GIES Case Study on Qin County Millet Shangdang Basin

Song, W.[1*] Yan, P. Y.[2] Liu, J.[2] Chen, W.[3] Zhang, M. M.[4] Wei, Q. X.[5] Duan, Y. Q.[6] Shi, R. X.[1] Chen, M. F.[7] Yu, H.[1] Zhang, X. Y.[1] Sheng, S. Q.[1] Sun, Q. Q.[1] Chen, Y. J.[1] Huang, S. W.[1] Liu, S. H.[1] Ji, C. H.[1] Han, Y. N.[4]

1. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China;
2. People's Government of Qin County, Qin County 046400, China;
3. Investment Promotion Center of Qin County, Qin County 046400, China;
4. Agricultural Quality Brand Development Center of Qin County, Qin County 046400, China;
5. Bureau of Agriculture and Rural Development of Qin County, Qin County 046400, China;
6. Institute of Agricultural Products Processing of the Chinese Academy of Agricultural Sciences, Beijing 100193, China;
7. Shanxi Qinzhouhuang millet (Group) Co., Ltd., Qin County 046400, China

Abstract: Qin County in Shanxi Province is located between the Taihang Mountains and the Taiyue Mountains, the northern edge of the Shangdang Basin. It experiences a warm temperate continental monsoon climate, characterized by cold, dry winters and warm, humid summers. The soil, predominantly loam and sandy loam, is rich in organic matter, nitrogen, phosphorus, potassium, and trace elements, offering fertile conditions free from environmental pollution. Irrigation water quality meets the national standards for dryland crops. This study proposes a new model for ecological environment protection and sustainable development of premium millet cultivation in Qin County. It summarizes the sustainable development model for Qin County millet in the Shangdang Basin from 6 perspectives: ecological and geographical environment, variety and quality, product development, socio-economic growth, management practices, and historical traditions. The dataset supporting this study consists of 5 components: (1) Spatial boundaries of the case study area; (2) Natural geographical conditions; (3) Characteristics of Qin County millet varieties and quality; (4) Population and socio-economic development data; (5) Management practices and historical and cultural traditions. The data are available in multiple formats, including. xlsx, .shp, .tif, .jpg and .docx, with a total size of 188 MB (compressed to a file of 57.3 MB).

Keywords: Qin County; millet; Shangdang Basin; GIES; Case 21

DOI: https://doi.org/10.3974/geodp.2024.03.05

CSTR: https://cstr.escience.org.cn/CSTR:20146.14.2024.03.05

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data*

Received: 02-08-2024; **Accepted:** 28-08-2024; **Published:** 25-09-2024

Foundation: Qin County Agriculture and Rural Bureau (11N0124105762024204)

***Corresponding Author:** Song, W. 0000-0003-4039-2339, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, songw@igsnrr.ac.cn

Data Citation: [1] Song, W., Yan, P. Y., Liu, J., *et al*. GIES case study on Qin County Millet Shangdang Basin [J]. *Journal of Global Change Data & Discovery*, 2024, 8(3): 267–285. https://doi.org/ 10.3974/geodp.2024.03.05. https://cstr.escience.org.cn/CSTR:20146.14.2024.03.05.

[2] Song, W., Yan, P. Y., Liu, J., *et al*. GIES case dataset on Qinxian Millet Shangdang Basin, Shanxi Province of China [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2024. https://doi.org/10.3974/geodb.2024.12.01.V1. https://cstr.escience.org.cn/CSTR:20146.11.2024.12.01.V1.

Repository at: https://doi.org/10.3974/geodb.2024.12.01.V1 or https://cstr.escience.org.cn/CSTR:20146.11.2024.12.01.V1.

1 Introduction

Millet (*Setaria italica* L.), also known as foxtai millet, is a staple cereal crop of the Poaceae family, depending on the variety, it can be further divided into multiple types. It is widely cultivated in temperate and subtropical regions[1]. Hulled grain, referred to as millet[2–4]. As an ancient cereal crop, millet has excellent characteristics such as drought tolerance and strong vitality[5,6]. China is the origin and leading producer of millet, which can be traced back to the Yellow River Basin in China, with the most concentrated cultivation in Shanxi Province[7]. Qin County millet is dryland crops and is one of the high-quality local specialty grains in Shanxi Province[8,9]. In the long-term life of local people, especially among the elderly, the weak, and women, Qin County millet has become an essential food, occupying a pivotal position in people's lives and the grain market.

Qin County has a long history of millet cultivation and rich cultural heritage. Its cultivation history can be traced back to the era of the Shen Nong's Emperor Yan. The "Pashancao" millet was designated as a royal tribute during the Jiajing period of the Ming Dynasty[10]. In the Kangxi era of the Qing Dynasty, it was granted the title "Qinzhouhuang"[11]. From 1984 to 1988, Qin County successfully bred a series of excellent millet varieties[12]. The improved millet varieties had an average yield of 16.68 kg per ha and a maximum yield of 27.01 kg, which was 5–8 times higher than the original yield. These advances led to the widespread promotion of Qin County millet. After more than 50 years of scientific research, the "Qinzhou" brand has been awarded several prestigious honors, including "China Geographical Indication Product", "Eco-Origin Protected Product", and "China Famous Agricultural Product". Additionally, Qin County millet has obtained national green food certification and organic food certification, promoting the millet industry to become the leading industry of "one county, one industry" and being known as one of the "Four Famous Millets" in China[13,14].

This study analyzes various data, including natural geographical data, ecological environment data, product characteristics data, product development and management data, as well as socio-economic development and historical traditions, to explore the coordination between environmental protection and sustainable development in the case area. The aim is to provide technological support for the ecological environment protection and sustainable development of Qin County millet in the Shangdang Basin region[15,16].

2 Metadata of the Dataset

Information on the metadata of the GIES case dataset on Qinxian Millet Shangdang Basin, Shanxi Province of China[17] is summarized in Table 1.

3 Case Study Data Development

3.1 Geographical Extent of the Study Area

Qin County is located in the southeastern part of Shanxi Province, the northern part of Changzhi City, the hilly area east of Taiyue Mountain and west of Taihang Mountain, between 112°27′E–112°53′E and 36°25′N–36°58′N (Figure 1). Qin County is located within the 36°N latitude zone, globally recognized as the "golden agricultural belt" for crop cultivation. This region is renowned for its favorable soil, abundant water resources, and optimal climate, all of which contribute to the production of high-quality crops. Qin County is connected to Wuxiang County and Xiangyuan County in the east, Qinyuan County in the west, Tunliu County in the south, and Wuxiang County and Pingyao County in Jinzhong City in the north. Qin County jurisdiction Dingchang Town, Guocun Town, Xindian Town,

Table 1 Metadata summary of the GIES case dataset on Qinxian Millet Shangdang Basin

Items	Description
Dataset full name	GIES case dataset on Qinxian Millet Shangdang Basin, Shanxi Province of China
Dataset short name	QinzhouhuangCase21
Authors	Song, W., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, songw@igsnrr.ac.cn Yan, P. Y., People's Government of Qin County, PengyunYan_1979@outlook.com Liu, J., People's Government of Qing County, liujia269@126.com Chen, W., Qin County Investment Promotion Center, chenwei2408@126.com Zhang, M. M., Qingxian Agricultural Quality Brand Development Center, zmm01012024@163.com Wei, Q. X., Qin County Agriculture and Rural Affairs Bureau, wqx07092024@163.com Duan, Y. Q., Institute of Agricultural Products Processing, Chinese Academy of Agricultural Sciences, duanyuquan@caas.cn Shi, R. X., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, shirx@igsnrr.ac.cn Chen, M. F., Shanxi Qinzhouhuang Millet Company Limited Yu, H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, yuhhao@yeah.net Zhang, X. Y., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, zxy374260025@163.com Sheng, S. Q., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Shengsq_up@163.com Sun, Q. Q., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, sunqq_cug@163.com Chen, Y. J., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, chenyijing269@gmail.com Huang, S. W., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, seuwon4867@163.com Liu, S. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 727348915@qq.com Ji, C. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, jichuhan2003@163.com Han, Y. N., Qin County Agricultural Quality Brand Development Center, hanyanan2024@126.com
Geographical region	Qin County, Shanxi Province (112°27′E–112°53′E, 36°25′N–36°58′N)
Year	2024
Data format	.xlsx, .shp, .tif, .jpg, .docx
Data size	188 MB (compressed into 1 file, 57.3 MB)
Data files	(1) spatial extent of the case area; (2) natural geographic conditions; (3) varieties and quality characteristics of Qin County millet; (4) population and socio-economic development data; and (5) business management and historical and cultural traditions
Foundation	Qin County Agriculture and Rural Affairs Bureau (11N0124105762024204)
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 per cent 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[18]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

Guxian Town, Cecun Town, Zhangyuan Town, Nanli Town, Qinzhouhuang Town, Songcun Town, Niusi Township, Yang'an Township 11 township-level administrative divisions, Dongyuan, Xiyuan, Xihu, Yucai, Beiguan, Nanguan 6 Community Residents' Committee, 218 administrative villages[19]. Qin County has a total area of 1,320 km^2, with a total county household population of 168,800[19].

3.2 Ecological and Environmental Data

3.2.1 Topography

Qin County, the entire territory of the terrain around the rise, flat in the middle, the terrain of

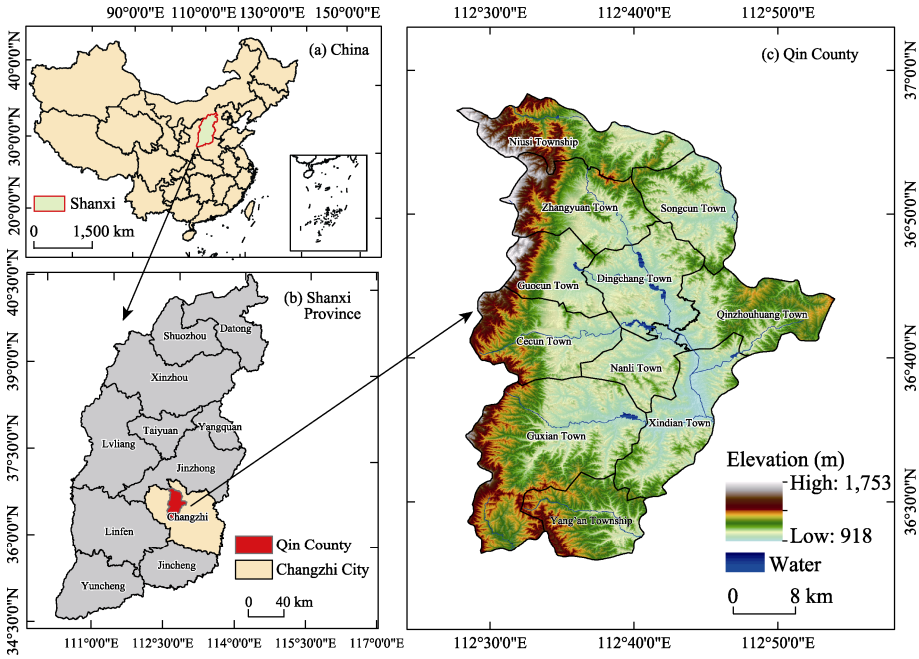

Figure 1 Map of Geographic location of the case area

the east low and high in the west, low in the south and high in the north, steep in the west and slow in the east (Figure 2), the western part is close to the Funiu Mountain, is a mountainous and semi-mountainous area, the central part of the loess hills, the eastern part of the hilly area is dominated by hills, hilly area between the small basins, the geomorphological characteristics of the formation of natural buffer zones, which is conducive to blocking the outside world of atmospheric pollutants. The average altitude of 1,000–1,100 m, the highest altitude of 1,740 m, is located in the western part of Qin County, Guocun Town, Qipan Mountain; the lowest altitude of 917 m, is located in the southeastern part of Qin County, Xindian Town, South Pond, two Shenkou River Valley. Within the territory of the valley terrace, hills, low mountains in three geomorphological zones, respectively, accounting for 11.9%, 64.4%, 23.7% of the total area of the county. Topographical data for Qin County are sourced from NASA[1]. The terrain slope of Qin County has the largest distribution area of 3–15 degrees (Figure 3), which is suitable for the growth of foxtail millet.

3.2.2 Climatic Resources

Qin County is a warm temperate continental monsoon climate, dry and windy in the spring, hot and rainy in the summer, the temperature difference between morning and evening in autumn, and cold and less snow in winter, which is the golden zone for the growth of temperature-loving and drought-resistant cereals. Qin County has an average annual sunshine hours of 2,820 h, an average annual frost-free period of 168 d, an average annual temperature of 9.3 °C, the highest average monthly temperature of 22.5 °C, the lowest average monthly temperature of –6.9 °C, an average annual rainfall of 606 mm, an average monthly actual evaporation of 61.2 mm, an average annual relative humidity of 11.2%, and an average annual wind speed of 1.5 m/s (Figure 4), which provides a suitable cereal planting for Qin County millet habitat. The climate data for Qin County are primarily sourced from the overview of Qin County[19] and ERA5[2].

[1] National Aeronautics and Space Administration. https://search.earthdata.nasa.gov/search.

[2] European Space Agency. https://cds.climate.copernicus.eu/.

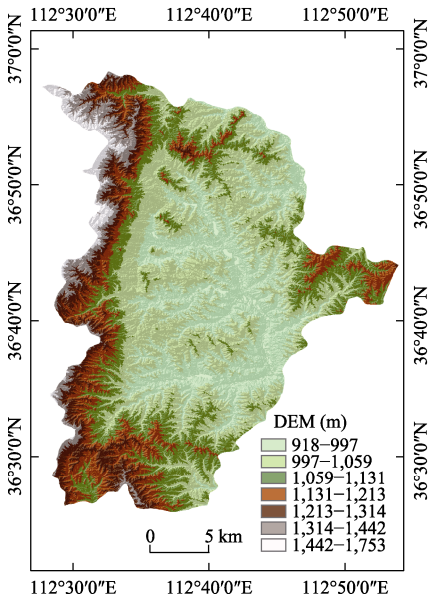

Figure 2 Map of Elevation in Qin County

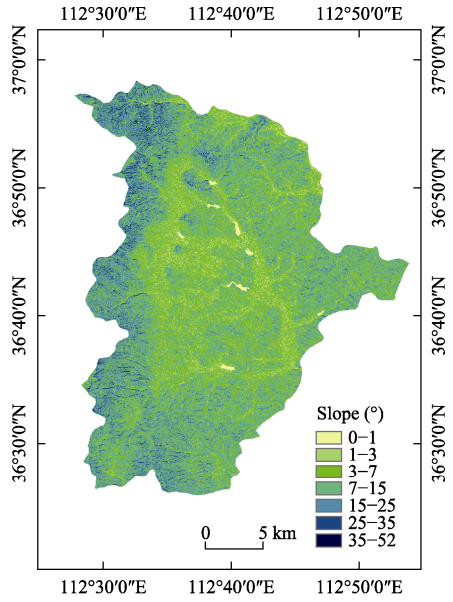

Figure 3 Map of land slope in Qin County

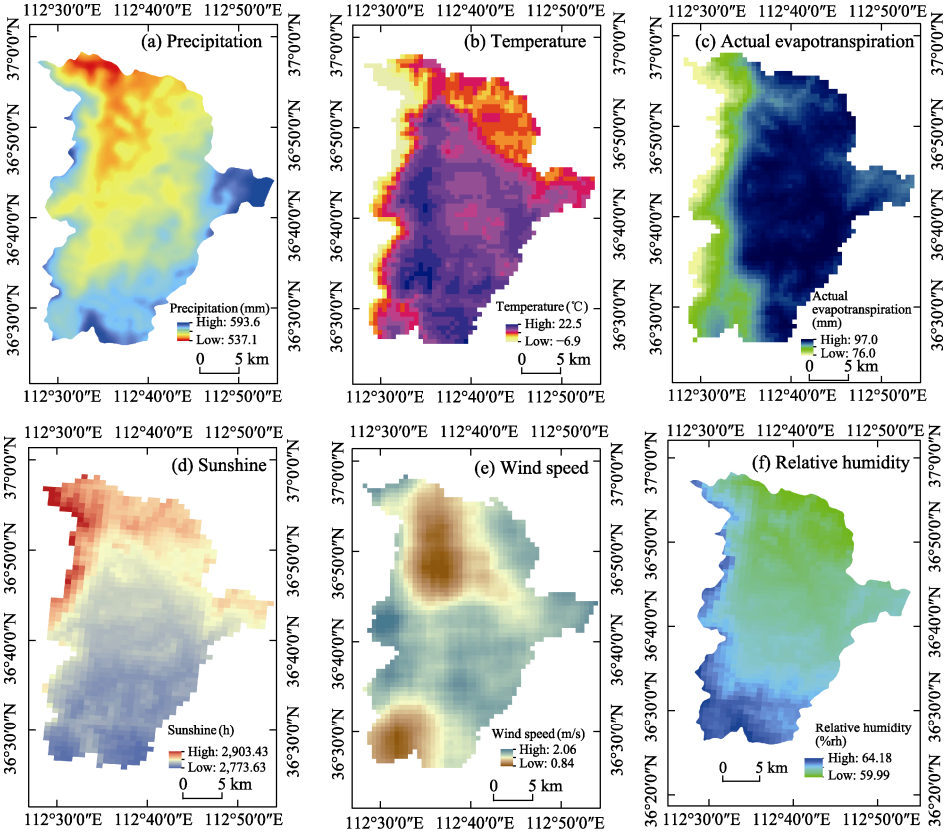

Figure 4 Maps of climatic resources in Qin County

3.2.3 Water Conditions

Qin County is rich in water resources, is the source of the turbid Zhanghe River, the

birthplace of the Haihe River. There are 126 rivers in the territory, and the total reserves of water resources in the county are 1.21×10^8 m^3. Due to the fact that millet in Qin County is dryland grain and mainly relies on natural precipitation, excessive sampling has not been conducted for water resource testing. In this study, one sampling site was set up in Zhangyuan Town and one in Cecun Town (Figure 5). When sampling, take care not to stir the sediments at the bottom of the water, and avoid floating objects on the surface of the water to enter the sampling container. Referring to the basic control items stipulated in the Standard for Irrigation Water Quality (GB 5084—2021)[20], the test items were pH, suspended solids, five-day biochemical oxygen demand, chemical oxygen demand, anionic surfactant, chloride, sulphide, total salt, total lead, total cadmium, chromium (hexavalent), total mercury, total arsenic, the number of faecal coliform bacteria and the number of Ascaridium eggs. A total of 15 items. The test results show that the case area irrigation water quality indicators do not exceed the standard (Table 2), in line with the Standard for Irrigation Water Quality (GB 5084—2021)[20] in the dry land crop limits, in line with the Qin County millet production of the origin of water quality requirements.

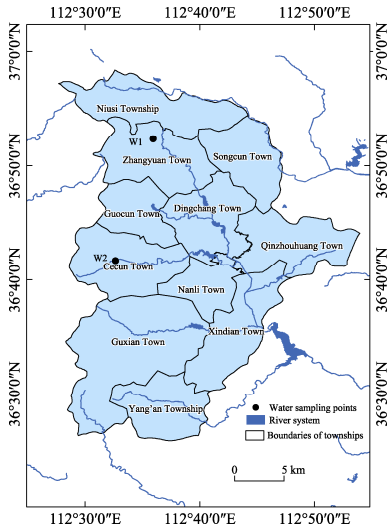

Figure 5 Map of water sampling sites in the case area

Table 2 Statistics of irrigation water quality testing

Pollutant Items	Limit value (≤)	W1	W2
pH	5.5–8.5	7	7.2
Suspended solids/(mg/L)	100	11	11
Five-day biochemical oxygen demand (BOD^-)/(mg/L)	100	7.5	7.6
Chemical oxygen demand (COD_{Cr})/(mg/L)	200	19	19
Anionic surfactants/(mg/L)	8	not detected	not detected
Chloride (as Cl^-) /(mg/L)	350	20.4	20.9
Sulfide (as S^{2-}) /(mg/L)	1	not detected	not detected
Total salt/(mg/L)	1,000	344	348
Total lead/(mg/L)	0.2	not detected	not detected
Total cadmium/(mg/L)	0.01	not detected	not detected
Chromium (hexavalent)/(mg/L)	0.1	not detected	not detected
Total mercury/(mg/L)	0.001	0.000,07	0.000,08
Total arsenic/(mg/L)	0.1	not detected	not detected
Fecal coliform count/(MPN/L)	40,000	not detected	not detected
Ascaris lumbricoides egg count/(pcs/10L)	20	not detected	not detected

3.2.4 Soil Condition

The case area is located in the loess hilly mountainous area, dominated by brown soil, red loam, sandy loam and meadow soil, with the top layer of soil being yellow and the bottom layer being reddish in colour. The topography of the whole area is uplifted in the surrounding area and low in the centre, and under the natural buffer zone of the hilly terrain, several "micro-regions" and "micro-climates" have been formed, and the grain planting landscape of Qin County millet is therefore relatively rich and unique. In this study, the soil of Qin County millet planting area was sampled and examined, and nine soil profile sampling sites were set up in Qin County (Figure 6), including the origin of Qin County millet in Cicun,

Qinzhouhuang Town.

Soil profiles were laid out at 9 sites, and soil samples were collected in layers of 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm. Each layer of soil samples collected about 1 kg, into the sample bag; sampling at the same time, a person to fill in the sample labels, sampling records; labels in duplicate, one into the bag; Based on the soil monitoring items specified in the Technical Specification for Soil Environmental Monitoring (HJ/T 166—2004)[21] and the Soil Environmental Quality Risk Control Standard for Soil Contamination on Agricultural Land (Trial) (GB 15618—2018)[22], this study conducted 21 tests on 0–20 cm surface soil samples, encompassing basic soil properties, soil fertility indicators, and environmental quality metrics. For deeper soil layers (20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm), 11 tests were performed, focusing on basic soil properties and fertility indicators.

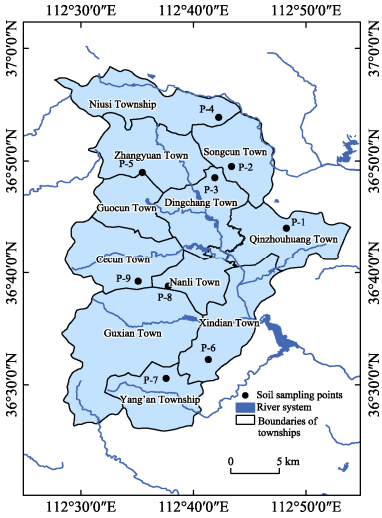

Figure 6 Maps of soil sampling points in the case area

(1) Surface soil conditions

The pH of 0–20cm surface soil in the case area is 6.8–7.9, which is neutral and slightly alkaline. The test results of soil environmental indicators refer to the Soil Environmental Quality Risk Control Standard for Soil Contamination of Agricultural Land (Trial) (GB 15618—2018)[22], and all the test indicators are lower than the soil pollution risk screening value (Table 3). This indicates that the soil environment in the case study area is of good quality, providing a favorable condition for the cultivation of Qin County millet.

Table 3 Statistics of soil environmental indicator test results

Pollutant items	Risk screening value (mg/kg)	Test results (mg/kg)								
		P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9
Cd	0.6	0.11	0.21	0.08	0.08	0.10	0.08	0.12	0.09	0.08
Hg	3.4	0.037,8	0.041,2	0.060,9	0.071,3	0.011,0	0.103,0	0.042,0	0.083,3	0.053,3
As	25	10.7	13.8	9.11	11.2	12.4	15.4	13.6	13	10.8
Pb	170	20	21.8	15.7	14.6	18.6	19.7	9.06	13.3	12.3
Cr	250	71	58	58	50	54	57	18	45	75
Cu	100	22	26	14	12	18	20	33	12	12
Ni	190	26	35	12	17	31	27	30	34	25
Zn	300	82	89	69	59	78	88	28	54	32
Hexachloroc-yclohexane	0.1	not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected
DDT	0.1	not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected

Note: P-1 is located in Qinzhouhuang Town, P-2 is located in Songcun Town, P-3 is located in Dingchang Town, P-4 is located in Niusi Township, P-5 is located in Zhangyuan Town, P-6 is located in Xindian Town, P-7 is located in Yang'an Township, P-8 is located in Nanli Town, and P-9 is located in Cecun Town.

It is a key indicator of soil fertility. Organic matter, nitrogen, phosphorus, potassium, and trace elements in the soil are crucial factors for evaluating fertility. According to the soil nutrient classification standards from the National Second Soil Survey, the soil fertility indicators for Qin County show that in the 0–20 cm surface soil layer of the case study area (Table 4), the nutrient levels are relatively high. Specifically, organic matter, total nitrogen, and available potassium exceed the first-level standard, while available phosphorus, available manganese, and available iron meet the second-level standard. Available copper and zinc

conform to the third-level standard. This is likely due to the application of organic fertilizers in local farming practices, which not only provide nitrogen, phosphorus, potassium, and organic matter but also introduce various trace elements, thereby enhancing the nutritional value of Qin County millet.

Table 4 Soil fertility indicator test results in the case study area

No.	Organic matter (g/kg)	Total nitrogen (g/kg)	Available potassium (mg/kg)	Available phosphorous (mg/kg)	Available manganese (mg/kg)	Available iron (mg/kg)	Available copper (mg/kg)	Available zinc (mg/kg)	Selenium (mg/kg)
P-1	18.4	1.09	191	25.6	18.6	16.3	0.90	0.71	0.07
P-2	17.1	0.93	271	8.2	17.2	9.7	0.55	0.59	0.13
P-3	16.9	0.88	145	10.3	16.8	11.0	0.92	0.41	0.12
P-4	12.7	0.85	147	11.5	14.9	11.9	0.79	0.60	0.08
P-5	10.5	0.90	205	19.5	38.5	22.4	1.01	0.36	0.08
P-6	4.20	0.39	213	12.8	12.7	16.9	0.77	0.23	0.06
P-7	29.6	1.79	363	26.1	24.6	18.9	0.97	1.12	0.12
P-8	20.3	1.13	176	11.4	22.3	11.9	0.88	0.40	0.13
P-9	12.8	1.05	206	20.7	22.0	18.7	1.02	0.70	0.12

(2) Deep soil conditions

This study established 9 soil profile sampling points across various locations, including Qinzhouhuang Town, Dingchang Town, Songcun Town, Zhangyuan Town, Niusi Township, Xindian Town, Yang'an Township, Nanli Town, and Cecun Town. The standard dimensions of the soil profiles were 1.5 m in length, 0.8 m in width, and 1.0 m in depth. During the excavation of the soil profiles, it was essential to ensure that the observation surface faced the sunlight, with the surface soil and underlying soil placed on opposite sides. The profile was then leveled, excess rough material was removed, and photographs were taken for documentation (Figure 7).

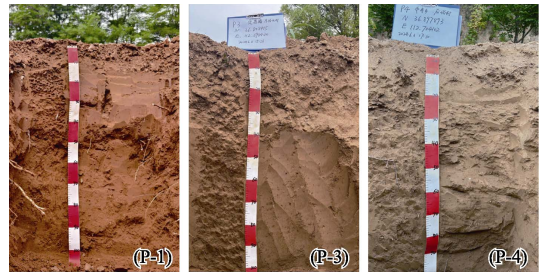

Figure 7 Distribution of soil sampling points in the case area
Note: P-1 is located in Qinzhouhuang Town, P-3 is located in Dingchang Town, P-4 is located in Niusi Township.

Soil cation exchange capacity (CEC) is a crucial indicator for evaluating soil's ability to retain nutrients. As an important soil chemical property, CEC reflects the soil's capacity to hold nutrients and its ability to buffer against environmental changes. The CEC value indicates the potential amount of nutrients that the soil can retain (Table 5). The cation exchange capacity (CEC) of soils in Dingchang Town (P-3) and Niusi Township (P-4) is relatively lower compared to other sampling points, with smaller variations in CEC between soil layers. The CEC values in the case study area range from 12.2–28.9 cmol(+)/kg, indicating that the deep soils in the area possess good nutrient retention capacity. This ability to effectively adsorb and retain nutrients helps reduce nutrient leaching, promoting better nutrient uptake by the deeper roots of millet.

The soil fertility indicators for different soil layers are shown in Figures 8 and 9. Analysis of the data from each sampling point reveals that the organic matter content in the 0–20 cm surface soil is the highest among all soil layers, ranging from 4.22–29.6 g/kg, with an average content of 15.84 g/kg (Figure 8a). This value exceeds the first-level standard (4%) for soil nutrient content set by the National Second Soil Survey, indicating high organic matter content in the surface soil of Qin County. However, significant variation in organic matter content is observed across different sampling points, with Xindian Town (P-6) showing notably lower organic matter content, and Yang'an Township (P-7) exhibiting the highest levels. As soil depth increases, the organic matter content generally decreases,

reflecting the migration and transformation patterns of organic matter in the soil profile. Surface soils are more affected by biological activity and environmental factors, making them more dynamic, while deeper soils are relatively stable and more evenly distributed.

Table 5 Statistics of cation exchange capacity (CEC) test results

Soil Depth (cm)	CEC / (cmol(+)/kg)									
	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	Mean
0–20	23.2	26.2	13.4	14.1	22.3	24.1	21.3	18.6	21.4	20.5
20–40	22.4	28.9	12.9	13.4	22.8	24.2	21.1	17.2	25.5	20.9
40–60	22.0	28.4	12.6	12.2	23.4	24.2	22.0	17.5	24.2	20.7
60–80	22.7	28.5	12.3	12.4	23.7	24.2	24.5	17.2	20.8	20.7
80–100	22.7	28.1	12.9	12.7	23.1	23.1	28.1	17.0	21.9	21.1

The trend in total nitrogen content mirrors that of organic matter (Figure 8b). The average total nitrogen content in the surface soil is 1 g/kg, exceeding the first-level standard (0.2%) from the National Second Soil Survey, indicating a high total nitrogen content in Qin County's surface soil. In terms of available phosphorus, the surface soil also shows the highest content, ranging from 8.2–26.1 mg/kg, with an average of 41.78 mg/kg (Figure 8c), meeting the first-level standard (40 mg/kg) from the National Second Soil Survey. Nutrient content is abundant, although there is considerable variation between sampling points. Songcun Town (P-2) has the lowest content, while Yang'an Township (P-7) has the highest. In Xindian Town (P-6), there is minimal variation in available phosphorus content across the 0–100 cm soil layers, while other sampling points exhibit significant differences in available phosphorus between the surface and deeper layers. Additionally, the surface soil shows relatively high levels of available potassium, with an average value of 213 mg/kg (Figure 8d), which meets the first-level standard (200 mg/kg) from the National Second Soil Survey, indicating high nutrient content.

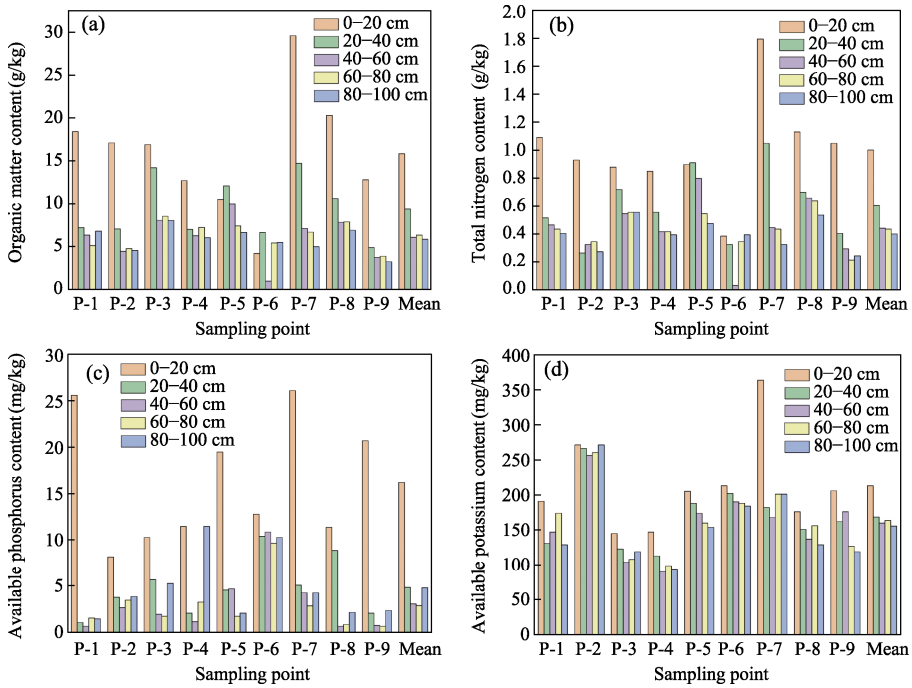

Figure 8 Soil organic matte, total nitrogen, available phosphorus and quick-acting potassium content in different soil layers

The soil in the case study area is rich in selenium, with the highest selenium content found in the surface soil, averaging 0.1 mg/kg (Figure 9a). There is minimal variation in selenium content across different soil layers. Moreover, according to the soil nutrient classification standards from the National Second Soil Survey, the deep soils in the case study area exhibit relatively high levels of trace elements (Figure 9). This enhances the absorption of trace elements by the deeper roots of millet, which is crucial not only for the growth and development of the millet but also for human health, as the adequate intake of these trace elements plays an important role in maintaining physiological well-being.

3.2.5 Land Use

The 2023 land use status of Qinxian County is based on remote sensing monitoring data from the U.S. Landsat 8 satellite, with imagery from 2020 and 2023 compared and analyzed. The data were interpreted manually through visual analysis. The primary land use types in Qin County include cultivated land, forest land, grassland, water bodies, and built-up areas (Figure 10). Among these, cultivated land and forest land occupy the majority of the area, with cultivated land widely distributed in flatter regions, making it the predominant land use type. Forest land is more common in mountainous and hilly areas, while grassland is mainly found in higher-altitude regions. Both forest and grassland ecosystems play a crucial role in

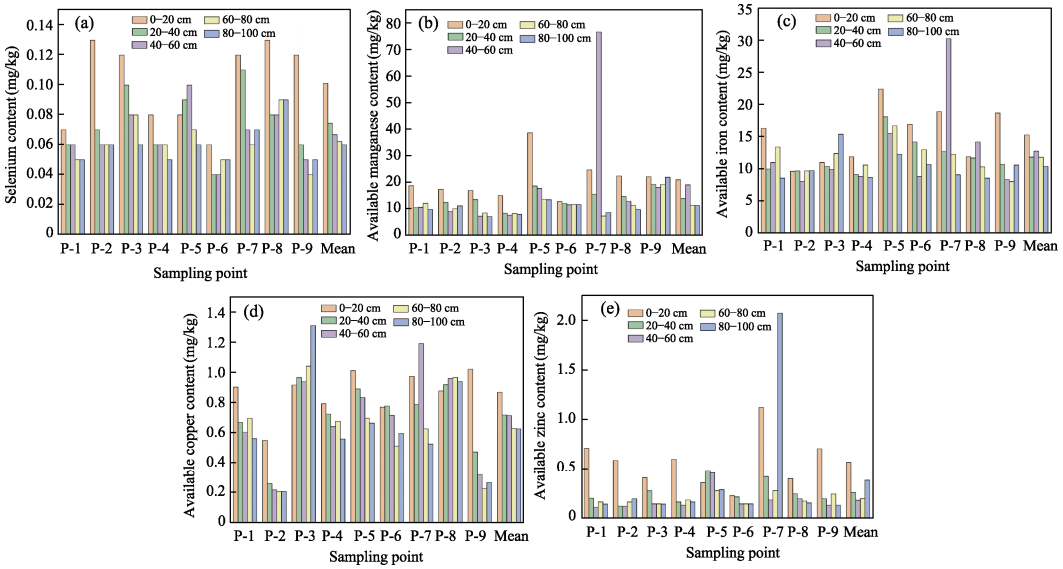

Figure 9 Soil selenium, effective manganese, effective iron, effective copper, and effective zinc contents in different soil layers

protecting the local ecological environment. The water body area in Qin County is relatively small, but it includes significant rivers and reservoirs that provide irrigation and ecological protection for millet cultivation.

3.3 Product Characteristics Data

3.3.1 Qin County Millet Varieties and Characteristics

Qin County people has continuously worked on improving the Qin County millet. In the 1980s, a research group was established in the county to conduct studies on the Qin County millet variety[23]. At present, Qin County millet germplasm resources are mainly Jingu 40, Jingu 21, Changnong 48, Changsheng 07, Jingu 56, Changsheng 13, Qinhuang No.2 and so on.

(1) Qinhuang No.2

Qinhuang No.2 fertility period of 112 d or so, strong growth potential, young leaves and

leaf sheaths green, seed roots, secondary roots strong, developed, stem base with tillers, the main stem height of 158 cm, the number of nodes of the stalk 14 sections, the spike length of 31.5 cm, the spike long spindle, bristles in the long, the main spike weight of 35.6 g, the spike weight of 31.2 g, the grain rate of 87.6%, 1,000 grains of weight of 3.0 g, the white grain of yellow rice, the rate of rice for 80%. The rice quality is japonica. Strong resistance to black spindle disease, white disease, drought tolerance, barrenness tolerance[24].

(2) Jingu 40

Fertility period of about 120 d, seedling green, single culm does not tiller; main stem height 144.8 cm, the average spike length of the main spike 21.3 cm, spike is fusiform, spike thickness of 4.8 cm; small yards of tight, full seed, less grain, branch spike density of 4.82 pic/cm, short spiny hairs, the average grain weight of a single plant is 16.9 g; the grain rate of 80.3%, the white grain of yellow rice, the rice grain is neat, good commercial, drought tolerance. It has good commerciality, drought resistance, and good greening performance during maturity. The crude protein content is 11.97%, crude fat content is 5.69%, lysine content is 0.24%. Resistant to grain plague, high resistance to grain rust, medium resistance to white disease, medium insect resistance[24].

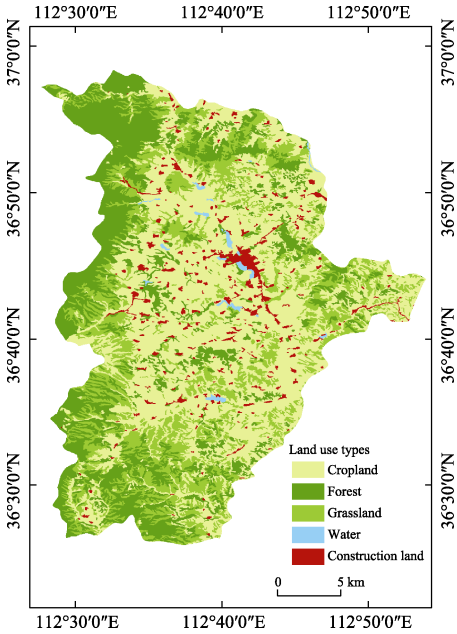

Figure 10 Map of land use types in Qin County

3.3.2 Nutrition Analysis of Millet in Qin County

Regarding the quality of Qin County millet, this study entrusted Jiangsu Hua Ce Pin Biao Testing and Certification Technology Co., Ltd. to conduct quality testing. According to the National Food Safety Standard—Maximum Levels of Mycotoxins in Food (GB 2761—2017)[25], National Food Safety Standard—Maximum Levels of Contaminants in Food (GB 2762—2022)[26], National Food Safety Standard—Maximum Residue Limits for Pesticides in Food (GB 2763—2021)[27] and Geographical Indication Products Qinzhouhuang Foxtail-millet (GB/T 19503—2008)[28], the quality indicators selected for this study include four aspects: sensory requirements, processing quality, cooking and nutritional quality, safety and hygiene indicators. Among them, sensory requirements include colour, transparency, odor, grain shape, taste quality assessment of five test items; processing quality indicators include processing accuracy, imperfect grains, miscellaneous grains, broken rice, moisture, five test items; cooking and nutritional quality indicators include gelatin consistency, protein, crude fat, vitamins, dietary fibre and other 24 test items; safety and hygiene indicators include the content of four pollutants: lead, cadmium, arsenic, chromium, aflatoxin B1, arsenic, chromium, and other contaminants. Safety and health indicators include 4 pollutants of lead, cadmium, arsenic and chromium, 2 mycotoxins of aflatoxin B1 and ochratoxin A, and 104 pesticide residues such as fenpyroximate, with a total of 110 indicators.

(1) Sensory quality

In terms of sensory, Qin County millet has the natural fragrance inherent in the region's millet. Jingu 40 and Qinhuang No.2 varieties of millet have the natural fragrance inherent in the region's millet, bright yellow colour and lustre, no obvious sensory colour difference, no mildew, uniform and full grains of rice, translucent, rice greasy, and a high score of palatable quality, which is basically in line with the Geographical Indication Product Qinzhouhuang

Foxtail-millet (GB/T 19503—2008)[28] in the provisions of the organoleptic quality superior standard (Table 6).

Table 6 Qin County millet organoleptic index test results

Items	Standard of Excellence[28]	Jingu 40	Qinhuang No.2
Colour	Bright yellow, no obvious organoleptic colour difference, no mildew	conform	conform
Transparency	Translucent and greasy	conform	conform
Odours	The natural fragrance inherent to millet in the region, with no other odours	conform	conform
Granularity	Grain uniformity and fullness	conform	conform
Taste quality assessment	After steaming, the millet has a strong aroma, the grains are complete and golden, soft and not sticky, good taste, and does not return to hardness after cooling; soup is millet, soup fusion, soup colour is pure, aroma is strong, the solids content in the millet soup is high, the millet grains are swollen low, and the taste is good; the score is required to be ≥ 85 (in percent)	Conform; 90.4	Conform; 89.8

(2) Processing quality

In terms of processing quality, the processing accuracy, imperfect grains, impurities, broken rice, and moisture content of Qin County millet all meet the superior processing quality standards specified in the Geographical Indication Product Qinzhouhuang Foxtail-millet (GB/T 19503—2008)[28] (Table 7). The processing precision of Jingu 40 reaches 98%, while that of Qinhuang No. 2 is 97%. The proportion of imperfect grains is minimal, with only 0.2% for Jingu 40 and 0.3% for Qinhuang No. 2. Furthermore, both Jingu 40 and Qinhuang No. 2 are free from impurities.

Table 7 Qin County millet processing quality index test results and reference values

Items			Standard of Excellence[28]	Jingu 40	Qinhuang No.2
Processing accuracy (grains with largely removed seed coat)/%			≥95	98	97
Imperfect grain/%			≤0.8	0.2	0.3
Contaminants/%	Overall amount		≤0.3	0	0
	Included among these	Millet grain	≤0.2	0	0
		Minerals	≤0.02	0	0
Broken millet/%			≤4.0	0.8	2.2
Water content/%			≤13.0	11.2	11.0

(3) Cooking and nutritional quality

Millet is hardy and drought-resistant, with a wide range of varieties and a high capacity for adapting to acid and alkaline environments, making it easier to cultivate than other crops. It is rich in nutrients, has an excellent taste, contains fat, protein, carbohydrates and other nutrients that are comparable to or even richer than those of major cereals such as wheat and rice, and is rich in a large number of unsaturated fatty acids, vitamins, inorganic salts, and amino acids essential for human beings[29]. Qin County millet is a speciality of Qin County in Changzhi, Shanxi Province, and is known as “the gold of millet” because of its full and rounded grains, translucent golden yellow color, rich aroma, smooth and delicate texture, sweet taste, and rich in protein, amino acids, calcium, iron, zinc, and other 45 kinds of micronutrients required by the human body[30]. In this study, Qinhuang No.2 and Jingu 40 were used as examples to analyze the nutritional quality components of Qin County millet and explore the unique nutritional quality substances of Qin County millet.

In terms of cooking and nutritional quality, the straight-chain starch content, gel consistency, alkali elimination value, protein content and crude fat content of Qin County millet met the superior cooking and nutritional quality standards stipulated in the

Geographical Indication Products Qinzhouhuang Foxtail-millet (GB/T 19503—2008)[28] (Table 8). In addition, the fat, carbohydrate, dietary fiber and trace element contents of millet were examined in this study. The results showed that the content of mineral trace elements in Qin County millet was high, with potassium content of 216–237 mg/100g, calcium content of 16–19 mg/100g, iron content of 1.76–2.44 mg/100g, zinc content of 1.63–2.47 mg/100g and selenium content of 0.064,3 mg/kg.

Compared to other regional speciality millets, Qin County millet is not only rich in nutrients, but also has a lower pastillation temperature, a higher viscosity, and a relatively low content of straight-chain starch, making it particularly suitable for cooking. Differences in millet quality have a lot to do with the climate and hydrology of different regions, soil texture, altitude, fertilizer application and cultivation practices[31,32].Qin County millet is aromatic and layered in taste with high nutrient content. Liu *et al*[33] showed that the average protein content of national grain samples was 10.4 g/100g, the average crude fat content was 3.3 g/100g, the average dietary fibre content was 322 g/100g, and the average content of vitamin B_1 was 0.237 mg/100g. The protein, crude fat and dietary fiber content of Qin County millet is higher than the national average, and the contents of vitamin B_1 and selenium are higher than the national average.

Qin County millet is highly nutritious, which is not only due to the unique climatic conditions and the special substance-rich dark brown clayey soil, but also closely related to the traditional "wo yang" fertilization technique. This fertilization method provides nutrient-rich organic fertilizer for millet planting and optimizes the soil structure.

Table 8 Qin County millet cooking and nutritional quality index and reference value

Items	unit	Standard of Excellence[28]	Jingu 40	Qinhuang No.2
Amylose	%	14.0–20.0	17.31	15.60
Gel consistency	mm	≥100	108	110
Alkali spreading value	level	2.0–4.0	3.5	3.3
Protein	%	≥9.0	10.6	12.3
Crude fat	%	≥3.0	3.5	3.7
Vitamin B_1	mg/100g	≥0.60	0.318	0.435
Fat	g/100g	—	4.2	4.1
Carbohydrate	g/100g	—	67.23	64.27
Dietary fiber	g/100g	—	5.82	7.36
Potassium	mg/100g	—	216	237
Calcium	mg/100g	—	16.0	19.0
Magnesium	mg/100g	—	99.7	121
Iron	mg/100g	—	2.44	1.76
Selenium	mg/kg	—	not detected	0.064,3
Zinc	mg/100g	—	2.47	1.63

(4) Safety and hygiene quality

In this study, 4 pollutant contents and 104 pesticide residues were detected and analyzed in two varieties of Jingu 40 and Qinhuang No.2 (Table 9). The test results showed that except for arsenic content, which was detected (the test results were much smaller than the national maximum residue limit[26]), the test results of the other indicators were not detected. The safety and hygiene indexes of Qin County millet are all in accordance with the corresponding national standards, and its production process complies with the safety and hygiene regulations, thus effectively guaranteeing its safety and hygiene quality.

4 Millet Industry Development and Government Role

4.1 Government Helps Revitalise Millet Industry

The most significant safeguard for the sustainable development of Qin County millet relies

Table 9 Qin County millet safety and health index

Items	Category	Limits/Maximum Residue Limits	Jingu 40	Qinhuang No.2
Total Arsenic	Pollutant	0.5 mg/kg	0.017 mg/kg	0.034 mg/kg
Other 109 items	—	—	not detected	not detected

Note: The other 109 indicators include 3 pollutants (lead, cadmium, chromium), 2 mycotoxins (aflatoxin B1, ochratoxin A), and 104 pesticides (fenpyroximate, flupyradifuranone, cypermethrin, cypermethrin, aminobenzosulfuron, bacitracin, fenitrothion, propylparaben, oxamectin, chlormequat, dicamba, diuronitrile, dichlorvos, dithiothrin, dichlorvos, toxaphene, parathion), dicofol, dibromophos, flumioxazin, flusilazole, fluazifop, fluconazole, fenitrothion, heptenphos, cyclobutrazol, methamidophos, methomyl, methomyl, metsulfuron, chlorpyrifos-methyl, parathion-methyl, thiocyclam methyl, isoflumuron-methyl, mefenamic acid and spermicarb, methomyl, monocrotophos, resmethrin, carbaryl, carbofuran, letharomefen, aluminium phosphide, endosulfan, thiophos, thiosephon, chlorphenesulfuron, chlorphenesulfuron, chlorphenesulfone, chlorpheniramid Benzamide, chloropicrin, chlorsulfuron, chlortetracycline, chlorophthalic acid, methyl chlorophthalate, malathion, moclobemide, imidacloprid and imidacloprid manganese salts, meclobutanil, methomyl, methomyl, methomyl, meclobemid, zinphosgene, trifluralin, dicofol, triazophos, triadimefon, triadimefon, aminophos, dicamba, fenitrothion, phorate, hydramidophos, speedphos, tetradimethalin, terazophos, pentamethalin, enfenvalerate, ethyl enfenvalerate, difenoconazole, octenphos, bromomethane, deltamethrin, oxytetracycline, etofenprox, chlorpyrifos, indoxacarb, synergistic ether, aldrin, DDT, dieldrin, toxaphene, hexachlor, chlordane, methomyl, heptachlor, endrin, imidacloprid, pirimiphos-methyl, pyraclostrobin, pyrethrin, sulfosulfuron, butoxyfenpyrazon, pidemethanil, cyclobutazole, thiabendazole, aconitroxam, (methomyl, methoxystrobin, pendimethalin, aliconazole, nitroxsulfuron).

on government support. The Qin County government places high importance on the large-scale, standardized, and branded development of the millet industry, as well as the cultivation of leading enterprises[34]. In promoting the high-quality development of the Qin County millet industry and the construction of industrial parks, the government plays a guiding role by strengthening policy support, platform development, and service optimization. By emphasizing the dominant role of the market in resource allocation, the government focuses on optimizing resource distribution, activating key entities, and improving efficiency through scientifically-driven production based on market demand. Currently, Qin County should aim for high-quality development across the entire millet industry chain. The county is exploring the construction of a multi-dimensional, collaborative development model for the millet industry that integrates government, industry, academia, and research. This model includes the "Chain Leader System" for the Qin County millet industry, the Qin County millet industry technology innovation strategic alliance to drive technological advancements, agricultural science and technology promotion services to disseminate knowledge, and the Qin County millet industry supply chain alliance to ensure a stable supply.

4.2 Optimise the Millet Industry Chain and Strengthen the Brand of "Qinzhouhuang"

Industrialized production provides a solid foundation for brand development, and successful brand building can enhance product market value and competitiveness. As the birthplace of "Qinzhouhuang Millet", brand development is crucial for the protection and growth of the Qin County millet industry. Over the years, governments at various levels have placed great importance on building the "Qinzhouhuang Millet" brand, promptly registering trademarks, emphasizing intellectual property protection, and strengthening origin protection and "Two Products and One Standard" certification. This ongoing effort has significantly enhanced brand protection, safeguarded the product's brand image, and increased its overall competitive strength.

Currently, Qin County millet has registered 16 trademarks, including "Qinzhou", "Gu Zhi Ai", "Tan Shan Huang", "Wu Ge Lao" and "Bei Fang Shui Cheng". Notably, the "Qinzhou" trademark was awarded the title of "China Famous Trademark" in 2006. In 2019, Qin County millet was included in the 2019 Agricultural Brand Directory of China as a regional public brand of agricultural products. As a leading industry in Qin County, the millet sector

has developed a comprehensive industry chain—encompassing scientific research, seed breeding, base planting, product processing, and marketing—under the leadership of the national-level agricultural industrialization leading enterprise, Shanxi Qinzhouhuang Millet (Group) Co., Ltd.

4.3 Sustainable Monitoring Techniques Provide Scientific Basis for Millet Production

The advancement of industrialized and sustainable development in the Qin County millet industry is inseparable from modern technology[35]. Qin County has established meteorological and hydrological stations at millet planting bases, equipped with remote monitoring facilities. The county has developed a Geographic Information System (GIS) for landmark habitats, which records environmental conditions in real time, including temperature, precipitation, wind speed and direction, air pressure, humidity, soil temperature, soil moisture, solar radiation, CO_2 concentration, $PM_{2.5}$, PM_{10}, and noise levels (Figure 11). Furthermore, Qin County has set up a meteorological and millet growth management database, exploring the digitalization of the millet industry to support the transition from traditional to modern and digital agriculture.

Sustainable monitoring of millet fields provides essential data on crop growth, pest control, and climate change, allowing agricultural experts to optimize practices, implement necessary measures, and improve both yield and quality. It also enables tracking of pesticide residues, heavy metal content, and other indicators, facilitating the timely identification of potential food safety issues and ensuring consumer health. Sustainable monitoring is a critical component of the Qin County millet industry's development, benefiting not only farmers by improving millet quality, yield, and food safety, but also promoting ecological protection and sustainable growth.

Figure 11 Photos of smart IoT information system for Qin County millet

5 Social and Economic Development, Management, History and Tradition of Qin County

5.1 Population and Socio-Economic Development

In 2023, Qin County had a total household population of 168,800, of which 124,600 were rural, accounting for 73.82%; 44,200 were urban households, with an urbanization rate of 26.18%[19]. The county's gross regional product was 4.33 billion CNY, an increase of 3.3%, and the county's three industries accounted for 23.8%, 18.2%, 58.0%[36]. The per capita GDP of Qin County was 32,375 CNY, and the annual per capita disposable income of urban permanent residents was 27,516 CNY, with a growth rate of 4.5%; the per capita disposable income of rural permanent residents was 11,210 CNY, with an increase of 11.2%[36]. Qin County, as an important helping county for rural revitalization in Shanxi Province, needs to focus on how to expand ways to increase farmers' incomes in order to promote the development of Qin County during the stage of consolidating and expanding the results of poverty alleviation and effectively connecting rural revitalization.

5.2 Qinzhou Yellow Foxtail-Millet Business Management

5.2.1 Management of Millet Cultivation

Qin County millet promotes a traditional farming system characterized by a three-year crop rotation, weed control along field edges, soil fumigation and composting, mid-cultivation weeding, and autumn plowing to enhance soil fertility. Organic "Qinzhouhuang" millet strictly prohibits the use of pesticides, chemical fertilizers, herbicides, plant growth regulators, and other banned substances. Instead, it relies on the unique "red soil," which provides a variety of essential nutrients. In the cultivation process, deep plowing techniques are employed to effectively loosen the soil and optimize its water, nutrient, air, and temperature conditions, creating favorable conditions for crop root growth. The deep plowing of the soil, combined with the covering of surface layers, promotes the mixing and even distribution of soil nutrients, accelerates the decomposition and accumulation of nutrients, and enhances the soil's effective fertility[37]. Moreover, deep plowing helps eliminate weeds, reduce pest and disease outbreaks, and improve the overall soil environment for crop growth. This practice fosters the development and expansion of crop root systems, improving their ability to absorb soil nutrients and laying a solid foundation for high-quality and high-yield crop production[38]. Deep plowing also helps prevent wind and water erosion, enhance the soil's water retention and moisture conservation capabilities, which is crucial for sustainable agricultural development.

5.2.2 Millet Harvesting and Storage Management

In the harvest and storage management of Qin County millet, strict adherence to national standards is followed to ensure the high quality and safety of the millet throughout the entire process, meeting consumer demands for food quality and safety. The optimal harvest time is ensured the millet grains fully maturing with an appropriate moisture content. Specialized harvesting machinery, meeting necessary standards, is used, with parameters adjusted to minimize grain damage. After harvesting, the millet is transported to processing facilities for initial cleaning and sorting, removing impurities and immature grains to ensure hygienic safety. Storage facilities are required to be light-free, cool, dry, and protected from pests and rodents. Regular inspections and treatments are conducted to ensure the quality and nutritional value of the millet are maintained during storage. This rigorous process ensures that Qin County millet retains its premium quality from field to consumer.

5.2.3 Product Process Management

Qin County millet production enterprises make full use of advanced technologies to ensure

the high quality, safety, and nutritional value of their products. These enterprises have established a comprehensive product traceability system, recording key processing parameters and quality data, with electronic management systems used for data recording and archiving. This allows for quick traceability of product origins and processing stages. Moreover, Qin County has focused on the development of the entire millet industry chain, implementing both internal cultivation and external investment attraction strategies. The millet processing industry has expanded from basic millet products to include processed snacks, beverages, brewing products, and other sectors. Innovatively developing deep-processed millet products to extend the industry chain is an important approach to enhancing the overall value of the millet industry.

5.3 Promotion and Transmission of Millet Culture

Qin County's long history of millet cultivation and its deep agricultural civilization have fostered a rich and vibrant folk millet culture, which includes traditional knowledge, songs, proverbs related to millet production, as well as its dietary culture and the rural ethos of family education. These cultural elements, rich in philosophical thought and human spirit, are core components of Qin County millet's traditional farming system and local heritage worthy of preservation and transmission[39]. Qin County has made full use of its cultural resources by organizing the "Qinzhouhuang Millet Cultural Festival" which reenacts the historical legend of the millet's imperial naming by Emperor Kangxi. This event has contributed to the interpretation, protection, and transmission of Qin County millet culture, accelerating the integration of agriculture, culture, and tourism. In the future, Qin County should increase its publicity through digital media and other channels, actively participate in national and provincial art festivals, tourism events, and exhibitions of famous, high-quality, and special products. While promoting Qin County millet and its processed products, the county can widely disseminate the unique culture of Qin County millet[40].

6 Discussion and Conclusion

The case area is located at the northern edge of the Shangdang Basin area, with the terrain high in the west and low in the east, and the loess hilly area in the center, with geomorphological features forming a natural buffer zone, blocking pollution from the outside world. The area has a favorable climate, fertile soil rich in trace elements and good water quality conditions. The unique soil, water and climate environment provide good habitat conditions for the cultivation of Qin County millet. Qin County millet has good quality, containing a variety of trace elements, and its sensory quality, processing quality, cooking and nutritional quality are in line with or higher than the national superior standards. Qin County millet safety and health indicators are also in line with national standards, the production process in line with safety and health regulations, effectively guaranteeing the safety and health quality. In recent years, Qin County has developed a strategic plan, and launched support measures to promote the Qinzhouhuang high-quality development, expanding the area of grain cultivation. To comprehensively promote the expansion of the industry, it is committed to achieving high-quality development of the millet industry. In the process of promoting the scientific integration of ecology and economy, it is necessary to seek a balance between ecological environmental protection and economic development, and to realize the common enhancement of social, economic and ecological benefits. Adopting the mode of "enterprise + science and technology + base + cooperative + farmers", we will continue to cultivate county-level and above agricultural industrialization leading enterprises to promote the development of Qinzhouhuang industry. At the same time, to build a complete whole industry chain of green development system, covering planting, processing,

warehousing, logistics, sales and related services, to achieve sustainable development of the industry. This study will further improve Qin County millet yield and quality, increase farmers' income, and promote ecological environmental protection and sustainable development.

Author Contributions

Song, W. made the overall design of the case; Song, W., Yan, P. Y., Liu, J., Chen, W., Zhang, M. M., Wei, Q. X., Duan, Y. Q., Shi, R. X., Yu, H., Chen, Y. J., Huang, S. W. and Ji, C. H. took part in the field study of the case study, and carried out the collection and testing of the soil and water samples; Chen, M. F. provided the enterprise management data; Song, W., Yu, H., Zhang, X. Y., Sheng, S. Q., Sun, Q. Q., Chen, Y. J., Huang, S. W., Liu, S. H. and Ji, C. H. wrote the paper.

Acknowledgements

We thank Liu, C. of the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, for her guidance and assistance in the completion of the data and thesis in this case! We thank the leaders at all levels in Qin County for their support and cooperation, as well as the staff who assisted in the soil and water sample collection process! The authors also express their deep gratitude.

Conflicts of Interest

The authors declare no conflicts of interest.

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