Journal of Global Change Data & Discovery. 2025, 9(4): 454-468
www.geodoi.ac.cn

GIES Case Study on Fangxian Black Fungus Interforest Facility Agriculture

Yang, L. H.[1,2*] Yang, D. H.[3] Lin, Y. G.[3] Deng, J.[4] Liu, M. D.[5] Cheng, X. Y.[1,2] Tian, M. C.[6] Chen, Z. H.[7] Shi, Z.[5] Yang, Y. L.[7] Liu, R.[7] Yang, F.[1,2] Jiang, C.[1,2] Bian, Y. B.[8] Zhang, F. G.[9] Meng, T. L.[10] Wang, M. A.[7] Fang, S. H.[7] Ma, J.[11] Chen, Y. B.[12] Tang, L.[13] Guan, J.[14] Tang, S. B.[15] Xie, R.[16] Wang, H.[17] Deng, M.[18] Liu, J.[19]

1. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100010, China; 2. University of Chinese Academy of Sciences, Beijing 100049, China; 3. People's Government of Fangxian County, Fangxian County 442100, China; 4. Agriculture and Rural Affairs Bureau of Fangxian County, Fangxian County 442100, China; 5. Development and Reform Bureau of Fangxian County, Fangxian County 442100, China; 6. Forestry Bureau of Fangxian County, Fangxian County 442100, China; 7. Vegetable Service Center of Fangxian County, Fangxian County 442100, China; 8. College of Plant Science and Technology, Huazhong Agricultural University, Wuhan 430072, China; 9. Meteorological Bureau of Fangxian County, Fangxian County 442100, China; 10. Agricultural Technology Extension Service Center of Fangxian County, Fangxian County 442100, China; 11. Fangxian County Xincai Capital Operation Group Co., Ltd., Fangxian County 442100, China; 12. People's Government of Tucheng Town, Fangxian County, Fangxian County 442115, China; 13. People's Government of Qingfeng Town, Fangxian County, Fangxian County 442101, China; 14. People's Government of Jundian Town, Fangxian County, Fangxian County 442104, China; 15. People's Government of Baihe Town, Fangxian County, Fangxian County 442100, China; 16. People's Government of Mengusi Town, Fangxian County, Fangxian County 442108, China; 17. People's Government of Zhongba Township, Fangxian County, Fangxian County 442109, China; 18. People's Government of Wanyuhe Township, Fangxian County, Fangxian County 442102, China; 19. People's Government of Shahe Township, Fangxian County, Fangxian County 442102, China

Abstract: Fangxian black fungus is a specialty product of Fangxian County in Hubei Province, China. It is Geographical Indication product of China, and it was listed at the EU-China GI Agreement products, renowned for its unique quality and nutritional value. The ecological environment, cultivation techniques, product quality, and business management of Fangxian black fungus was investigated. A model of habitat conservation and sustainable development for black fungus interforest facility agriculture was explored. The case area lies between the Daba and Wudang Mountains and is characterized as a hilly-mid-mountain region. The black fungus planting areas utilize 2 cultivation methods: log-grown black fungus and bag-grown black fungus. The substrate is rich in organic matter, and the water used for spraying meets higher quality standards than those specified in the Standard for irrigation water quality (GB 5084—2021), the product

Received: 12-06-2025; **Accepted:** 11-11-2025; **Published:** 24-12-2025
Foundation: Shiyan Development and Reform Commission of Hubei Province (2024)
***Corresponding Author:** Yang, L. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, yanglihu@igsnrr.ac.cn
Data Citation: [1] Yang, L. H., Yang, D. H., Lin, Y. G., *et al*. GIES case study on Fangxian black fungus interforest facility agriculture [J]. *Journal of Global Change Data & Discovery*, 2025, 9(4): 454–468. https://doi.org/10.3974/geodp.2025.04.09.
[2] Yang, L. H., Yang, D. H., Lin, Y. G., *et al*. GIES case dataset on Fangxian black fungus interforest facility agriculture [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2025. https://doi.org/10.3974/geodb.2025.09.06.V1.

quality meets or exceeds the national standard. The case dataset consists of 4 parts: case-area boundary, physical geographic data, black fungus variety characteristics, and management and cultural traditions. The data are archived in .shp, .xlsx, .docx, .jpg, .txt and .tif formats.

Keywords: Fangxian County; black fungus; facility agriculture; GIES; Case 27

DOI: https://doi.org/10.3974/geodp.2025.04.09

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.2025.09.06.V1.

1 Introduction

With the growing demand for healthy foods, black fungus, as an edible mushroom with high nutritional value, has gradually become a popular product in the market[1]. Fangxian County is located in the northwest of Hubei Province, in the hilly-mid-mountain area between the Daba and Wudang Mountains. It lies in the northern subtropical zone, with a mild climate and abundant rainfall, which are highly suitable for the growth of black fungus.

Fangxian black fungus, with its unique texture and rich nutrient content, has become an important source of production and livelihood for local farmers. The ecological environment, cultivation techniques, product quality, and business management of Fangxian black fungus was investigated. A model of habitat conservation and sustainable development for black fungus interforest facility agriculture was explored.

2 Metadata of the Dataset

The metadata of the GIES case dataset on Fangxian black fungus interforest facility agriculture[2] is summarized in Table 1. It includes the dataset full name, short name, authors, year of the dataset, data format, data size, data files, data publisher, and data sharing policy, etc.

Table 1 Metadata summary of GIES case dataset on Fangxian black fungus interforest facility agriculture

Items	Description
Dataset full name	GIES case dataset on Fangxian black fungus interforest facility agriculture
Dataset short name	FangxianBlackFungusCase27
Authors	Yang. L. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, yanglihu@igsnrr.ac.cn Yang, D. H., People's Government of Fangxian County Lin, Y. G., People's Government of Fangxian County Deng, J., Agriculture and Rural Affairs Bureau of Fangxian County Liu, M. D., Development and Reform Bureau of Fangxian County Cheng, X. Y., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 1163716758@qq.com Tian, M. C., Forestry Bureau of Fangxian County Chen, Z. H., Vegetable Service Center of Fangxian County Shi, Z., Development and Reform Bureau of Fangxian County Yang, Y. L., Vegetable Service Center of Fangxian County Liu, R., Vegetable Service Center of Fangxian County Yang, F., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 1228382850@qq.com Jiang, C., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, jiangchao23@mails.ucas.ac.cn Bian, Y. B., College of Plant Science and Technology, Huazhong Agricultural University, bianyinbing@mail.hzau.edu.cn Meng, T. L., Edible Mushroom Industry Association of Fangxian County Wang, M. A., Vegetable Service Center of Fangxian County Fang, S. H., Vegetable Service Center of Fangxian County Ma, J., Fangxian County Xincai Capital Operation Group Co., Ltd. Chen, Y. B., People's Government of Tucheng Town, Fangxian County

(*To be continued on the next page*)

(*Continued*)

Items	Description
	Tang, L., People's Government of Qingfeng Town, Fangxian County Guan, J., People's Government of Jundian Town, Fangxian County Tang, S. B., People's Government of Baihe Town, Fangxian County Xie, R., People's Government of Mengusi Town, Fangxian County Wang, H., People's Government of Zhongba Township, Fangxian County Deng, M., People's Government of Wanyuhe Township, Fangxian County Liu, J., People's Government of Shahe Township, Fangxian County
Geographical region	Fangxian County, Shiyan City, Hubei Province
Year	2000–2025
Data format	.shp, .xlsx, .docx, .jpg, .txt, .tif
Data size	90.4 MB
Data files	Case area boundary, physical geographic data, black fungus variety characteristics, and management and cultural traditions
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) *Data* are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use *Data* subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute *Data* subject to written permission from the GCdataPR Editorial Office and the issuance of a *Data* redistribution license; and (4) If *Data* are used to compile new datasets, the "ten percent principal" should be followed such that *Data* records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[3]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

3 Case Dataset Development

3.1 Case Area

The black fungus cultivation area in Fangxian County is located in the northwest of Hubei Province and the southern part of Shiyan City, between the Daba and Wudang Mountains. It is a hilly and mountainous region and one of China's famous black fungus production bases, known as the "Hometown of Black Fungus"[4]. Due to the diversity of terrain and landforms, the advantage of microclimate is obvious, which is very suitable for the growth of edible fungi.

The case area includes 8 townships: Tucheng Town, Qingfeng Town, Jundian Town, Baihe Town, Mengusi Town, Zhongba Township, Wanyuhe Township, and Shahe Township (Figure 1). The total area is about 2,600 km^2, with a total population of 191,419, including 22,534 in Tucheng, 35,339 in Qingfeng, 38,792 in Jundian, 32,833 in Baihe, 33,837 in Mengusi, 11,284 in Zhongba, 8,112 in Shahe, and 8,688 in Wanyuhe (Table 2).

3.2 Topography

The terrain of Fangxian County is high in the west and low in the east, steep in the south and gentle in the north, with valley plains in the middle. Based on analysis of ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM data[1], the elevation in Fangxian County ranges from 160 m to 2,470 m (Figure 2). Taking the Qingfeng fault zone as a boundary, the northern mountainous area has elevations of 800–1,000 m, with mountain ranges mainly oriented east-west, northeast, or southeast. The ridges are broad and the mountaintops are table-like, with interspersed valley basins that are the main production areas of maize, rice, wheat and black fungus. A narrow and elongated faulted basin is formed in the central region centered on the Malan River Valley, with an altitude of 400–600 m. It is

[1] National Aeronautics and Space Administration. https://asterweb.jpl.nasa.gov/gdem.asp.

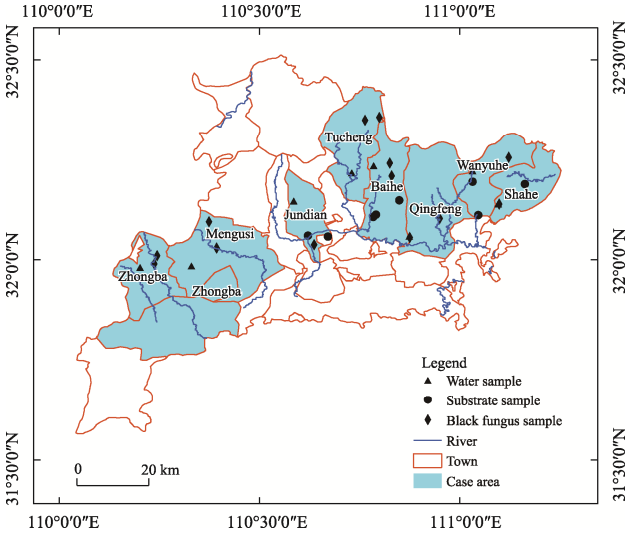

Figure 1 Geo-location, boundary and sampling-point distribution map of the case area in Fangxian County

Table 2 Statistics of area and total population of the 8 townships in the case area (2024)

Item	Tucheng	Qingfeng	Jundian	Baihe	Zhongba	Mengusi	Shahe	Wanyuhe	Total
Population (person)	22,534	35,339	38,792	32,833	11,284	33,837	8,112	8,688	191,419
Area (km^2)	353.01	415.00	160.70	228.79	224.00	306.00	236.00	192.40	2,115.9

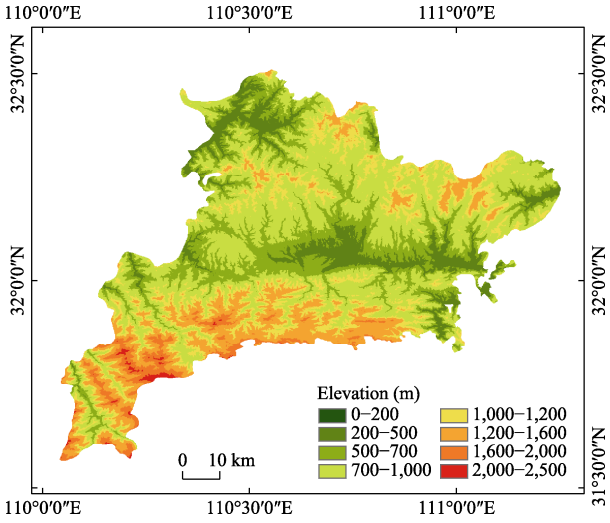

Figure 2 Elevation-classification map of Fangxian County

not only an important grain producing area, but also a major base for the development of fruit and wood orchards[5]. The southern part is a high-mountain area, mostly above 1,000 m, with steep terrain. It is the main production area of maize, miscellaneous grains, and timber forests.

The altitude difference in the whole county is significant, with the highest point Shangkan Guanjiaya in the southwest (2,485.6 m) and the lowest point Damujiangjiapo (180 m), with a relative height difference of 2,306 m. This unique combination of terrain and climate conditions provides an important natural basis for the spatial differentiation of agricultural

production in Fangxian County[6].

The terrain slope of Fangxian County presents a feature of low in the middle and high around, and the overall terrain gradually rises from the central valley plain to the surrounding mountains. This pattern is mainly shaped by tectonic movements in the Qinling-Daba Mountains and the long-term fluvial incision of the Hanjiang River system, forming a basin-like landform structure centered on the Fangxian County Basin and surrounded by medium-low mountains.

The central area is relatively flat, with slopes mostly below 15 ° (Table 3 and Figure 3), and is the main area of town agglomeration and cultivated agriculture. The surrounding area is mostly mountainous with an angle of over 15 °, and high forest coverage.

Table 3 Statistics of slope-class areas

Slope (°)	Area (km^2)	Slope (°)	Area (km^2)	Slope (°)	Area (km^2)
<1	21.01	[7,15)	1,016.63	[25,35)	1,271.99
[1,3)	100.10	[15,25)	1,870.97	≥35	570.56
[3,7)	284.27				

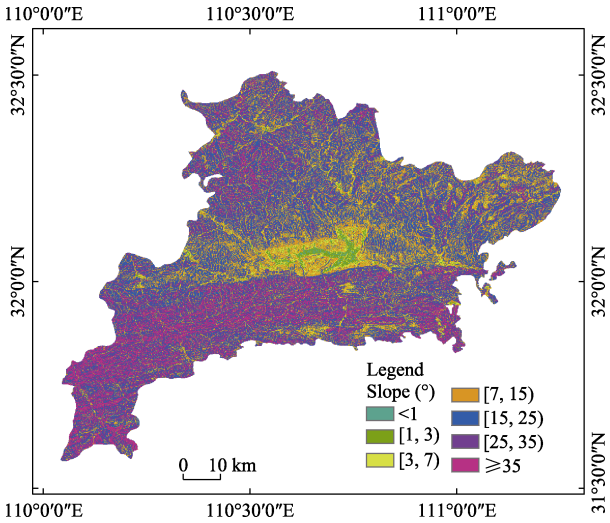

Figure 3 Slope-classification map of Fangxian County

3.3 Climatic Data

Fangxian County is located in the subtropical monsoon climate zone and exhibits distinct vertical climatic characteristics. The region has long winters and short summers, distinct 4 seasons, and a pronounced vertical climate gradient. According to data from the Fangxian County Meteorological Station on the China Meteorological Data Service Center for 2000–2024[2], the annual mean relative humidity in the area is 75.1% (Figure 4), the annual mean temperature is 15.0 ℃, and annual sunshine duration is 1,376–1,938 h. The frost-free period is 223 d. Annual precipitation is 550.2–1,237.0 mm, concentrated from April to October, which accounts for 86.3% of the total annual precipitation, showing a gradient of increase from north to south. The number of rainy days ranges from 101 to 137, with a mean of 121 d per year. Major agrometeorological disasters in the area include late spring cold spells, summer droughts (“neck-choking drought”), and cool/wet weather in autumn, all of which have significant impacts on crop growth.

[2] China Meteorological Data Service Centre. https://data.cma.cn/.

3.4 Land-use and Vegetation Coverage

Based on Sentinel-2 L2A imagery of Fangxian County in 2022 (cloud cover < 30%)[3], monthly median composites were generated after cloud-mask processing. 10 spectral bands (B2–B8A, B11–B12), 4 vegetation indices (NDVI, NDWI, EVI, SAVI), and their annual statistics (median, mean, standard deviation, extrema) were extracted as features. A random-forest classifier was then used to carry out land-use classification for Fangxian County (Figure 5).

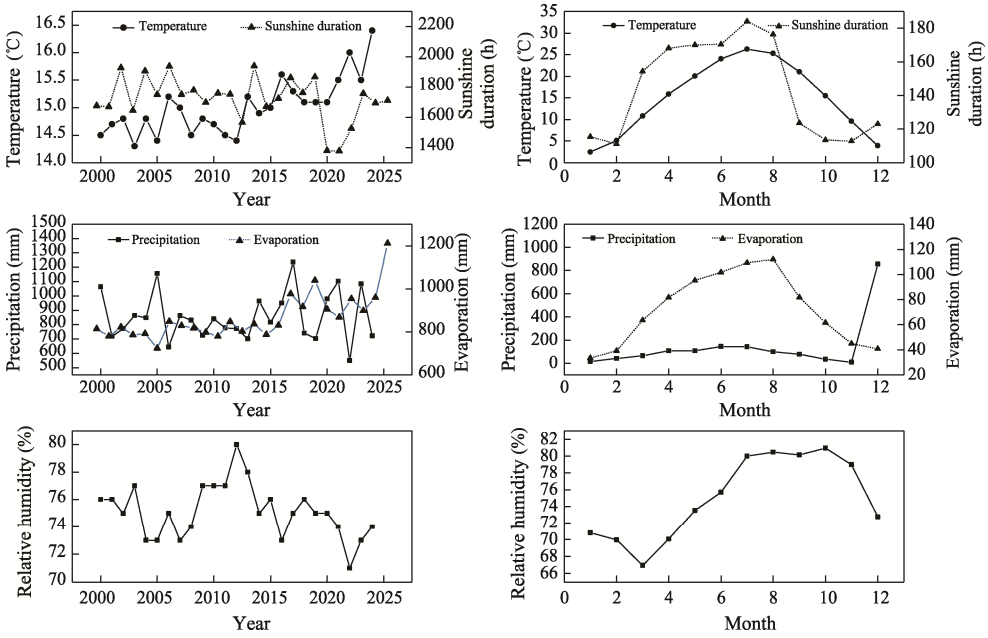

Figure 4 Statistics of climatic characteristics in Fangxian County

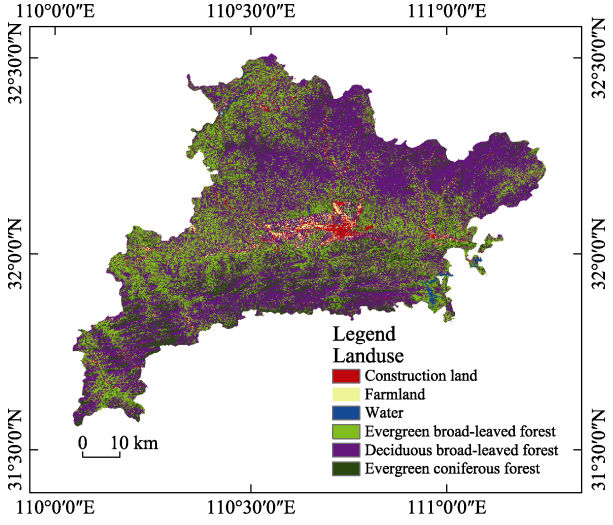

Figure 5 Land-use and forest-distribution map of Fangxian County

[3] European Space Agency (ESA). Sentinel-2 imagery. Copernicus Open Access Hub. https://scihub.copernicus.eu/.

The evergreen broad-leaved forests in Fangxian County are mainly distributed in the central, northwestern, and southwestern mountainous areas, the deciduous broad-leaved forests are mainly distributed in the northwestern and southern mountainous areas, and the evergreen coniferous forests are mainly distributed in the southern mountainous areas. The total area of forest land is 4,355.5 km^2, with forest area of 3,941.9 km^2 and forest cover of 84.6%. The forests (mainly Quercus variabilis) used for log-grown black fungus belong to deciduous broadleaf forests, with an area of 1,632.8 km^2 and an annual timber increment of 220,000 m^3. On average, Fangxian County produces 65,000 racks of logs per year for log cultivation, consuming about 13,000 m^3 of timber, which accounts for 5.9% of the annual increment of oak resources. All timber is sourced from within Fangxian County. In addition, 15.8 million cultivation bags are produced annually, using 13.8 million kg of substrate materials, of which 87.4% are locally supplied.

3.5 Physicochemical Analysis of Cultivation Substrates

The cultivation substrates of Fangxian black fungus are mainly of 2 types: bag-grown substrate and logs. According to the cultivation distribution in the case area, samples of both bag substrate and logs were collected by the authors in December 2024 (Figure 1) and sent to the Physicochemical Analysis Center of the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (IGSNRR, CAS), for testing.

The testing indicators included As, Cd, Pb, Cr, Ni, Cu, Zn, Hg, TN, TC, C/N, and organic matter. The nitrogen content in the bag substrate and logs used for cultivation ranged from 0.42% to 1.99%, and carbon content from 39.90% to 53.00%, with C/N of 20.25–106.55, indicating relatively high nitrogen and carbon contents. Organic matter content ranged from 68.79% to 91.38%, showing rich organic matter. The heavy-metal contents (in both bag substrate and logs) were much lower than the agricultural-land soil-pollution risk screening values in the Soil environmental quality risk control standard for soil contamination of agricultural land (Trial) (GB 15618—2018)[7] (Table 4).

Table 4 Statistics of the physicochemical indicators in log/bag substrates in the case area

Test item	Max.	Min.	Avg.	GB 15618—2018 limiting value[7]	Test item	Max.	Min.	Avg.	GB 15618—2018 limiting value[7]
As (mg/kg)	ND	ND	ND	≤ 30	Zn (mg/kg)	113.08	25.79	50.32	≤ 250
Cd (mg/kg)	ND	ND	ND	≤ 0.3	Hg (mg/kg)	ND	ND	ND	≤ 2.4
Pb (mg/kg)	5.95	2.09	3.56	≤ 120	TN (%)	1.99	0.42	0.85	
Cr (mg/kg)	72.54	14.80	28.11	≤ 200	TC (%)	53.00	39.90	43.48	
Ni (mg/kg)	3.04	0.00	0.89	≤ 100	C/N	106.55	20.25	62.02	
Cu (mg/kg)	11.21	3.00	6.74	≤ 100	Organic matter (%)	91.38	68.79	74.96	

Note: “ND” indicates “not detected”.

3.6 Water Conditions Data

Fangxian County is relatively rich in water resources. There are 1,261 rivers of various sizes with a total length of 3,455 km. There are mainly 4 major rivers in Fangxian County, namely Nanhe, Duhe, Beihe, and Guanshan rivers, with a total length of 2,612 km. The Panyu, Ximen, Shagou, Baojia, and Malan rivers converge in the central urban area, with a drainage area accounting for 100% of Fangxian County. There are 77 reservoirs of Grade-II or above in the county, including 1 large, 4 medium, 13 small-I and 59 small-II reservoirs, with a total storage capacity of 584.27 million m^3. The theoretical hydropower potential is 350,000 kW, of which more than 316,200 kW can be developed.

In August 2025, 8 sampling sites were set up in the case area (Figure 1) to collect water samples used for spraying. Water quality was analyzed according to the basic control

indicators in the Standard for irrigation water quality (GB 5084—2021)[8]. The test results (Table 5) show that pH ranged from 7.1 to 7.9, and that all 16 basic indicators, including water temperature, suspended solids, BOD_5, COD, anionic surfactants, Cl, S, total salinity, Pb, Cd, Cr, Hg, As, fecal coliform count, and helminth eggs, were below the limit values in the Standard for irrigation water quality. The water quality also fully met the Standards for drinking water quality (GB 5749—2022)[9], indicating the excellent quality of water used in black fungus cultivation.

Table 5 Summary of water-quality indicators in the case area

Test item	Max.	Min.	Avg.	GB5084—2021 limiting value[8]	GB5749—2022 limiting value[9]
pH	7.9	7.1	7.5	5.5–8.5	6.5–8.5
Water temperature (℃)	28.6	24.0	26.5	35	
Suspended solids (mg/L)	7.0	0.0	0.9	60	
BOD_5 (mg/L)	2.1	0.9	1.4	40	
COD (mg/ L)	10	4	6.6	100	
Anionic surfactant (mg/L)	0.06	ND	0.01	5	
Cl (mg/L)	8.4	1.8	4.6	350	250
S (mg/L)	ND	ND	ND	1.0	
Total salt content (mg/L)	210	38	123.0	1,000	
Pb (mg/L)	0.008	0.000	0.004	0.2	0.01
Cd (mg/L)	0.001	ND	0.000	0.01	0.005
Cr (mg/L)	0.0	ND	0.000	0.1	50
Hg (mg/)	ND	ND	ND	0.001	0.001
As (mg/L)	0.010	ND	0.003	0.1	10
Number of fecal coliforms (MPN/L)	5,400	230	1,585	20,000	
Number of ascaris eggs (per 10L)	ND	ND	ND	20	

Note: “ND” indicates “not detected”.

3.7 Product Quality Data

The testing data for Fangxian black fungus fully demonstrate its outstanding quality characteristics and nutritional value. Based on testing of log-grown and bag-grown samples from townships in the case area (Tables 6 and 7), the nutritional features can be summarized as follows. The dry-to-fresh ratio of log-grown black fungus had a mean of 1:11.2, and that of bag-grown black fungus 1:9.6, both meeting the national standard for black fungus (GB/T 6192—2019, ≥1:9)[10], with log-grown black fungus having a higher rehydration ratio than bag-grown fungus. Ash content ranged from 4.40% to 5.30% (mean 4.85%), which is within a reasonable range and reflects that necessary mineral components are retained after scientific processing, indicating precise process control.

Nutritional indicators were particularly remarkable. Total sugar (as invert sugar) in log-grown black fungus was 45.50%–56.50% (mean 52.1%), and in bag-grown black fungus 47.8%–62.6% (mean 55.4%), more than twice the minimum requirement (≥22%) in GB/T 6192—2019[10]. Crude protein averaged 9.8% (maximum 10.9%) in log-grown and 9.6% (maximum 9.8%) in bag-grown samples, which is high among edible fungi and confirms that black fungus is a high-quality source of plant protein. Crude fat content was 0.40%–0.50% (mean 0.42%), satisfying modern dietary demands for low-fat foods. Crude fiber ranged from 3.1% to 5.8% (mean 4.6%), ensuring both dietary-fiber health benefits and good palatability.

Food-safety indicators showed that methyl mercury (as Hg) was 0.01–0.02 mg/kg, arsenic 0.02–0.08 mg/kg, lead (Pb) 0.16–0.41 mg/kg, and cadmium 0.04–0.26 mg/kg, all far below the national limits for edible fungi in the National food safety standard—maximum levels of

contaminants in food (GB 2762—2022)[11] (Hg ≤ 0.1 mg/kg, As ≤ 0.5 mg/kg, Pb ≤ 1.0 mg/kg, Cd ≤ 0.5 mg/kg). The pesticide residues DDT and HCH were not detected, meeting the local standard for geographical indication product Fangxian black fungus (DB42/T 598—2010)[12].

Overall, Fangxian black fungus achieves a dual guarantee of nutrition and safety through strict quality control. The synergy of multiple indicators provides it with high nutritional value, functional properties, and food safety, making it a typical example of high-quality edible fungi. With its "high protein, high fiber, low fat, and low sugar" nutritional profile and significant spatial differentiation in ash content, Fangxian black fungus not only meets modern dietary needs, but also supports its uniqueness and certification feasibility as a high-quality geographical-indication product at the biochemical-indicator level.

Table 6 Statistical results of quality indicators of log-grown black fungus in the case area

Test item	Max.	Min.	Avg.	GB/T 6192—2019 limiting value[10]	DB42/T 598—2010 limiting value[12]
Dry-wet ratio	1:10.6	1:11.8	1:11.2	1:9 or above	1:12
Water content (%)	11.5	11.9	11.7	≤12.0	≤14.0
Ash (by dry weight) (%)	4.8	5.3	5.0	≤6.0	≤6.0
Total sugar (by converted sugar) (%)	45.5	56.5	52.1	≥22.0	≥23.0
Crude protein (%)	9.3	10.9	9.8	≥7.0	≥7.0
Crude fat (%)	0.4	0.4	0.4	≥0.4	
Lead (by Pb) (mg/kg)	0.298	0.382	0.344	≤1.0	≤0.5
Cadmium (by Cd) (mg/kg)	0.040	0.249	0.128	≤0.5	≤0.8
Inorganic arsenic (by As) (mg/kg)	0.022	0.084	0.051	≤0.5	≤0.5
Methyl mercury (by Hg) (mg/kg)	0.008	0.015	0.012	≤0.1	≤0.15
DDT (mg/kg)	ND	ND	ND		≤0.1
Hexachlorocyclohexane (mg/kg)	ND	ND	ND		≤0.2

Note: "ND" indicates "not detected".

Table 7 Statistical results of quality indicators of bag-grown black fungus in the case area

Test item	Max.	Min.	Avg.	GB/T 6192—2019 limiting value[10]	DB42/T 598—2010 limiting value[12]
Dry-wet ratio	9.3	9.9	9.6	1:9 or above	1:12
Water content (%)	11.5	11.9	11.8	≤12.0	≤14.0
Ash (by dry weight) (%)	4.4	4.9	4.6	≤6.0	≤6.0
Total sugar (by converted sugar) (%)	47.8	62.6	55.4	≥22.0	≥23.0
Crude protein (%)	9.5	9.8	9.6	≥7.0	≥7.0
Crude fat (%)	0.4	0.5	0.4	≥0.4	
Crude fiber (%)	3.1	5.8	4.6	3.0–6.0	3.0–6.0
Lead (by Pb) (mg/kg)	0.162	0.225	0.188	≤1.0	≤0.5
Cadmium (by Cd) (mg/kg)	0.050	0.100	0.063	≤0.5	≤0.8
Inorganic arsenic (by As) (mg/kg)	0.026	0.061	0.042	≤0.5	≤0.5
Methyl mercury (by Hg) (mg/kg)	0.005	0.012	0.008	≤0.1	≤0.15
DDT (mg/kg)	ND	ND	ND		≤0.1
Hexachlorocyclohexane (mg/kg)	ND	ND	ND		≤0.2

Note: "ND" indicates "not detected".

In addition, amino-acid analysis of different varieties of black fungus showed that amino-acid content is rich, especially essential amino acids such as proline, leucine and phenylalanine (Table 8). Leucine, as a branched-chain amino acid, plays an important role in muscle metabolism and immune regulation[13]; phenylalanine participates in protein synthesis and serves as a precursor of tyrosine, dopamine and adrenaline, which are

important for neurotransmission, metabolic regulation and emotional stability[14]; proline is involved in collagen synthesis and antioxidant regulation[15]. Compared with black fungus from northeastern China, Fangxian black fungus has an advantage in the proportion of essential amino acids and the balance of key amino acids such as leucine and phenylalanine. For example, the proline contents in black fungus from 4 production regions (Yanji City, Mudanjiang City, Zhashui County and Zhuoni County) are 0.33, 0.35, 0.43 and 0.46 mg/kg, respectively, all lower than those in Fangxian black fungus[16].

Table 8 Statistical results of amino-acid contents in black fungus in the case area

Test index	Min. (g/100g)	Max. (g/100g)	Avg. (g/100g)	Test index	Min. (g/100g)	Max. (g/100g)	Avg. (g/100g)
Leucine	0.410	0.740	0.563	Isoleucine	0.110	0.130	0.120
Phenylalanine	0.310	0.400	0.345	Alanine	ND	ND	ND
Glycine	ND	ND	ND	Glutamic acid	ND	ND	ND
Proline	1.050	1.520	1.283	Methionine	ND	ND	ND
Arginine	0.440	0.650	0.524	Histidine	0.560	0.690	0.640
Aspartic acid	ND	ND	ND	Serine	ND	ND	ND
Tyrosine	ND	ND	ND	Lysine	0.450	0.630	0.514
Valine	0.073	0.180	0.134				

Note: “ND” indicates “not detected”.

4 Black Fungus Industry Management

4.1 Socio-economic Development of Fangxian County

Statistics show that from 2015 to 2024 the populations of the 8 typical townships in the case area all decreased, with the largest declines in Jundian (−7.06%) and Shahe (−9.49%), mainly due to accelerated out-migration of young and middle-aged people and limited urban and rural capacity to absorb them (Table 9). Baihe saw only a 2.05% population decline, indicating relatively strong demographic stability. Overall, Fangxian County has experienced sustained population loss and ageing pressure over the past decade, especially affecting the rural labor structure.

Table 9 Population change in townships in the case area (2015–2024)

Township	Population in 2015 (person)	Population in 2024 (person)	Change in population (person)	Change percentage (%)
Tucheng	23,557	22,534	–1,023	–4.34
Qingfeng	36,952	35,339	–1,613	–4.37
Jundian	41,737	38,792	–2,945	–7.06
Baihe	33,520	32,833	–687	–2.05
Zhongba	11,980	11,284	–696	–5.81
Mengusi	35,074	33,837	–1,237	–3.53
Shahe	8,963	8,112	–851	–9.49
Wanyuhe	9,097	8,688	–409	–4.50

In terms of income, the black fungus industry has become a pillar industry driving farmers’ income growth (Table 10). For example, in Yupinghe Village of Qingfeng Town, per capita annual income from black fungus cultivation reaches 8,421 CNY, accounting for 55% of total household income, while per capita income from employment in breeding, log cutting, transportation and processing reaches 7,227 CNY, accounting for 47% of total income. In Shuanghe and Yanhe villages in Baihe Town, the share of income from the black fungus industry is also close to 50%, indicating a high degree of dependence. Although overall income levels in Tucheng are relatively lower, in Tanggeng Village the combined

share of income from black fungus cultivation and related labor exceeds 60%, making it still the primary source of household income.

Table 10 Per capita income and black fungus-related income in typical townships in the case area

Township	Village	Permanent residents (person)	Per capita income from growing black fungus (CNY/year)	Percentage of total income (%)	Per capita income of black fungus workers (CNY/year)	Percentage of total income (%)
Tucheng	Tanggeng	1,450	5,895	38	4,526	29
Qingfeng	Yupinghe	1,540	8,421	55	7,227	47
Qingfeng	Longwanggou	1,527	7,485	49	5,800	38
Baihe	Donglang	1,782	7,699	50	6,164	40
Baihe	Yanhe	425	7,218	47	5,818	38
Baihe	Shuanghe	453	7,442	48	7,077	46

The employment structure further confirms this pattern (Table 11). In typical villages, the number of people engaged in local black fungus cultivation and labor accounts for 20%–30% of the permanent population, forming a "village-clustered employment pattern" for the industry. The proportion of residents working in black fungus production outside the local area is relatively low, indicating that a fairly complete local chain of production, processing and marketing has been established, absorbing most of the surplus labor.

Table 11 Employment in the black fungus industry in typical townships in the case area

Township	Village	Number of local planting population (person)	Number of local processing/labor workers (person)	Number of people going out for planting (person)	Number of people going out for processing or labor (person)
Tucheng	Tanggeng	152	38	0	0
Qingfeng	Meihuashan	57	16	0	0
Qingfeng	Longwanggou	171	43	0	0
Baihe	Donglang	266	67	0	0
Baihe	Shuanghe	258	65	0	0
Baihe	Yanhe	133	33	0	0

4.2 Historical Tradition of Black Fungus Cultivation

Fangxian County has a long history of black fungus cultivation. According to Tangbencaozhu, Fangxian black fungus was already cultivated more than 1,300 years ago in the Tang Dynasty. After the founding of P. R. China, the local government actively encouraged black fungus cultivation. Over the long term, people in Fangxian County have continually accumulated experience and improved production techniques, eventually forming a high-yield, high-quality and efficient cultivation model. Before the founding of P. R. China, black fungus production in Fangxian County remained at a semi-artificial cultivation level in wild habitats. In 1968, the Hubei Provincial Supply and Marketing Cooperative and the Ministry of Commerce of China successively held provincial and national on-site meetings on black fungus irrigation and production in Fangxian County, breaking the traditional notion of "man plants, but heaven manages" and greatly increasing yield. In 1980, at the request of the All-China Federation of Supply and Marketing Cooperatives, the Fangxian County Supply and Marketing Cooperative compiled Three-character classic of black fungus production, which was used nationwide to promote log-cultivation techniques. From 1979 to 1982, China Central Television, Hubei Television, Shanghai Television and the Science and Education Film Studio produced science films and news documentaries such as Black fungus, Qianli Fangxian black fungus harvest, and Log cultivation of black fungus in Fangxian County. In 2009, the Fangxian black fungus was approved to be the Geographical Indication of China. In 2020, it was on the list of the EU-China GI Agreement products.

Fangxian County domesticated and selected local wild strains to obtain varieties suitable for local cultivation, and established non-polluted planting areas. Deep-hole, dense-planting, sprinkler irrigation technologies and cultivation models of small bags in spring and large bags in autumn were promoted. No chemical fertilizers or pesticides are used in production; pest and disease control relies on traditional agricultural, physical and biological methods, and the biological conversion rate exceeds 85%. Leading enterprises are supported to carry out Good Agricultural Practice certification, quality-management and food-safety management-system certification, as well as organic and green food certification.

4.3 Development of Interforest Facility Agriculture

As one of China's major black fungus production areas, Fangxian County has interforest facility agriculture infrastructure at a leading level within Hubei Province. Focusing on the whole industrial chain of black fungus, the county has gradually formed a complete supporting system covering strain propagation, substrate production, cultivation management, storage and preservation, processing and circulation. In the production segment, there are 3 strain and substrate factories in the county: Fangxian County Yueming Strain Factory in Jundian Town, Fangxian County Tianhe Fungi Industry Strain Factory in Tucheng Town, and Hubei Junxiangyuan Biotechnology Co., Ltd. in Qingfeng Town. These enterprises not only have strong capacity for strain research and production, but have also introduced and applied advanced technologies such as liquid spawn. Their annual outputs reach 5.7 million kg of solid spawn and 700,000 L of liquid spawn.

With regard to supporting infrastructure, in 2024, 1,524 double-layer drying greenhouses have been built, covering 81.33 ha. A total of 864 ponds, water cellars and storage tanks have been constructed for black fungus production. Micro-sprinkler facilities have been installed for 100% of bag-grown black fungus production and for 85% of log-grown production. Meanwhile, 34 cold storage units with a total capacity of 3,800 m^3 have been built, effectively improving storage and preservation capacity. In terms of logistics and marketing, the Green Agricultural Port Edible Mushroom Trading Market in Baihe Town covers 6.33 ha, including 3,800 m^2 for edible mushroom trading, serving as an important distribution hub for black fungus.

In the processing segment, there are 12 black fungus processing enterprises in the county, with an annual processing capacity of 5,400 t. In 2024, total black fungus output in Fangxian County approached 4,000 t, with a comprehensive output value of 1.5 billion CNY, sales revenue of 640 million CNY, and annual export earnings of 15 million USD. Overall, the construction of interforest facility agriculture for black fungus in Fangxian County ensures stable and efficient production, underpins its industrial advantage as the "Hometown of Black Fungus in China", and provides a solid industrial foundation for characteristic regional agriculture and rural revitalization.

4.4 Cultivation Management of Black Fungus

Fangxian black fungus is mainly cultivated in 2 forms: log-grown and bag-grown (Figure 6)[17]. Log-grown black fungus is mainly planted in Qingfeng, Baihe and Mengusi; bag-grown black fungus is mainly cultivated in Tucheng, Jundian and Baihe (Table 12). In the case area, up to 2024, 15.5 million cultivation bags and 55,000 log racks are used, with Tucheng having the largest number of bags (10 million) and Qingfeng having the largest number of log racks (12,000).

A special leading group for production management has been established in the black fungus planting area of Fangxian County. The chief executive of each township serves as the group leader, and members include village chief executives and council members. Unified organization and standardized management are implemented to ensure standardized production of black fungus. Full-time personnel are assigned to black fungus production, and cultivation technicians are invited to carry out technical training and on-site guidance.

Figure 6 Black fungus (left: log-grown; right: bag-grown)

Table 12 Planting statistics of black fungus in the case area (2024)

Township	Bag-grown black fungus (thousand bags)	Log-grown black fungus (thousand frames)
Tucheng	10,000	5
Qingfeng	2,000	12
Jundian	1,000	0
Baihe	1,000	10
Mengusi	500	10
Zhongba	500	5
Wanyuhe	0	8
Shahe	0	5
Total	15,500	55

The research and development of the Fangxian black fungus case was conducted through a seven-in-one approach integrating industry, academia, research, government, association, farmers, and media. The collaboration among Fangxian County Xincai Capital Operation Group Co., Ltd., the College of Plant Science and Technology, Huazhong Agricultural University, IGSNRR, CAS, the Fangxian County Government, the Agriculture and Rural Affairs Bureau of Fangxian County, the Development and Reform Bureau of Fangxian County, the Geographical Society of China, local villagers in various towns of Fangxian County, and the Editorial Office of the *Journal of Global Change Data & Discovery* ensured the success of this case. During the R&D process, the Fangxian County Government and Fangxian County Xincai Capital Operation Group Co., Ltd. established a unified production process archive for black fungus, documenting the entire production cycle according to standardized requirements to facilitate traceability management.

4.5 Harvesting, Processing Management

Harvesting and processing of black fungus follow standardized procedures to ensure product quality and safety. According to the processing technical specification of Fangxian black fungus (Q/FXME-003), processing plants must be located away from pollution sources, and workshops must be equipped with facilities against insects and rodents, as well as changing and disinfection rooms. Processing personnel must hold valid health certificates and wear standardized work clothes.

After harvesting, raw materials are accepted strictly according to grade, color and impurity levels. Qualified raw materials are spread to pre-dry to about two-thirds moisture content, and then dried in dryers. A stepwise temperature-rising method is used, starting from 30 ℃ and increasing by 5 ℃ every 3 h, with a final temperature not exceeding 45 ℃. Final moisture content must be below 12%.

The processing flow includes screening, drying, grading and packaging. Grading is based on the completeness of ears, color, thickness and impurity content, and products are classified into first, second, third and substandard grades. Packaging materials must meet the sanitary standard GB 4806.7—2023, and product labels must be clear and complete.

Finished products are stored in dedicated warehouses, protected against mold and insects. During transportation, direct sunlight and rain must be avoided, and black fungus must not be transported together with toxic or hazardous goods. According to differences in harvest seasons, black fungus is divided into spring fungus (best quality), summer fungus (medium) and autumn fungus (intermediate), and is managed separately to optimize product value.

Through full-process technical control, the sensory quality, sanitary safety and market competitiveness of Fangxian black fungus are effectively ensured.

4.6 Traceability Technology for Fangxian Black Fungus

Traceability data for Fangxian black fungus mainly include 3 categories: cultivation and production, environmental monitoring (ground stations), and processing and storage. Through full-process data collection and management, product traceability and quality assurance are realized. In the production link, information such as strain ID, strain source and activity test reports is recorded. Near real-time data collection is realized via GIES ground station (Figure 7), enabling dynamic monitoring of the growth environment. 13 indicators are monitored: air temperature, wind speed, wind direction, air pressure, humidity, soil temperature, soil moisture, total radiation, atmospheric CO_2, $PM_{2.5}$, PM_{10} and noise. Continuous monitoring provides data on crop growth, pest and disease occurrence, and climate change. By linking these monitoring data with strain IDs and plot information, visualization and fine-scale management of production are enhanced, and robust data support is provided for risk early warning, quality evaluation and storage/preservation. In the processing link, processing parameters (drying temperature gradient, moisture control), quality grades and microbiological indicators (e.g., Escherichia coli, Salmonella and other 5 pathogenic bacteria) are recorded. In the storage link, warehouse temperature, relative humidity, real-time monitoring data and sampling results for quality inspection are documented.

Figure 7 GIES ground station for Fangxian black fungus

5 Discussion and Conclusion

The black fungus cultivation area in Fangxian County is located in the northwest of Hubei Province. Its unique natural environment has given rise to high-quality black fungus with distinct geographical characteristics. To ensure the high-quality development of Fangxian black fungus in the future, efforts can be further strengthened in several aspects, including standardized management of black fungus cultivation, quality assurance, and sustainable development of the ecosystem. By addressing these issues, Fangxian black fungus can achieve sustainable development, further enhance local economic development, and contribute to rural revitalization.

Author Contributions

Yang, L. H. designed the overall case study and implementation plan; Yang, D. H., Lin, Y. G., Deng, J., Liu, M. D., Chen, Z. H. and Shi, Z. coordinated the field investigation in the case area; Yang, Y. L., Tian, M. C. and Zhang, F. G. provided data on ecological environment, cultivation management and industrial operation; Meng, T. L., Wang, M. A., Fang, S. H., Ma, J., Chen, Y. B., Tang, L., Guan, J., Tang, S. B., Xie, R., Wang, H., Deng, M. and Liu, J.

assisted in field surveys and sample collection; Bian, Y. B. reviewed the paper; Yang, L. H., Cheng, X. Y., Yang, F., Yang, Y. L. and Liu, R. participated in field investigations in the case area and collected and analyzed water, log substrates, bag substrates and black fungus samples; Yang, L. H., Cheng, X. Y. and Jiang, C. completed the compilation of the dataset, mapping, and writing of the paper.

Acknowledgements

The authors express their sincere thanks to leaders at all levels in Fangxian County for their support and cooperation, and to all staff members who assisted in the collection of water, log, bag substrate and black fungus samples. We sincerely thank Liu, C., Song, X. F., Wang, Z. B. and Zhang, S. D. of the Geographical Indication Research Center of IGSNRR, CAS, for their assistance and helping in the project initiation and data collection.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Yang, Y. N., Zhang, S. Q., Liu, Y. J. Nutritional components and functions of black fungus [J]. *Agricultural Product Processing*, 2024(15)：91–93. DOI: 10.16693/j.cnki.1671-9646(X).2024.15.021.

[2] Yang, L. H., Yang, D. H., Lin, Y. G., *et al*. GIES case dataset on Fangxian black fungus interforest facility agriculture [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2025. https://doi.org/10.3974/geodb.2025.09.06.V1.

[3] GCdataPR Editorial Office. GCdataPR data sharing policy [OL]. https://doi.org/10.3974/dp.policy.2014.05 (Updated 2017).

[4] Ming, C. C., Jia, M., He, W., *et al*. The development history and prospects of edible fungi industry in Fangxian County [J]. *Anhui Agricultural Science Bulletin*, 2021, 27(16): 33–34. DOI: 10.16377/j.cnki.issn1007-7731.2021.16.011.

[5] Ji, D. C. Research on the current situation of utilization and development of edible fungi resources in Fangxian County [D]. Wuhan: Wuhan Polytechnic University, 2021. DOI: 10.27776/d.cnki.gwhgy.2021.000078.

[6] Liang, W., Zhao, S, D. Research on the path for high-quality development of the edible fungi industry in Fangxian County [J]. *Journal of Hubei Vocational and Technical College*, 2023, 36(6): 42–45.

[7] Ministry of Ecology and Environment of P. R. China, State Administration for Market Regulation. Soil environmental quality risk control standard for soil contamination of agricultural land (Trial) (GB 15618—2018) [S]. Beijing: China Environment Publishing Group, 2018.

[8] Ministry of Ecology and Environment of P. R. China, State Administration for Market Regulation. Standard for irrigation water quality (GB 5084—2021) [S]. Beijing: China Environment Publishing Group, 2021.

[9] State Administration for Market Regulation, National Standardization Administration. Standards for drinking water quality (GB 5749—2022) [S]. Beijing: Standards Press of China, 2022.

[10] State Administration for Market Regulation, National Standardization Administration Committee. Black fungus (GB/T 6192—2019) [S]. Beijing: Standards Press of China, 2019.

[11] National Health Commission of P. R. China, State Administration for Market Regulation. National food safety standard—maximum levels of contaminants in food (GB 2762—2022) [S]. Beijing: Standards Press of China, 2022.

[12] Hubei Provincial Bureau of Quality and Technical Supervision. Standard for geographical indicationproduct—Fangxian Black fungus (DB42T598—2010) [S/OL]. 2010. https://std.samr.gov.cn/db/search/stdDBDetailed?id=91D99E4D522B2E24E05397BE0A0A3A10.

[13] Sun, B., Sun, Y. C., Han, X. S., *et al*. Leucine supplementation alleviates immune and antioxidant function damage in adult rats induced by early weaning [J]. *The Journal of Nutrition*, 2023, 153(5): 1607–1617.

[14] Berguig, G. Y., Martin, N. T., Creer, A. Y., *et al*. Of mice and men: plasma phenylalanine reduction in PKU corrects neurotransmitter pathways in the brain [J]. *Molecular Genetics and Metabolism*, 2019, 128(4): 422–430.

[15] Yusuf, M., Khan, T. A., AlBlooshi, F. S., *et al*. Unveiling the protective role of silicon dioxide nanoparticles against copper-induced oxidative damage in soybean plants through altered proline metabolism and antioxidants [J]. *Plant Nano Biology*, 2025, 12: 100149.

[16] Li, T., Yu, K. N., Wang, X. W., *et al*. Analysis of nutritional quality of black fungus from 4 provinces [J]. *Arid Agriculture Science*, 2025, 4(2): 140–147.

[17] Guo, M. R. Key technologies for high-quality and high-efficiency bagged cultivation of black fungus [J]. *Southeast Horticulture*, 2023, 11(1): 66–69. DOI: 10.20023/j.cnki.2095-5774.2023.01.013.