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Continuing the Path of Green Income Growth to Realize the Dream of Industrial Revitalization

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Abstract Pan'an faces the dual transformation challenges of ecological protection and increasing farmers' income. To this end, it actively practices the development concept of "Green water and green mountains are gold and silver mountains", implements innovative measures such as "Our Happiness Plan", and explores new paths to enrich the people through ecology. Taking Pan'an County, Zhejiang Province as an example, this study explores how the green development path of agriculture driven by biological resources and biotechnology can help rural industrial revitalization. It analyzes the rich natural biological resources and ecosystem service value of Pan'an, summarizes the innovation of agricultural production models led by "Our Happiness Plan", discusses the practical application of agricultural biotechnology such as biological breeding, biological control, and agricultural product processing in Pan'an's industrial revitalization, and sorts out the development path of the integration of the first, second, and third industries of green agriculture, including the agricultural production, processing, and marketing coordination mechanism, the value of ecological science popularization in the integration of agriculture and tourism, and the construction practice of the rural circular bio-economic system. On this basis, the current challenges in the field of agricultural biology are analyzed. The study believes that the development paradigm of "biology + ecology" integration not only reshapes the value of the agricultural industrial chain, achieves a win-win situation of ecological protection and economic development, but also provides a sustainable practice paradigm for rural revitalization in the new era. This study hopes to provide reference for biological-oriented agricultural green income increase and rural industrial revitalization.
Keywords Pan'an; Rural revitalization; Green development; Ecological agriculture; Biotechnology; Ecosystem services

1 Introduction

Located in the mountainous area of central Zhejiang, Pan'an County has a superior ecological environment, but agricultural development has long been restricted by the mountainous terrain. How to lead farmers to increase their income and become rich while protecting the green mountains and rivers is a prominent challenge facing local agriculture. In the past, extensive agriculture often sacrificed the environment in exchange for production growth, but this model is unsustainable, and ecologically fragile areas especially need to explore the path of green transformation. Pan'an has a forest coverage rate of up to 83.6%, and is known as the "green lung of central Zhejiang". The environment carries important functions such as water conservation and climate regulation. At the same time, Pan'an is also an old revolutionary base with a relatively weak economic foundation, limited per capita arable land, and traditional agricultural income is not enough to support the goal of common prosperity. This contradiction between "enriching the county with ecology" and "enriching the people and increasing their income" requires the transformation of the agricultural development model from extensive and high-consumption to green and efficient. In order to solve this problem, Pan'an has adhered to the development strategy of "enriching the people with ecology and strengthening the county with ecology" in recent years. Through institutional innovation and industrial innovation, it has strived to transform ecological advantages into economic advantages and embark on a green income increase path with mountain characteristics (Wei, 2023; Weng et al., 2024). In particular, the practical exploration represented by the "Our Happiness Plan" is committed to allowing more farmers to share the dividends brought by green mountains and clear waters, and to achieve the simultaneous advancement of ecological protection and farmers' income growth. This exploration is a microcosm of the transformation of agricultural ecological economy under the background of rural revitalization.

The development of modern agriculture increasingly relies on the integration of science and technology with ecological concepts. The progress of biotechnology has provided new impetus for the sustainable development of agriculture. For example, technologies such as genomic breeding, molecular marker selection, and CRISPR gene editing can cultivate new crop varieties that are resistant to pests and diseases and stress, while reducing the use of pesticides and fertilizers while increasing yields and nutritional quality. Studies have shown that the creation of insect-resistant and disease-resistant crops through biotechnology can significantly reduce the amount of pesticides used and soil damage, achieving a win-win situation of environmental friendliness and increased agricultural production. The application of biofermentation engineering, enzyme preparations, etc. in the processing and storage of agricultural products has increased the added value and processing efficiency of agricultural products (DeClerck et al., 2016; Rehman et al., 2022). At the same time, the importance of ecosystem services is becoming increasingly prominent in the sustainable development of agriculture. Healthy agricultural ecosystems can provide a variety of services including soil nutrient cycling, water conservation, pollination, and biological control. For example, soil microbial communities contribute to nutrient cycling and crop health; pollinating insects increase crop fruiting rates; and natural enemies can control pest populations. These services are essential to ensuring agricultural productivity and ecological environmental quality. Integrating the concept of ecosystem services into agricultural management can reduce dependence on chemical inputs and achieve synergy between agricultural production and ecological protection. Therefore, modern agriculture needs to give full play to the dual role of biotechnology and ecosystem services, improve resource utilization efficiency and system stability through scientific and technological innovation and ecological optimization, and thus provide support for the green development of agriculture.

Green development has become the basic strategic orientation of my country's agricultural transformation in the new era. General Secretary Xi Jinping pointed out that "promoting the green development of agriculture is a profound revolution in the concept of agricultural development" and emphasized the dialectical unity of green waters and green mountains and gold and silver mountains. Since 2017, my country has launched the Green Development Action for Agriculture and issued a series of policies to encourage agricultural input reduction, resource recycling, and environmentally friendly technology promotion. These strategic measures have created favorable conditions for the biological upgrading of the agricultural industry. On the one hand, green development requires reducing the use of chemical fertilizers and pesticides, which objectively promotes the research and development and application of technologies such as biofertilizers and biopesticides. For example, by promoting biological control and integrated pest management (IPM) strategies, natural enemy insects, microbial preparations, etc. are used to replace some chemical pesticides, achieving the goal of reducing pesticides and increasing efficiency. As of recent years, the application area and market scale of biopesticides and biofertilizers in China have continued to expand, with an average annual growth rate of about 11% from 2018 to 2022, indicating that green plant protection is gradually being accepted by agricultural production (Wu et al., 2024). On the other hand, the green development strategy emphasizes the resource utilization of agricultural waste and the construction of a circular agricultural system, which provides an opportunity for the development of agricultural biomass energy and bioprocessing industries. For example, livestock and poultry manure can be used to produce organic fertilizer and biogas through biological fermentation, and straw can be converted into feed or base material through microbial treatment, which not only reduces pollution but also creates additional benefits. These practices reflect the combination of biotechnology and the concept of circular economy, and help to open up the transformation channel of the "two mountains" in agriculture. Under the guidance of policies, more and more agricultural enterprises and university research institutions are participating in agricultural green technology innovation, and the pace of agricultural biotechnology achievement transformation is accelerating. It can be said that the green development strategy has given traditional agriculture the wings of "biological upgrading" and accelerated the transformation of agricultural production methods to high efficiency, cleanliness and recycling. As a national pioneer county in agricultural green development, Pan'an has actively explored this aspect, such as being selected as the first batch of agricultural green development demonstration counties, creating a Chinese medicinal material specialty agricultural product advantage zone, and obtaining organic or geographical indication certification for many agricultural products. These all reflect the strong traction of the green strategy on the upgrading of the agricultural industry.

This study will evaluate Pan'an's biological resource advantages and regional ecosystem value, including natural resource endowment, ecosystem service functions and the agricultural value transformation of local characteristic species, analyze the agricultural biological model innovation contained in Pan'an's "Our Happiness Plan", such as ecological breeding and farming, agricultural product ecological certification, "company + cooperative + farmer" mechanism, etc., explore its role in increasing farmers' income and ecological protection, discuss the specific application practice of agricultural biotechnology in industrial revitalization, summarize the development path of green agricultural industry integration, including biological synergy of the first, second and third industries, ecological education function in agricultural and tourism integration, and the construction of a circular bio-economic system, analyze the challenges encountered by Pan'an in the process of promoting bio-oriented green industries, and put forward targeted development suggestions, and emphasize the value of bio-oriented green industrial chain reconstruction for achieving a virtuous cycle of ecological economy, point out the paradigm significance of Pan'an's experience for rural revitalization, and the sustainable development potential of the ecological-biological-economic integration model. This study sorts out and analyzes how the green agricultural income-increasing model driven by biological resources and biotechnology can help rural industrial revitalization, and provides experience reference based on the practice of Pan'an County, hoping to provide a reference for industrial revitalization ideas for regions with similar ecological and environmental conditions, that is, to embark on a sustainable development path of using biological resources and technology to achieve "green income increase".

2 Biological Resources and Ecosystem Value in the Region

2.1 Natural resources and biodiversity of Pan'an

Pan'an is located in the remnant of the Kuancang Mountains. The Dapanshan National Nature Reserve is located within its territory and has a superior mountain and water ecosystem. The county is full of rolling mountains and dense vegetation, with a forest coverage rate of up to 83.6%. The air and water quality maintain the national Class I standard all year round. It is known as the "ancestor of mountains and the source of water". The good ecology has nurtured rich biodiversity and unique natural landscapes - cliff waterfalls, deep ravines and dense forests, and misty alpine environments, providing habitats for a variety of animals and plants. In the long process of evolution, Pan'an has formed a variety of types including subtropical evergreen broad-leaved forest ecosystems and mountain stream wetland ecosystems, which contain extremely high species diversity (Zhang et al., 2018; Liu et al., 2024). According to statistics, there are more than 1,800 vascular plants in the territory, including dozens of national key protected wild plants; wildlife resources are also quite rich, with a wide variety of birds, insects, amphibians and reptiles. Not only that, Pan'an is also known as the "Millennium Medicine Town" with rich Chinese medicinal materials resources. Today, there are more than 700 known Chinese medicinal materials. A considerable part of the local "Eight Flavors of Zhejiang" comes from Pan'an, which provides a good foundation for the development of the authentic medicinal materials industry. Pan'an is also a famous tea town and honey producing area. The Yushan Ancient Tea Farm has a long history of tea production and is known as the "living fossil" of Chinese tea culture. There are more than 15,000 ancient tea trees in the county with various varieties. More than 80% of the farmers in Huanglinkeng Village, Shanghu Town, the "No. 1 Bee Village in Central Zhejiang", raise Chinese bees, with more than 600 beehives and an annual honey production of more than 10,000 kilograms. This series of data and facts shows that Pan'an has unique biological resources and ecological diversity advantages, providing a rich material basis and gene pool for agricultural development. When implementing industrial revitalization, fully recognizing and utilizing these natural assets is a prerequisite for achieving sustainable income growth.

2.2 Ecosystem service functions

The mountain, water, forest, farmland, lake and grass ecosystems of Pan'an not only nurture biodiversity, but also support regional agriculture and human well-being through diverse ecosystem services. The first is supply services. Forests and farmlands provide society with food crops, Chinese medicinal materials, tea, honey and other material products; abundant forests conserve water sources, and streams flow all year round, providing guarantees for agricultural irrigation and water supply for residents' lives. The second is regulation services. The high-coverage

forest ecosystem plays a key role in soil and water conservation and climate regulation. Pan'an has undulating terrain, and forest vegetation reduces the risk of rainstorm runoff and soil erosion, protecting farmland from floods and waterlogging disasters; the transpiration of vegetation and the evaporation of water bodies help regulate the local climate, alleviate the high temperature and drought in summer, and form a good microclimate for crop growth (Li and Wang, 2019; Yang et al., 2023). At the same time, healthy ecosystems provide services such as pollination and biological control: Pan'an's abundant rapeseed, buckwheat and other nectar plants and abundant wild flowers create habitats for pollinating insects such as bees, and pollinator activities improve the yield and quality of fruit and vegetable crops; forests and wetlands near farmland provide shelter for natural enemies such as frogs, spiders, and birds, which prey on pests and help control crop diseases and pests. This ecological self-regulation function reduces the demand for pesticide input and is conducive to the production of green organic agricultural products. Pan'an's unique landscape and biodiversity also have cultural service value - the beautiful rural landscape and rich medicinal tea culture have attracted a large number of tourists to experience leisure agriculture and rural tourism, and ecotourism has become an important part of the local industry (Figure 1). In short, from providing material products to maintaining environmental quality to supporting cultural and educational activities, ecosystem services permeate all aspects of Pan'an's agricultural and rural development. As pointed out by the International Research Institute: "Healthy ecosystems provide services such as clean water, pollination, soil conservation and climate regulation, which are indispensable for food production." In the process of promoting the revitalization of the agricultural industry, Pan'an attaches great importance to protecting and giving play to these ecological functions, and achieves a win-win situation between man and nature through ecological benefits.

Figure 1 Beautiful pastoral landscape environment of Pan'an County (Photographed by Wenjun Cai)

2.3 Agricultural potential of local species

Pan'an has many local species and varieties with unique characteristics. They are not only an important part of biodiversity, but also a potential treasure trove for agricultural efficiency improvement. In recent years, the local area has actively promoted the domestication, selection and branding of characteristic species, transforming the advantages of biological resources into industrial advantages. The most representative are the five major traditional Chinese medicinal materials known as the "Pan Five Flavors", including *Corydalis*, *Atractylodes*, *Scrophularia*, *Polygonatum*, *Curculigo*, etc. (Zhou et al., 2024). These medicinal materials are famous for their long history of growth and high quality in Pan'an. In 2019, Pan'an was recognized as a national advantage zone for characteristic agricultural products of Chinese medicinal materials. "Pan Five Flavors" has become a regional public brand, and the Chinese medicinal materials industry has entered the fast lane of standardized and large-scale development. Taking Polygonatum as an example, Pan'an implemented the "Ten Billion-level Key Technology Research and Development for Polygonatum Industrialization" project, and cooperated with university scientific research teams to carry out variety selection and breeding and standardized planting technology research. Over the past three years, researchers have successfully bred a new strain of high-yield and high-quality *Polygonatum sibiricum*, and demonstrated and promoted the simulated wild cultivation model under the forest, which significantly increased the yield per mu of *Polygonatum sibiricum* and the content of effective ingredients such as polysaccharides, and promoted the development of *Polygonatum sibiricum* cultivation in dozens of local villages, and the purchase price of medicinal materials has steadily increased. Another example is Pan'an's traditional high-quality tea variety "Pan'an Yunfeng", which is awarded the national agricultural product

geographical indication protection because it grows in the misty mountains and has a unique harvesting and processing process, and the tea quality is first-class. Through unified brand marketing, the price and sales volume of "Pan'an Yunfeng" tea have continued to rise, and tea has become the "golden leaf" for local farmers to increase their income. Another example is the specialty vegetable variety of high-altitude wild rice, which can be planted in the cold and cool environment of Pan'an at a higher altitude to avoid the high incidence of insect pests in low-altitude areas. It is crisp and refreshing, and has also obtained the national agricultural product geographical indication certification. The planting area of high-altitude wild rice in Pan'an currently reaches thousands of acres. Due to pollution-free ecological planting and staggered listing, the market is in short supply. Pan'an also vigorously develops local native chickens (native breeds of native chickens) and native bees and other specialty breeding. Pan'an native chickens are famous both inside and outside the province for their delicious meat and rich nutrition. Pan'an native eggs have passed the pollution-free livestock product certification and have won awards at the Agricultural Expo many times. They have become a well-known green agricultural product brand. The honey brewed by Pan'an native bees (Chinese bees) is pure and natural and also enjoys a high reputation. The local native honey was successfully registered as a geographical indication certification trademark in 2021, and the market price is more than 30% higher than ordinary honey. It can be seen that through measures such as variety selection, standard certification and brand building, Pan'an has successfully transformed many local species that were originally "raised in the mountains and unknown to people" into "gold and silver mountains" industries, realizing the effective transformation of ecological value into economic value. The development of these specialty species industries not only provides consumers with high-quality and safe specialty agricultural products, but also increases farmers' income and injects vitality into rural revitalization.

3 Agricultural Biological Model Innovation in the “Our Happiness Plan”

3.1 Eco-certification systems based on “natural farming”

In order to achieve a win-win situation of ecological protection and farmers’ income increase, Pan’an launched the “My Happiness Plan” in Panfeng Township in 2012, and upgraded it to the “Our Happiness Plan” covering the whole county in 2021. Its core is to introduce the concept of “natural farming” into agricultural production and establish strict ecological breeding standards and certification systems. In practice, Pan’an has explored the order agriculture model of “company + cooperative + base + farmer”: leading enterprises provide high-quality seedlings and technical guidance, farmers produce according to the ecological planting standards formulated by the enterprises, and the enterprises repurchase the products at a protective price higher than the market (Liang et al., 2023). For example, the earliest farmers participating in the plan in Panfeng Township were required to apply organic fertilizers, control the amount of pesticides, interplant green manure crops to protect soil fertility when planting rice, and follow the ecological agricultural norms from sowing to harvesting. In return, the company purchased rice at a price of 2.8 yuan per kilogram, which is about twice the market price during the same period, greatly increasing farmers' income from growing grain. This model essentially builds a set of ecological certification system for agricultural products, in which enterprises and the government jointly supervise the production process of farmers to ensure that agricultural products meet pollution-free or organic standards, and then put on a unified brand label to enter the market for sale. Pan'an native eggs, Yunfeng tea, high-mountain vegetables, etc. have all achieved standardized production and branded marketing under this system. At the same time, the government has introduced support policies to reward owners who participate in the "Happiness Plan" and reach a certain scale of acquisition, such as a reward of 60,000 yuan for annual acquisitions of more than 5 million yuan, etc., to encourage enterprises to strictly implement ecological production standards. After years of practice, Pan'an has initially formed an ecological agricultural product certification system covering multiple fields such as grain, oil, vegetables, tea, livestock and poultry, and Chinese medicinal materials, and the quality and safety level of agricultural products ranks among the top in the province. The brand effect based on ecological certification has also gradually emerged - consumers recognize the quality of the "Pan'an Mountain Residence" series of green agricultural products and are willing to pay a premium. This certification system guided by natural farming not only protects the ecological environment of cultivated land and the quality and safety of agricultural products, but also allows farmers to share the added value of the industrial chain, realizing "producing green products and harvesting golden benefits" (Figure 2).

Figure 2 Implementation of "our happiness plan" (Photographed by Wenjun Cai)

3.2 Ecological stability of diversified breeding systems

In traditional agriculture, single breeding is often prone to disease proliferation and market risks. Pan'an has created a "small-scale, multi-variety" ecological breeding system by developing diversified local specialty breeding such as native chickens, native pigs, and native bees, thereby improving the ecological stability and risk resistance of the entire breeding industry. First, Pan'an vigorously promotes the forest chicken farming model. Local farmers adapt to local conditions and raise native chickens under the bamboo forests in the mountains, allowing the chickens to move freely and forage for insects and weeds. This not only reduces the input of feed and veterinary drugs, but also uses chicken manure to fertilize the forest to form an ecological cycle. Practice has shown that the disease incidence rate of native chicken farming under the forest is significantly lower than that of high-density enclosures, and the quality of chicken eggs is excellent, which is in short supply in the market. Through cooperative organizations, the county unites scattered native chicken farmers to develop a "10,000-feather ecological native chicken" base. By the end of 2021, the county's native chicken breeding volume reached 200,000 driving more than 300 households to increase their income, and the reputation of the native chicken and egg brands has grown. The second is ecological native pig breeding. Pan'an has developed the "Thousand Native Pigs" project by combining rural kitchen waste resource recycling and forest grazing. Farmers raise local black pigs, and the feed is mainly coarse materials such as rice bran and potato vines and kitchen waste. The pig houses are regularly cleaned of manure for composting and returning to the fields. Some towns have also built "shared pig pens", where the village collective builds standardized pig houses, low-income farmers adopt them for breeding, and the company provides repurchase contracts and technical support. Under this model, the incidence of pigs is lower, and the meat quality is more popular with consumers. Each ecological native pig can be sold for more than 20% more than feed pigs (Bai et al., 2019).

Driven by the "company + farmers", the annual output of Pan'an native pigs has stabilized at a scale of thousands of heads, which not only protects the ecological environment from large-scale breeding pollution, but also allows retail investors to share the market dividends. Secondly, Pan'an has made full use of the Chinese bee breeding tradition to create characteristic bee industries such as "the first bee village in central Zhejiang". 80% of farmers in Huanglinkeng Village, Shanghu Town, breed Chinese bees (Chinese honey bees), and there are more than 600 beehives in the village. The village has established an ecological medicinal honey cultural park and planted 300 acres of Chinese medicinal flowers and nectar plants to ensure sufficient nectar sources. Beekeepers strictly use traditional methods to breed Chinese bees, without using antibiotics and other drugs, so that honey is pure and natural and pollution-free. In the spring of 2025, the first batch of spring honey harvested in Huanglinkeng Village weighed 150 kilograms, bringing in more than 30,000 yuan in income. Today, bee breeding has become the "common wealth industry" of the village, with an annual honey output value of hundreds of thousands of yuan. More importantly, the bee industry has driven the protection of the local ecological environment, and the villagers have spontaneously maintained the diversity of the surrounding vegetation to create a good home for the bees. Through the above diversified ecological breeding practices such as native chickens, native pigs, and native bees, Pan'an has built an agricultural ecological network with diverse species and complementary functions. Diversified breeding improves system resilience. When an industry is hit by the market or epidemics, farmers can rely on other industries to maintain their income, reducing the risks brought by a single industry. At the same time, ecological reciprocity has been formed between different breeding systems: raising chickens and bees under the

forest improves the sanitation and pollination environment of the forest, and local pig manure provides organic nutrients for the planting industry, realizing the cycle of planting and breeding. The diversification of agricultural systems helps to enhance ecological stability and sustainability (Cui, 2024). The experience of Pan'an shows that by developing diversified ecological breeding with local characteristics, it not only protects biodiversity, but also opens up a new path for increasing rural income.

3.3 Micro-ecological management in highland rice and vegetable cultivation

Pan'an has many mountains, and the cool microclimate in the mountains provides special conditions for the development of alpine vegetables and high-quality rice. According to the characteristics of different altitudes and seasons, the local area has innovated a series of microecological planting and management technologies to achieve the combination of planting and breeding and ecological cycle, which not only improves the quality of crop yields, but also protects the agricultural ecological environment. A typical case is the development experience of Guo Linming, a farmer in Panfeng Township. He was originally a low-income farmer. With the support of the "Happiness Plan", he began to grow late rice and interplant Chinese medicinal materials in rice fields. After the rice is harvested every year, water-resistant Chinese medicinal herbs such as Polygonatum are planted in the rice fields, and the rice is turned over and planted the next year to achieve rice-drug rotation.

The late rice maturity period avoids the peak of pests and diseases, and the interplanted Chinese medicinal herbs can suppress weeds to a certain extent. The application of pesticides is reduced during the entire planting process, and the quality of rice is improved. Medicinal herbs grow well in the moist soil environment of rice fields, bringing additional income. In 2020, Guo Linming's total income from planting late rice and interplanting Polygonatum reached 170,000 yuan, a large part of which came from the sale of medicinal herbs. This "rice-drug co-cultivation" model has increased the land multiple cropping index and unit area benefits, and has become an innovation in the alpine terraced field area. Similar to this is the "rice-fish symbiosis" technology. Some alpine terraced fields in Pan'an adopt the rice field fish farming model, raising carp, rice flower fish and other varieties in the rice fields. The fish eat Cordyceps and stir the muddy water, which not only reduces pests and weeds, but also provides natural fertilizer for rice. In the end, rice production increased and fish became a by-product (Huang and Li, 2024). Another example is the promotion of leguminous green manure and cash crop rotation and intercropping technology in alpine vegetable bases. For example, planting green manure crops such as astragalus before and after planting alpine cabbage and cauliflower can improve the soil and beautify the countryside; or intercropping beans between corn rows to meet part of the nitrogen fertilizer demand with leguminous nitrogen fixation.

These microecological management measures are more effective when combined with modern biotechnology. Pan'an Agricultural Department has introduced microbial preparations, such as EM bacteria, which are used to compost and ferment alpine vegetable straw to make organic fertilizer and return it to the field to enhance soil microbial activity; another example is the use of traps and biological pesticides to control alpine vegetable pests, which has achieved significant results in the high-altitude and cold environment with low insect population density, and basically no chemical pesticides are used. Mihrete and Mihretu (2025) pointed out that diversified crop planting methods such as intercropping and intercropping can help optimize resource utilization and improve yield stability (Figure 3). It is through these microecological technologies that Pan'an's alpine agriculture has achieved "small ecology" to promote "large production".

At the same time, the integrated cultivation and breeding of alpine vegetables and rice fields is developed according to local conditions, which not only improves the product quality (alpine vegetables generally have low nitrate content and good taste, and alpine rice has small and plump grains and strong rice fragrance), but also forms a terraced landscape and rice field fishing song culture with sightseeing value, further promoting the development of leisure agriculture and rural tourism. Alpine vegetable and rice microecological cultivation is another agricultural biological innovation model explored by Pan'an based on mountain ecological conditions, which has turned green waters and green mountains into a continuous source of gold and silver.

Figure 3 Crop diversification in agriculture as manifested by inter-cropping and agro-forestry practices (Adopted from Mihrete and Mihretu, 2025)

4 Practical Application Cases of Agricultural Biotechnology in Industrial Revitalization

4.1 Breeding and genetic resource utilization

The application of biological breeding technology is an important means for Pan'an to improve the quality and efficiency of agriculture. Faced with the demand for high-quality varieties in the agricultural product market and the challenges brought by climate change, Pan'an relies on its rich biodiversity to carry out germplasm resource protection and new variety breeding to enhance the competitiveness of characteristic industries. For example, in the tea industry, in response to the problem of insufficient stress resistance of traditional varieties, researchers used molecular marker-assisted breeding technology to select excellent genotypes from 15,000 ancient tea trees for breeding new tea seedlings. At the same time, an ancient tea tree germplasm resource garden was established to collect and preserve the largest number and most complete varieties of ancient tea tree germplasm, laying the foundation for the future cultivation of new tea tree varieties with high fragrance and high stress resistance. In terms of Chinese medicinal materials, Pan'an implemented the "unveiling the list and taking charge" scientific and technological research, and the expert team of Zhejiang Agricultural and Forestry University undertook the key technology research and development tasks for the industrialization of *Polygonatum odoratum*. The project team collected and evaluated wild *Polygonatum sibiricum* germplasm, selected excellent strains with short growth cycles and high content of effective ingredients, and developed tissue culture rapid propagation technology and forest-based simulated wild cultivation technology, which greatly improved the supply of *Polygonatum sibiricum* seedlings and the success rate of planting. Through genetic fingerprinting technology, the DNA identification standard of Pan'an authentic medicinal materials (*Rhizoma Corydalis*, *Atractylodes macrocephala*, etc.) was established, effectively protecting the authentic medicinal materials brand (Pan et al., 2024; Yang et al., 2024).

In terms of livestock and poultry varieties, Pan'an cooperated with scientific research institutes to carry out seed conservation and breeding of local native pig and chicken breed resources. Using molecular breeding methods, the new Pan'an black pig strain has the characteristics of improved growth performance while retaining meat flavor; Pan'an native chickens have improved egg production through family selection, and the annual egg production of each hen has increased from 80 to more than 120, while the egg quality still maintains the rich flavor of native eggs. Biological breeding is not only reflected in variety improvement, but also includes the construction of a good variety breeding system. Pan'an has established a provincial rice and vegetable seed breeding base, introduced advanced seed processing and preservation technologies, and ensured the large-scale promotion of excellent varieties.

Through the exploration of germplasm resources and biotechnology breeding, the speed of variety renewal of Pan'an's main crops and characteristic economic crops has been significantly accelerated, and the yield and quality

have been significantly improved. For example, the new variety "Panruanxiang" glutinous rice has a 15% increase in yield compared with the old variety, and has a lower amylose content and is softer and more glutinous, which is popular in the market. It can be said that biological breeding has injected scientific and technological genes into agriculture and provided a continuous new impetus for industrial revitalization. As Pal et al. (2024) pointed out, biotechnology can cultivate crops that are resistant to pests and diseases and richer in nutrition, achieving both current production increases and future resource conservation. In Pan'an, this is well confirmed: relying on the combination of rich local species resources and modern breeding technology, traditional industries have been rejuvenated, farmers have increased their income, and the ecology has been protected by the use of local varieties.

4.2 Biological pest management and eco-control

The extensive use of chemical pesticides has been a stumbling block to the green development of agriculture. It not only aggravates environmental pollution, but also leads to excessive residues in agricultural products and loss of biodiversity. To this end, Pan'an vigorously promotes biological control measures in agricultural pest control, and strives to achieve the green management goal of "no extinction of pests and no increase in pesticides". Specific measures include: First, protect and utilize natural enemy resources. By planting flowering plants around farmland to provide a habitat for beneficial insects such as bees, aphid flies, and lacewings; hang artificial nest boxes in orchards and vegetable gardens to attract insectivorous birds; protect the ecological environment of rice fields to facilitate the reproduction of frogs, loaches, etc. (Figure 4) (Ali et al., 2019). These beneficial organisms effectively reduce the base number of pest populations. According to observations by the agricultural department, the incidence of pests in fields where biodiversity optimization management is implemented has decreased by more than 20%. Second, artificial release of natural enemies. Pan'an has established a parasitic bee breeding farm. Every year, trichogrammatids are released in rice fields to control the striped stem borer, and swollen-legged bees are released in citrus orchards to parasitize psyllids. Good results have been achieved - the parasitism rate of rice stem borer eggs has reached 80%, and the population density of citrus psyllids has dropped by more than 70%, thus controlling the occurrence of diseases and pests such as stem borers and Huanglongbing. The third is biological pesticide substitution. The county promotes Bt preparations, insect-proof fungi, and bio-source pesticides (such as matrine and rotenone) to replace highly toxic and highly residual pesticides. The application of *Bacillus thuringiensis* preparations in vegetables and tea leaves is focused on testing, and the control effect against cabbage worms, tea caterpillars, etc. is as high as 90%, and it is safe for natural enemies and has low residues. The fourth is physical entrapment and control technology combined with biological control (Zhang and Wang, 2024). For example, solar insecticidal lamps are installed in the field to lure and kill adult noctuids, or sex attractants are used to interfere with the mating of rice leaf rollers.

At the same time, traditional ecological methods such as raising ducks and fish in rice fields are combined to achieve multiple measures. Due to the comprehensive application of various green control technologies, the green control coverage rate of major crop pests and diseases in Pan'an has reached more than 80%, the use of chemical pesticides has been reduced by nearly half compared with 2015, and the qualified rate of pesticide residues in agricultural products has remained stable at more than 99%. It is worth mentioning that these biological control measures are also closely integrated with agricultural product certification and brand building-only vegetables and fruits produced by bases that adopt green control can be labeled as "Pan'an ecological agricultural products" for sale, thereby improving product competitiveness and prompting farmers to consciously adopt them. This confirms the sustainability of IPM (integrated pest management): "IPM encourages natural pest control mechanisms to play a role by minimizing interference with farmland ecosystems."

Pan'an's experience shows that driven by both policies and markets, biological control technology can gradually replace chemical pesticides and become the mainstream, safeguarding agricultural production. At present, the global biopesticide industry is also rising rapidly, and the biopesticide market will maintain double-digit growth from 2018 to 2022. As a pioneering region for green agricultural development, Pan'an will continue to introduce advanced biological control technologies, such as RNA interference insecticides and new insect virus preparations, to further consolidate the results of green pest control and achieve the coordinated coexistence of agricultural production and the ecological environment.

Figure 4 Flowering plants (sunflower, marigold, cosmos) grown on the bunds in rice plots to provide resources for biocontrol agents, especially parasites/parasitoids, in rice landscapes (Adapted from Ali et al., 2019)

4.3 Biotechnology in agricultural processing

In addition to the breeding and farming links, Pan'an also introduces biotechnology in agricultural product processing and comprehensive utilization, extending the agricultural industry chain and increasing added value. First, the deep processing of Chinese medicinal materials uses biological extraction technology. Through biotechnology such as enzymolysis, fermentation, and supercritical extraction, Chinese herbal medicine companies in Pan'an have extracted effective ingredients from medicinal materials such as polygonatum and scrophularia, and developed new products such as polygonatum polysaccharide oral liquid and scrophularia fermented beverage. Compared with traditional medicinal pieces, these products have increased the utilization rate and functionality of medicinal materials, and significantly increased the income of farmers. For example, a company used multi-strain combined fermentation technology to convert polygonatum into complex polysaccharides, which improved its antioxidant activity. The product was well received on the market. Second, biological fermentation and microbial agents are used in tea processing. Pan'an tried to imitate the production process of black tea, introduced specific strains to ferment "Pan'an Yunfeng" green tea, and made unique fermented tea products, which improved the diversity of tea. At the same time, the branches and leaves pruned from the tea garden and the tea dregs are used to improve the soil of organic tea gardens after being composted by microorganisms, forming a circulation model. Third, the application of enzyme preparations in food processing. Pan'an's traditional food processing such as dried potatoes, kudzu powder, and soy products are gradually adopting enzymatic technology to replace chemical methods to improve quality and output rate. For example, pectinase is used to clarify kudzu starch to improve transparency; composite protease is used to hydrolyze soybean meal feed in advance to improve the conversion rate of livestock and poultry feed. These measures have achieved significant results. Fourth, biomass conversion of agricultural and forestry waste. In response to the large amount of crop straw and forestry waste generated by mountain agriculture, Pan'an actively explores the use of biomass energy and materials. Small-scale biogas projects are built to ferment livestock and poultry manure and straw to produce

biogas for villagers' cooking and lighting, and the by-product biogas residue and liquid are used as fertilizer to achieve a win-win situation of clean energy and fertilizer. At the same time, edible fungi mycelium is used to decompose sawdust, straw, etc. to produce edible fungi, and then the waste fungus bran is processed into organic matrix or biomass pellet fuel. This "fungus-feed-fertilizer (energy)" cycle not only reduces environmental pollution, but also creates millions of yuan of economic benefits for the local area every year. It is worth noting that emerging biotechnologies such as synthetic biology also show prospects in the utilization of agricultural waste. Researchers are studying the use of engineered bacteria to convert cellulose in bamboo and wood waste into bio-based chemicals such as lactic acid, and to use enzymes to process remaining fruits and vegetables into feed additives. Once these technologies are maturely applied, they will further expand the agricultural product processing field in Pan'an. The intervention of biotechnology has enabled traditional agricultural product processing to move from extensive to sophisticated and from low value to high value, opening up new growth space for Pan'an's agricultural industry. As Sadh et al. (2023) pointed out in their study of circular bioeconomy, agricultural waste can be transformed into bioenergy or bio-based products through biotechnology, thereby replacing fossil resources and achieving both environmental and economic benefits. Pan'an's practice confirms this view: relying on biotechnology to "turn stone into gold", realizing the development of the entire value chain of agricultural products, and promoting the transformation of agriculture from an increase in production orientation to an increase in quality and efficiency orientation, is of great significance to the revitalization of industries in mountainous counties.

5 Integrative Green Development Pathway

5.1 Synergistic biological mechanisms across primary, secondary, tertiary sectors

The integrated development of primary, secondary and tertiary industries in agriculture is an important path for rural revitalization. Through the introduction of biotechnology and ecological concepts, Pan'an has opened up the synergy mechanism of the entire industrial chain of planting, breeding, processing and marketing, and formed a green agricultural industry system with efficient output and complete chain. In the primary industry, biotechnology is applied to improve the production efficiency and product quality of the planting and breeding links, such as the aforementioned biological breeding and ecological planting and breeding models, to ensure the supply of high-quality primary agricultural products. In the secondary industry, namely the agricultural product processing industry, primary agricultural products are deeply processed through fermentation engineering, enzymatic hydrolysis technology, etc. to increase added value, and the by-products and waste generated during the processing process are reused as biomass energy or organic fertilizer to achieve a closed production loop. In the tertiary industry, Pan'an vigorously develops e-commerce and logistics distribution to sell green and good products in mountain villages to all parts of the country. At the same time, relying on good ecological resources, it has cultivated service industries such as leisure agriculture and health tourism to add new sources of income to agriculture. A typical case is the "Happy Pastoral" complex project in Panfeng Township. The project is led by a leading agricultural enterprise, which transfers thousands of acres of terraced fields to develop organic rice planting (primary industry), builds grain processing workshops and breweries in nearby villages, processes rice into high-end rice, rice vinegar, rice wine and other products (secondary industry), and combines the terraced scenery to create agricultural experience, rice field homestay and other tourism projects (tertiary industry). Visitors can come to plant rice in spring and participate in harvesting and threshing in autumn to experience farming culture. The product processing workshop is also open to tourists, showing traditional winemaking techniques, and tourists can buy freshly baked products to take away. In this organic integration model of the first, second and third industries, "enterprises + farmers + tourists" each get what they want: enterprises and farmers share product sales and tourism income, and tourists get ecological experience. Another example is the Gongfu Chicken Farm project in Shuangfeng Township, which integrates free-range chickens (primary industry), deep processing of chickens (such as smoked chicken production, secondary industry) and sightseeing picking (tertiary industry) to form a complete value chain. In these integrated formats, biological synergy mechanisms are everywhere. For example, fish raised in rice fields are used for catering services for tourists, and fish manure is used to fertilize rice fields; wine lees produced by breweries are fed to pigs, and pig farm manure is fermented to generate biogas to provide hot water for homestays; scenic area restaurants purchase vegetables and fruits from

local farmers, and the leftovers from farmhouses are used to raise pigs and chickens, realizing a circular link. It can be said that Pan'an connects the pre-production, production, and post-production links of agriculture through biomass flows and value flows, avoiding disconnection of the industrial chain and waste of resources, and enhancing the resilience and overall benefits of the industrial system. This experience is consistent with the exploration of other regions - studies have shown that through the extension of the industrial chain and the integration of multiple formats, agriculture can obtain scale externalities and added value, and achieve a development pattern of one industry after another (Li et al., 2024). Pan'an also realized in its exploration that government guidance and services are crucial to building a collaborative mechanism. The local government has built platforms such as industrial alliances and production and marketing docking to promote collaborative cooperation among large-scale farmers, processing companies, e-commerce companies, and tourism companies, and provides policy support and financial credit support to reduce the risk cost in the early stages of integrated development. Because of this, Pan'an can smoothly shift from "one industry alone" to "industrial integration", so that farmers can not only earn money from farming and breeding, but also share the benefits of processing and service links. This realization of full-chain value-added has explored a practical path for rural industrial revitalization.

5.2 Science education and biodiversity tourism integration

In the integrated development of agriculture and tourism, Pan'an fully utilizes the advantages of ecological environment and biodiversity, transforms agricultural production scenes into tourism resources, integrates science education into leisure experience, and achieves the unity of social, ecological and economic benefits. First of all, Pan'an has built a number of agricultural sightseeing and science bases based on beautiful rural scenery and the display of good varieties and good methods. For example, Huaxi Village in Anwen Street is located at the foot of Dapan Mountain. It is rich in biodiversity and has been developed into an ecological scenic spot integrating sightseeing, science and research. Tourists walking in it can see the gurgling stream, lush bamboos on both sides, and various animals and plants full of vitality. A biodiversity exhibition hall and a research base have been established in the village to display local rare animal and plant specimens, ecological protection achievements, and traditional farming culture, so that tourists can be influenced by ecological knowledge during their visit. Huaxi Village has developed tourism while protecting the ecology through the "scenic village co-construction" model. In 2022, it will achieve tourism income of more than 26 million yuan, the village's collective economic income will reach one million yuan, and the average annual income of farmhouses and homestays will be more than 400 000 yuan. It can be seen that the beauty of ecology has been transformed into tangible economic benefits, and the villagers have also felt the benefits of protecting the environment. Secondly, in the process of integrating agriculture and tourism, Pan'an pays attention to experiential agricultural production labor and biological knowledge. For example, in the Jiushan Camping Festival held in the Gaoer Township Camp Park, tourists participated in farming activities such as transplanting rice and catching loaches, and experienced the fun of farming firsthand. Some medicinal material bases have launched a "drug-hunting trip", where local old Chinese medicine practitioners lead tourists to the mountains to identify and dig medicines, and explain the efficacy and planting knowledge of each herb. It is not only a unique tourism project, but also a living Chinese herbal medicine science classroom. In the beekeeping tourist park, tourists can wear bee-proof suits, learn to harvest honey under the guidance of beekeepers, and learn about the habits of Chinese bees and beekeeping knowledge. These experience activities enhance tourists' understanding of agriculture and biodiversity, and cultivate awareness of environmental protection and love for agriculture. Studies have shown that agricultural tourism experience can enhance tourists' sense of environmental responsibility and promote their green consumption behavior. Pan'an's practice also confirms this: many children from the city have a strong interest in insects and plants after participating in rural research and study, and they cherish food and nature more. Thirdly, the integration of agriculture and tourism has built a bridge for scientific research and popular science. Pan'an invites agricultural scientists and ecological experts to enter the scenic area to conduct public lectures and interactions, such as holding a bee science popularization day in the Bee Culture Park, and holding an ancient tea-making technique display and tea science lectures at the Tea Culture Festival. These activities have not only improved the taste of the scenic area, but also popularized scientific knowledge, and are popular among tourists. In this way, agriculture

is no longer just a synonym for hard work, but has become a new carrier for people to learn science and relax and entertain. Pan'an has cleverly integrated agricultural production, ecological protection, and tourism science and education, turning the countryside into a classroom and farm work into an experience, and has embarked on an innovative path of combining "industry, education, and tourism". Its effectiveness is not only reflected in economic benefits, but also in social and cultural aspects: it has raised the ecological civilization awareness of the whole people, attracted a group of urban residents to start businesses or settle in the countryside, and promoted urban-rural exchanges and the return of talents. This agricultural and tourism integration model is a vivid interpretation of the rural revitalization of "both the pocket and the mind" and has broad promotion value (Yi et al., 2019).

5.3 Circular bioeconomy systems in rural industries

Constructing a circular bio-economic system is a key link in achieving sustainable agriculture and green rural development. In the process of promoting rural industrial revitalization, Pan'an attaches great importance to the closed loop within the agricultural industrial chain. Through technological and management innovation, it links all links of agricultural production to minimize waste and achieve efficient resource utilization. Its specific measures include: (1) Circulation of agricultural inputs. Pan'an actively promotes measures such as soil testing and formula fertilization, and the use of biological organic fertilizers instead of chemical fertilizers to recycle soil nutrients. A large amount of livestock and poultry manure is fermented into organic fertilizer and returned to the fields through biocomposting. In recent years, tens of thousands of tons of commercial organic fertilizer have been produced each year, part of which is supplied to surrounding counties and cities, which not only reduces the use of chemical fertilizers but also treats manure. The comprehensive utilization rate of straw is over 90%, part of which is used as livestock feed and edible fungus base material, and the other part is crushed and returned to the field to improve soil organic matter. (2) Recycling of agricultural post-production waste. In view of organic waste such as rice husks, rice bran, and fruit peels generated in grain processing and non-staple food processing, the county guides enterprises to make resource utilization. For example, rice husks are used to produce biomass fuel pellets and supplied to tea processing plants as fuel; fruit and vegetable peels are fermented through anaerobic fermentation to produce biogas for use in park boilers or power generation, and the fermentation liquid is made into liquid fertilizer. A fruit canning factory produces 300 tons of fruit pomace each year, which used to be discarded. Now, after fermentation, 200,000 cubic meters of biogas and 200 tons of liquid fertilizer are produced, realizing the transformation of waste into treasure. (3) Utilization of renewable energy in rural areas. Pan'an combines rural energy construction with ecological circulation and vigorously develops household biogas, solar energy, and biomass energy. More than 1,200 biogas digesters have been built in the county, processing nearly 10,000 tons of human and animal feces and straw each year, producing clean gas to replace traditional firewood. In energy-consuming scenarios such as tea and mushroom drying, straw-shaped fuel boilers and biogas boilers have been introduced, which not only reduces firewood felling, but also reduces carbon emissions. Some towns also use small hydropower and photovoltaic power generation to supply village collective cold chain storage facilities to serve agricultural post-harvest fresh-keeping storage. (4) Extension of the circular industrial chain. Based on the main agricultural industry, Pan'an actively introduced biomass processing-related industries to form a closed-loop economic circle. For example, relying on traditional Chinese medicine residues and bamboo chips, a biomass board factory was introduced to process these waste materials into environmentally friendly building templates and furniture boards, consuming 50,000 tons of agricultural and forestry residues each year, with an output value of over 100 million yuan, and the products are sold all over the country. For example, in the main production area of *Torreya grandis* (a local specialty dried fruit), a *Torreya grandis* shell activated carbon production workshop was established to make high-grade activated carbon through high-temperature carbonization and chemical activation of discarded *Torreya grandis* shells for use in the pharmaceutical and environmental protection industries, with a value of over 10,000 yuan per ton, greatly increasing the value of agricultural waste. Through these explorations, Pan'an has initially formed a number of circular industrial chains, including grain-livestock-fertilizer, vegetable-mushroom-fertilizer, forest-livestock-energy, and agricultural product processing-biomaterials. Compared with the traditional linear agricultural model, under the circular bioeconomy model, resources are recycled many times in the industrial chain, and the small amount of unusable

parts are finally treated harmlessly, which greatly reduces the impact on the environment. At the same time, recycling itself also creates economic value and employment opportunities. For example, returning biogas fertilizer to the fields improves the quality of agricultural products, straw feed reduces breeding costs, and by-product processing has spawned new product categories. The circular bioeconomy replaces fossil resources by reducing the use of primary resources, recycling materials, restoring ecosystems, and converting inevitable waste into energy or products (Pal et al., 2024). Pan'an's practice well illustrates this concept. In future development, Pan'an plans to further improve the rural environmental monitoring and waste collection system to improve the efficiency of recycling; at the same time, with the help of digital technology, it can realize the intelligent control and optimization of the rural resource circulation process (such as the Internet of Things monitoring the operation of biogas tanks, blockchain tracking agricultural product inputs, etc.). By continuously improving the circular bio-economy system, Pan'an is expected to achieve "zero waste" in agriculture and "zero pollution" in rural areas, providing a model for the construction of rural ecological civilization across the country.

6 Challenges and Recommendations Related to Biological Development

6.1 Weak platforms for biological research and application

Although Pan'an has achieved certain results in promoting agriculture with biotechnology, overall, the local area lacks a high-level agricultural biological research and technology transformation platform, which to a certain extent restricts the in-depth and continuous innovation. The study pointed out that compared with developed agricultural technology countries such as Israel and Japan, my country's ecological agriculture development model is still relatively single, with a shortage of high-quality professional talents, and relatively backward agricultural infrastructure and scientific and technological innovation capabilities. These problems are particularly evident at the county level. Pan'an has not yet established a special agricultural research institute or key laboratory, and its scientific research force mainly relies on the assistance and cooperation of superior scientific research units. For example, the Polygonatum project needs to rely on the provincial university team to solve the problem, and the local area lacks independent scientific research capabilities. Some biotechnologies suitable for local characteristic industries have not been fully developed, such as tissue culture and rapid propagation of rare medicinal materials, and the development of new biological fertilizers, which require stronger platform support. The channels for technology transformation and promotion also need to be unblocked. Many farmers reported that there are limited information channels for obtaining practical new technologies and few training opportunities. Traditional agricultural technology extension stations are understaffed, knowledge is not updated in a timely manner, and interaction with farmers is not close enough. This makes it difficult for some advanced biotechnologies to be popularized in production in a timely manner. A study on agricultural technology promotion in China also revealed similar problems: the current promotion system has the phenomenon of "technological disembeddedness", technology promotion is out of touch with farmers' actual needs, and many classroom training contents do not match farmers' actual production. The situation in Pan'an is the same. Some farmers are still accustomed to traditional experience farming, and know little about or cannot operate new technologies such as precision fertilization and biological pest control, and miss the opportunity to increase production and improve quality. Therefore, it is imperative to strengthen the construction of agricultural biological research and promotion platforms. First, establish a regional agricultural biotechnology research and development center or joint laboratory, integrate scientific research resources in local characteristic industries (such as Chinese medicinal materials, tea, bees, etc.), strive for joint construction by universities and enterprises, and carry out targeted technical research. Second, build an industry-university-research collaborative innovation platform, such as setting up an "Agricultural Biological Industry Innovation Alliance", regularly organize scientific researchers, new professional farmers and agricultural enterprises to connect and exchange, and accelerate the trial demonstration and transformation of scientific research results in Pan'an. Third, strengthen the capacity building of grassroots agricultural technology promotion systems. Increase fiscal investment, enrich the staffing of township agricultural service centers, and introduce or cultivate compound agricultural technicians who understand both biotechnology and farmers' needs. Explore the "Internet + agricultural technology promotion" model, use digital platforms to publish technical information, conduct online training and remote diagnosis, and make up for the shortage of manpower. In particular, we can learn from the experience of Digital Agricultural Technology Extension Service

(DATES). The use of digital agricultural technology services can significantly increase the probability of farmers adopting new technologies (Singh et al., 2023). Pan'an can also develop tools such as WeChat applets to push customized planting and breeding suggestions and pest and disease warnings to farmers, so that technology can be accurately delivered to households. Only by improving the scientific research and promotion platform and opening up the last mile from "laboratory to field" can biotechnology truly play a role in driving industrial revitalization.

6.2 Shortage of high-level talent in agricultural biosciences

The lack of talents in the field of agricultural biology is another bottleneck encountered by Pan'an in promoting biological upgrading. The shortage of high-quality talents is reflected in two aspects: first, there is a shortage of professionals who master modern biotechnology, especially in high-tech fields such as biological breeding, agricultural bioengineering, and intelligent equipment. There is almost no local talent reserve. Many key positions (such as plant molecular breeders, agricultural environmental engineers, etc.) can only rely on short-term support from external experts, and it is difficult to form a long-term mechanism. There is a talent gap in some key links in my country's agricultural science and technology field, and the lack of professional talents poses a challenge to the innovation and development of agricultural science and technology. The reality of Pan'an also reflects this problem-for example, professional and technical personnel who know how to extract active ingredients from Chinese medicinal materials or develop microbial fertilizers are almost blank in the local area. Second, rural grassroots cannot retain talents. Due to the relatively difficult working and living conditions in rural areas and low salaries, most agricultural biological talents trained by universities are unwilling to work in counties and villages, and even if they come, they are easy to lose. In recent years, Pan'an has introduced several agricultural masters to serve rural revitalization, but some of them have been civil servants or jumped back to the city after working for one or two years. At the village level, there are still few new professional farmers and science and technology demonstration households that lead farmers to apply new technologies. Some farmers have insufficient knowledge of modern agricultural science and technology and lack relevant knowledge and skills, which makes it difficult to implement good technology. Talent shortage has become a common problem that restricts the modernization of agriculture and rural areas.

For high-level talents, a multi-level talent introduction and training mechanism should be established. On the one hand, make good use of policy incentives to increase the intensity of "introduction". The local government can introduce special policies to give preference to housing subsidies, children's education, and scientific research start-up funds to attract agricultural biotechnology talents to Pan'an for innovation and entrepreneurship. For example, a one-time subsidy and project funding will be given to a doctor in the agricultural field to encourage him to establish a workstation or studio locally.

On the other hand, more attention should be paid to the "cultivation" link. Strengthen cooperation with agricultural universities and research institutes, establish a targeted training mechanism, select local outstanding young people to study agricultural biology-related majors in well-known universities, return to their hometowns to serve after graduation, and provide corresponding positions and benefits. At the same time, a continuing education system for agricultural technicians should be established in the county, and regular training and further studies should be organized to update the knowledge structure. For grassroots farmers and practical rural talents, the incentive mechanism and training system should be improved. We can establish grass-roots organizations such as ecological agricultural cooperatives and technical associations, absorb farmers with culture, technology and management skills to join and play a backbone role, and build a team of local "leading geese". Support excellent new professional farmers in terms of credit, land use, social security, etc. to enhance the attractiveness of the profession.

Explore the establishment of a rural talent title evaluation and incentive system, such as selecting "agricultural technology experts", "field scholars" and "local experts" to improve their social status and sense of honor. In addition, through government procurement of services and other means, we can hire a team of university experts to support rural areas and form a "migrant bird" talent supplement. There is no shortcut to the talent problem.

Only by investing in policies, guiding them emotionally, and building a stage for all kinds of talents to have great potential in rural areas can we inject inexhaustible power into the development of the agricultural bio-industry.

6.3 Need for ecosystem monitoring and agricultural bioinformatics infrastructure

In the process of promoting the green development of biological-oriented agriculture, making full use of modern information technology to monitor, analyze and manage the ecological environment and agricultural production will help improve the scientific nature of decision-making and management efficiency. Pan'an currently has a relatively weak foundation in ecological environment and agricultural informatization, and needs to strengthen system construction. First, there are insufficient ecological monitoring methods. Although Pan'an's overall ecological environment is good, it lacks a precise dynamic monitoring network. For example, there is a lack of real-time monitoring data support for forests, biodiversity, water quality and soil, and it can only rely on regular manual sampling and monitoring, which makes it difficult to timely discover environmental problems or evaluate the ecological impact of industrial activities. Second, the degree of dataization of agricultural production processes is low. Most farmers do not use technologies such as the Internet of Things and big data, and data in the production process (such as soil nutrients, pest prediction, and growth status) cannot be automatically collected and uploaded. Government departments lack real-time and comprehensive grasp of the agricultural operation of the county. This makes it difficult to carry out scientific management and precise services.

It is recommended to establish and improve the county-level ecological-agricultural information monitoring system: (1) Build an ecological monitoring network. Deploy environmental monitoring stations and sensors in key river basins, protected areas, and concentrated breeding areas to monitor indicators such as water quality, air, soil moisture and nutrients, and use remote sensing to monitor forest coverage and habitat changes, so as to realize real-time collection of ecological data. (2) Create an agricultural Internet of Things demonstration. Select major grain production functional areas and characteristic industrial bases, build smart agriculture demonstration sites, install soil moisture monitors, insect monitoring lights, video surveillance and other equipment, and link them with smart irrigation and smart fertilization systems to achieve automated control. For example, deploying small meteorological stations and insect monitoring systems in alpine vegetable bases can provide early warnings of frost and insect pests and guide farmers to take preventive measures. (3) Develop an agricultural bioinformation management platform. Integrate ecological and agricultural production data to establish a county-level agricultural big data platform. On the one hand, upload the environmental and production data obtained from monitoring to the cloud for analysis and modeling to form a decision support system for managers, assist in the formulation of industrial planning, pest control plans, disaster reduction plans, etc. On the other hand, develop farmer-side mobile applications to provide weather, market, and technical information services, and record agricultural operations to achieve traceable management from field to table. Practice has proved that the application of digital technology can effectively promote the adoption and promotion of green agricultural technology. Farmers who use digital agricultural technology promotion services are significantly more likely to adopt measures such as organic fertilizers. Pan'an can also consider establishing a comprehensive "digital village" platform to integrate agricultural technology promotion, e-commerce, financial insurance and other services, so that farmers can obtain the information and services they need without leaving their homes (Reffatti et al., 2022).

In terms of environmental supervision, introduce technical means such as drone inspections and AI recognition to promptly detect illegal hunting, deforestation, pollution emissions and other behaviors to ensure ecological security. Through these measures, Pan'an can achieve dual refined management of the ecological environment and agricultural production, so that "green waters and green mountains" can better benefit "gold and silver mountains" for a long time. The construction of information systems requires certain investment and technical support. It is recommended to actively strive for funds for digital agricultural construction projects at higher levels, and cooperate with universities and enterprises to develop localized applications. As long as we persist in promoting it, ecological monitoring and agricultural bioinformatization will surely become a new support for the revitalization of Pan'an's agricultural industry, helping traditional agriculture to fly higher with the wings of science and technology.

7 Concluding Remarks

The practice in Pan'an shows that reshaping the agricultural industry chain with biological resources and biotechnology as the guide can open up a new value path for green income increase. On the one hand, by developing ecological agriculture and circular agriculture, the originally separated links of planting, breeding and tourism are organically connected, and resources are recycled within the industry chain, reducing dependence on external inputs and pressure on the environment, and achieving simultaneous improvement of economic and ecological benefits. Farmers are no longer just providers of primary products, but sharers of value-added in the entire industry chain, gaining more benefits from green production. On the other hand, we should fully tap the endowment of local biological resources, use scientific and technological means to enhance their added value, and transform natural capital into economic capital. For example, the value of authentic medicinal materials and special forest products has increased exponentially through branding and deep processing. This model breaks through the limitations of traditional agricultural value creation and makes "green waters and green mountains" truly a sustainable "gold and silver mountain". The combination of biotechnology and ecological concepts runs through the entire process of industrial chain reshaping. From breeding of fine varieties, ecological breeding to processing and value-added, each link has the injection of scientific and technological innovation, making each link of the industrial chain both independent and efficient and synergistic in value-added. This endogenous growth model overcomes the bottleneck of extensive growth and explores a path for high-quality development for mountainous counties. In short, the bio-oriented green industrial chain provides a new value creation mechanism for rural revitalization: it not only maintains the natural background of the countryside but also activates the economic elements of the countryside, and truly achieves a win-win situation in economic, social and ecological benefits. This is also of great reference significance for other regions with rich ecological resources but underdeveloped economies. China's exploration of green agricultural development will provide valuable experience for the world. The case of Pan'an is a vivid embodiment of this view: through trial and error, a successful paradigm for biotechnology to promote the green transformation of agriculture has been explored, and its value path is worthy of wider promotion and application.

After more than ten years of iteration and improvement, Pan'an's "Our Happiness Plan" has become a banner for the common prosperity of mountainous villages, and its connotation practice includes a wealth of biological strategy applications. From the formulation of ecological breeding standards to the layout of diversified biological industries, to the promotion of production-village integration and cultural tourism integration, all revolve around the purpose of "ecological priority and enriching the people". The successful implementation of this plan proves the feasibility of leading industrial revitalization with the concept of ecological civilization, and also provides a paradigm reference for rural revitalization across the country. First, the "Happiness Plan" highlights ecological industrialization and has embarked on a road of common prosperity that combines agricultural efficiency and ecological value-added. Its core experience lies in giving full play to the power of the three parties of government, enterprises and farmers: the government provides policies and public services, leading enterprises drive technology and market development, and thousands of households actively participate in production to jointly build a vibrant rural industrial ecosystem. The practice of "first the rich lead the poor, build and share common prosperity" has enabled more than 3,000 households and tens of thousands of farmers to increase their income at their doorsteps, with an annual total increase of more than 15 million yuan. This co-construction and sharing model is a vivid annotation of the goal of "common prosperity" in rural revitalization in the new era. Secondly, the "Happiness Plan" combines traditional culture with modern industries to promote the overall progress of rural society. While developing ecological agriculture, Pan'an pays attention to inheriting the culture of medicine, tea culture, and folk culture, and integrates them into industrial planning. For example, the Chinese medicinal materials industry chain has driven the cultural tourism of traditional Chinese medicine, and the development of farmhouse homestays has promoted the culture of rural hospitality. These have enhanced the connotation of rural revitalization. Thirdly, the "Happiness Plan" creatively integrates biotechnology elements to improve the scientific and technological content of rural revitalization. From the introduction of improved varieties, biological control to processing research and development, and brand building, each step has been injected with scientific and technological power, so that rural industrial revitalization is not a return to backward self-sufficient agriculture,

but a step towards modern and efficient agriculture. In this sense, the "Happiness Plan" is not only a development initiative of a region, but also represents a rural revitalization paradigm led by ecological civilization. It tells us that as long as we firmly practice the concept of "green water and green mountains are gold and silver mountains" and give full play to resource endowments and technological advantages according to local conditions, we can fully explore a rural revitalization path that suits our own reality, so that green waters will always be green, villages will always be prosperous, and people will always be rich. It can be foreseen that with the continuous support of policies and the continuous promotion of experience, the Pan'an-style ecological co-enrichment model will bear fruit in more places and make greater contributions to my country's rural revitalization cause.

The ecological-biological-economic integrated development model explored by Pan'an has not only achieved the current revitalization goals, but also demonstrated strong sustainable development potential. First of all, from the perspective of environmental sustainability, this model is based on ecological carrying capacity, follows the laws of nature, and avoids over-exploitation of resources and environmental overdraft. For example, the reduction of agricultural inputs and the recycling of waste ensure that soil fertility and biodiversity can be maintained for a long time, and the ecosystem service function has increased rather than decreased, leaving green assets for future generations.

This has laid a sustainable ecological foundation for rural revitalization. Secondly, from the perspective of economic sustainability, through the industrial upgrading driven by biotechnology, the endogenous growth momentum of the rural economy has been enhanced. The extension of the industrial chain and the increase in value have increased the resilience of rural areas to macroeconomic fluctuations; the diversified industrial layout has reduced the risk of a single industry; and the circular economy has reduced dependence on external inputs. All these have made the rural economic system more resilient and dynamic, and can continue to create jobs and income. Moreover, rural industries are gradually integrated with urban markets and international markets, and the supply capacity of high-quality green agricultural products and ecological services has been continuously enhanced, with a promising long-term development prospect. Thirdly, from the perspective of social sustainability, this model has promoted rural social governance and cultural revitalization. Farmers' income has increased, the number of young people returning to their hometowns to start businesses has increased, and the rural population structure has improved; joint participation in ecological industries has strengthened the village collective economy and enhanced the cohesion of grassroots organizations; ecological civilization education has been deeply rooted in the hearts of the people and promoted the green transformation of lifestyles.

These positive changes at the social level have provided a guarantee for the long-term stability and prosperity of rural areas. It can be said that the ecological-biological-economic integrated development model not only focuses on the present, but also looks to the long term, and meets the basic requirements of sustainable development. Of course, to fully unleash the potential of this model, it is necessary to continue to exert efforts in policies, technology, and investment. First, in terms of policy, a sound mechanism for realizing the value of ecological products should be established to provide institutional guarantees for the transformation of green waters and green mountains into gold and silver mountains. Improve ecological compensation, green finance, etc., so that the subjects engaged in ecological agriculture can get due returns. Second, in terms of science and technology, we must continue to strengthen the research and development of applicable technologies, such as carbon sink agricultural technology and biodiversity-friendly production technology, to cope with new challenges such as climate change and maintain the advancement and competitiveness of the model. Third, in terms of investment, we need to increase the construction of rural green infrastructure and public services, especially in the fields of digital new infrastructure and human settlement environment improvement, to lay a solid foundation for sustainable development. In short, the ecological-biological integrated revitalization model represented by the Pan'an experience is an important path for China's rural revitalization. It proves that protecting the ecological environment and developing the economy are not contradictory, but can complement and enhance each other. In the future, we have reason to believe that with the continuous improvement and promotion of this model, more green revitalization paths with their own characteristics will emerge in China's vast rural areas, contributing the "Chinese example" to global sustainable development.

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