized cultivation management technologies, and deepen technological innovation and empowerment.

As the scale of *G. lucidum* cultivation continues expanding, continuous cropping obstacles have become a bottleneck problem constraining the development of the *G. lucidum* industry in Jiaohe City, demanding effective solutions urgently. In the short term, there is a need for the comprehensive optimization of cultivation methods, soil disinfection, and biological control and regulation techniques. In the medium term, variety selection and breeding and facility construction need strengthening. In the long term, regional crop rotation planning

and ecological circular agriculture should be promoted. Furthermore, promoting base-oriented operations centered on land transfer is a key measure to propel the Jiaohe *G. lucidum* industry beyond land resource constraints. First, diversified models such as reverse contracting through “cooperatives+farmers”, large-scale leasing by enterprises, or joint-stock cooperation should guide farmers to transfer scattered land long-term and concentratedly to new types of agricultural business entities, forming large-scale cultivation bases with clear property rights and stable tenure. Second, unified planning and zoning should be implemented for the transferred contiguous land, promoting a rotation system of “*G. lucidum* cultivation-green manure incorporation/fallow-soil disinfection”. Finally, integrated policy support should be strengthened, with the government establishing transfer service platforms, providing fiscal and financial support, and building a solid coupling mechanism for risk-sharing and benefit-sharing.

7.2 Improving Standard Systems, Strengthening Market Supervision, and Enhancing Brand Influence

Currently, most health foods derived from sporoderm-broken *G. lucidum* spore powder use total triterpenoid content as a functional marker. However, national standards, health food catalogs, and technical requirements lack clear stipulations on the detection method for total triterpenoids specific to spore powder and derived products. The domestic *G. lucidum* spore powder industry is characterized by a competitive landscape of “numerous enterprises, low concentration, regional brands predominating, and uneven quality”. Industrial brand building is lagging, with low market recognition and weak competitiveness, hindering the realization of premiums for high quality. The National report on the development of characteristic rural industries (2024)^[7] pointed out a lack of distinctive *G. lucidum* varieties and severe homogeneous competition, making it difficult to meet the demand for high-quality, differentiated raw materials in specific medical and health care fields, thus hampering the enhancement of industrial added value. In the future, efforts should focus on innovating product types, improving quality testing and environmental protection standard systems, expanding the industrial chain, strengthening brand building, enhancing market supervision and risk warning, adapting to market environment changes, and ensuring the high-quality development of the *G. lucidum* industry.

Author Contributions

Li, D. F. formulated the case implementation plan and survey/sampling scheme; Liu, Y. Y., Xu, L. C., Wu, J. X., Liu, Y. N., and Li, L. P. provided historical meteorological, soil quality, and water environment data from the case area; Guo, L. S., Jia, J. G., Ji, X. B., Liu, X., Zhu, J. Q., Wang, D. Q., and Yan, F. F. provided data on *G. lucidum* product characteristics, cultivation management, and industrial operations; Li, D. F., Yang, J. J., Liu, Y. Y., Chen, W. M., Ma, F. W., Chen, S. K., Xu, D. C., Wang, P. X., and Liu, S. P. conducted the field investigations and sampling in the case area; Li, D. F., Hu, S., Wang, Z. B., Liu, J. Y., and Wang, P. X. completed the sample testing and manuscript preparation; Liu, X. L. provided valuable suggestions for the revision of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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