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Main Bottlenecks and Countermeasures for the High-quality Development of Selenium-enriched Industries in the Xunyu Plain

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Abstract Guigang City of Guangxi, located in the Xunyu Plain, has abundant selenium-enriched soil resources as the core foundation for the development of selenium-enriched industries in the region. However, the coexistence of heavy metals in some of its selenium-enriched soils has become the main bottleneck problem restricting the sustainable and high-quality development of selenium-enriched industries in the region. Based on field sampling data from a 1 : 50 000 soil geochemical survey in the five districts of Guigang City, combined with the results of heavy metal pollution detection in crop samples, the analysis on characteristics of heavy metal content in crops and the industrial impact is carried out, and the situation of heavy metal exceeding the standard in agricultural product samples in the five districts is identified. The multiple threats of heavy metals to the quality and safety of selenium-enriched agricultural products, industrial brand image, market competitiveness, and sustainable utilization of selenium-enriched soil resources are revealed. A comprehensive prevention and control system needs to be constructed from the dimensions of source prevention and control, soil remediation, variety screening, and standard control, to ensure the green, safe, and high-quality development of selenium-enriched industry.

Key words Selenium-enriched industry; Selenium-enriched soil; Resource utilization; Quality and safety of agricultural products; Prevention and control of heavy metals

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Under the background of rural revitalization strategy, the high-quality development of characteristic agricultural industries has become the core path to strengthen local economic competitiveness. Soil is the core resource of agricultural production, supporting nearly 95% of the global food supply[1]. Guangxi has the largest area of selenium-enriched soil resources in China, but its utilization of selenium-enriched soil resources faces constraints from the coexistence of selenium and heavy metals such as cadmium, which leads to excessive cadmium in selenium-enriched agricultural products and endangers human health. Strengthening geological work to serve the development of agriculture, rural areas, and farmers, and promoting the standardized development of the selenium-enriched industry have become policy guidance and practical needs. The Department of Land and Resources, the Department of Agriculture, and the Geological and Mineral Exploration and Development Bureau of Guangxi Zhuang Autonomous Region have clearly proposed to carry out a 1 : 50 000 geochemical evaluation of land quality by relying on special financial funds, to clarify the basic quality of agricultural land, promote the transformation of achievements to cultivate and strengthen green agriculture and selenium-enriched industries, and provide support for agricultural modernization construction. The selenium-enriched industry is a characteristic industry that develops selenium-enriched agricultural products, food, and related derivatives based on selenium-enriched soil. The selenium content in the soil of the five districts of Guigang City is generally higher than the national average, which has extremely high economic value and market potential. According to the survey results, the soil pH in Guigang area is 4.5-8.5, and the soil area with selenium content ≥0.4 mg/kg accounts for more than 70% of the total area. The average soil selenium content is 0.68 mg/kg[2]. The area of selenium-enriched soil is vast, and major crops such as rice, peanuts, and corn have a high selenium enrichment rate, which has a natural advantage for developing the selenium-enriched industry. However, heavy metal pollution in soil has become a highly concerned environmental issue[3]. Heavy metals are typical cumulative pollutants with characteristics such as non degradability, biotoxicity, and persistence[4]. Soil heavy metal elements pose potential threats to soil health, crop safety, and ecological environment[5]. As a key fac-

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tor affecting the quality and safety of agricultural products, soil heavy metal elements will reduce the market competitiveness of selenium-enriched agricultural products in Guigang City and restrict the large-scale development of the industry. Therefore, it is crucial to promote sustainable development of the industry by conducting a thorough analysis on the impact of excessive heavy metals on the selenium-enriched industry in Guigang and proposing countermeasures.

Through investigation and sampling, it was found that heavy metals such as Cd in crops in some areas of Guigang City exceeded the standard to varying degrees. The antagonistic effect between heavy metals and selenium may affect the absorption and accumulation of selenium by crops, thereby reducing the quality of selenium-enriched agricultural products. At the same time, consumers are highly concerned about the heavy metal content in selenium-enriched agricultural products. Once the problem of heavy metal exceeding the standard occurs, it will not only damage the brand image of the regional selenium-enriched industry, but also weaken the market competitiveness of the products, thereby restricting the long-term development of the industry.

1 Materials and methods

1.1 Surveyed and sampled materials The sampling range of crops covered all five districts of Guigang, and local planting areas were randomly selected for sample collection in each district. They are Gangbei District (rice, corn, peanut, mustard, sweet potato, green beans), Gangnan District (rice, sugarcane stem, sugarcane root), Qintang District (early rice, late rice, corn in early season, corn in late season, peanut), Pingnan County (rice, lychee, longan), Guiping City (rice, sugarcane, lychee, cassava) in Guigang City, Guangxi. It can better reflect the accumulation of heavy metals in agricultural products and can be used to evaluate the impact of excessive heavy metals on the high-quality development of the selenium-enriched industry.

1.2 Sample preparation method Rice is tested on its seeds, which are dried, shelled, and husked before being crushed into powder. Fresh corn cob and mature peanuts are sun dried and threshed, then shelled and crushed into powder. Mustard and sweet potatoes are tested based on their roots, green beans are tested based on their seeds, and lychee and longan are tested based on their flesh, all of which are preserved and sampled after collection. Cassava tubers are harvested. Sugarcane is divided into two types: sugarcane stem and sugarcane root system, and sugarcane juice and root system dry powder are measured. The average contents of 8 heavy metal elements in the collected samples are tested, including As, Hg, Cd, Cr, Cu, Ni, Pb, and Zn.

1.3 Data processing method The standard deviation of each heavy metal element in this paper is estimated using the range method (assumption of normal distribution) based on the content range, and the formula is: $SDest \approx \frac{\text{Range}}{6}$. The results are expressed as mean ± estimated standard deviation, with 4 decimal places retained uniformly.

2 Sampling analysis of heavy metal content in major crops in the Xunyu Plain

2.1 Food crops A total of 100 rice samples, 40 corn samples, and 12 sweet potato samples were collected in Gangbei District of Guigang City; 130 rice samples were collected in Pingnan County; 248 rice samples were collected in Guiping City; 128 rice samples (30 early rice samples and 98 late rice samples) and 64 corn samples (28 corn samples in early season and 36 corn samples in late season) were collected from Qintang District. The average contents of 8 heavy metal elements were tested, including As, Hg, Cd, Cr, Cu, Ni, Pb, and Zn, and the results were as shown in Table 1. From the perspective of overall crop differences, rice has higher levels of various heavy metals than corn and sweet potato, making it the variety with relatively higher levels of heavy metals among the three food crops. From the comparison of rice in different regions, Guiping City has the highest Cd and Cr contents among rice in each region (contents of Cd and Cr are 0.211 0 and 0.400 0 mg/kg). The As content in rice in Gangbei District is higher than that in the other three regions (up to 0.168 0 mg/kg). The overall heavy metal content of rice in Pingnan County and Qintang District is at a moderate to low level. Additionally, the values of various heavy metal indicators in corn in Qintang District are generally low, and the differences in content between different planting seasons are not significant. Only the Pb content in corn in Gangbei District is relatively high, but still lower than most rice samples. The heavy metal detection values of sweet potatoes in Gangbei District are all at a low level.

2.2 Cash crops The cash crop samples were collected from Gangbei District (30 peanut samples), Qintang District (9 peanut samples), and Guiping City (61 sugarcane samples), and the heavy metal detection results were as shown in Table 2. Based on the analysis of the current *National Food Safety Standard—Limits of Contaminants in Food* (GB 2762 – 2022), it is found that there are significant regional and crop differences in the characteristics of heavy metal exceedance in cash crops in Guigang City. Among them, the average contents of Hg, As, and Cd in peanuts in Gangbei District are 0.070 0, 0.700 0, and 0.170 0 mg/kg, respectively, all of which exceeds the standard limits. The Cd content (0.431 0 mg/kg) of peanuts in Qintang District exceeds the standard. The Hg, As, Cd, Cr, and Pb contents in sugarcane in Guiping City are 0.142 0, 2.229 0, 10.821 0, 8.851 0, and 7.735 0 mg/kg, respectively. The surveyed samples exceed the limit requirements for sugar crops. The average Pb content in cassava is 1.204 0 mg/kg, which also exceeds the limit standard for potatoes (≤ 0.2 mg/kg).

2.3 Fruit and vegetable crops Samples of fruit and vegetable crops were collected from Gangbei District (20 mustard samples, 3 green beans samples), Pingnan County (21 lychee samples, 21 longan samples), and Guiping City (90 lychee samples). Based on the standard (GB 2762 – 2022), the overall pollution level of heavy metals in fruit and vegetable crops in Guigang City is relatively low, and there is no phenomenon of exceeding the standard. The Hg, As, Cd, Cr, and Pb contents in mustard and green beans in Gangbei District are far below the corresponding limit standards. All tested heavy metal indicators in lychee and longan from Pingnan County and lychee from Guiping City meet the limit requirements for fruits, and the content of Cu, Ni, and Zn is also within a reasonable range. Compared with cash crops and grain crops, the overall risk of heavy metal exceedance in fruit and vegetable crops is controllable, and there has been no situation of multi-element exceedance. Statistic results of heavy metal content in fruit and vegetable crops are as shown in Table 3.

Table 1 Statistics of heavy metal content in food crops mg/kg

Sampling area	Sampling crop	Hg	As	Cd	Cr	Pb	Cu	Ni	Zn
Gangbei District	Rice	0.003 8 ± 0.002 0	0.168 0 ± 0.065 7	0.164 0 ± 0.088 5	0.125 0 ± 0.190 8	0.057 0 ± 0.009 0	–	–	–
Pingnan County	Rice	0.004 3 ± 0.001 4	0.070 0 ± 0.010 0	0.160 0 ± 0.120 0	0.220 0 ± 0.070 0	0.040 0 ± 0.020 0	2.900 0 ± 0.700 0	0.380 0 ± 0.120 0	14.560 0 ± 1.570 0
Guiping City	Rice	0.007 0 ± 0.004 0	0.155 0 ± 0.079 0	0.211 0 ± 0.189 0	0.400 0 ± 0.175 0	0.070 0 ± 0.050 0	3.328 0 ± 1.059 0	0.190 0 ± 0.092 0	21.086 0 ± 3.346 0
Qintang District	Early rice	0.004 0 ± 0.001 0	0.119 0 ± 0.025 7	0.196 0 ± 0.077 0	0.085 0 ± 0.003 3	0.011 0 ± 0.002 7	2.661 0 ± 0.608 3	0.304 0 ± 0.130 7	16.773 0 ± 1.450 0
Qintang District	Late rice	0.003 0 ± 0.000 8	0.102 0 ± 0.028 8	0.174 0 ± 0.211 5	0.123 0 ± 0.024 5	0.035 0 ± 0.006 5	2.224 0 ± 0.650 0	0.203 0 ± 0.117 0	16.041 0 ± 1.401 3
Qintang District	Corn in early season	0.000 5 ± 0.000 1	0.003 0 ± 0.000 3	0.011 0 ± 0.007 7	0.086 0 ± 0.005 7	0.010 0 ± 0.002 0	2.760 0 ± 0.270 0	0.093 0 ± 0.039 7	24.050 0 ± 1.100 0
Qintang District	Corn in late season	0.001 0 ± 0.000 5	0.031 0 ± 0.005 2	0.007 0 ± 0.005 3	0.122 0 ± 0.014 8	0.036 0 ± 0.005 7	2.003 0 ± 0.344 0	0.202 0 ± 0.117 7	23.417 0 ± 4.088 3
Gangbei District	Corn	0.001 0 ± 0.001 8	0.047 0 ± 0.005 3	0.008 0 ± 0.003 2	0.098 0 ± 0.006 5	0.060 0 ± 0.003 8	–	–	–
Gangbei District	Sweet potato	0.000 2 ± 0.000 1	0.008 0 ± 0.001 2	0.007 0 ± 0.002 3	0.030 0 ± 0.002 5	0.052 0 ± 0.036 2	–	–	–

Note: The data on the average contents of heavy metals is from the *Land Quality Geochemistry Evaluation Results Report of Gangbei District, Guangxi*, the *Land Quality Geochemistry Evaluation Results Report of Qintang District, Guigang City, Guangxi*, and the *Land Quality Geochemistry Evaluation Results Report of Guiping City, Guangxi*.

Table 2 Statistics of heavy metal content in cash crops

Sampling area	Sampling crop	Hg	As	Cd	Cr	Pb	Cu	Ni	Zn
Gangbei District	Peanut	0.070 0 ± 0.006 2	0.700 0 ± 0.062 7	0.170 0 ± 0.041 7	0.100 0 ± 0.018 3	0.070 0 ± 0.006 7	–	–	–
Qintang District	Peanut	–	0.018 0 ± 0.007 5	0.431 0 ± 0.200 0	0.091 0 ± 0.005 5	0.049 0 ± 0.009 2	10.404 0 ± 1.220 0	5.183 0 ± 2.573 3	43.559 0 ± 4.583 3
Guiping City	Sugarcane	0.142 0 ± 0.133 0	2.229 0 ± 0.762 0	10.821 0 ± 6.737 0	8.851 0 ± 4.129 0	7.735 0 ± 5.370 0	55.664 0 ± 30.186 0	23.503 0 ± 7.081 0	354.423 0 ± 192.236 0
Guiping City	Cassava	0.001 0 ± –	0.007 0 ± 0.012 0	0.029 0 ± 0.020 0	0.026 0 ± 0.010 0	1.204 0 ± 2.070 0	0.774 0 ± 0.225 0	0.216 0 ± 0.129 0	5.103 0 ± 2.735 0

Note: Unit of heavy metal content in sugarcane is μg/L, while unit of heavy metal content in others is mg/kg. The data on the average contents of heavy metals is from the *Land Quality Geochemistry Evaluation Results Report of Gangbei District, Guangxi*, the *Land Quality Geochemistry Evaluation Results Report of Qintang District, Guigang City, Guangxi*, and the *Land Quality Geochemistry Evaluation Results Report of Guiping City, Guangxi*.

Table 3 Statistics of heavy metal content in fruit and vegetable crops mg/kg

Sampling area	Sampling crop	Hg	As	Cd	Cr	Pb	Cu	Ni	Zn
Gangbei District	Mustard	0.001 0 ± 0.000 3	0.025 0 ± 0.020 2	0.041 0 ± 0.023 0	0.055 0 ± 0.029 5	0.029 0 ± 0.016 0	–	–	–
Gangbei District	Green beans	0.000 15 ± –	0.005 0 ± 0.000 3	0.003 0 ± –	0.012 0 ± 0.000 5	0.007 0 ± 0.000 3	–	–	–
Pingnan County	Lychee	0.000 5 ± 0.000 1	0.007 0 ± 0.003 0	0.004 0 ± 0.002 0	0.020 0 ± 0.001 0	0.003 0 ± 0.001 0	1.090 0 ± 0.330 0	0.120 0 ± 0.050 0	1.590 0 ± 0.390 0
Pingnan County	Longan	<0.0001	0.009 0 ± 0.009 0	0.004 0 ± 0.002 6	0.026 0 ± 0.002 5	0.003 4 ± 0.002 9	1.200 0 ± 0.380 0	0.096 0 ± 0.058 0	1.720 0 ± 0.350 0
Guiping City	Lychee	0.000 29 ± –	0.004 0 ± 0.004 0	0.005 0 ± 0.002 0	0.020 0 ± 0.002 0	0.003 0 ± 0.003 0	1.552 0 ± 0.294 0	0.160 0 ± 0.076 0	1.777 0 ± 0.304 0

Note: The data on the average contents of heavy metals is from the *Land Quality Geochemistry Evaluation Results Report of Gangbei District, Guangxi*, the *Land Quality Geochemistry Evaluation Results Report of Qintang District, Guigang City, Guangxi*, and the *Land Quality Geochemistry Evaluation Results Report of Guiping City, Guangxi*.

2.4 Characteristics of heavy metal bioaccumulation in crops in Gangnan District A total of 75 rice samples and 150 sugarcane samples (including 110 sugarcane stem samples and 40 sugarcane root samples) were collected in Gangnan District for testing, and the results were as shown in Table 4. The results show that there are significant differences in the biological enrichment characteristics of heavy metals in rice and different parts of sugarcane in Gangnan District. Among them, the enrichment ability of sugarcane roots for various heavy metals is generally stronger than that of rice, and both have Cd enrichment coefficients greater than

Table 4 Statistical analysis of heavy metal bioaccumulation factors in sampled crops in Gangnan District

Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Rice	0.011 0 ± 0.003 8	1.243 0 ± 1.053 7	0.001 0 ± 0.001 7	0.108 0 ± 0.032 5	0.032 0 ± 0.017 5	0.025 0 ± 0.023 7	0.001 0 ± 0.000 5	0.258 0 ± 0.093 2
Sugarcane root	0.124 0 ± 0.089 8	1.505 0 ± 0.444 3	0.065 0 ± 0.014 7	0.317 0 ± 0.084 2	0.904 0 ± 0.361 7	0.243 0 ± 0.098 0	0.180 0 ± 0.049 0	0.413 0 ± 0.164 7
Sugarcane stem	0.001 0 ± 0.001 0	0.159 0 ± 0.216 0	0.001 0 ± 0.000 5	0.004 0 ± 0.002 7	0.005 0 ± 0.003 7	0.003 0 ± 0.002 5	0.001 0 ± 0.000 3	0.005 0 ± 0.002 7

Note: The data on heavy metal bioaccumulation factor is from the *Land Quality Geochemistry Evaluation Results Report of Gangnan District, Guigang City, Guangxi*.

1 (rice of 1.243, sugarcane roots of 1.505), showing a clear Cd enrichment tendency. The enrichment coefficient of Hg in sugarcane roots is 0.904, and the enrichment ability of Zn, Cu, As, Ni, Pb and other elements in sugarcane roots is significantly higher than that in rice and sugarcane stems. However, the enrichment coefficients of all heavy metals in sugarcane stems are at an extremely low level, indicating that heavy metals are mainly enriched in sugarcane roots and have weak migration ability to aboveground stems.

3 Impact of excessive heavy metals on the development of selenium-enriched industry in the Xunyu Plain

3.1 Reducing the quality and safety level of selenium-enriched agricultural products The quality and safety of selenium-enriched agricultural products are closely related to the elements in the soil. Heavy metal elements have strong accumulation and toxicity, and will accumulate in the edible parts of crops after absorption. Among various heavy metal pollutants, Cd has received widespread attention due to its strong toxicity, high mobility, and easy accumulation in the food chain, posing a potential threat to human health[6]. Through heavy metal testing of crops in some areas of the five districts of Guigang City, it is found that Cd is the main element that exceeds the standard in many crops: the Cd exceeding rate in rice samples in Gangbei District reaches 12%; the Cd exceedance rate in early rice and late rice in Qintang District reaches 33.33% and 30.61%, respectively, with a higher exceedance rate in peanut samples; the Cd enrichment factors of rice and sugarcane roots in Gangnan District are both greater than 1, indicating a significant tendency towards Cd enrichment; the sugarcane in Guiping City has a significant ability to enrich Cd, Zn, and Cu elements. These exceedances not only result in some selenium-enriched agricultural products, especially rice and peanuts, not meeting standards such as the *National Food Safety Standard—Limits of Contaminants in Food* (GB 2762-2022), but also lower the overall quality and safety level of selenium-enriched agricultural products, posing safety risks for consumption. If the heavy metal content of selenium-enriched agricultural products in Guigang City exceeds the national food safety standards, it will lose the core market competitiveness of "high-quality and selenium-enriched" and even endanger consumer health, causing a crisis of market trust.

3.2 Restricting the efficient utilization of selenium-enriched soil resources Excessive heavy metal content can result in some selenium-enriched soils being unable to be developed or facing restrictions on development. Guigang City has superior endowment of selenium-enriched soil resources, but some heavy metal elements in the region have strong activity. Heavy metal elements in the soil are prone to migrate and accumulate towards crops[7]. Due to this characteristic, major crops such as rice and peanuts in the local area are at a potential risk of exceeding heavy metal standards. Once heavy metals of crops exceed the standards, it will directly cause difficulties in the normal development of some high-quality selenium-enriched farmland, and even lead to restrictive control measures, resulting in idle high-quality selenium-enriched soil resources and low utilization efficiency, thereby restricting the large-scale development of the selenium-enriched industry. At the same time, there are differences in the degree of heavy metal exceedance in different plots, making it difficult to adjust the planting structure and field management mode uniformly, and unable to form a standardized selenium-enriched production technology system, which is not conducive to industrial intensive management and regional public brand building.

3.3 Affecting the brand building and market competitiveness of selenium-enriched industry The core advantage of the selenium-enriched industry lies in the product quality and development concept of "selenium rich + safety". The problem of excessive heavy metals will directly impact the industry brand and even the image of Guigang as a "Chinese Selenium Port". Cadmium pollution in farmland soil may not only inhibit crop growth, affect crop yield and quality, but also pose certain public health risks through the transmission pathway of "soil - crop - human body"[8]. Currently, consumers have increasingly high requirements for the quality and safety of agricultural products, and the excessive heavy metal content in selenium-enriched agricultural products has attracted public attention. If there is an incident of excessive heavy metals in selenium-enriched products, it will not only weaken the credibility of the Guigang regional brand, but also cause market problems such as product unsold, thereby reducing its competitiveness and value enhancement in the national selenium-enriched agricultural product market, and bringing negative impacts to the scale and intensive development of the industry.

3.4 Increasing the cost of industrial development to cope with the situation of heavy metals exceeding the standard Although Guigang City has the advantage of selenium-enriched soil resources, the problem of excessive heavy metals in some areas of soil still needs to be highly valued. The harm and impact of excessive heavy metals in soil on agricultural planting are significant. It can better ensure the quality and yield of agricultural production, as well as the personal health of consumers by strengthening the control of excessive heavy metals in soil[9]. In order to effectively solve the problem of excessive heavy metals in the region, it is necessary to integrate multiple forces and invest a large amount of governance costs in order to use them for normal production. The industrial sector needs to invest additional testing costs to increase batch testing for heavy metals in agricultural products and soil. In addition, soil remediation itself is also a considerable cost. Whether it is using passivators, organic fertilizers for improvement, or plant remediation, microbial remediation, *etc.*, for the selenium-enriched industry in Guigang, which is mainly composed of farmers and small and medium-sized cooperatives, this cost is difficult to bear in the long term and will directly increase planting costs. Instead, it weakens the advantages of the selenium-enriched industry. These additional expenses directly increase the production and operation costs of the selenium-enriched industry, compress the profit margins of enterprises and farmers, and affect the profitability of the industry, enterprises, and farmers.

4 Prevention and control measures for heavy metals in soil of selenium-enriched areas

4.1 Strengthening the control of heavy metal sources The *Soil, Groundwater, and Rural Ecological Environment Protection Plan during the "14th Five-year" Plan Period* proposes to carry out source investigation of heavy metals in farmland soil, strengthen source control, and ensure ecological environment improvement and safe utilization of farmland[10]. The sources of heavy metals in soil are mainly influenced by the parent material of the soil. However, the interference of human factors cannot be ignored. Human factors such as agricultural activities (pesticide spraying, fertilization, irrigation, *etc.*), industrial and mining activities, and urban life activities not only increase the input of heavy metals, but also change the physical and chemical properties of regional soils, leading to the easier enrichment and activation of heavy metals in carbonate rock parent rocks[4]. To this end, a source investigation of heavy metals in the soil of selenium-enriched areas in Guigang City can be carried out. By focusing on identifying sources such as industrial pollution, mining, and pesticide and fertilizer abuse, a pollution source list and dynamic monitoring system can be established to strictly control environmental access. The construction of high polluting enterprises in the vicinity of selenium-enriched industrial parks should be prohibited, the supervision of key pollution sources such as existing thermal power plants, sugar factories, and industrial and mining enterprises should be strengthened, and time limited rectification or relocation measures for polluting enterprises should be implemented. In terms of agricultural pollution control, green agricultural inputs can be promoted, and the use of heavy metal pesticides and fertilizers can be restricted to reduce external heavy metal inputs from the source and prevent heavy metal migration to the soil.

4.2 Promoting the remediation of heavy metals in soil Soil is the foundation of agricultural production, and its quality directly affects the safety and yield of agricultural products[11]. The implementation of regional soil pollution zoning governance conforms to the objectivity and human nature of soil pollution[12]. The core idea of soil heavy metal remediation is to reduce the effectiveness of heavy metals in soil, block the food chain, completely remove or stabilize them in the long term. The mainstream technologies are divided into four categories: physical, chemical, biological, and agronomic regulation for the remediation of polluted soil. For farmland with mild heavy metal exceeding the standard, it is advisable to adopt comprehensive restoration methods such as adjusting and optimizing agricultural planting structure, scientifically applying passivators, *etc.* to reduce the absorption and accumulation of heavy metals by crops. Additionally, it is also a feasible way to promote selenium enrichment in crops by activating endogenous selenium in soil. For farmland with moderate to severe heavy metal exceeding the standard, bioremediation and chemical improvement methods can be combined. Through comprehensive remediation techniques such as plant enrichment and rational application of soil amendments, it can gradually reduce soil heavy metal stocks and improve the environmental quality of farmland. For irreparable heavy metal exceeding plots, it should adjust land use in accordance with the law and carry out land planning and management to avoid using them for the cultivation and production of selenium-enriched agricultural products. Centralized governance and management methods should be adopted for key areas exceeding the standard. It should establish special governance projects, increase investment in special funds and technical personnel, and prioritize the restoration of heavy metal exceeding plots with selenium enrichment advantages.

4.3 Establishing a quality and safety supervision system for selenium-enriched agricultural products The detection technology of heavy metal inventory in food is an important research direction in the field of food safety[13]. Establishing a comprehensive monitoring network, implementing strict product testing, and promoting traceability management are powerful regulatory systems to ensure the quality and safety of selenium-enriched agricultural products. It is necessary to regularly sample and test the soil, irrigation water, and crops in selenium-enriched planting bases to grasp the dynamic changes in heavy metal content in real time, in order to timely warn and avoid pollution risks. At the same time, selenium-enriched agricultural product production enterprises are required to establish a self inspection system to test the heavy metal content of listed products. After passing the test, they can be circulated in the market. Corresponding measures to investigate and control are taken for unqualified agricultural products in accordance with the law. In terms of market supervision, a traceability system for selenium-enriched agricultural products can be established. Consumers can scan the QR code on the product packaging to query information such as the soil condition of the planting base, the use of agricultural inputs, the production and processing process, and the test results, achieving full traceability from the field to the dining table, enhancing consumer trust, and ensuring the quality, safety, and reliability of selenium-enriched agricultural products supplied to the market.

5 Countermeasures for the development of selenium-enriched industry

5.1 Scientifically planning the cultivation of selenium-enriched crops The layout of planting areas should be optimized. Based on soil selenium content and heavy metal exceeding standards, core planting areas, suitable planting areas, and restricted planting areas for selenium-enriched agricultural products could be designated. Priority should be given to selecting plots with no excessive heavy metals and high selenium content in the core planting area, focusing on developing advantageous selenium-enriched crops such as rice, peanuts, and corn. It is strictly prohibited to plant selenium-enriched agricultural products for direct consumption in restricted planting areas, and the economic value can be increased by developing feed crops or economic forests. It should reasonably plan and select planting varieties. Combined with the enrichment characteristics of heavy metals in crops, varieties with low heavy metal enrichment coefficients could be chosen for planting. For example, rice, lychee, and longan in Pingnan County have weak heavy metal enrichment ability, and heavy metals have not exceeded the standard. They can be promoted and planted locally to form advantageous economic crops. For crops with high Cd enrichment coefficients, their enrichment ability can be reduced through variety improvement.

5.2 Strengthening policy support and guidance of selenium-enriched industry To cultivate an industry, it is necessary to provide strong support in the initial stage. Through the "accomplishing a great task with little effort by clever maneuvers" effect of fiscal leverage, it could promote the establishment of Guigang's selenium-enriched industry as an emerging characteristic agricultural industry in Guangxi as soon as possible[14]. The government needs to pay attention to the series of issues related to the development of the local selenium-enriched industry. By establishing a special fund for the development of the selenium-enriched industry, cultivating leading enterprises, and focusing on supporting core links such as selenium-enriched technology research and development, standard system construction, demonstration base construction, deep processing upgrading, brand cultivation, and soil heavy metal treatment, the government should support a group of leading enterprises with strong driving capabilities to continuously optimize and build the deep processing production of the entire upstream, midstream, and downstream chain of the selenium-enriched industry in Guigang City. It is committed to integrating selenium-enriched resources in the five districts and breaking away from the market competition mode of a single "selenium rich" label. At the same time, preferential policies such as financial subsidies, loan interest subsidies, and tax reductions could be provided to selenium-enriched production enterprises, cooperatives, and scientific research projects that meet the conditions, to reduce the production costs of enterprise entities. Social capital and financial institutions should be strongly encouraged to participate in the development of the selenium-enriched industry, broaden financing channels, and promote the formation of a diversified investment mechanism of "government guidance, enterprise leadership, and social participation".

6 Conclusions

In the process of agricultural development, crops have strict requirements for soil. If the soil quality deteriorates or even the heavy metals exceed the limit, it will directly affect crop growth, and reduce their yield and quality, not conducive to the long-term development of agriculture[15]. The advantage of selenium-enriched resources in the five districts of Guigang City has made the selenium-enriched industry a characteristic and potential industry. However, the potential risk of excessive heavy metals in soil has become one of the key factors restricting the high-quality development of the industry, mainly reflected in affecting the quality and safety of agricultural products, reducing the utilization rate of soil resources, hindering brand credibility construction, and increasing development costs. To achieve the sustainable development goal of the selenium-enriched industry in Guigang, it is necessary to work together from multiple aspects such as source control, pollution control, quality supervision, industrial layout, technology research and development, and policy support, to build a full chain guarantee system of "prevention and control – governance – supervision-enhancement", and transform the advantages of selenium-enriched resources from resource based to technology-based, brand based, and efficiency based, effectively promoting the rural revitalization and upgrading of characteristic industries in Guigang City.

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