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Study on How Technology Empowers the Yuxi Plateau's Specialty Agriculture Base in China to Improve Quality and Efficiency, and Its Current Challenges

Zefeng Li, Tianyong Xu*, Hongli Li, Huiqing Xu

Yuxi Agricultural Vocational Technical College, Yuxi 653100, Yunnan, China

***Corresponding author*:** Tianyong Xu, jason202410@126.com

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Abstract: Yuxi City in China is using its unique plateau climate and rich resources to push the transformation and upgrading of highland specialty agricultural bases through modern facility farming. This paper, based on the theory of new agricultural productivity, builds a three-step analysis framework of "technology embedding—factor upgrading—value realization." By looking at typical cases like Chengjiang blueberries, Tonghai vegetables, Hongta flowers, and Huaning citrus, it explores how technology boosts the quality and efficiency of highland specialty agriculture. The study finds that technology reshapes production decisions through facility replacement and digital integration, upgrades factor systems through improvements in labor tools, laborers, and labor objects, and completes value conversion through efficiency gains, quality standardization, and brand empowerment. These three mechanisms form a stepwise causal chain, but each level faces structural challenges: technology mismatch and promotion obstacles limit the depth of tech embedding, seed industry gaps and talent shortages restrict factor upgrading, and poor outcomes transfer along with uneven benefit distribution weaken value realization. Tackling these issues requires coordinated efforts in tech adaptation, seed industry breakthroughs, talent cultivation and introduction, innovation in transformation mechanisms, and optimizing benefit links, helping tech empowerment move from a "demonstration bonsai" to a "beneficial landscape."

Keywords: Science and technology empowerment; Plateau characteristic agriculture; Quality and efficiency enhancement; Mechanism of action; Practical constraints

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1. Introduction

The 2024 Central Rural Work Conference clearly proposed to "develop new-quality agricultural productivity according to local conditions," pointing the way for the modernization of highland specialty agriculture.

New-quality agricultural productivity is an advanced form of productivity driven by technological innovation at its core, aimed at achieving a qualitative leap in total factor productivity. In Yuxi City, the per capita arable land is only 0.76 mu, and in Chengjiang, out of 200,500 mu of farmland, 175,800 mu are in the Fuxian Lake watershed, making the traditional model of heavy water and fertilizer use part of the negative list. This dual pressure of "tight resource constraints + strict ecological constraints" forces Yuxi to take the path of technology-intensive and facility-intensive modern agriculture.

However, a deeper question worth exploring is: through what causal chain does technology empowerment actually achieve quality and efficiency improvements? What structural bottlenecks has this chain encountered in practice in Yuxi? Existing research has accumulated rich insights on how new-quality agricultural productivity empowers agricultural modernization. For example, Gu Guangtong et al. (2026) demonstrated five mechanisms through which new-quality agricultural productivity drives technological innovation, activates data factors, promotes institutional innovation, and more [1]; Xie Hualin et al. (2025) revealed the empowerment mechanisms on three levels: technology helping farmers, factors helping farmers, and industry helping farmers [2]; Du Ying et al. (2025) systematically summarized the achievements of Yunnan's highland specialty agriculture and pointed out key bottlenecks such as insufficient seed industry innovation and low-end operation along the "three chains" [3]. However, most existing studies focus on macro provincial areas or plains, meaning systematic research on the technology empowerment mechanisms in highland specialty agriculture bases is still lacking. This paper takes Yuxi City as the research subject, building a three-layer analysis framework of "technology embedding—factor leap—value realization," and, based on multiple case practices like Chengjiang blueberries, Tonghai vegetables, Hongta flowers, and Huaning citrus, attempts to form a closed loop in both mechanism revelation and problem diagnosis.

2. Theoretical analysis and research framework

2.1. The theoretical connotation and analytical perspective of new-quality agricultural productivity

New-quality agricultural productivity is the specific embodiment of "new-quality productivity" in the agricultural sector. Its theoretical roots can be traced back to Marxist productivity theory. Marx broke down productivity into three basic elements: labor resources, laborers, and the objects of labor, and pointed out that "the distinction between different economic eras does not lie in what is produced, but in how it is produced and what labor resources are used." The core idea of new-quality agricultural productivity is to drive the qualitative leap and optimized combination of the three elements of labor resources, laborers, and objects of labor through technological innovation, thereby promoting a qualitative change in total factor productivity [4]. New-quality agricultural productivity focuses on improving total factor productivity, with technological innovation upgrading production factors and transforming production methods, thereby leading to a qualitative change in the agricultural productivity system.

New-quality agricultural productivity has particularities that distinguish it from general new-quality productivity. First, agriculture is an industry where natural reproduction and economic reproduction are intertwined; the objects of labor have life characteristics, and natural conditions impose constraints that cannot be completely removed. Second, land, as a basic production factor, is irreplaceable, and spatial constraints are rigid boundaries for the adoption of agricultural technology. Third, the main actors in adopting agricultural technology are dispersed small farmers, and the organizational threshold constitutes a structural

barrier to technology diffusion. These particularities mean that technologically empowering agricultural base transformations cannot simply apply the "technology substitution" logic used in industrial sectors; it must consider the adaptability of technology to natural conditions and social organization.

From the above theoretical perspective, the essence of technologically empowering highland specialty agricultural bases is to embed modern science and technology systematically into the agricultural production process, driving a qualitative leap in the three elements of productivity, and thereby changing the way and efficiency of value creation. This process is not a single-step technical transformation but a chain reaction from technology embedding to factor upgrading and finally to value realization.

2.2. Three-layer mechanism model of technology empowering agricultural base transformation

The internal logic of technology enabling the transformation of agricultural bases can be summarized as a three-layer progressive chain: "technology function mechanism → changes in productivity structure → value creation enhancement" (see **Figure 1**).

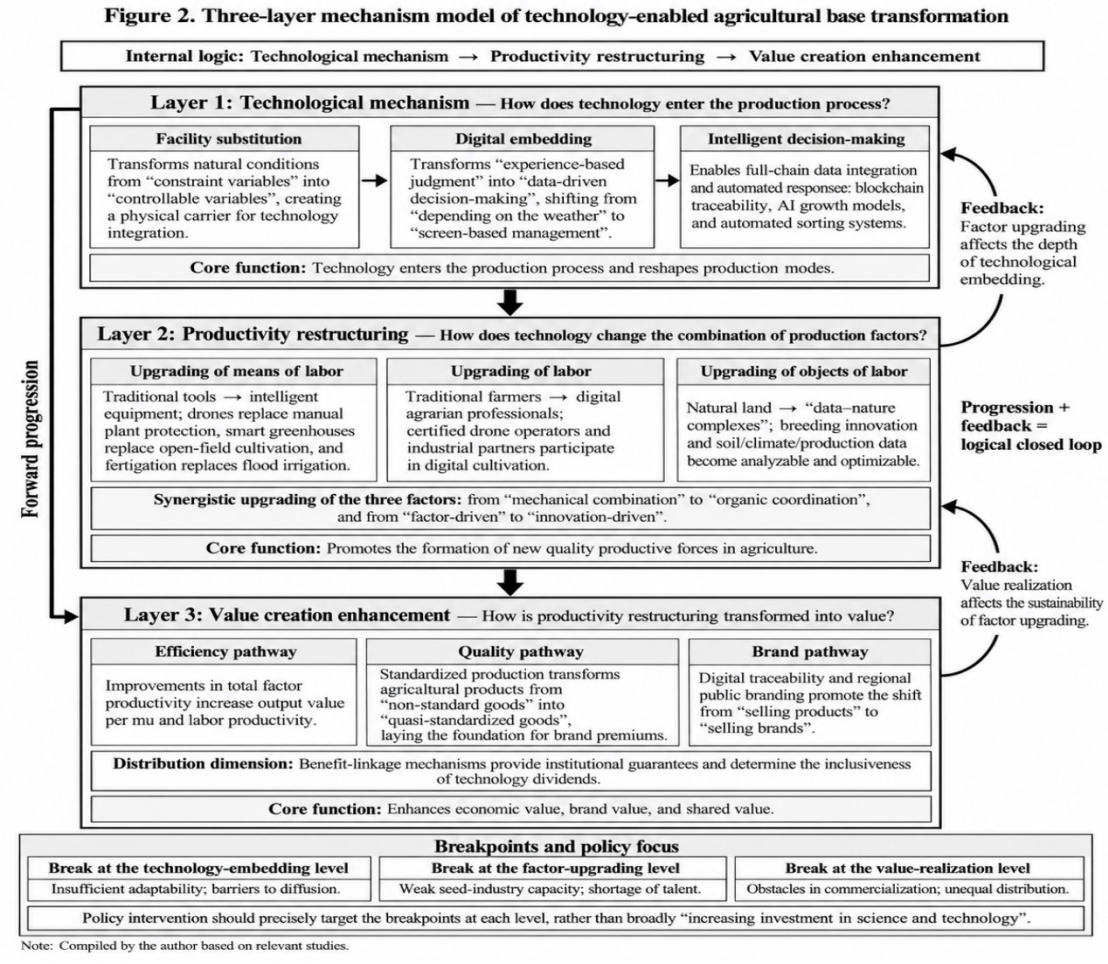


Figure 1. A Three-layer mechanism model of technology empowering agricultural base transformation.

2.2.1. Layer one: Mechanism of technology—How does technology enter the production process?

The first step in tech empowerment is technology embedding, which means integrating modern technical

equipment and digital systems into agricultural production. Technology embedding follows the evolution path of "facility substitution → digital embedding → intelligent decision-making." The core function of facility substitution is to transform natural conditions from a "constraint variable" to a "controllable variable," creating a physical base for subsequent technology integration—without greenhouses, IoT sensors have no space to deploy, and integrated irrigation and fertilization networks cannot be laid out. The core function of digital embedding is to turn "experience-based judgment" into "data-driven decisions"—sensors collect environmental parameters in real time, systems automatically regulate temperature, humidity, and water and fertilizer supply, shifting producers from "farming according to the weather" to "management via screens" [5]. The core function of intelligent decision-making is to enable end-to-end data connectivity and automatic responses—blockchain traceability, AI growth models, and automatic sorting systems integrate production, processing, and circulation into a unified data loop.

2.2.2. Second layer: Changes in the productivity structure — How technology alters the combination of factors?

The strong effect of technology isn't in the equipment itself but in how it drives a qualitative leap in the three elements of productivity. The leap in labor tools shows a jump from traditional farming tools to smart equipment: drones replace manual pest control, smart greenhouses replace open-field planting, and integrated water and fertilizer systems replace flood irrigation. The leap in laborers shows a shift from traditional farmers to digital new farmers: drone operators get certified through "theory + simulation + hands-on" training, and industry partners acquire management skills through participation in digital farming. The leap in labor objects shows an expansion from natural land to "data–nature complexes": crop innovation transforms varieties from being "naturally given" to "artificially designed," and activated data elements turn soil, weather, and production data into analyzable and optimizable objects. The new-quality agricultural productivity drives the modernization of agricultural operators, production methods, and the industry system through the three dimensions of upgrading labor quality, smartening labor tools, and expanding and optimizing labor objects [6].

These three-layer upgrades don't happen in isolation but form a mutually reinforcing combination effect. Smart equipment (labor tools) requires digital new farmers (laborers) to operate it, and the improvement of digital new farmers' skills relies on decision support from data platforms (labor objects). This coordination of the three elements shifts the productivity structure from "mechanical combinations" to "organic collaboration," and from "factor-driven" to "innovation-driven" [2].

2.2.3. Third layer: Value creation enhancement — How do changes in productivity structure translate into value?

The qualitative leap in productivity structure ultimately needs to be tested through value creation. Value creation enhancement unfolds along three paths: the efficiency path — improvements in total factor productivity lead to growth in output per unit area and output per capita, reflected in measurable gains like per-acre output value and labor productivity; the quality path — standardized production turns agricultural products from "non-standard" into "quasi-standard" items, with consistent quality laying the foundation for brand premiums; the brand path — digital traceability and regional public brand construction upgrade products from "selling products" to "selling brands," achieving a leap from product value to brand value.

Value creation enhancement also involves a distribution dimension. If technology empowerment only

improves efficiency without improving distribution, the tech dividends may be concentrated in capital-intensive leading enterprises, leaving small and medium farmers out. Therefore, interest linkage mechanisms form the institutional guarantee for value realization — they determine how widely technology dividends are shared and whether technology empowerment can move from being just a "demonstration model" to a "beneficial landscape" [7].

2.3. The progressive logic and closed-loop operation of the three-level mechanism

The three levels work in a strict progressive order: technology embedding is the starting point, factor upgrading is the process, and value realization is the result. Without technology embedding, factor upgrading lacks a material carrier; without factor upgrading, value realization lacks an efficiency foundation; and without value realization, technology embedding and factor upgrading lose their economic sustainability.

At the same time, there is also feedback between the three levels. The effect of value realization impacts the sustainability of factor upgrading—if tech dividends are unevenly distributed, small and medium farmers will lack the incentive to continue adopting technology; the quality of factor upgrading affects the depth of technology embedding—if workers lack skills, advanced equipment will be "built but unused." This interplay of forward progression and backward feedback forms a complete logical loop for tech-empowered agricultural base transformation.

Problems arise at breakpoints in this three-level chain. Breaks at the technology embedding level show up as poor adaptability and promotion bottlenecks; at the factor upgrading level, as shortcomings in seed industries and talent shortages; and at the value realization level, as poor results conversion and unequal distribution. Policy interventions should precisely target these breakpoints rather than generally "increasing investment in technology."

3. The development basis and current manifestation of Yuxi Plateau's characteristic agricultural base empowered by technology

3.1. Scale expansion and structural upgrade of facility agriculture

Since the 14th Five-Year Plan, the total output value of Yuxi's agriculture, forestry, animal husbandry, and fishery has jumped from 34.353 billion yuan to 43.112 billion yuan, with the added value of the primary industry exceeding 25.9 billion yuan. Facility agriculture has become a key driver for transformation and upgrading. So far, the city's facility agriculture covers 650,400 mu, basically forming several leading characteristic industry clusters in the province, including flowers, blueberries, vegetables, and edible fungi, achieving increased industry efficiency, collective income growth, and shared prosperity for farmers. By the first half of 2026, the total area of facility agriculture in the city is expected to reach 796,300 mu, accounting for 18.31% of the city's total cultivated and garden land, with high-end facilities making up 14.32% and mid-range facilities 16.64%. The city plans to implement 175 key facility agriculture projects, each exceeding 5 million yuan, with a total planned investment of 4.713 billion yuan.

A total of 1.5882 million mu of high-standard farmland has been built, covering 52.19% of the arable land, which is an increase of 17.57 percentage points compared to the end of the 13th Five-Year Plan. By the end of June 2026, the city has 10,236 agricultural enterprises and 2,395 farmer cooperatives, with 15 newly cultivated leading enterprises, totaling 460. By implementing the "1+7+N" industrial system, Yuxi has established a coordinated development pattern for key specialty industries such as tobacco, vegetables, fruits,

flowers, Chinese medicinal materials, edible fungi, and livestock and poultry. The output value of vegetables has exceeded 11 billion yuan. By 2025, the city's flower planting area will reach 149,500 mu, with a total output value of 4.458 billion yuan, including 87,200 mu of fresh-cut flowers, producing 3.5 billion stems worth 3.358 billion yuan. Agricultural product exports reached 1.472 billion yuan, a year-on-year increase of 12.6%.

3.2. Evolution stages of technology integration

Looking at the evolution stages of technology integration, Yuxi has gone through three progressive stages (see **Figure 2**).

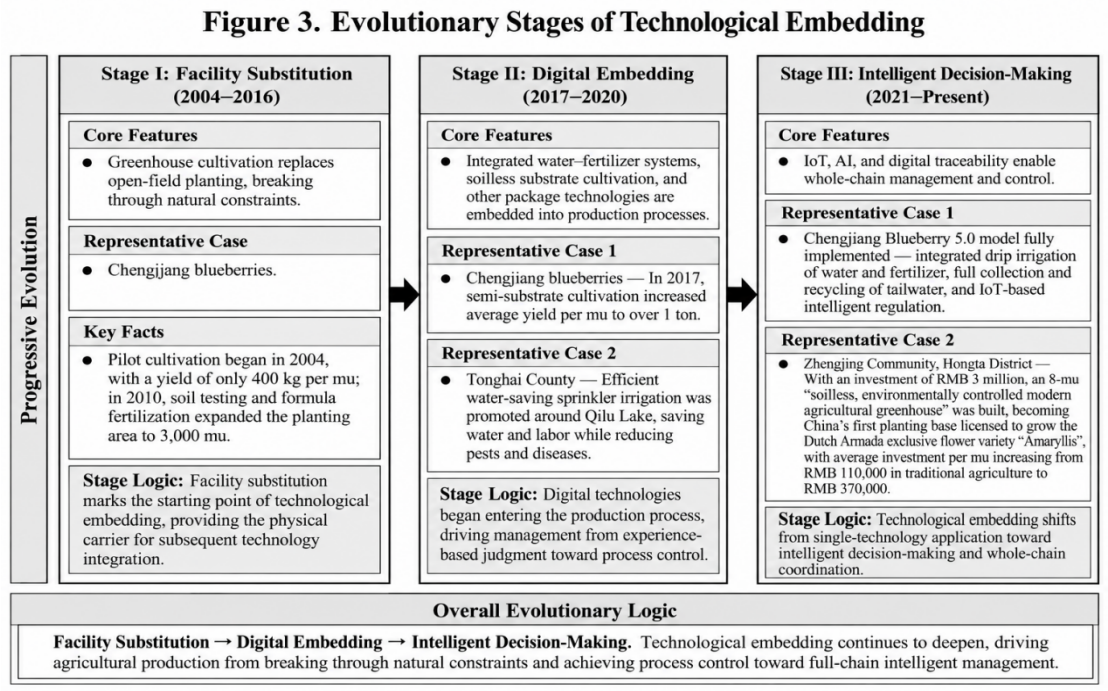


Figure 2. Evolution stages of technology integration.

The first stage was the facility replacement stage (2004–2016), characterized by replacing open-field planting with greenhouses, breaking through the rigid constraints of natural conditions on production. Take Chengjiang blueberries as an example: when the trial planting started in 2004, the yield was only 400 kg per acre. By 2010, using soil-testing-based fertilization expanded the planting area to 3,000 acres. Facility-based cultivation solved the problem of "can it be grown or not."

The second stage was the digital embedding stage (2017–2020), marked by integrating technologies like water and fertilizer integration and soilless substrate cultivation into the production process, achieving a leap from "can grow" to "grow precisely." In 2017, semi-substrate cultivation of Chengjiang blueberries pushed yield per acre to over 1 ton. Tonghai County promoted efficient water-saving sprinkler irrigation around Qilu Lake, saving both water and labor while reducing pests and diseases.

The third stage is the intelligent decision-making stage (2021 to present), defined by using IoT, AI, and digital traceability to achieve a fully closed-loop data system with automatic responses. The Chengjiang Blueberry 5.0 model was fully implemented, with integrated solutions like water-fertilizer drip irrigation, full reuse of tailwater, and IoT smart controls. In Hongta District, Zhengjing Community invested 3 million yuan

to build an 8-acre "soilless environmentally controlled modern agricultural greenhouse," becoming the first base in the country to grow the Dutch Armada exclusive flower variety "Amaryllis." This project raised the per-acre investment from 110,000 yuan in traditional farming to 370,000 yuan, showing how smart controlled facilities boost both capital intensity and output efficiency.

3.3. Overview of typical cases

Looking at the distribution of typical cases, Yuxi has formed four recognizable technology-enabled models. The blueberries in Chengjiang represent the digital facility agriculture model of "full substrate + integrated water and fertilizer + IoT." The blueberry planting area in Chengjiang City has rapidly grown to 39,600 mu, and by 2025, the total output value of blueberries in Chengjiang is expected to exceed 2.3 billion yuan. Through years of effort, a technical support system integrating "full substrate cultivation + tail liquid recycling + digital management" has been perfected, promoting blueberries into a fully replicable 5.0 smart facility planting stage. With 600 to 800 blueberry plants per mu, the yield per mu can at least double, reaching over 1.8 tons, and the output value per mu can exceed 90,000 yuan.

Vegetables in Tonghai represent the green and efficient facility model of "high-efficiency water-saving sprinkler irrigation + export standardization." Tonghai County has 249,700 mu of arable land, with less than 0.7 mu per farmer, yet the total vegetable output of the county reaches 915,000 tons, with an output value of 2.897 billion yuan, accounting for 57.5% of the total output of the county's agriculture, forestry, animal husbandry, and fishery sector. Seventy percent of the county's vegetables are sold to more than 130 major cities nationwide, while 30% are exported to Southeast Asia and the Middle East, accounting for more than one-third of Yunnan's agricultural exports. Tonghai has become a major vegetable production base in Yunnan and an important vegetable distribution hub in Southwest China. By 2025, the vegetable planting area in Tonghai County is expected to reach 283,100 mu, with an output of 915,100 tons and an output value of 2.989 billion yuan.

Hongta Flowers represents a high-end facility flower model of "smart environment control + soilless cultivation." Hongta District, through the "big industry + new players + new platforms" approach, has built modern flower parks and standardized production bases, boosting the annual output of cut flowers to over 900 million stems. A team of science and technology experts brought a new solution: soilless cultivation with coconut coir combined with integrated water and fertilizer precise irrigation, doubling or tripling flower yields, with over 60-70% of flowers reaching quality grade B or higher. Considering farmers' input costs, the experts also innovatively promoted a "semi-substrate" planting method (soil at the bottom + coconut coir on top), lowering the barrier to adopting the technology.

Huaning Citrus represents a low-altitude economic model of "drone plant protection + mountain adaptation." Huaning County is located on the central Yunnan Plateau, with a large proportion of mountainous terrain, complex landscapes, and extensive steep farmland. By May 2026, the county had promoted a total of 1,015 agricultural drones, trained 1,293 certified operators, and achieved a plant protection operation area of over 380,000 mu, marking a leap from scattered pilot projects to full-scale county-wide adoption. A single drone can spray 160 mu of orchard in 8 hours, equivalent to the workload of 30 people, saving 35-40% of pesticides and a significant amount of water. From 2025 to 2026, Huaning County ranked first among counties in Yunnan Province in the number of drones promoted, plant protection service area, and certified operators, becoming a benchmark county for empowering mountain agriculture with a low-altitude economy and supporting rural revitalization in Yunnan.

4. The mechanism of how technology empowers Yuxi Plateau's specialty agriculture bases to improve quality and efficiency

4.1. Technology integration and transformation of production decision-making

Technology integration is the first layer of how technology empowers agriculture. Its core function is to turn natural conditions from "constraints" into "controllable variables" and transform experience-based judgments into data-driven decisions.

Facilities provide the physical foundation for subsequent technology integration. Yuxi City has innovatively activated 198,000 mu of land through three methods: "exchanging land on hills," "expanding land in plains," and "gathering land in parks," while simultaneously building 1.552 million mu of high-standard farmland. This has turned "small scattered fields" into "standard fields" and upgraded "fragmented land" into "treasure troves." Chengjiang County introduced advanced technology to concentrate a thousand-mu intelligent greenhouse blueberry base in high-altitude areas, achieving exponential growth in output value per unit area within limited space. This "spatial intensification + technology integration" model shows that spatial restructuring is a prerequisite for technology integration—dispersed plots cannot support IoT systems that require unified control or the installation of integrated water and fertilizer networks.

Digital integration shifts the decision-making mode from "experience-based" to "data-driven." The Chengjiang blueberry base is densely equipped with sensors, with precise drip irrigation from an integrated water-fertilizer system, real-time pest monitoring devices, and small weather stations regulating temperature and humidity—all controllable with a single click via smartphone or tablet. In Huanglong Community Base, Tonghai County, IoT control systems and integrated water-fertilizer facilities enable intelligent management of greenhouse temperature, humidity, and irrigation through "one-click mobile control." The quantitative results are impressive: the Chengjiang blueberry base's wastewater recycling system saves 30% of water and reduces fertilizer use by 26%. In Yuxi City, facilities grow blueberries on 21,000 mu, with an average output value of about 100,000 yuan per mu. Total output exceeds 2.3 billion yuan, making it one of the largest early-ripening blueberry production areas in the country.

4.2. Element leap and productivity restructuring

The second mechanism of technology empowerment is the systemic leap in elements. The leap in means of labor is reflected in the jump from traditional tools to smart equipment. Huanning County, located on the central Yunnan Plateau, has a large proportion of mountainous area, complex terrain, and widespread steep farmland, and agricultural production has long faced structural difficulties such as difficult transportation, high labor costs, low efficiency, and challenges in implementing mechanization. The county used agricultural drones as a breakthrough, creating an integrated development system of "policy coordination, technology adaptation, market operation, and talent support." Drone operation efficiency exceeds that of manual labor by more than 30 times, pesticide usage is reduced by 30%-40%, and labor input is decreased by 40%-60%. By 2024, the total area covered by drone operations in the county will reach 210,000 mu, saving farmers 8.4 million yuan in costs, with expected savings of up to 14 million yuan in 2025. In Zhengjing Community, Hongta District, an 8-mu "soilless environmentally controlled modern agricultural greenhouse" was built, increasing investment per mu from 110,000 yuan in traditional agriculture to 370,000 yuan, and raising per-mu revenue from 20,000 yuan to 100,000 yuan. Relying on the Asia Flower Sci-Tech Innovation Valley, Jiangchuan District has successively developed 349 new flower varieties, obtained 118 national patents, published 30 monographs, and issued 592 research papers, 66 of which are included in SCI.

The rise of workers is reflected in the shift from traditional farmers to new digital-age farmers. Huaning County has implemented a "theory + simulation + hands-on" teaching model to train drone pilots. By 2025, Huaning County's Homin Agricultural Machinery Service Cooperative had trained over 500 new drone pilots, all of whom obtained both the agricultural drone flight and lifting drone certificates. These young pilots drive pickup trucks across the fields. Yang Xinwei, 27, a native of Huaning, has been a certified agricultural drone pilot for more than 5 years. The "industry partner" system at the Chengjiang blueberry base allows farmers to avoid heavy investments and focus only on daily maintenance and fresh fruit picking, while the company provides greenhouses, substrate, technology, and market channels. The cooperative forms a "company + cooperative + farmer" planting model by affiliating with large enterprises, hiring over 20,000 seasonal blueberry pickers and supervisors annually, with each person earning an additional 20,000 to 30,000 yuan per year.

The leap in labor objects is shown in the expansion from natural land to a "data–nature complex." Yuxi City has established the provincial-level Yuxi Repository for Crop Germplasm Resources in Yunnan. By the end of 2025, it had preserved 10,631 pieces of various germplasm resources, created 4,557 breeding materials in 2025, and completed the registration and identification of 18 new varieties. Innovations in the seed industry have turned labor objects from "naturally given varieties" into "artificially designed varieties." At the same time, activating data elements has made the soil, weather, and production data of each base analyzable and optimizable. Yunnan Lvjulong Biotechnology Co., Ltd. was established in Jiuxi Town, Jiangchuan District, in the Asian Flower Sci-Tech Valley through investment promotion. It has more than 500 varieties of phalaenopsis orchids, 80% of the varieties have plant variety rights, produces over 10 million phalaenopsis seedlings annually, and has an annual output value of 20 million yuan.

4.3. Realizing value and converting technology dividends

The third mechanism of tech empowerment is turning technological advantages into economic value. Efficiency improvements are reflected in measurable gains in total factor productivity. Taking blueberries as an example, with 600 to 800 plants per acre, the yield per acre can at least double, exceeding 1.8 tons, with a value of over 90,000 yuan per acre. In Tonghai County, the vegetable industry can rotate 3 to 4 different varieties of vegetables throughout the year, selling them all year round. Tonghai County's Jinhai Agricultural Company, using soilless cultivation technology, can grow 8 batches a year, producing 60 million stems of fresh-cut flowers annually—three times the yield of soil-based cultivation. The company's chairman, Dong Chunfu, said, "This year, we'll apply for 27 new patents. It's like we've covered 10 years in just one year."

Standardizing quality has transformed agricultural products from "non-standard items" to "quasi-standard items." Chengjiang's blueberry tailwater recycling system has improved fruit quality from 18+ to 20+ and 22+. Tonghai County has improved its traceable safety system for agricultural products and strengthened the regional public brand "Tonghai Vegetables." The deeper meaning of quality standardization is that it lays the foundation for brand premiums in agricultural products.

Brand empowerment and industrial chain extension allow a shift from "selling products" to "selling brands." According to research, Yuxi City has a total of 153 units with valid certificates for green, organic, and premium new agricultural products, comprising 611 products, which is an increase of 38 units and 311 products compared to 2020. "Yuanjiang Jasmine Tea" has been selected for the Brand Boutique Cultivation Program by the Ministry of Agriculture and Rural Affairs. Online, e-commerce and live-streaming sales of agricultural products continue to grow; offline, the market in South and Southeast Asia is being consolidated,

400 export filing bases have been stabilized, and emerging markets are being expanded.

The profit-sharing mechanism is the institutional guarantee for value realization. In the Chengjiang "industrial partners" system, companies invest in and build blueberry greenhouses as project sponsors, providing full material and technical support such as substrates, water and fertilizer, and collection of tail liquids, while farmers just need to take care of daily plant maintenance and pick the fresh fruit. The innovation of this mechanism lies in the fact that, under a capital-intensive, tech-enabled model, it still leaves small farmers a way to participate and share in the profits.

5. The practical challenges of using technology to upgrade and improve efficiency in Yuxi Plateau's specialty agricultural bases

5.1. Adaptation barriers and promotion bottlenecks at the technology integration level

The lack of technology adaptability shows up as a mismatch between general-purpose technologies and the specialty agriculture of the plateau. Existing technical equipment is mostly suited for large-scale crops on plains, with insufficient dedicated growth models and smart equipment for plateau specialty crops. In most cases, the application of digital technology is limited to basic data collection. Data gathered by IoT devices hasn't effectively been turned into decision-making tools, leading to situations where technology is idle or built but unused. According to Cao Yanxiong and Liu Qixin (2026) [8], smart agriculture faces the challenge of "insufficient core technology and system coordination capabilities," which in Yuxi shows as IoT data not being effectively used for decisions, with devices either built and unused, or used but not efficiently.

High equipment costs create a barrier for small and medium participants. At the Chengjiang blueberry base, the investment per mu is about 90,000 yuan, and the cost of digital upgrades per mu ranges from 5,000 to 8,000 yuan. Although the "industry partner" system lowers the asset threshold for farmers, the high investments on the enterprise side still need to be balanced through profit-sharing mechanisms. When market prices fluctuate significantly, balancing enterprise profits and farmer incomes becomes challenging. Zhang Hongmei and others (2025) pointed out the "conflict between small farmers' paying capacity and the high cost of digital technology' from an evolutionary game perspective, which is also seen in Yuxi [9].

Bottlenecks in the promotion system make the "last mile" of technology diffusion difficult. The grassroots agricultural science and technology promotion system in Yunnan is still not well-established, and the "last mile" issue remains unsolved. There has long been a shortage of grassroots agricultural extension workers, and the team is weak. On top of that, some areas are remote and hard to reach, making full coverage of technology promotion difficult. Yuxi's grassroots agricultural extension team faces issues like insufficient numbers and serious aging, with young and skilled talent continually leaving rural areas. These promotion bottlenecks mean that advanced technologies end up "built but unused, no one maintains them," with some equipment left idle quite often.

5.2. Weak links in the seed industry and talent gaps for upgrading key elements

The lack of independent innovation in the seed industry creates a risk of breaks in the upstream empowerment chain. In Yuxi's flower industry, lilies have long depended on imported bulbs, and rose varieties are aging; the citrus industry suffers from insufficient updates of new varieties and a "bottleneck" problem in seeds. Du Ying and others (2025) clearly pointed out that insufficient innovation in the seed industry is one of the core bottlenecks restricting the upgrading of plateau specialty agriculture in Yunnan

[3]. The difficulties and problems in Yunnan's agricultural science and technology innovation mainly show up in six areas: insufficient investment, an incomplete system, weak capabilities, lack of drive and vitality, low results conversion rate, and inadequate talent support. Although Yuxi has established a provincial crop germplasm bank and preserved 10,631 germplasm resources, there is still a significant gap between the overall innovation capacity of the seed industry and the scale of the industry. In Tonghai County, the vegetable export industry still faces issues such as weak independent seed production and R&D capabilities.

The shortage of versatile talents is causing a "handover gap" in technological efficiency. Smart agriculture needs people who understand both agriculture and IT, but at the grassroots level, there is a general lack of professionals with digital skills. In Jiangchuan District, there are relatively few technical talents in the flower industry. Only 114 professional and technical personnel are currently recorded in the whole district, and most practitioners are local farmers with low educational levels. They lack professional skills in flower production, manage and operate their farms in a rough way, and technical, informational, and circulation services are inadequate, resulting in low overall planting efficiency. In Yuxi City, grassroots agricultural technicians face a significant gap in professional knowledge because they cannot access effective continuing education and training. They know little about the new knowledge, technology, and trends in the industry and even less about mastering them, making it hard to meet the needs of modern plateau-specific agriculture. The talent shortfall makes it difficult for advanced technology and equipment to function effectively.

The insufficient activation of data elements hinders the transformation from "silent resources" to "core assets." In most bases in Yuxi, data usage is limited to collection, lacking analysis capabilities and application scenarios. Agricultural data is scattered across departments, highlighting the problem of "data islands" at the county level, and there are no standards for data sharing. Production data, quality inspection data, and market sales data in the bases have not been effectively connected, slowing down the process of turning data into assets. Li Hongjie (2026) pointed out that empowering agriculture with computing power faces the dilemma of "lagging data element governance" [10].

5.3. Barriers to value realization and imbalanced distribution

The "two skins" situation in converting scientific and technological achievements has led to structural mismatches between technology supply and demand. The main bottleneck in Yunnan's agricultural science and technology development is that the economic benefits of converting achievements are not obvious, with most going through public promotion channels. Related local universities and research institutes have long experienced varying degrees of disconnect between research topics and industry development needs. Some basic agricultural research in certain institutions and universities has yet to be practically applied. In applied research, while some results have shown certain success in field trials, they have not been precisely aligned with actual industry development and farmers' needs, making large-scale promotion difficult. The conversion of agricultural university research results still faces practical challenges, such as low efficiency in stakeholder collaboration, biased evaluation systems, incomplete service chains, and insufficiently detailed policy implementation.

The weak ability of brand premium limits the leap from "product advantage" to "brand advantage." Cheng Guoqiang and Shi Jiageng (2026) pointed out that specialty agriculture on the Yunnan Plateau generally faces the problem that "endowment advantages have not been fully converted into competitive advantages" [11]. Except for a few categories like Chengjiang blueberries and Tonghai vegetables, most bases

still sell their products as primary agricultural goods, lacking brand recognition and bargaining power.

Unequal distribution of benefits poses a challenge for the inclusive distribution of technological dividends. If tech-enabled solutions lean too much toward capital-intensive "high-standard facility agriculture," it could deepen internal divisions within the bases. While the Chengjiang "industry partner" system is innovative, its long-term sustainability still needs testing — when market prices fluctuate greatly, how to balance company profits and farmer income, and whether the collection of village collective management fees could eat into farmers' benefits as the scale expands, are all issues that affect whether technological dividends can be distributed inclusively.

6. Conclusions and policy recommendations

6.1. Research conclusions

This paper takes the highland specialty agricultural base in Yuxi City as the research object and systematically reveals a three-level progressive mechanism of technology empowering quality improvement and efficiency. The technology embedding mechanism, through facility substitution and digital embedding, turns natural conditions from limiting variables into controllable ones and transforms decision-making from experience-based to data-driven. The factor upgrading mechanism promotes the leap of labor resources from traditional tools to intelligent equipment, of workers from traditional farmers to digital new farmers, and of labor targets from natural land to a "data–nature complex." The value realization mechanism transforms technological advantages into economic value through efficiency improvement, quality standardization, brand empowerment, and benefit linkage. These three mechanisms form a progressive causal chain, with difficulties arising at the breaking points in each layer: insufficient technology adaptation and promotion barriers limit embedding depth; shortcomings in the seed industry and talent scarcity restrict upgrading potential; poor achievement transformation and unequal distribution weaken effectiveness.

6.2. Policy recommendations

First, smooth the integration of technology. Promote the development of specialized growth models and smart equipment tailored to crops like blueberries, flowers, and citrus, turning "technology idling" into "deep tech cultivation." Encourage low-cost, applicable technologies such as "semi-substrate" methods, and explore flexible mechanisms like "digital service vouchers" and "equipment leasing + service purchasing" to reduce one-time costs for adopting technology. Using platforms like "Science Courtyards" and "Field Schools," build a four-level diffusion network of "experts—technicians—demonstration households—spread households." For mountainous areas, focus on promoting lightweight tech solutions like Huaning drone crop protection, allowing tech empowerment to move from "showcase models" to "broad benefits."

Second, smooth the upgrading of key resources. Rely on platforms such as the Yuxi Collection of Provincial Crop Germplasm Resources in Yunnan Province to establish a breeding innovation loop of "industry demand—scientific research breakthroughs—base validation," with a focus on overcoming bottlenecks like domestic production of flower bulbs and citrus variety updates. Include smart agriculture as a recognized skill in Yuxi's list of urgently needed talents, improve certification and incentive mechanisms for local experts, and establish an order-based training system of "companies propose problems, universities solve them, government pays." Set up city-level agricultural data sharing standards and exchange mechanisms to achieve "one digital record per base."

Third, smooth out the value realization layer. Promote reforms in the benefits-sharing system for researchers when their results are commercialized, and spread the experience of the "posting challenges and taking the lead" system — agricultural companies or cooperatives put forward technical needs, the government posts them online, research institutions "take on the challenge," the government provides subsidies, and companies offer matching funds and resources. The research teams then tackle the problems directly, hitting the pain points. Lead with regional public brands and build a three-tier brand system of "regional brand + corporate brand + product brand." On top of the "industry partner" system, introduce a "guaranteed income + variable sharing" mechanism to create a flexible connection where risks are shared and rewards are mutual.

6.3. Research limitations and prospects

This study focuses on cases in Yuxi City where facility agriculture is relatively well-developed in the plains and mid-mountain areas, with insufficient coverage of bases in mountainous and mid-mountain regions where the level of facility agriculture is lower. The applicability of the three-layer mechanism model in these areas still needs to be tested. The research data are mainly qualitative, obtained through semi-structured interviews and field observations, and do not provide systematic panel data on input-output at the base level, making it difficult to measure the causal effects of technology empowerment rigorously. Additionally, the research subjects are mainly base leaders, cooperative managers, and grassroots agricultural technicians, which limits the depth of investigation into ordinary farmers, especially smallholders, regarding their participation experience, perception of benefits, and willingness for continued participation. The analysis of the equitable distribution of technology benefits still needs to be deepened.

Future research can expand the scope of the survey to include bases in mountainous and mid-mountain areas for comparative analysis; use longitudinal tracking methods to reveal the dynamic evolution of technology empowerment; supplement micro-level data at the farmer level to examine the impact of technology empowerment on farmers' income, skill improvement, and willingness to participate; and conduct cross-regional comparative research, comparing the Yuxi experience with other highland specialty agricultural areas in Yunnan Province, in order to extract more generalizable mechanisms.

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