Journal of Global Change Data & Discovery. 2026, 10(3): 297-315
www.geodoi.ac.cn

GIES Case Study on Helong Toudao Wild and Forest-Grown Ginseng Temperate Mixed Coniferous and Broad-Leaved Forest

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Abstract: Helong City, located in the southeastern part of Jilin Province within the southern region of the Yanbian Korean Autonomous Prefecture, lies on the eastern foothills of the Changbai Mt. During the Qing Dynasty, Ying'e Ridge of the Changbai Mt. was a major royal tribute area for wild ginseng, and the case area, Toudao Town in Helong City, was one of the core regions of its production. It covers a total area of 514.3 km^2, administers 2 communities, 16 administrative villages, and 136 villager groups, and has a total population of 25,200. From 1962 to 2024, Helong recorded an average annual temperature of 5.36 ℃, an average annual sunshine duration of 2,321.89 h, and an average annual precipitation of 549.68 mm. The soil in the case area is classified as acidic dark brown forest soil (pH 4.55–6.10), with no soil environmental pollution. Forest-grown ginseng growth relies on natural precipitation, and local water quality surpasses the national irrigation water standard (GB 5084—2021). This study focuses on wild ginseng, strictly defined as ginseng sown and naturally grown in deep mountain forests for more than 15 years (GB/T 18765—2015). The deep coupling of this unique geographical background and plant growth facilitates a significant accumulation of active compounds. The content of total ginsenosides (5.34%), ginsenoside R_{b1} (1.16%), and R_e+R_{g1} (1.77%) in wild ginseng all surpass the minimum thresholds set by national standards (4.40%, 0.60%, 0.40% respectively, under GB/T 18765—2015 and GB/T 19506—2009). Other physicochemical and hygiene indicators also comply with national

Received: 14-10-2025; **Accepted:** 28-04-2026; **Published:** 25-06-2026
Foundation: Jilin Provincial Administration for Market Regulation (2025)
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Data Citation: [1] Wang, H., Jin, R. G., Hu, W., *et al*. GIES case study on Helong Toudao wild and forest-grown ginseng temperate mixed coniferous and broad-leaved forest [J]. *Journal of Global Change Data & Discovery*, 2026, 10(3): 297–315. https://doi.org/10.3974/geodp.2026.03.06.
[2] Wang, H., Jin, R. G., Hu, W., *et al*. GIES case dataset on Helong Toudao wild and forest-grown ginseng temperate mixed coniferous and broad-leaved forest [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2026. https://doi.org/10.3974/geodb.2026.03.04.V1.

standards. Capitalizing on its geographical and environmental advantages, Helong City has developed a sustainable model of “forest cultivation with ginseng” centered around the case area. In 2021, its “Jilin Helong Forest-Grown Ginseng and Ganoderma Cultivation System” was recognized as part of the sixth batch of China’s Important Agricultural Heritage Systems. The case dataset encompasses geographic scope, ecological environment, varietal characteristics, socioeconomic and management data, consisting of .shp, .tif, .xlsx, .jpg, and .pdf formats, with a total size of 178 MB (compressed into a 61.6 MB file).

Keywords: Changbai Mountain; Helong; ginseng; wild ginseng; GIES; Case 33

DOI: https://doi.org/10.3974/geodp.2026.03.06

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.2026.03.04.V1.

1 Introduction

Ginseng (*Panax ginseng* C. A. Mey.) is a perennial herbaceous plant in the family Araliaceae. Owing to its root’s resemblance to the human body and its exceptional medicinal properties, it has been revered since ancient times as the “divine herb”[1]. The medicinal use of ginseng can be traced back to the Shang Dynasty, where the pictograph for “shen” appeared on bronze vessels. The earliest extant Chinese pharmacopoeia, Shennong Bencao Jing, categorized ginseng as a “superior grade” herb, noting that it “nourishes the five viscera, calms the spirit, stabilizes the soul, relieves palpitations, expels pathogenic qi, brightens the eyes, benefits the mind, and prolongs life with long-term use”. The Pharmacopoeia of China: 2020 Edition[2] also specifies that ginseng replenishes vital energy, restores pulse, strengthens the spleen and lungs, generates fluids, nourishes blood, and calms the mind. Its primary active ingredients are saponins (ginsenosides), which have been demonstrated to exert pharmacological effects such as anti-fatigue, antioxidant, and immunomodulatory activities[3–12].

Figure 1 Forest-grown ginseng of Toudao Town, Helong City

However, ginseng has stringent habitat requirements, weak natural reproductive capacity, and a long growth cycle, making wild resources extremely scarce[13]. Historical over-harvesting and the impacts of climate change have further exacerbated its decline, leading to the near disappearance of wild ginseng in original habitats such as the Tai hang Mountain[14,15]. Today, the main production areas have gradually shifted northward to the Changbai Mt., giving rise to the saying: “For ginseng in the world, look to China; for ginseng in China, look to Jilin” (Figure 1)[16]. At present, truly wild ginseng[17] (original ecological ginseng naturally disseminated and grown in deep mountain forests) in the Changbai region has become exceedingly rare and has been classified as Critically Endangered (CR) in the “China Biodiversity Red List: Higher Plants”. Consequently, ginseng available on the market largely depends on artificial cultivation. Among cultivated forms, forest-grown mountain ginseng[2] (commonly referred to as forest-grown ginseng) has garnered significant attention due to its potential quality advantages. It specifically refers to ginseng that is artificially sown and subsequently grows naturally in a wild mountain forest environment. Its growth cycle is protracted, typically taking about 15 years to progress from the one-year-old “three-leaflet” stage to the typical “four-compound-leaf” morphology. Wild ginseng is defined by the national standard Identification and grade quality standards of wild ginseng (GB/T 18765—2015)[17] as “ginseng sown and naturally grown in deep mountain forests for more than 15 years”. Comparative genetic studies of garden ginseng, transplanted mountain ginseng, wild ginseng, and naturally wild ginseng suggest no significant differences at the

genetic level; however, morphological traits and phytochemical composition of wild ginseng are strongly associated with age and environmental conditions[17,18]. Because its growth is entirely dependent on natural ecosystems, wild ginseng accumulates abundant bioactive constituents and possesses distinct medicinal value. Research has shown that ginsenoside content increases with plant age and stabilizes after approximately 15 years[19–22].

Helong City, located on the eastern slopes of the Changbai Mt., is characterized by high forest cover, fertile soils, and balanced hydrothermal conditions, providing an optimal natural habitat for ginseng. The Dayang Gorge of Toudao Town in Helong has served as a royal tribute ginseng production site since the Qing Dynasty, reflecting its deep cultural heritage. Building on over 1,300 years of ginseng collection and nurturing traditions, Helong has in recent years actively promoted a sustainable development model of "forest cultivation with ginseng". Through forest-grown ginseng cultivation systems, the region has achieved both ecological conservation and resource utilization, enhancing ginseng production while serving as a model for biodiversity conservation. Against this backdrop, the present study takes the forest-grown ginseng cultivation area in Toudao Town, Helong City as a case study. By integrating scientific data, it systematically elucidates the distinctive quality attributes and ecological value of ginseng from the Changbai Mt.-Helong region, aiming to provide a scientific basis for ecological resource conservation and sustainable utilization in temperate mountainous ecosystems.

2 Metadata of the Dataset

Information on the GIES case dataset on Helong Toudao wild and forest-grown ginseng temperate mixed coniferous and broad-leaved forest[23], including its name, authors, geographic region, year of the dataset, dataset files, etc., is summarized in Table 1.

Table 1 Metadata summary of the GIES case dataset on Helong Toudao wild and forest-grown ginseng temperate mixed coniferous and broad-leaved forest

Items	Description
Dataset full name	GIES case dataset on Helong Toudao wild and forest-grown ginseng temperate mixed coniferous and broad-leaved forest
Dataset short name	HelongGinsengCase33
Authors	Wang, H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, wanghong@igsnrr.ac.cn Jin, R. G., People's Government of Helong City, hlgsbgs@163.com Hu,W., Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, huwei@iga.ac.cn Wang, H. J., Shenyang Agricultural University, 2017500069@syau.edu.cn Wang, D., School of Life Sciences, Henan University, wangdong19882005@163.com Xu, Y. H., Helong Municipal Administration for Market Regulation, 272837522@qq.com Yin, H. Y., Helong Municipal Administration for Market Regulation, 272837522@qq.com Cui, B., Helong Municipal Bureau of Agriculture and Rural Affairs, hltcz@163.com Guan, H. Y., Helong Municipal Bureau of Agriculture and Rural Affairs, hltcz@163.com Huang, Y., People's Government of Toudao Town, Helong City, tdzdw@163.com Yu, J. M., Helong Meteorological Service, Jilin Province, helongqixiang@163.com Zhang, Z. Y., Helong Meteorological Service, Jilin Province, helongqixiang@163.com Zhu, S. N., Helong Water Resources Bureau, zhusn1984@163.com Li, H. R., Helong Municipal Bureau of Natural Resources and Forestry, 577538320@qq.com Wang, T. R., Yanbian Dayang Ginseng Industry Co., Ltd., dayangshenye@163.com Chen, P., Yanbian Dayang Ginseng Industry Co., Ltd., 1298787251@qq.com Wang, T. T., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, wangtt@igsnrr.ac.cn Ma, Y. Y., China University of Geosciences, Wuhan, MYY616@outlook.com Cui, H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, cuihe295@gmail.com Ding, Y. L., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 526434774@qq.com

(*To be continued on the next page*)

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Items	Description
Geographical region	Toudao Town, Helong City, 128°46′53″E–129°10′38″E, 42°34′57″N–42°57′15″N
Year	2025
Data formats	.xlsx, .shp, .tif, .jpg, .pdf
Data size	178 MB
Data files	The case area boundary, ecological environment data, product characteristics data, management and operational data, etc.
Foundation	Jilin Provincial Administration for Market Regulation (2025)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	(1) *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 principle" 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[24]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

3 Case Dataset Development

The case dataset is composed of 4 subsets: (1) geographical extent of the case area, (2) ecological environment data, (3) product characteristics data, and (4) management and operational data, etc.

3.1 Case Area

Helong City is situated in the southeastern part of Jilin Province, in the southern region of the Yanbian Korean Autonomous Prefecture, on the eastern foothills of the Changbai Mt., with geographic coordinates ranging from 128°22′42″E to 129°24′17″E and 41°59′44″N to 42°57′15″N (Figure 2). Toudao Town, located 28 km northeast of Helong City, covers an administrative area of 514.3 km^2, administers 2 communities, 16 administrative villages, and 136 villager groups, and has a total population of 25,200[25], with coordinates from 128°46′53″E to 129°10′38″E and 42°34′57″N to 42°57′15″N. The case area lies within the 42°N "golden latitude" zone, characterized by a temperate monsoon climate with abundant sunlight, large diurnal temperature variation, and coinciding rainfall and heat, which are conducive to photosynthesis and dry matter accumulation in crops, thereby enhancing agricultural product quality. This region is internationally recognized as the "golden maize belt" and "golden rice belt". According to the 2024 survey on forest-grown ginseng cultivation in Helong City, plantations are primarily concentrated in the Changren Forest Farm and Yadong Reservoir areas of Toudao Town, an estimated total yield of about 7,800 kg across different ginseng ages. The core production area is located in Dayang Gorge, accounting for over 60% of the total planting area and more than 75% of the total yield.

3.2 Ecological Environmental Data

3.2.1 Topography

The physiological traits of ginseng—preferring shade and being sensitive to both waterlogging and drought—require its growing environment to provide shading, gooddrainage, and sufficient moisture. Helong City is located on the eastern foothills of the Changbai Mt., surrounded by mountain ranges with prominent peaks and rugged terrain. The three major mountain chains—Zengfeng Ridge, Nangang Mt., and Ying'e Ridge—extend across the western, southeastern, and northern parts of the region, respectively, forming a topographic gradient that descends from southwest to northeast. The highest point, Zengfeng

Mt., reaches 1,676.6 m above sea level in the southwest of Qingshan Village, Longcheng Town, while the lowest point, at 250 m, is located in Piyan Village, Dongcheng Town, within the Pinggang Plain[25]. The geomorphology is diverse, comprising fluvial and volcanic-karst landforms, and includes mountains, hills, terraces, valley plains, and river valleys, representing multiple hierarchical units[25,26]. Based on terrain data from the ALOS (Advanced Land Observing Satellite)[1], Toudao Town, in particular, is predominantly mountainous with limited flat areas, with elevations ranging from 272.3 m to 1,192.8 m and an average slope of 11.48° (Figure 3). This undulating mountainous terrain, together with suitable slopes, effectively prevents soil waterlogging; combined with dense forest canopy cover and a thick humus layer, it provides forest-grown ginseng with a natural microclimatic environment characterized by good drainage, aeration, and moisture retention.

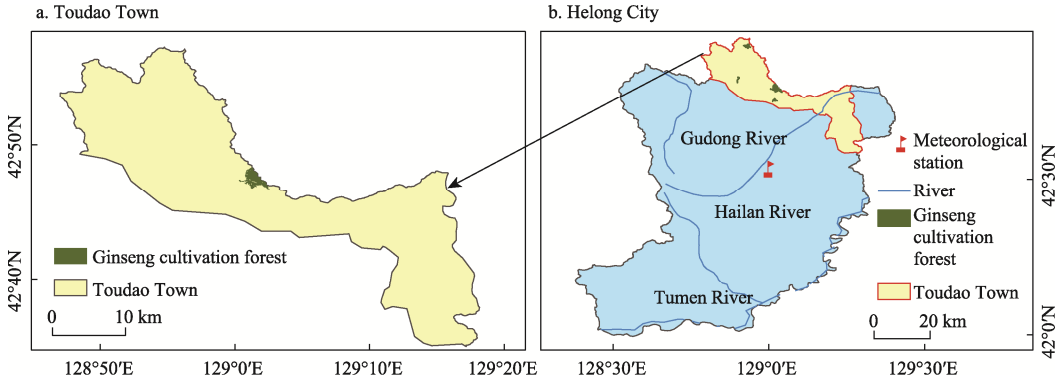

Figure 2 Geo-location map of the case area

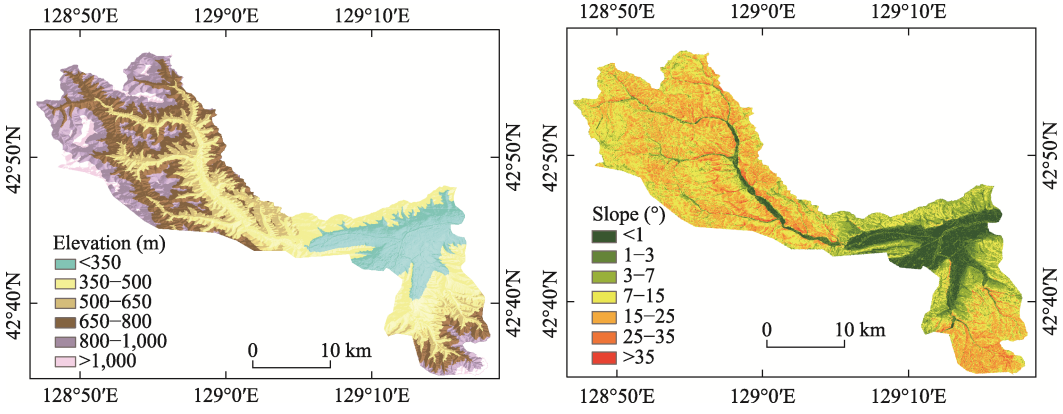

Figure 3 Elevation-classification, slope-classification maps of Toudao Town

3.2.2 Climatic Conditions

The spatial variation and seasonal distribution of climatic factors significantly influence the ecological suitability and distribution patterns of ginseng[27–29]. Helong City is located in a mid-temperate monsoon climate zone. Observations from the Helong Meteorological Station from 1962 to 2024 indicate a long-term mean annual precipitation of 549.68 mm. Although a slight increasing trend of approximately 8.50 mm per decade has been observed, this trend is not statistically significant ($p > 0.05$), indicating a relatively stable annual precipitation pattern (Figure 4). Precipitation is notably concentrated during the growing season, with 62.74% of annual rainfall occurring from June to August (Figure 5). This period coincides mountainous terrain, together with suitable slopes, effectively prevents soil waterlogging;

[1] JAXA, Japan Aerospace Exploration Agency. https://search.asf.alaska.edu/#/.

combined with dense forest canopy cover and a thick humus layer, it provides forest-grown ginseng with a natural microclimatic environment characterized by good drainage, aeration, and moisture retention.

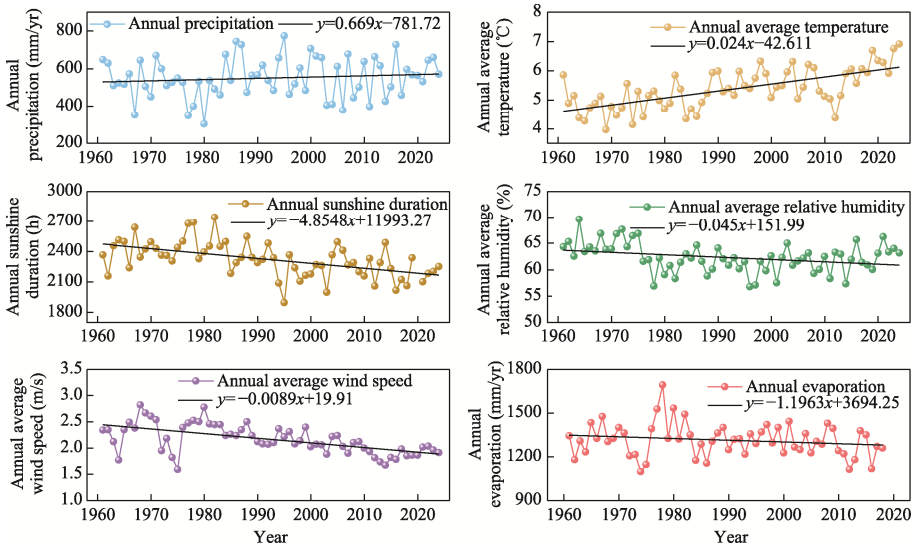

Figure 4 Statistical analysis chart of interannual variations of meteorological elements in Helong City (1962– 2024)

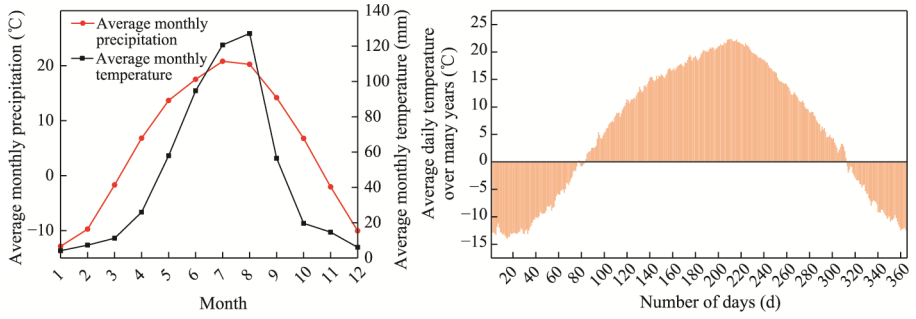

Figure 5 Statistical analysis chart of long-term mean intra-annual variations of temperature and precipitation in Helong City

Temperature is a crucial environmental factor influencing ginseng growth, dormancy, and the accumulation of bioactive compounds[27,30,31]. Over the past 63 years, the average annual temperature has been 5.36 ℃, showing a significant increasing trend ($p < 0.01$) at a rate of 0.26 ℃ per decade (Figure 4). Winters are cold, with an average January temperature of −12.80 ℃, providing the necessary chilling conditions for dormancy and winter survival. Summers are warm but moderate, with average temperatures of 20.86 ℃ in July and 20.31 ℃ in August, aligning with ginseng's preference for avoiding excessive heat (Figure 4). Other climatic characteristics include an average annual sunshine duration of 2,321.89 h, a mean relative humidity of 62.27%, an average wind speed of 2.16 m/s, and pan evaporation (D20 type) of 1,316.45 mm[32] (Figure 4). Overall, Helong exhibits a climate pattern of synchronized rainfall and heat in the summer, cool summer temperatures, and severe winter cold, providing favorable conditions for the growth and development of ginseng.

3.2.3 Soil Conditions

The soil types in Toudao Town mainly include dark-brown forest soil, white-gray forest soil, meadow soil, and alluvial paddy soil. Among these, dark-brown forest soil is the most common in the forest-grown ginseng cultivation areas in this case, followed by white-gray

forest soil. Previous studies indicate that the average length of wild ginseng main roots is typically less than 10 cm[33], while the root zone can extend several to more than 10 cm[34]. Research on soil nutrients, fertility, and root exudates in forest-grown ginseng areas generally sampled soil to depths not exceeding 20 cm[34–36]. In accordance with the Technical regulations of *Panax ginseng* cultivated forest-grown production (DB22T 1730—2012)[37] and national and local standards such as the Technical procedures for the third national soil census[38] and the Specification of land quality geochemical assessment (DZ/T 0295 — 2016)[39], soil sampling in forested areas is recommended at 0–20 cm. In this study, a stratified auger sampling method was employed in the forest-grown ginseng cultivation area, with samples collected from 2 depth layers (0–20 cm and 20–40 cm). 12 sampling points were established (Figure 6), resulting in a total of 24 soil samples to systematically assess the soil environmental quality of the forest-grown ginseng habitat.

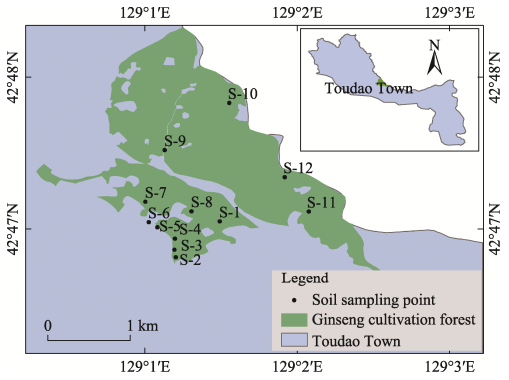

Figure 6 Spatial distribution map of soil sampling points in Toudao Town

According to the Operation rules of comprehensive protection and cultivation of wild ginseng (GB/T 22531—2015)[18], soils in ginseng cultivation areas should comply with the Soil environmental quality risk control standard for soil contamination of agricultural land (Trial) (GB 15618—2018)[40]. According to this standard, mandatory monitored elements for screening soil pollution risks in agricultural land include cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb), copper (Cu), zinc (Zn), and arsenic (As). Analysis of the soil samples revealed that all measured pollution indicators were below the screening limits for agricultural land (Table 2), indicating that the soils in the case area are clean and safe, and can meet the basic requirement of a pollution-free habitat for ginseng cultivation.

Ginseng prefers slightly acidic soils, and analysis of 24 soil samples in the case area (Figure 7a) showed an average pH of 5.31, ranging from 4.55 to 6.10, indicating generally weakly acidic conditions suitable for ginseng growth. The topsoil (0–20 cm) and subsoil (20–40 cm) had average pH of 5.23 and 5.39, respectively, with minimal differences, suggesting stable acidity across soil layers. Soil organic matter (SOM), crucial for root development and nutrient availability, averaged 101.00 g/kg in the topsoil and 42.50 g/kg in the subsoil (Figure 7b), consistent with the preferred structure for wild ginseng, where the upper layer retains natural soil and the lower layer consists of loose, well-aerated sandy loam[18]. This soil configuration provides adequate nutrients, good aeration, and drainage, effectively supporting healthy ginseng root growth and preventing waterlogging-induced root rot.

3.2.4 Water Conditions

According to the Operation rules of comprehensive protection and cultivation of wild ginseng (GB/T 22531—2015)[18], the water quality in wild ginseng growth areas should meet the relevant requirements for agricultural irrigation water. In this study, surface water (ponds) and groundwater (springs) in the forest-grown ginseng cultivation area were systematically monitored (Figure 8) in accordance with the Standard for irrigation water quality (GB 5084—2021)[41]. The monitored parameters included physicochemical properties (pH, suspended solids, five-day biochemical oxygen demand BOD_5, chemical oxygen demand COD_{Cr}), common inorganic pollutants (anionic surfactants, chloride, sulfide, total dissolved solids), and heavy metal risk factors (total lead, total cadmium, hexavalent chromium, total mercury, total arsenic), providing a comprehensive assessment of water quality.

The results indicated that all measured indicators in both surface water and groundwater were within the standard limits (Table 3). The pH ranged from 6.9 to 7.0, and suspended

Table 2 Statistical testing results of soil heavy metal content in Toudao Town

Sampling point	Soil layer depth (cm)	Test item (mg/kg)							
		Cd	Cr	Hg	Ni	Pb	Cu	Zn	As
Limits[40]		≤0.3	≤150	≤1.3	≤60	≤70	≤50	≤200	≤40
S-1	0–20	0.06	52.00	0.07	16.00	34.10	17.00	99.00	6.32
	20–40	0.04	59.00	0.04	19.00	33.90	14.00	86.00	6.04
S-2	0–20	0.09	56.00	0.04	20.00	30.60	15.00	106.00	5.86
	20–40	0.06	57.00	0.04	19.00	30.20	15.00	95.00	5.43
S-3	0–20	0.25	48.00	0.09	20.00	35.50	19.00	136.00	5.35
	20–40	0.12	56.00	0.04	22.00	32.60	16.00	137.00	5.33
S-4	0–20	0.20	38.00	0.09	20.00	35.80	18.00	112.00	5.34
	20–40	0.11	53.00	0.06	29.00	33.80	24.00	121.00	6.82
S-5	0–20	0.16	36.00	0.08	17.00	38.30	17.00	100.00	4.95
	20–40	0.14	57.00	0.05	20.00	33.60	20.00	106.00	4.66
S-6	0–20	0.08	54.00	0.11	17.00	34.90	11.00	92.00	8.34
	20–40	0.05	65.00	0.06	16.00	37.20	12.00	100.00	9.09
S-7	0–20	0.05	41.00	0.04	14.00	27.80	9.00	92.00	4.11
	20–40	0.04	45.00	0.04	13.00	30.40	8.00	93.00	3.67
S-8	0–20	0.07	53.00	0.07	16.00	37.20	17.00	119.00	8.47
	20–40	0.06	61.00	0.06	18.00	33.70	16.00	112.00	7.17
S-9	0–20	0.08	25.00	0.07	10.00	30.30	10.00	73.00	4.11
	20–40	0.02	49.00	0.03	12.00	24.70	6.00	54.00	3.48
S-10	0–20	0.07	57.00	0.06	19.00	26.60	13.00	95.00	7.56
	20–40	0.05	68.00	0.05	20.00	29.90	15.00	106.00	9.13
S-11	0–20	0.10	31.00	0.07	10.00	30.90	10.00	76.00	3.65
	20–40	0.08	32.00	0.06	10.00	29.50	10.00	83.00	3.94
S-12	0–20	0.06	66.00	0.07	25.00	27.40	19.00	115.00	7.17
	20–40	0.05	70.00	0.07	22.00	28.50	19.00	106.00	7.42

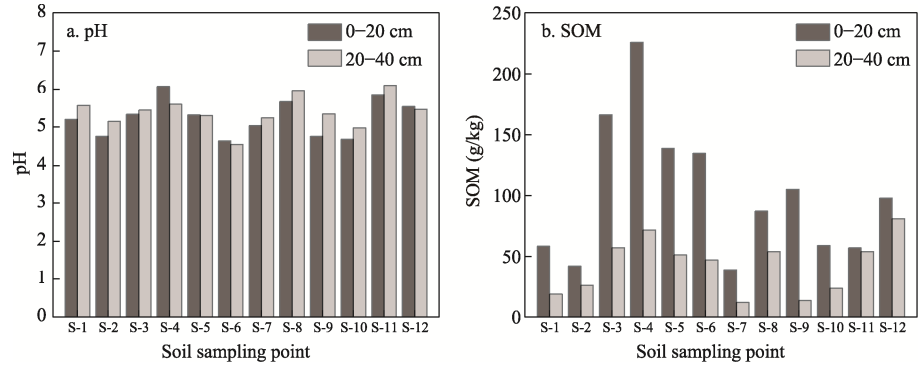

Figure 7 Soil pH and soil organic matter (SOM) content at different sampling points and depths

solids, BOD_5, and COD_{Cr}) were well below the allowable thresholds. Chloride and total dissolved solids were at low levels, while sulfide and anionic surfactants were undetected. Heavy metals (Pb, Cd, Cr, Hg, and As) were also not detected, indicating no significant industrial or agricultural non-point source pollution. Overall, the surface and groundwater in the case area are of high quality, meeting and exceeding the requirements of GB 5084—2021[41], providing a favorable water environment for wild ginseng growth.

3.2.5 Land Use and Vegetation Conditions

Ginseng is a semi-shade plant that is sensitive to direct sunlight[13,27]. Broadleaf forested

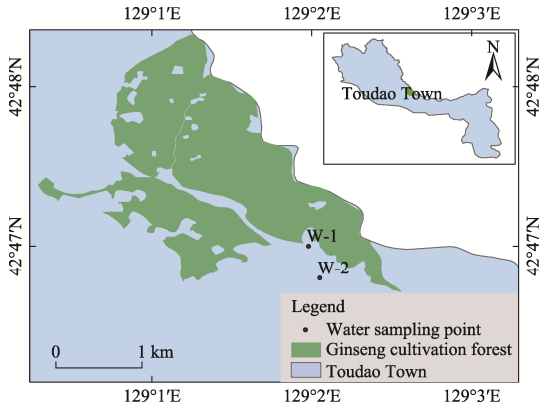

Figure 8 Distribution map of groundwater (W-1) and surface water (W-2) sampling points in Toudao Town

Table 3 Statistical testing results of main irrigation water quality in Toudao Town

Test item	units	Limits[41]	Surface water	Ground water
pH	–	5.5–8.5	7.0	6.9
Suspended solids	mg/L	≤100	11	15
Five-day biochemical oxygen demand (BOD_5)	mg/L	≤100	10.8	11.5
Chemical oxygen demand (CODcr)	mg/L	≤200	27	29
Anionic surfactants	mg/L	≤8	ND	ND
Chloride (Cl^-)	mg/L	≤350	26.30	29.2
Sulfide (S^{2-})	mg/L	≤1	ND	ND
Total dissolved solids	mg/L	≤1,000	278	315
Total lead	mg/L	≤0.2	ND	ND
Total cadmium	mg/L	≤0.01	ND	ND
Hexavalent chromium (Cr^{6+})	mg/L	≤0.1	ND	ND
Total mercury	mg/L	≤0.001	ND	ND
Total arsenic	mg/L	≤0.1	ND	ND

Note: ND indicates not detected; – indicates no corresponding data.

areas, due to better canopy shading, provide more favorable conditions for ginseng growth than coniferous forests[42]. Analysis for the 10-m resolution Sentinel-1 and Sentinel-2 satellite imagery[2] of Helong City indicates that the main land use types in the region include forest, shrubland, farmland, grassland, wetland, water bodies, and built-up land (Figure 9). In Toudao Town, the main land use type is forest, plus, the specific proportions are as follows: forest 59.93%, shrubland 13.00%, farmland 23.18%, grassland 1.23%, wetland 0.33%, built-up land 2.05%, and water bodies 0.28%. Results derived from Sentinel-2 indicate that the average Normalized Difference Vegetation Index in the case area is 0.31. According to the 2024 survey of understory ginseng plantations in Helong City, the canopy closure in ginseng distribution plots is mostly between 0.6 and 0.8, thus meeting its requirement for low-light (shade) habitat conditions. The main tree species include oak, linden, birch, elm, maple, poplar, walnut, and other broadleaf species, as well as associated coniferous species such as larch and spruce, with detailed proportions shown in Figure 10, Table 4. The surrounding vegetation of ginseng can be classified into 3 layers: tree, shrub, and herbaceous, which contribute to climate regulation and ecological adaptation. Studies indicate that in the sampled plots, the average heights are 15.62 m for the tree layer, 5.46 m

[2] European Space Agency (ESA). https://scihub.copernicus.eu/.

for the sub-tree layer, 1.25 m for the shrub layer, and 0.62 m for the herb layer[43], meeting the natural barrier requirements specified in the Operation rules of comprehensive protection and cultivation of wild ginseng (GB/T 22531—2015)[18]. In addition, the area is rich in plant diversity, containing 194 taxa in total, including 178 species from 58 families and 131 genera, 6 subspecies, 9 varieties, and 1 form[43].

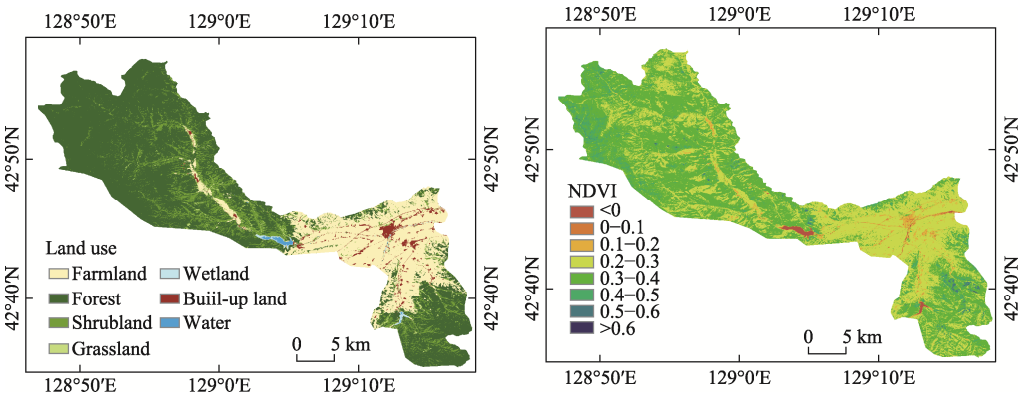

Figure 9 Land use and NDVI maps in Toudao Town

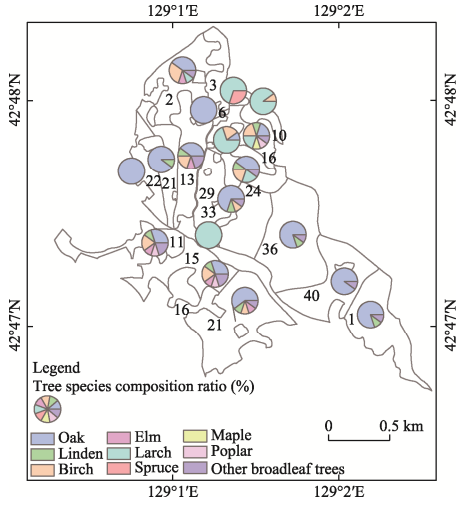

Figure 10 Statistical chart of the major tree species and their composition ratios in each sub-compartment of forest land planted with ginseng

3.3 Product Quality Data

According to the Jilin ginseng industry regulations[44], ginseng-related producers and operators are required to conduct quality and safety testing of their products (Article 31); products sold under the name "wild ginseng" must comply with the standards specified in Identification and grade quality standards of wild ginseng (GB/T 18765—2015) (Article 34)[17]. In this study, following this standard, samples of dried wild ginseng were collected from the understory ginseng plantations in Dayang Gorge, Toudao Town, Helong City. The samples were systematically analyzed for the main physicochemical indicators (total saponins, ginsenoside R_{b1}, R_e+R_{g_1}, total ash, acid-insoluble ash, moisture) and safety indicators (residues of organochlorine and organophosphorus pesticides, and harmful elements). All analyses were conducted by the National Ginseng Products Quality Inspection Testing Center, aiming to comprehensively evaluate the quality traits, medicinal value, and consumption safety of wild ginseng in the study area through quantitative data.

Table 4 Tree species composition and ratio of forest land planted with ginseng

No.	Oak	Linden	Birch	Elm	Larch	Spruce	Maple	Poplar	Other broadleaf trees
1	90%	–	–	–	–	–	–	–	10%
2	80%	10%	–	–	–	–	–	–	10%
3	70%	10%	10%	–	–	–	–	–	10%
4	–	–	–	–	100%	–	–	–	–
5	40%	10%	20%	10%	–	–	–	–	20%
6	90%	10%	–	–	–	–	–	–	–
7	100%	–	–	–	–	–	–	–	–
8	40%	10%	20%	–	20%	–	–	–	10%
9	40%	–	30%	10%	10%	–	–	–	10%
10	–	–	–	–	70%	30%	–	–	–
11	–	–	10%	–	90%	–	–	–	–
12	100%	–	–	–	–	–	–	–	–
13	20%	10%	20%	–	20%	–	10%	10%	10%
14	10%		20%	–	70%	–	–	–	–
15	30%	10%	20%	10%	–	–	–	10%	20%
16	30%	10%	20%	10%	–	–	–	10%	20%
17	–	–	–	–	–	–	–	–	–
18	60%	10%	10%	10%	–	–	–	–	10%
19	80%	10%	–	–	–	–	–	–	10%

Note: – indicates no corresponding data.

3.3.1 Sensory Quality

The wild ginseng produced in the case area exhibits all five shapes—rhizome (lu), adventitious roots (deng), grains (wen), body (ti), and fibrous roots (xu)—showcasing displaying diverse shapes and remarkable vitality. The grains are deeply textured and the bark is mature, while the nodes in the shape of bowls are uniform and densely packed. For wild ginseng aged over 20 years, the rate of high-grade classification (special grade, first grade, and second grade) can reach approximately 50%.

3.3.2 Physicochemical Quality

The test results (Table 5) show that the total ginsenoside content of the dried wild ginseng samples in this study is 5.34. Specifically, the ginsenoside R_{b1} content was 1.77%, while the combined R_e+R_{g1} content was 1.16%, all exceed the requirements specified in the national standard Identification and grade quality standards of wild ginseng (GB/T 18765—2015)[17]. Meanwhile, according to the Pharmacopoeia of China: 2020 Edition[2], the R_{b1} content in ginseng medicinal material must not be below 0.18%, and the combined R_e+R_{g1} content must not be below 0.27% (Table 6). The values measured in this study are well above these thresholds, confirming that the samples meet the required medicinal quality standards. Further comparison with 10 national standards, including the Product of geographical indication-Jilin Changbaishan ginseng (GB/T 19506—2009)[45], and 12 group standards such as Wild ginseng (T/THRS 11—2021)[46], shows that the key ginsenoside contents of these samples are at superior levels (Table 6), indicating high accumulation of active compounds and excellent overall quality.

Table 5 Statistical testing result of major physicochemical properties of dried wild ginseng

Test item	Limits[17,45]	Test results	Testing methods
Total ginsenosides in ginseng (%)	≥4.40	5.34	GB/T 18765—2015[17]
Ginsenoside R_{b_1} (%)	≥0.40	1.77	GB/T 18765—2015[17]
Ginsenosides R_e + R_{g_1} (%)	≥0.60	1.16	GB/T 18765—2015[17]
Total ash (%)	≤5.00	4.16	GB/T 18765—2015 5.4.2[17]
Acid-insoluble ash (%)	≤1.00	0.02	GB/T 18765—2015 5.4.2[17]
Moisture content (%)	≤12.00	10.6	GB 5009.3—2016 Method I[49]

Table 6 Comparison of ginsenoside content across different technical standards Unit: %

	Technical standards	Items	Ginsenoside Rb_1	Ginsenosides (R_e+R_{g1})	Total ginsenosides
National standard	Product of geographical indication-Jilin Changbaishan ginseng[45]	Dried wild ginseng	≥0.60	≥0.40	≥4.40
	Identification and grade quality of transplanted ginseng[50]	Dried transplanted ginseng	≥0.30	≥0.40	≥3.50
	Grade quality of cultivated ginseng[51]	Cultivated ginseng	≥0.20	≥0.30	≥2.50
	Grade quality of red ginseng[48]	Red ginseng	≥0.20	≥0.25	≥2.00
	Grade quality of dried ginseng[47]	Dried ginseng	≥0.20	≥0.30	≥2.50
	Grade quality of boiled ginseng[52]	Boiled ginseng	≥0.20	≥0.25	≥2.00
	Grade quality of lyophilized ginseng[53]	Lyophilized ginseng	≥0.20	≥0.25	≥2.00
	Grade quality of fresh-keeping ginseng[54]	Fresh-keeping ginseng	≥0.20	≥0.25	≥2.50
	Grade quality of sugar ginseng[55]	Sugar ginseng	≥0.10	≥0.15	≥0.50
	Grade quality of honeyed ginseng[56]	Honeyed ginseng	/	/	≥0.80
Pharmacopoeia of China	Pharmacopoeia of China: 2020 Edition[2]	Ginseng slices	≥0.18	≥0.27	/
Group standard	Wild ginseng[46]	Wild ginseng root and rhizome/ ginseng powder	≥0.40	≥0.60	≥4.40
		Wild ginseng slices	≥0.28	≥0.42	≥3.08
	Transplanted ginseng[57]	Transplanted ginseng root and rhizome/ ginseng powder	≥0.30	≥0.40	≥3.50
		Transplanted ginseng slices	≥0.21	≥0.28	≥2.45
	Cultivated ginseng[58]	Cultivated ginseng	≥0.20	≥0.30	≥2.50
	Red ginseng[59]	Red ginseng root and rhizome/ ginseng powder	≥0.20	≥0.25	≥2.50
		Red ginseng slices	≥0.14	≥0.18	≥1.80
	Dried ginseng[60]	Dried ginseng root and rhizome/ ginseng powder	≥0.20	≥0.30	≥2.50
		Dried ginseng slices	≥0.14	≥0.21	≥1.8
	Boiled ginseng[61]	Boiled ginseng	≥0.20	≥0.25	≥2.00
	Lyophilized ginseng[62]	Lyophilized ginseng	≥0.20	≥0.25	≥2.00
	Fresh-keeping ginseng[63]	Fresh-keeping ginseng	≥0.20	≥0.25	≥2.50
	Sugar ginseng[64]	Sugar ginseng	≥0.10	≥0.15	≥0.50
	Honeyed ginseng[65]	Honeyed ginseng	/	/	≥0.80
	Geographical indication product-Kuandian mountain ginseng[66]	product-Kuandian Mountain Ginseng	≥0.40	≥0.60	≥4.40
	Edible ginseng powder[67]	Dried ginseng powder	/	/	≥2.00
		Red ginseng powder	/	/	≥1.60
	This study	Dried wild ginseng	1.77	1.16	5.34

Note: / indicates no corresponding standard limit.

The total ash content of the samples was 4.16%, and acid-insoluble ash was 0.02%, both below the national limits, indicating low inorganic impurities and high purity. The moisture content was 10.6%. Since the Identification and grade quality standards of wild ginseng (GB/T 18765—2015)[17] only specifies physicochemical indicators for wild ginseng powder and slices, without addressing dried wild ginseng, and considering the variation in moisture content, reference was made to the standards for dried wild ginseng in the Product of geographical indication-Jilin Changbaishan ginseng[45], Grade quality of dried ginsen[47], and Grade quality of red ginseng[48] (all requiring moisture content ≤12.00%). Based on these

criteria, the samples can also be considered compliant. This indicates that the processing and storage conditions were properly controlled, ensuring stable quality and enhancing suitability for long-term preservation and further medicinal processing.

3.3.3 Hygienic and Safety Quality

The hygienic indicators included residues of organochlorine pesticides (HCH, DDT, pentachloronitrobenzene, heptachlor, aldrin + dieldrin, and cypermethrin), organophosphorus pesticides (malathion, parathion, monocrotophos, dimethoate, methamidophos, carbofuran, and chlorpyrifos), and toxic elements (Pb, Cd, As, Hg, and Cu). The test results showed that residues of both organochlorine and organophosphorus pesticides were not detected. Levels of Pb, Cd, As, and Cu were far below national limits, and Hg was undetectable. These results indicate that the wild ginseng was not subjected to pesticide or heavy metal contamination during its growth, demonstrating the characteristics of a green and naturally derived medicinal material, and confirming its safety and reliability (Table 7).

Table 7 Statistical testing result of hygiene indicator analysis for dried wild ginseng Unit: mg/kg

Test item	Limits[45]	Test result	Test method
Pb	≤0.50	0.19	GB 5009.12—2023 Method II[68]
Cd	≤0.50	0.086	GB 5009.15—2023 Method II[69]
As	≤2.00	0.026	GB 5009.11—2024 Part I, Method I[70]
Hg	≤0.10	ND	GB 5009.17—2021 Part I, Method I[71]
Cu	≤20.0	5.70	GB 5009.13—2017 Method III[72]

Note: ND indicates not detected.

4 Industrial Development and Sustainable Management

4.1 Government Guidance and Policy Support

Jilin Province, as one of China's primary ginseng-producing regions, has consistently emphasized the protection of ginseng resources and the development of the industry under national strategic guidance and local policy support. Over time, this has led to the establishment of a relatively comprehensive institutional framework. In 2022, 6 national ministries jointly issued the Opinions on supporting the high-quality development of Jilin's ginseng industry, providing clear directions and policy support for cultivation model improvement, germplasm conservation, and industrial structure optimization. On the provincial level, Jilin introduced the Jilin ginseng administration measures in 2010, which was later upgraded in 2015 to the Regulations on the ginseng industry of Jilin Province, and followed by a series of normative documents including the 13th and 14th Five-Year Plans and various implementation opinions issued between 2016 and 2024, all aimed at strengthening resource protection, industrial regulation, and brand building. Under this provincial guidance, Helong City leveraged local resources and industry characteristics, and issued the Management measures for the protection of wild ginseng cultivation systems in 2019, incorporating wild ginseng cultivation into a legalized and institutionalized framework. Through the establishment of protective mechanisms, policy support, and standardized management, these measures lay a solid foundation for the scientific conservation and sustainable use of wild ginseng.

4.2 Leading Enterprises and Industrial Coordination

Yanbian Dayang Ginseng Industry Co., Ltd. originated from a state-owned ginseng farm established in the late 1950s and was restructured into a corporate entity in 1997. It is the earliest enterprise in Yanbian Prefecture engaged in forest-grown medicinal herb production, pioneering large-scale cultivation of ginseng under natural forest conditions. As a leading enterprise in Helong City, the company leverages the superior ecological environment of Dayang Gorge, Toudao Town, and has gradually developed an industrial system centered on

forest-grown ginseng. The forest-grown ginseng stock totals approximately ten million plants, of which 5 million are over 15 years old. Annual harvesting exceeds 30,000 plants, generating annual sales revenue of over 35 million CNY. Relying on the natural forest ecosystem, the forest-grown cultivation model avoids fertilization and pesticide use, ensuring ginseng grows naturally for over 15 years and thereby retaining the medicinal value characteristic of wild ginseng. The company's products primarily include fresh wild ginseng, dried wild ginseng, wild ginseng powder, and slices, while also developing value-added products such as ginseng flower honey, and ginseng honey slices. The cultivation base has established the "Jilin Helong Forest-Grown Ginseng and Ganoderma Cultivation System", which was recognized as part of the sixth batch of China's Important Agricultural Heritage Systems in 2021. It has also been designated as National Agricultural Comprehensive Standardization Demonstration Zone, a Jilin Province Wild Ginseng Conservation Demonstration Base, and the National Wild Ginseng Base of Dayang Gorge, Helong City. Practical experience demonstrates that leading enterprises play a critical role in technology diffusion, risk sharing, and market expansion. Their active participation not only drives the advancement of the forest-grown ginseng industry but also provides a model for the sustainable transformation of regional ecological industries.

4.3 Ecological Environment Traceability for Ginseng

To strengthen habitat monitoring for forest-grown ginseng, GIES ground station has been installed in the core distribution areas of forest-grown ginseng (Figure 11), recording real-time environmental conditions of the cultivation bases. The monitored parameters include key indicators such as air temperature, precipitation, wind speed, wind direction, atmospheric pressure, humidity, soil temperature, soil moisture, soil electrical conductivity, negative oxygen ions, light intensity, and phenology. Furthermore, both government and enterprises have introduced meteorological monitoring, UAV patrols, and IoT sensing technologies to establish a multi-source, data-driven habitat traceability system, enhancing the transparency, market credibility, and added value of ecological ginseng products.

Figure 11 GIES ground station in Toudao Town

5 Socioeconomic Development and Cultural Heritage Preservation

5.1 Socioeconomic Development

By the end of 2024, the total population of Helong City was approximately 147,300, showing a declining trend over the past decade (Figure 12a). The city is home to 11 ethnic groups, including Korean, Han, Manchu, Mongol, Hui, and Zhuang, with Koreans accounting for about 50% of the total population, Han about 48%, and other ethnic groups about 2%. In recent years, the regional gross domestic product (GDP) has shown an increasing trend, reaching 4.371 billion CNY in 2024 (Figure 12b). Toudao Town administers 2 communities, 16 administrative villages, and 136 villager groups, with a total of 9,661 households and a population of 25,200[25]. In recent years, under the guidance of rural revitalization and green development strategies, Helong City has formed an economic development pattern supported by ecological agriculture, border trade, and cultural tourism. The forest-grown ginseng industry, as an important ecological sector, not only enhances the efficiency of forest resource utilization but also serves as a significant driver of regional economic growth.

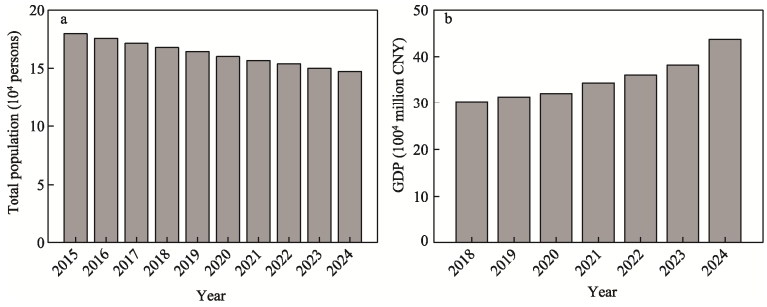

Figure 12 Registered population and GDP of Helong City

5.2 Historical Evolution of Ginseng Cultivation

The history of ginseng collection in Helong City can be traced back to 742 AD during the Bohai Kingdom period. At that time, Helong hosted Zhongjing Xiande Prefecture, one of the political and economic centers of the Bohai Kingdom. According to the Old Book of Tang-Bohai Biography, the Bohai Kingdom contributed high-quality wild ginseng from the Changbai Mt. to the Tang Dynasty, and in local barter trade.

In the early Qing Dynasty, the "Eight Banner Mountain Allocation System" was implemented, under which ginseng mountains were designated for harvesting by the Eight Banners. Ying'e Ridge, as part of the Plain Yellow Banner territory, thus became a core area for imperial ginseng tribute since the early Qing. In 1677 (the 16th year of Emperor Kangxi), the Qing government designated the Changbai Mt., including the entirety of Helong, as a restricted zone, strictly prohibiting private harvesting[26]. In the mid- to late Qing period, overharvesting and illegal collection brought wild ginseng to the brink of exhaustion, prompting secret experiments in transplantation and forest-grown sowing[73]. In 1881, the Qing government legalized seedling cultivation (artificial cultivation) and established ginseng management offices. By the late Qing, state-run ginseng enterprises declined, while private cultivation became the foundation for the modern industry[15,74]. After the founding of P. R. China, in 1954, agricultural cooperatives pioneered ginseng cultivation, followed by state farms in 1959, though many efforts failed due to poor management. Subsequent government funding and technological improvements increased production. During the 1980s, the contractual system transformed operations: state farms continued, while many collective farms became private, resulting in a decrease in ginseng planting area[26,75–77]. In 1999, Dayang Ginseng Industry integrated state-owned resources, gradually modernizing the forest-grown ginseng industry chain. Key milestones include the inclusion of forest-grown ginseng in the Pharmacopoeia of China (2005) and its classification as wild ginseng under national standard Identification and grading quality of wild ginseng (GB/T 18765—2008). The 2015 revision (GB/T 18765—2015) mandated that wild ginseng must grow naturally for at least 15 years, shifting the industry to standardized development[28]. The forest-grown cultivation system involves direct sowing of ginseng seeds in suitable forest environments, without fertilizers or pesticides, representing an effective approach to pollution-free ginseng production. Through a historical trajectory from wild harvesting and technical exploration to large-scale production, Helong City has developed an industry system centered on simulated wild cultivation techniques. Its recognition as a national agricultural cultural heritage site exemplifies the synergy between ecological conservation and economic development.

5.3 Ethnic Culture and the Heritage of Ginseng Culture

Helong has long been home to Jurchen (Manchu), Han, and Korean communities, where ethnic traditions and ginseng culture have been deeply intertwined and continuously evolved through generations. Ginseng is not only an important medicinal and economic resource but also embodies health aspirations, social rituals, and spiritual symbolism, earning it the title "King of Herbs". Local communities continue mysterious ginseng-harvesting traditions that

incorporate ecological ethics such as “harvest large, leave small” and “nurture the mountains, protect the forest”, along with traditional techniques like “timing the harvest by observing the mountains” and “arranging combs and sticks”, forming a distinctive ginseng cultural system. Based on generations of accumulated experience, biomimetic cultivation techniques such as shaded forest cultivation and humus soil management have been developed, promoting the scientific development of the forest-grown ginseng industry. With the scale-up of the industry, related skills and cultural practices are systematically preserved through intangible cultural heritage programs, festivals, and integration with cultural tourism, creating a sustainable development model of “forest cultivation with ginseng”.

6 Discussion and Conclusion

As an integral part of the temperate mountain ecological barrier of the Changbai Mt., Helong City, with its unique geography, climate, and soil conditions, provides an ideal environment for forest-grown ginseng cultivation. Studies indicate that in the case area, the synchrony of rainfall and temperature, coupled with cool summers, severe winters, and the combination of suitable soil, vegetation conditions, and high-quality water resources, jointly create an optimal ecological niche for forest-grown ginseng growth. Wild ginseng from this area demonstrates distinct quality advantages in terms of physicochemical composition and hygienic safety standards.

The forest-grown ginseng cultivation model not only aligns with ecological protection and green development objectives but also achieves dual benefits in resource conservation and industrial efficiency. Collaborative development between government and leading enterprises has promoted the standardization and scaling of the industry, further ensuring ecosystem stability and economic sustainability. However, the uncertainties posed by climate warming remain one of the major challenges facing the ginseng industry. Future strategies should focus on deepening integration of production, research, and education, extending the industrial chain, enhancing the competitiveness of high-value-added products, and improving policy support and ecological compensation mechanisms. At the same time, strengthening policy support systems and ecological compensation mechanisms, as well as promoting cooperative development between enterprises and cooperatives, will help build a comprehensive green industrial system. Moreover, leveraging ginseng products and their cultural significance, in combination with modern technology and tourism, can foster a multi-dimensional “ecology+culture+industry” development model, thereby comprehensively enhancing regional competitiveness and advancing ecological civilization.

Author Contributions

Wang, H., designed the overall framework of this case study. Wang, H., Yin, H. Y., Chen, P., Wang, T. T., and Ding, Y. L. participated in the field investigations, including soil and water sampling. Jin, R. G., Xu, Y. H., Yin, H. Y., Cui, B., Guan, H. Y., Huang, Y., Yu, J. M., Zhang, Z. Y., Zhu, S. N., Li, H. R., Wang, T. R., and Chen, P. provided regional or enterprise-related data and other forms of support. Wang, H., Hu W., Wang, H. J., Wang, D., Ma, Y. Y. and Cui, H. contributed to data analysis and manuscript preparation.

Acknowledgments

The authors sincerely thank Professors Liu, C., Wang, Z. B., and Song, X. F. from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, for their valuable guidance and support during data collection and manuscript preparation. The authors also express their sincere gratitude to all relevant departments of Helong City and Yanbian Dayang Ginseng Industry Co., Ltd. for their strong support and cooperation throughout this study.

Conflicts of Interest

The authors declare no conflicts of interest.

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