A Study on the Integration Paradigm of Industrial Chain Driven by Intelligent Processing of Green Brick Tea and Deep Processing of Osmanthus Tea

— Digital transformation practice based on the resource endowment of "tea and osmanthus symbiosis" in Xianning

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Abstract. As the origin of the Eurasian tea ceremony and the largest production area of green brick tea in China, Xianning City was promoting the digital transformation of traditional processing modes. Based on the ecological endowment of "tea and osmanthus symbiosis", a dual core industrial chain paradigm of "intelligent processing of green brick tea - deep processing of osmanthus tea" was constructed: the green brick tea end integrates IoT, near-infrared spectroscopy (NIRS), and digital twin technology to achieve dynamic control of temperature and humidity in the pile, three-dimensional steam pressure modeling of "pressure time temperature", and blockchain full chain traceability; Osmanthus Tea pioneered the "digital fermentation process package", integrating AI models for predicting flowering periods, online monitoring of volatile components, and collaborative aroma enhancement technology of cold extraction vacuum freeze-drying, solving the problem of quality fluctuations in manual fermentation. Led by the chain owner enterprise, a digital common platform would be constructed, and standard groups such as the "Intelligent Processing Technology Regulations for Chibi Green Brick Tea" would be formulated. The "shared processing center+digital service station" sinking model would be promoted, and the technology equality between small and medium-sized initial processing plants and leading enterprises would be promoted. Simultaneously establish a three-level collaborative system of "standard as brand" to support the premium of the "Xianning Good Tea" regional public brand through the verifiability of the processing process. This paradigm combines technological adaptability, institutional embeddedness, and ecological inclusiveness, providing a replicable, assessable, and iterative digital revitalization path for traditional tea regions such as Wuling Mountain and Dabie Mountain.

Keywords: “Tea and osmanthus symbiosis”; Green brick tea; Osmanthus tea; digitalization

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1 Introduction

Xianning Tea Industry carries forward the millennia-old Chinese tea heritage: Starting from the Jin and Tang dynasties, it began harvesting tea from Wuchang Mountain, pioneering the tea culture of Jingchu; from the Song and Yuan dynasties onward, Yangloudong, leveraging its advantage as a land and water transport hub, became the core of the southern end of the Silk Road Tea Route, with dark brick tea faring well in Europe and Asia; during the Qing Dynasty, the "Chuanzi Brand" even reached St. Petersburg via camel caravans, becoming one of the most recognizable symbols of Chinese tea. After undergoing three transformative phases—decline during the late Qing Dynasty, reconstruction under the New China's state-led system, and rapid market-oriented development during reform and opening-up—Xianning has forged the foundation of its reputation as the "Hometown of Chinese Green Brick Tea" while also facing the imperative of structural upgrading[1-2]. At present, the annual production of green brick tea in Xianning is 82500 tons, and more than 30 leading companies are developing osmanthus tea. However, more than 70% of the initial production plants are still "small, scattered, and weak" workshops. The utilization rate of summer and autumn tea is less than 40%, and the proportion of deep processing output value is less than 8%, highlighting systemic bottlenecks such as experience led, extensive elements, lack of standards, and fragmented chains. Under the new paradigm of "precision production, functional development, and scenario based consumption" in the global tea industry, it is difficult to sustain pure expansion or overlapping categories. It is urgent to use digitalization as the underlying logic and core engine to systematically reconstruct the value distribution mechanism of the entire chain of "high-quality raw material traceability intelligent processing regulation brand value transmission terminal consumption response", and promote the fundamental transformation of the industry from "scale growth" to "quality leap".

This article focused on the two most representative and differentiated tea categories in Xianning green brick tea (a national intangible cultural heritage and geographical indication product), which is a living heritage of black tea, and Guihua tea, which showcases the innovative power of regional culture. It proposes a systematic transformation path of "dual core drive, standard foundation, chain integration, and brand empowerment". Different from existing research or tool based applications that focus on a single digital technology, or generalized analysis limited by macro policy recommendations, this study emphasizes the four-dimensional deep coupling of technological logic, standard system, organizational form, and market mechanism: Not only does it embed digital technology into core mechanisms such as dynamic modeling of fermentation temperature and humidity, optimization of osmanthus fermentation process parameters, but it also runs through the iteration of intelligent equipment, the design of new linkage mechanisms for cooperatives+leaders+farmers, and the entire process of product definition and channel adaptation based on consumer behavior data reverse drive. It is committed to building a digital transformation paradigm for tea producing areas with solid theoretical foundations, clear practical paths, replicable and promotable.

2 Theoretical Framework: Value Reconstruction Logic of Digital Technology Empowering Tea Processing

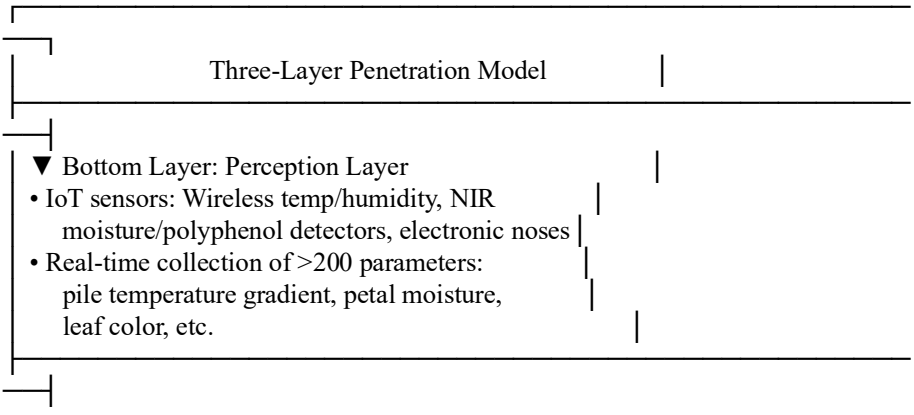
The essence of tea processing is a biochemical transformation process, and its core variables (such as the succession of microbial communities in green brick tea and the dynamic migration of linalool /β- ionone in *osmanthus* tea) (Table 1) have strong temporal, nonlinear, and environmental sensitivity. Traditional experience relies on "seeing, smelling, touching, and tasting", which has defects such as large individual differences, untraceable processes, and high quality fluctuations. Digital transformation is not simply about replacing equipment, but about activating process knowledge through data elements to make it explicit, standardized, and transferable[3].

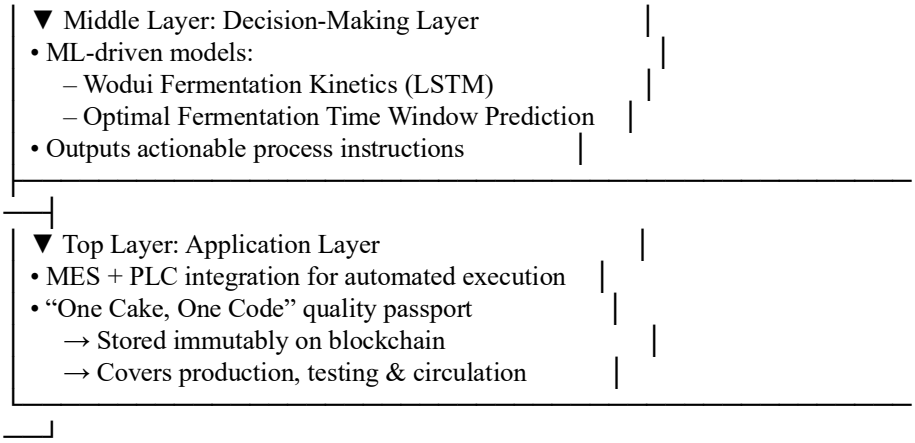
Table 1. OAV analysis of volatile compounds in osmanthus green tea.

Compound Name	class	threshold /(μg/L)	Aroma characteristics	OAVprice						
				CK	A	B	C	D	E	F
Linalool oxide II	alcohols	6	fragrance of a flower	0.26	0.92	1.83	3.56	3.68	3.70	4.41
β-Dihydrozepine	ketone	1.7	Mu Xiang, Osmanthus fragrance	1.90	1.95	3.82	5.03	5.96	5.86	10.72
β-Pyrrolidone	ketone	0.2	Violet, floral fragrance	23.30	27.30	32.28	42.23	35.23	69.90	106.93
Linalool oxide I	alcohols	0.19	Magnolia fragrance	10.63	46.79	43.03	90.24	99.24	91.16	119.89
Oxylinalol	alcohols	0.5	fragrance of a flower	1.21	3.70	13.97	12.82	5.27	11.37	14.49
linalool	alcohols	0.6	fragrance of a flower	2.3	5.6	4.4	9.4	8.1	4.5	5.0
Linalool oxide III	alcohols	0.5	Sweet and floral fragrance	2.81	8.34	13.14	14.50	15.41	14.75	20.38

Note: Green tea base material was processed together with fresh osmanthus flowers at various flower-to-tea ratio combinations to produce six varieties of osmanthus green tea, numbered sequentially as A (10:0.5), B (10:1), C (10:1.5), D (10:2), E (10:2.5), and F (10:1.5–one steaming and one extraction cycle).

This article constructs a theoretical model of "three-layer penetration"[4]:





This model breaks through the limitations of the "technical tool theory" and positions digital technology as a carrier of process knowledge and an infrastructure for industrial chain governance, providing a theoretical support for small and medium-sized tea enterprises to lower the threshold for technology adoption.

3 Dual Core Drive: Innovative Practice of Intelligent Processing of Green Brick Tea and Deep Processing of Osmanthus Tea

3.1 Green Brick Tea: Building a New Paradigm of Intelligent Processing with "Digital Twin+Closed loop Control"

The Xianning green brick tea pile stacking process has long relied on experienced craftsmen to "flip the pile based on experience", resulting in a high risk of excessive fluoride content and inconsistent aging cycles.In 2023, Chibi green brick Tea Research Institute and Huazhong Agricultural University jointly developed the "Wodui Digital Twin System": 64 distributed sensors were deployed in the pilot workshop of Zhao Liqiao Tea Factory to map the temperature and humidity field, CO_2 concentration, and pH value changes inside the pile in real time; By simulating the effects of different flipping strategies on microbial abundance using digital twins, the optimal solution of "micro flipping every 8 hours for the first 3 days+constant temperature for the 4th to 7th day" was optimized. Actual testing shows that the reactor cycle has been shortened by 12%, the quality rate has increased to 92.6%, and the fluorine content has remained stable at≤200mg/kg (the national standard limit of 300mg/kg).

More importantly, the system has derived the "Technical Regulations for Intelligent Processing of Chibi Green Brick Tea" (DB4212/T 2024) [5], which for the first time includes quantitative indicators such as "Wodui Temperature Control Accuracy±0.5" and "Steam Pressure Fluctuation≤0.3MPa" in local standards, and develops a lightweight APP for small and medium-sized factories to download and use. After the integration of three cooperatives in Tongcheng County, the model can be called through the

shared cloud platform to achieve process upgrades without the need for self built servers.

3.2 Osmanthus Tea: Breaking Through the Key Technological Bottleneck of "Digital Fermentation"

Xianning osmanthus tea has long been limited by pain points such as short flowering period (only from September to October), high fermentation loss (flower loss rate exceeding 40%), and easy aroma attenuation. The research team innovates the "three-level digital inspection method"(Table 2):

Table 2. Three-level digital inspection method.

Stage	Key Technology & Outcome
Pre- Prediction	AI model (91.3% accuracy) integrates satellite meteorology + local phenology to forecast peak osmanthus flowering — enables precise tea procurement planning.
Process Control	Real-time GC-MS monitoring (Guihua Industrial Park, Tongshan) of 12 key aroma compounds (e.g., linalool, nerolidol) (Table 3); dynamic adjustment of camellia ratio & fermentation time.
Backend Fragrance Locking	"Low-temp vacuum freeze-drying + microencapsulation" → 87.5% aroma retention (vs. 52% in conventional drying); cold-brew osmanthus green brick tea powder developed — 3× higher solubility.

Table 3. Aroma composition (alcohols) of Osmanthus green tea with varying flower-to-tea ratios.

Aromatic compounds	retention time/min	CAS	CK	A	B	C	D	E	F
alcohols			**17.46 (39.93%)**	**32.99 (54.95%)**	**48.11 (59.15%)**	**71.34 (62.84%)**	**64.12 (60.78%)**	**63.58 (61.80%)**	**81.42 (58.36%)**
Linalool oxide I	10.35	5989-33-3	2.02	8.89	8.18	17.15	18.86	17.32	22.78
Caryophyllene oxide II	10.86	34995-77-2	1.53	5.53	10.97	21.37	22.06	22.21	26.44
linalool	11.28	78-70-6	1.39	3.36	2.64	5.62	4.87	2.69	2.99
Caryophyllene oxide III	14.04	14009-71-3	1.40	4.17	6.57	7.25	2.71	7.38	10.19
Oxylinalool	14.26	39028-58-5	0.61	1.85	6.99	6.41	2.64	5.69	7.25
α-terpineol	14.96	98-55-5	0.31	0.29	0.43	0.26	0.28	0.17	1
Geraniol	18.10	106-24-1	2.95	0.75	0.31	1.62	1.06	0.68	1.49
Trans-orenthol	18.36	40716-66-3	0.24	0.53	0.84	0.37	0.93	0.45	1.01
β-Dihydro-proridol	27.31	3293-47-8	1	1	0.45	0.37	0.31	0.43	0.65

Note: Green tea base material was processed together with fresh osmanthus flowers at various flower-to-tea ratio combinations to produce six varieties of osmanthus green tea, numbered sequentially as A (10:0.5), B (10:1), C (10:1.5), D (10:2), E (10:2.5), and F (10:1.5–one steaming and one extraction cycle).

At present, the group standard for "Xianning Osmanthus Tea" (T/XNCC 001-2023)[6] has solidified digital fermentation parameters, and nearly 30 processing enterprises produce according to this standard, with a product premium of over 35%.

4 Industry Chain Integration: Organizational Change and Value Redistribution Driven by Digitization

If digitalization only stays at a single point of technology, it is difficult to shake the deep structure of the industrial chain. The practice in Xianning has shown that it is necessary to use standards as the link, platforms as the carrier, and organizations as the hub to promote full chain collaboration.

4.1 Standard Guidance: Building a Dual Governance Mechanism of "hard constraints+soft services"

The "General Specifications for Clean Tea Processing" were issued, mandating that primary tea processing plants install video surveillance systems and integrate them into the municipal regulatory platform; simultaneously, "Digital Service Stations" were established to provide free process diagnosis, standard interpretation, and equipment docking services for small factories in towns and villages.In 2024, the first batch of 27 small and micro factories passed the "Standard Compliance Certification" and were granted the "Xianning Good Tea" authorization mark, with a 40% increase in orders.

4.2 Platform Empowerment: Cracking the technological Gap between Small and Scattered Entities

To promote the improvement of tea industry quality, efficiency and digital transformation, Tongcheng County and Tongshan County jointly layout and construct three municipal level shared standardized tea processing centers. Each center was equipped with an intelligent withering machine (integrating precise temperature and humidity control), a high-precision near-infrared detector (realizing fast detection of key indicators such as fresh leaf moisture content and tea polyphenols), and fully connected to the cloud MES manufacturing execution system, connecting the entire data chain of "fresh collection processing quality inspection outbound". Retail tea farmers only need to send fresh leaves to the nearest center, scan the code to register, and generate personalized "processing prescription sheets" in real time, specifying the corresponding batch's withering temperature curve, rolling time, and drying parameters. They can also track the processing progress, process execution, and quality feedback through the mobile app. Practical data showed that the sharing mode significantly improved resource utilization efficiency, reducing the comprehensive cost of tea initial production by 18%; At the same time, due to stable processing quality and increased brand premium, the average selling price of fresh tea leaves for tea farmers had risen by 12%, effectively breaking

through the quality fluctuations and efficiency bottlenecks caused by scattered processing by small farmers, and injecting new momentum into the high-quality development of the regional tea industry.

4.3 Organizational Innovation: a Community of Shared Interests Consisting of "chain owners + cooperatives + farmers"

Hubei Green Brick Tea Industry Group takes the lead in establishing a "Digital Processing Consortium" to integrate high-quality Green brick tea production enterprises, cooperatives, and research institutions within the province, empowering traditional industries to upgrade through digital transformation. Unified procurement of intelligent equipment by the consortium to reduce the cost of technological transformation for individual enterprises; Build a regional shared quality inspection laboratory, equipped with a professional testing team and CMA certification qualifications, to achieve full cycle quality monitoring of raw materials, semi-finished products, and finished products; Collaborate to carry out the declaration of geographical indication special marks for Chibi green brick tea, and strengthen the legal protection of regional brands. Member units are connected to a unified block chain platform, and the core process data is recorded on the chain throughout the entire process, which is tamper proof and real-time traceable. Consumers can intuitively trace the complete life cycle of products from tea gardens to tea cups by scanning the code on their mobile phones, significantly enhancing consumer confidence and brand credibility.

4.4 Brand Building: Supporting Regional Brand Premium with Verifiable Processing Process

Traditional tea brand marketing often focuses on cultural narratives, while Xianning explores a new path of "processing as advertising": transforming the digital processing process into brand trust assets.

-Open a "Transparent Factory" live streaming channel on the official website of "Xianning Good Tea", showcasing in real-time the intelligent brick pressing production line for green brick tea and the cold extraction production line for osmanthus tea;

-Design a "standard ID card" label, indicating the implementation standard number (such as DB4212/T 2024), key process parameters (stack time, inspection frequency), and physical and chemical testing reports;

-Collaborate with JD.com to create a "digital tea warehouse" where consumers can trigger blockchain traceability queries upon placing an order, strengthening the "visible quality".

Osmanthus Tea had entered the flagship store of Tongrentang in Beijing and the high-speed railway business center, achieving a 58% increase in customer unit price with the "digital inspection" label; Green Brick Tea leverages the mutual recognition of geographical indications between China and Europe to open up the high-end Russian market with the hard indicator of "fluoride content $\leq$ 200mg/kg".

5 The Universal Value and Theoretical Implications of the Xianning Paradigm

The Xianning practice had a triple paradigm significance for similar tea producing areas:

Firstly, solve the dilemma of "technological suspension": Avoid blindly introducing high priced equipment, but instead use "lightweight digital toolkits" (apps, cloud platforms, shared centers) to reduce the adoption costs of small and medium-sized entities and demonstrate technological adaptability.

Secondly, reshape the governance logic of the industrial chain: Elevate digital technology from a production tool to a governance infrastructure, and achieve a virtuous cycle of "government guidance, chain owner drive, and small and micro participation" through a combination of standard enforcement and platform services.

Thirdly, innovate the sources of brand value: Beyond cultural symbol competition, shift towards a new dimension of "verifiability of processing processes" to provide scientific endorsement for regional public brands.

It should be pointed out that digital transformation is not a panacea. Xianning still faces challenges such as insufficient digital literacy among tea farmers and vague definition of data property rights. In the future, it is necessary to strengthen the formulation of local regulations for the "Agricultural Data Security Management Measures" and explore incentive mechanisms such as exchanging "digital skill points" for agricultural subsidies[6].

6 Conclusion

Xianning relies on the "dual engines" of intelligent processing of green brick tea and deep processing of osmanthus tea, innovatively constructing a full chain closed-loop development path of "digital technology deeply rooted in process mechanism - standard system solidification technology achievements - platform organization bridging the main gap - brand construction realizing digital value", successfully exploring a new paradigm for traditional tea areas to achieve high-quality development. The core breakthrough lies in a profound understanding of the essence of digital transformation: it is not simply replacing human labor with machines, but is committed to refining the implicit experience system passed down by experienced teachers into quantifiable, reusable, and inheritable explicit knowledge; Integrating and upgrading the technological capabilities, data resources, and market responsiveness of dispersed entities such as tea farmers, cooperatives, and processing enterprises through digital platforms into a systematic advantage of collaborative efficiency and strong resilience; Furthermore, the original extensive traditional production process will be transformed into a brand asset accumulation that covers the entire process of raw material traceability, intelligent temperature control, flavor modeling, and cultural narrative. The practice has formed a three-dimensional collaborative framework of "technology selection - system design - market response" with technology adaptability, system replicability and market penetration, which not only provides Mount Wuyi rock tea, Anhua black tea, Yunnan black

tea and other characteristic production areas with a transformation roadmap tailored to local conditions, but also provides a solid, scalable and sustainable grassroots practice sample and theoretical support for the in-depth implementation of the Outline of Digital Rural Development Strategy and the Guiding Opinions on Promoting the High Quality Development of the Tea Industry.

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