A STUDY ON THE SUSTAINABLE DEVELOPMENT OF THE YUNNAN TEA INDUSTRY UNDER THE PRESSURE OF CHINA'S TEA INVENTORY

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Abstract. This study systematically examines the dynamics of tea production, consumption, and inventory in China from 2018 to 2023, with a particular focus on Yunnan Province, to assess the extent of market saturation and its implications for industry sustainability. Based on comprehensive national and international datasets, the analysis reveals a substantial expansion in tea garden area, increasing by 447.37 thousand hectares to reaching 3433.17 thousand hectares in 2023, contributing over 94% to the global net increase. During the same period, national tea production grew by 924.7 thousand tons, of with Yunnan contributed 133.7 thousand tons. However, domestic consumption rose by only 494 thousand tons, resulting in a structural surplus. Inventory data indicate that primary tea stock reached 507 thousand tons and finished tea stock surged by 289.31% to 3.196 million tons. Despite the growth in niche categories such as yellow tea and the expansion of the tea beverage sector, overreliance on traditional green and black teas—comprising more than 72% of output—exacerbates the oversupply. Exports remain limited, with China accounting for only 21.16% of global tea exports and Yunnan contributing a marginal 0.24%. The observed decoupling of production and demand signals increasing market saturation. To ensure long-term sustainability, the industry must adopt targeted strategies including demand-driven production planning, structural optimization of tea types, and diversification of export markets.
Keywords: *sustainability, Pu'er tea, value chain, market saturation, export diversification, ecological agriculture*

Introduction

Tea (*Camellia sinensis* L.) is one of the world's most popular non-alcoholic beverages, and it is an important economic crop for many developing countries. The global tea industry is cultivated in over 60 countries, primarily throughout Asia, Africa, and South America, serving as a significant source of income for millions of smallholder farmers and contributing to economic resilience in rural communities (Pandey et al., 2021), and consumer of tea globally, plays a central role in the international tea economy. The National Bureau of Statistics of China added, and the International Tea Committee (ITC) noted that as of 2022, China has produced approximately 50% of the world's tea, with tea plantation areas being global cultivated areas.

Among the provinces producing tea in China, Yunnan is a remarkable region with unique historical and ecological importance. Yunnan is known as the original home of

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tea, and it also has the oldest cultivated tea trees, as well as the area with the most ancient tea gardens, globally (Li et al., 2023; Liu, 2023). It plays an impressively important role in both domestic and international production of tea. In 2022, the tea gardens in Yunnan occupied nearly 530.51 thousand hectares of land area, which was 9.97%% of the world's total tea cultivation area, and 15.63%% of China's total tea cultivation area. Regarding production of tea, Yunnan produced 533.9 thousand tons of tea in 2022, ranking second in the world after Kenya, accounting for 8.43%% of world tea production, and 15.73%% of national tea production (Li and Zhang, 2025; Zhang et al., 2022).

Although the Yunnan tea industry has ecological benefits and scale of production, it is facing increased challenges. The volume of global tea production has begun to consistently outpace consumption, resulting in excessive inventory, suppressed prices, and saturated market conditions. China's domestic tea production rose to 3.54 million tons in 2023 from 2.62 million tons in 2018, while exports stayed at around the same levels, hovering between 350–375 thousand tons each year. Overall, over that same period, domestic consumption increased less than 1000 tons (493.5). The widening gap between the supply and demand dynamic has exerted increased pressures on inventory levels, which are incredibly threatening to regional industries such as Yunnan's sustainability (Yu and Pujeeb, 2024).

The tea industry in Yunnan is especially exposed to weakness resulting from structural imbalances in the supply chain, lack of access to high-end markets, and poor transport and logistics infrastructure. Other weaknesses, such as lack of market knowledge, little product differentiation and reliance on low-priced, bulk tea, additionally contribute to these vulnerabilities. In sum, the province is facing a double threat of declining farmer incomes and loss of international competitiveness (Chen et al., 2011; Nurhayati et al., 2025).

In order to sustainably develop Yunnan's tea industry, expanding strategies will need to be put into practice, such as increasing government policy initiatives, advancing ecological management of tea gardens, modernization of cultivation techniques, and stimulating the production of high-value products like Pu'er tea (Koros et al., 2023; Mei and Liang, 2024; Ye et al., 2022). It is also essential to innovate based on science and technology, focused digital agriculture, precision agriculture, and supply chain innovation. Other avenues for value addition and income diversification are brand building, e-commerce channels enhancement, and promoting tea tourism (Qin and Zhou, 2024). The purpose of this research is to conduct an in-depth study of the sustainable development of the Yunnan tea industry in light of increasing tea inventory in China. By integrating ideas from the ecology, economy, and policy domains, the study analyzes the key existing challenges, pinpoints significant leverage points for intervention, and provides a strategic approach to support resilience and sustainable economic growth of the tea industry in the study region.

Methodology

The basis of this study is to clarify the current situation of China's tea supply and consumption.

Data

The data for this study originated from the International Tea Committee, the China Bureau of Statistics, and from two national and provincial tea industry associations: the China Tea Circulation Association and the Yunnan Tea Circulation Association. The data

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cover 2018 to 2023 and mainly include the tea garden area, tea yield, domestic sales, import volume, and export volume. The tea garden area includes the total tea garden area and the tea-picking area. The tea-picking area refers to the area picked in the tea-planting area. Tea yield includes primary tea yield and finished tea yield.

The area of tea plantations in Yunnan, in China, and in the world, from 2018 to 2023, is shown in *Figure 1*. The tea garden area in Yunnan increased from 466.58 thousand ha to 530.53 thousand ha, and the tea garden area in China expanded from 2985.80 thousand ha to 3433.17 thousand ha. The International Tea Committee has not yet announced the global tea garden area in 2023. The global tea garden area in 2022 was 5320.00 thousand ha, an increase of 430.00 thousand ha compared with the area in 2018. In the same period, China's tea garden area increased by 406.91 thousand ha, accounting for 94.63% of the worldwide tea garden area increment. Therefore, it is clear that the increase in the worldwide tea garden area from 2018 to 2023 was mainly driven by the increase in China's tea garden area.

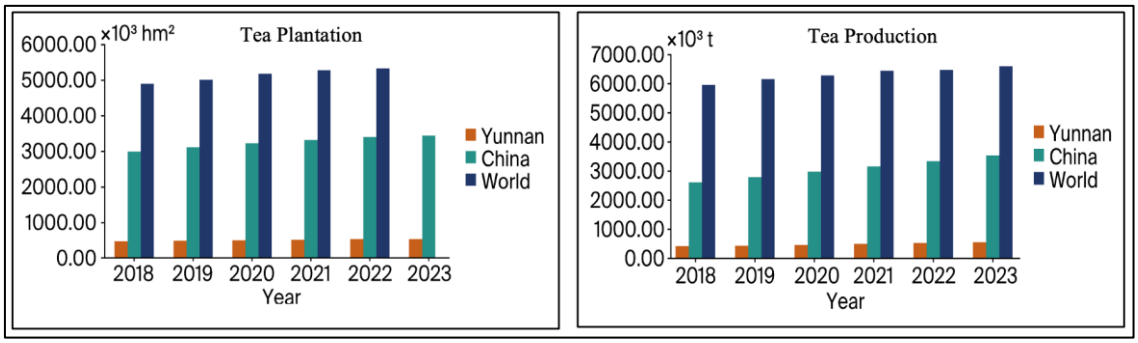

Figure 1. *Tea plantation area and Tea production in Yunnan, in China, and worldwide*

As shown in *Figure 1,* both China's tea plantation area and production have continued to increase year by year. Within this national trend, Yunnan's production rose from 423.3 thousand tons in 2018 to 557.0 thousand tons in 2023, an increase of 31.6%. Although Yunnan accounts for about 16% of national output, its growth trend is somewhat masked when presented together with the much larger national totals. Therefore, it is important to note separately that Yunnan's expansion mirrors the overall national increase, while contributing significantly to the country's total output. During the same period, China's tea production increased from 2.6164 million tons to 3.5411 million tons, an increase of 924,700 tons. According to the data of the International Tea Committee, worldwide tea production increased from 5.967 million tons to 6.604 million tons from 2018 to 2023, an increase of 637,000 tons. Thus, the increase in worldwide tea production was lower than the increase in China's tea production. This was mainly due to drought, the worldwide economic recession, and the effects of Coronavirus Disease 2019 (COVID-19) on tea plantation workers. Tea production in India, Vietnam, Bangladesh, Sri Lanka, Kenya, and other major tea-producing countries decreased to varying degrees (Fu et al., 2024; Saha, 2024; Koros et al., 2023).

In terms of tea exports, in 2023, Yunnan Province and China's tea export volumes were 4.2 thousand tons and 367.5 thousand tons, respectively, accounting for 0.24% and 21.16% of the world's tea export volume. In recent years, China's tea export volume was the highest in 2022, reaching 375.2 thousand tons, but it accounted for only 20.63% of the global tea export volume in that year. In 2019, Yunnan Province's tea export volume

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accounted for the highest proportion of the global tea export volume, with 0.42% of the world's tea exports and 8 thousand tons of export in that year. In general, the proportion of Yunnan and China's tea exports to world tea exports is much lower than the proportion of their tea production to global tea production, as shown in *Table 1*.

Table 1. *Tea exports from Yunnan, from China, and worldwide*

Production	2018	2019	2020	2021	2022	2023
Yunnan (thousand tons)	7.11	7.96	6.67	4.88	4.47	4.25
China (thousand tons)	364.74	366.56	348.81	369.35	375.20	367.54
Worldwide (thousand tons)	1854.00	1895.00	1822.00	1923.00	1819.00	1736.70

Data analysis

This study aims to focus on whether China's tea production is saturated; thus, it is necessary to determine the production, consumption, and inventory of primary tea and finished tea in the world, in China, and in Yunnan Province from 2018 to 2023. Primary tea is a product of fresh tea leaves after initial processing. It is the raw material for making tea products such as dark tea, green tea, and black tea. Finished tea, also known as refined tea, is a general term for the refined products of primary tea (Xu et al., 2018), which can be directly used in commodity trade and in consumption.

Stock level of primary tea

Measuring the inventory of primary tea can directly determine how much tea production in a tea garden is not processed into commercial tea and placed in a warehouse every year. This is an important indicator of China's tea inventory. According to customs' statistics, China's imported tea is basically finished tea; therefore, China's stock of raw tea can be determined by subtracting the amount of finished tea consumed from the total supply of primary tea. The initial stock of primary tea and the yield of primary tea constitute the supply of primary tea. At the same time, the proportion of the primary tea inventory is used to reflect the level of the primary tea inventory, that is, the proportion of the primary tea inventory at the end of the period and the annual supply of primary tea. The formula is as follows: inventory ratio = inventory/total output.

$$EI_{pt} = BI_{pt} + Y_{pt} - C_{pt} \quad \text{(Eq.1)}$$

$$IP_{pt} = (EI_{pt}/BI_{pt} + Y_{pt}) \times 100 \quad \text{(Eq.2)}$$

In the above equation, EI_{pt} is the final inventory of primary tea, IP_{pt} is the proportion of the final inventory of primary tea, BI_{pt} is the initial inventory of primary tea, Y_{pt} is the yield of primary tea, and C_{pt} is the consumption of finished tea.

Inventory of finished tea

The inventory of finished tea is the quantity of unsold finished tea. According to the basic constraint equation of the supply and demand balance model of agricultural products in the Institute of Agricultural Information, Chinese Academy of Agricultural Sciences, the inventory of finished tea at the end of the period is used to represent the

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annual inventory level of finished tea. The sum of the inventory of finished tea at the beginning of the period, the output of finished tea, and the import volume is the annual supply of finished tea. The annual supply of finished tea minus the total domestic sales and export volume is the final inventory of finished tea (Li et al., 2023; Liang et al., 2022; Zhonghua, 2019). At the same time, the proportion of the finished tea inventory is used to compare the level of the finished tea inventory in different years, that is, the proportion of finished tea inventory at the end of the period and the annual supply of finished tea. The formula is as follows:

$$EI_t = BI_t = Y_t + I_t - C_t - E_t \quad \text{(Eq.3)}$$

$$IP_t = (EI_t/BI_t + Y_t + I_t) \times 100 \quad \text{(Eq.4)}$$

In the above formula, EI_t is the inventory of finished tea at the end of the period, IP_{pt} is the proportion of finished tea at the end of the period, BI_t is the inventory of finished tea at the beginning of the period, Y_t is the output of finished tea, It is the import volume of finished tea, C_t is the total domestic sales of finished tea, and E_t is the export volume of tea.

Results and discussion

The stock level of primary tea

As can be seen from *Figure 2,* inventory of primary tea in China was under 500 tons from the year 2018 through until 2020. The percentage of primary tea to total year-end inventory was also consistently equal to or less than 0.020%. However, starting in the year 2021, the inventory of primary tea increased to above 100 thousand tons which made up a share of 3.20% of total year-end inventory. After year 2021, the levels of dry tea inventory has continually increased in the years following. By 2022, the level of primary tea in inventory grew to 262.6 thousand tons and made up 7.63% of total year-end inventory. Then, in 2023, we saw the level of primary tea experience its largest increase in recent years as the stock of primary tea grew even higher to the level of 507 thousand tons, which represented 13.33% of the total year-end inventory.

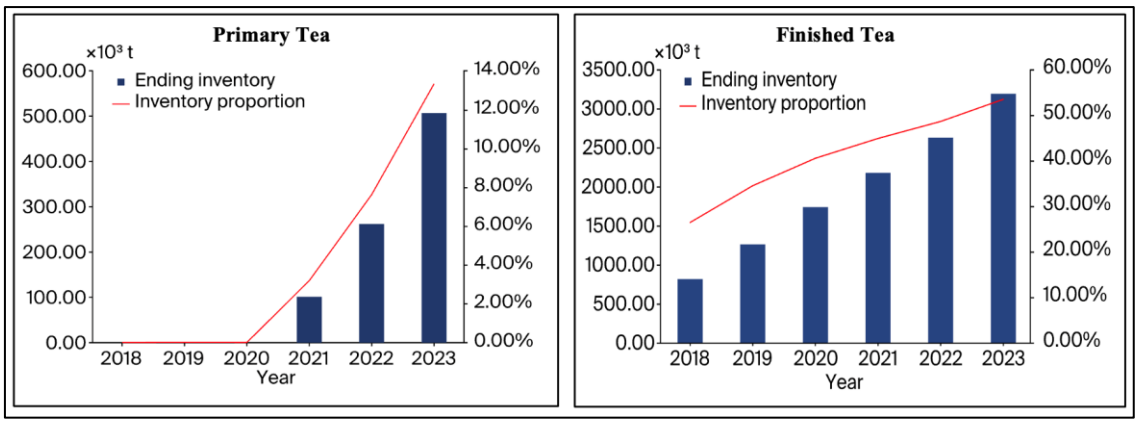

Figure 2. *Changes in the stock level of primary tea (2018–2023). The inventory growth reflects the fact that production increased faster than consumption during this period*

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We note that the basic reason for the increase in the primary tea inventory at the end of the period is that the annual output of primary tea is higher than the consumption of finished tea. From 2018 to 2023, the annual output of primary tea and the consumption of finished tea maintained an increasing trend. The consumption of finished tea increased from 2616.1 thousand tons to 3296.7 thousand tons, with an average annual growth rate of 5.95%. However, the annual output of primary tea increased by 7.86%. In 2018, the annual output of dry tea was 2616.4 million tons, which was only 0.3 thousand tons more than the consumption of finished tea. However, by 2023, the annual output of primary tea had reached 3541.1 thousand tons, which was 244.4 thousand tons more than the consumption of finished tea in the same period.

Comparable oversupply dynamics have been documented in India and Sri Lanka, where tea inventories also expanded due to stagnant demand and export constraints (Saha 2024; Koros et al., 2023). This suggests that China's surplus, including Yunnan's case, reflects not only local structural issues but also a broader global imbalance.

Trends in China and Yunnan tea production (2018–2023)

From 2018 to 2023, China's tea production increased from 2.616 million tons to 3.541 million tons, representing a net growth of 924.7 thousand tons (+35.3%). During the same period, Yunnan's production rose from 423.3 thousand tons to 557.0 thousand tons, an increase of 133.7 thousand tons (+31.6%). Although Yunnan maintained its role as the second-largest producing province, its share of national output declined slightly from 16.2% in 2018 to 15.7% in 2023. This indicates that while both China and Yunnan experienced steady production growth, Yunnan's expansion followed the national trend rather than outpacing it, reflecting similar oversupply pressures at both regional and national levels. As shown in *Figure 2,* the total stock level of primary tea in China continued to grow. This reflects the widening gap between supply and demand: between 2018 and 2023, tea production increased from 2.616 to 3.541 million tons, while consumption rose from 1.843 to 2.336 million tons. Thus, supply grew by 924.7 thousand tons, whereas demand increased by only 493.5 thousand tons, leaving a cumulative surplus of 431.2 thousand tons. These imbalances are not directly visible in the figure itself, which shows inventories, but they are the underlying cause of the rising stock levels.

The stock level of finished tea

Compared with primary tea, the inventory of finished tea is greater. As shown in *Figure 2,* in 2018, the final national inventory of finished tea was 820.96 thousand tons. By 2023, the final inventory of finished tea had increased to 3196.09 thousand tons, an increase of 289.31% compared to 2018. Similarly, the proportion of the finished tea inventory at the end of the period also increased, from 26.52% in 2018 to 53.56% in 2023. The sharp rise in finished tea inventory is not only a result of production exceeding consumption—a well-known economic principle—but is also distinguished by structural imbalances specific to China's tea sector. Between 2018 and 2023, production rose by 680.6 thousand tons, while consumption increased by only 493.5 thousand tons. More importantly, over 72% of output consisted of green and black teas, categories for which demand has stagnated, while demand for yellow and dark teas expanded. This structural misalignment, combined with limited export growth (China's share of world exports remaining around 21%), explains why inventory accumulation has intensified in China

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and particularly in Yunnan. Such findings provide new insight into the sustainability challenges of regional tea industries beyond the general supply-demand imbalance. As shown in *Figure 3,* from 2018 to 2023, domestic tea consumption continued to increase, from 1910.50 thousand tons to 2404.00 thousand tons, and tea consumption increased by 493.50 thousand tons. However, the increase in domestic tea production was even higher, from 2616.10 thousand tons to 3296.70 thousand tons, and the output increased by 680.60 thousand tons. Kenya, despite being the leading global black tea exporter, reported a 14% production increase between 2018–2022, but global demand lagged behind, leading to oversupply and price suppression (Koros et al., 2023). Our findings on Yunnan's rising finished tea inventories parallel these international patterns

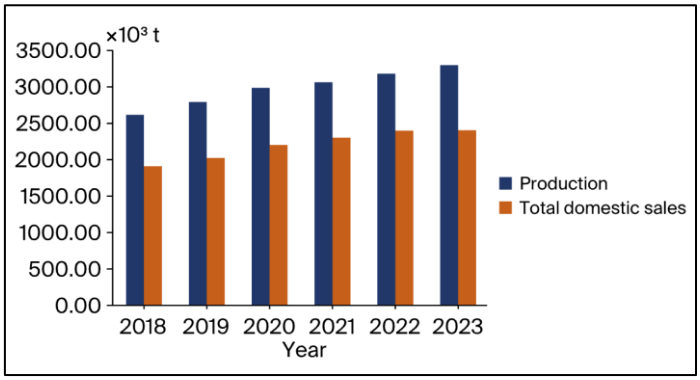

Figure 3. *Tea production and consumption*

Overview of tea consumption

Prior to addressing the contemporary circumstances surrounding tea consumption in China, it is important to recognize the rationale behind the recent increases in tea production. In recent years, tea-producing regions in China have increased their focus on the limits of expansion for tea-producing plantations, and the rate of establishing new tea garden areas has steadily decreased. At the same time, tea-producing regions have experienced increasingly warmer and drier weather patterns as well (Gong et al., 2018; Koros et al., 2023; Liu, 2023; Wang, 2022). Extended periods of drought during the winter and spring months—particularly in southwestern China, southern China, and regions north of the Yangtze River—negatively impacted tea yields in the spring months. However, the decrease in spring minimal decreases has been eclipsed by increased tea production numbers experienced during the summer and autumn months under wet conditions. The impacts of these changes to seasonal yields have determined the continuous annual increases of China's overall tea production (Mei and Liang, 2024).

At present, China's tea market can be divided into a market for traditional tea drinks and a market for new tea drinks. Traditional teas include the six major types of tea, such as green tea, black tea, dark tea, and so on. Because spring tea had the best taste qualities (Ye et al., 2022; Ma et al., 2022), Chinese consumers prefer to drink spring tea. Summer and autumn teas are less attractive, and among the six major tea types, spring tea is consumed most frequently. As shown in *Table 2,* the production, consumption, and inventories of the six major tea types are presented for 2022 and 2023. These two most recent years were selected in order to reflect the latest dynamics of structural imbalance, since earlier years (such as 2018) exhibited relatively stable proportions and would not

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provide additional insights for current adjustment strategies. Specifically, in terms of the supply and demand for the six major tea categories, as shown in *Table 2,* the production of green tea and black tea in 2023 accounted for 57.91% and 14.7%, respectively, of the total national output, totaling 72.61%, but the total domestic sales of green tea and black tea have shown a downward trend (Zhang et al., 2023). Dark tea, oolong tea, and yellow tea accounted for 13.7%, 10.0%, and 0.7%, respectively, of the total output, totaling 24.40%, but consumer demand is on the rise, especially for yellow tea. In China, consumer demand for yellow tea is 72.73% higher than it was in 2022 (Mei and Liang, 2024). In recent years, there has been an explosive growth in the new tea drink market. In 2023, there were more than 500,000 new tea shops, their annual output value was CNY 170 billion, and a total of 300 thousand tons of primary tea and finished tea was sold by these shops (Wang et al., 2022). More importantly, through innovative beverage forms and marketing methods, new tea drinks have enabled more young people to understand more traditional Chinese tea through the process of new tea consumption, and this has promoted the consumption of traditional finished tea by young people.

China's per capita tea consumption (~1.4 kg/person) is lower than in Turkey (~3.5 kg/person) and the UK (~1.9 kg/person) (ITC, 2022). This limited domestic absorption contrasts with other major tea-consuming nations and explains why China's rapid production growth, unlike in these countries, cannot be easily offset by higher per capita demand.

Table 2. *Production and consumption of the six major types of tea (thousand tons)*

Tea type	Production 2022	Consumption 2022	Inventory 2022	Production 2023	Consumption 2023	Inventory 2023
Green tea	1853.8	1311	542.8	1934	1289	645
Black tea	482	381	101	491.2	379	112.2
Dark tea	426.3	364	62.3	458	378	80
Oolong tea	311.3	248	63.3	332.8	256	76.8
White tea	94.5	81	13.5	100.2	83	17.2
Yellow tea	13	11	2	23.3	19	4.3

As shown in *Table 2,* the largest surpluses are found in green tea and black tea, with inventories of 645.0 thousand tons and 112.2 thousand tons in 2023, respectively. Together, these two categories account for over 75% of the surplus. In contrast, inventories of yellow and white teas are minimal (4.3 and 17.2 thousand tons, respectively), reflecting stronger demand growth. Dark and oolong teas also show moderate but rising inventories, suggesting the need for careful supply adjustments.

China's tea industry has inventory pressure and product supply-side structural imbalance

Based on the quantitative and qualitative analysis of China's tea supply and demand, it can be determined that the domestic consumption and supply of tea have maintained an upward trend, but the consumption is lower than the supply. Compared with other tea-producing countries, China's tea export volume is at a low level, and the international market expansion is insufficient. There is a certain imbalance between the production supply and market consumption demand for finished tea such as green tea and black tea,

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and there is a structural imbalance on the supply side of these products (Allameh and Orsat, 2023; Gong et al., 2018; Saha, 2024). Tea consumption is insufficient, and per capita tea consumption is low. In short, as a result of the increasing stock of primary tea and finished tea, China's tea industry faces greater inventory pressure. Similar supply-side structural issues are noted in Japan, where matcha consumption has surged while sencha stagnates (Allameh and Orsat, 2023). This reflects a global trend in which consumer demand shifts toward niche or innovative tea categories, echoing our findings on the rise of yellow tea and new tea beverages in China

Suggestions for the sustainable development of Yunnan's tea industry

Yunnan Province plays a vital role in China's tea industry, and the overall state of the national tea sector significantly influences Yunnan's tea economy. As previously noted, China's tea industry is currently facing substantial inventory pressure. Therefore, ensuring the high-quality and sustainable development of the tea industry—Yunnan's most important economic crop and agricultural product—is of critical importance. Moreover, the successful implementation of sustainable development strategies in Yunnan can serve as a valuable model for promoting high-quality growth in other tea-producing regions across China. Given that green tea alone contributes more than 645 thousand tons of surplus, policies should focus on slowing expansion in this category. By contrast, yellow tea demand grew by 72.7% in 2023 and its inventory remains very low (4.3 thousand tons), indicating strong market potential. Therefore, structural re-organization should prioritize diversifying production toward yellow, dark, and oolong teas, while controlling green and black tea output. The main tea products in Yunnan Province are Pu'er tea, green tea, and black tea. Yunnan Province is the only place in the world where Pu'er tea is produced. In the past ten years, the consumption of Pu'er tea in China has been high, and it is exported to Hong Kong, Japan, South Korea, the Association of Southeast Asian Nations (ASEAN) members, and multiple countries of the European Union (Yu and Pujeeb, 2024). Therefore, based on the actual situation of the Yunnan tea industry and the inventory pressure faced by the domestic tea industry, we believe that the development of an ecological tea industry and the utilization of diversified tea resources are the best paths for the sustainable development of the Yunnan tea industry.

Overall planning from "tea garden area expansion" to "ecological tea garden construction"

In 2017, Yunnan Province issued the "Notice of Action Plan for the Development of Tea Industry in Yunnan Province" (Saha et al., 2024). This plan called for "zero growth in the use of chemical fertilizers and pesticides, [for the tea industry] to vigorously promote the construction of demonstration counties of organic fertilizers instead of chemical fertilizers and green high-yield and high-efficiency demonstration counties, and for the building of high-efficiency and high-quality ecological tea gardens in the whole province." With this, the strategy of creating ecological tea gardens began in Yunnan Province (Li et al., 2020; Li and Zhang, 2025; Wang et al., 2024). This was based on the transformation and upgrading of the demands of China's population for a demand for food and clothing to a demand for nutrition and health, the oversupply of the global tea market, and the improvement of the quality and efficiency of the tea industry in achieving high-quality development. Prior to this, due to the low management efficiency of tea gardens and the

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lack of demonstration and promotion of green planting technology, tea gardens relied too heavily on chemical fertilizers and pesticides. Although tea production has increased, soil acidification and photosynthesis of tea trees have weakened (Zhang et al., 2024; Hasddin et al., 2025). Tea is also frequently unable to be exported because of excessive pesticide residues (Li et al., 2020). Promoting the development of an ecological tea industry in Yunnan Province is not only a key path for the sustainable development of the tea industry but also an important channel to achieve high quality tea, increase tea prices, and increase farmers' income. To promote the construction of ecological tea gardens in Yunnan Province, it is necessary to change conventional conceptions and pursue the economic benefits of the tea industry. From 2018–2023, China's tea garden area expanded by 447.37 thousand ha (94% of global net increase) (Qin and Zhou, 2024; Xu et al., 2023; Zhang et al., 2022). We should promote the construction of green and organic tea gardens. Ecological tea gardens can provide high-quality ecological tea products that not only have a high market unit price but also improve carbon sequestration (Fu et al., 2024; Zhang et al., 2024). At the same time, local functional departments strengthen ecological certification services and support tea farmers, cooperatives, and tea enterprises to carry out green tea garden, organic tea garden, green agriculture, and organic product certification. From 2018–2023, China's tea garden area expanded by 447.37 thousand ha (94% of the global increase), while consumption lagged behind production by 244.4 thousand tons in 2023. Thus, further expansion without ecological transition risks worsening oversupply.

Strengthen science and technology to build a technology system for an ecological tea industry

The development of a sustainable and ecological tea industry is based on science and technology. Like tea cultivation practices, the development of ecological tea gardens should be informed by a comprehensive assessment of geographic information, soil properties, water quality, climatic conditions, planting methods, and other ecological parameters. In Yunnan Province, it is important to study site-specific environmental conditions and ecological parameters for tea producing areas to determine where ecological tea agriculture can be developed, as suitable, marginal, or unsuitable (Pandey et al., 2021; Saha et al., 2024). Aiming at meeting the nutrient demand of ecological tea and the supply of soil nutrients, simple production technology and supporting facilities such as biochar utilization, and straw resource utilization were studied, and a formula of special organic fertilizer and liquid organic fertilizer was formed and applied in the industry to solve the problem of the soil's nutrient supply for ecological tea. Aiming at the prevention and control of pests and diseases in ecological tea production, based on the outbreak mechanism of key pests and diseases in tea gardens, the green prevention and control technology of key pests and diseases in organic agriculture was constructed from the perspective of resistance mechanisms and laws of occurrence (Gong et al., 2018; Wang, 2022). This includes screening and the innovative construction of a compound ecosystem for organic tea gardens, carried out according to local conditions, and including such strategies as forest–tea–poultry compound planting, tea–legume crops, tea–green manure planting, straw mulching of tea gardens, and other new compound ecological planting modes (Saha et al., 2024; Zhang et al., 2018). Finally, various tea-producing areas in Yunnan Province should coordinate diverse resources and encourage and support functional departments and new business entities to demonstrate and promote green production technology according to local conditions. Finished tea inventory grew by 289.31% between 2018 and 2023 (from 820.96 to 3196.09 thousand tons). This

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indicates that efficiency improvements and value-added processing technologies are urgently required to absorb surplus.

Supply-side structural adjustment and follow-up on the new tea consumption market

Compared with other tea-producing areas in China, Yunnan Province is dominated by large-leaf tea species, while medium-leaf species and small-leaf species account for a relatively small proportion of the total number of tea plants. Finished tea inventory surged by 289.31% between 2018 and 2023, indicating that efficiency improvements and value addition technologies are urgently required. Other tea-producing areas in China are mainly characterized by medium-leaf species and small-leaf species. After Yunnan big-leaf tea is refined, most of the finished tea that is produced is Pu'er tea, green tea, or black tea. In analyses of the general attributes of tea consumption in China, it has been found that the output of green tea and black tea exceeds 70% of the total output of finished tea, but the total domestic sales of green tea and black tea have shown a downward trend. Therefore, it is necessary to carry out structural adjustment on the supply side of Yunnan tea products to control or reduce the solid form of "leaf" in Pu'er tea, green tea, black tea, and other teas and make—through physical processing—traditional finished tea that enters the consumer market in the form of instant tea, tea-concentrate juice, superfine tea powder, and bagged tea (Wang et al., 2024). These highly processed tea products can not only expand the way in which tea is drunk but also improve the efficiency of tea resource utilization. Taking instant tea as an example, the processing technology mainly includes the technology used in the extraction process and the concentration process. The extraction methods include hot water extraction, enzyme-assisted extraction, microwave heating extraction, and ultrasonic-assisted extraction (Liang et al., 2022; Mei and Liang, 2024; Saha et al., 2024). The concentration methods include vacuum evaporation concentration, freeze concentration, and membrane concentration (Liang et al., 2022). After more than ten years of development, this technology is now stable and mature. If even 10% of Yunnan's 557,000-ton output in 2023 were converted into instant tea and high-value powders, this would absorb ~55,700 tons of leaf material and reduce finished tea inventories proportionally. In addition, consumers' demand for nutrition and health care is increasing. Instant tea products rich in theanine, catechins, and theaflavins have developed rapidly in the domestic consumer market (Li and Zhang, 2025). If 10% of Yunnan's 2023 output (557,000 tons) were processed into instant tea and tea powders, approximately 55,700 tons of leaf material would be diverted from traditional inventory, reducing finished tea stock pressures.

Strengthen the application of biochemical technology and expand the tea functional terminal products

Functional end products of tea are developed from the combination of advanced technologies in biochemical engineering, food engineering, formulation engineering, and separation and purification engineering (Zhang et al., 2022). Bioactive components from tea (i.e. tea polyphenols, theanine, theaflavins, tea polysaccharides, tea saponins, and caffeine) are extracted, refined, and developed into high value-added products including but not limited to health foods, natural medicines, additives for food, personal skin care products, plant protection agents, and additives for building materials (Zhonghua, 2019; Allameh and Orsat, 2023). For example, theanine, as a promising reactive chemical species (RCS) scavenger, can reduce the risk of various chronic diseases; as a result, it may constitute a dietary supplement that could be added to tea during processing (Saha

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et al., 2024). Tea pigments have shown a positive effect in maintaining muscle health. The organic compounds of Yunnan large-leaf tea are rich, and the content is much higher than that in small-leaf tea in other provinces in China. Therefore, Yunnan tea has more advantages in the development of tea functional terminal products than the tea from other areas (Xu et al., 2023). At present, Yunnan tea derivative products include tea perfume, lip balm made from tea seed oil, hand cream made from tea polyphenol, conditioner made from tea tree essence, masks made from alpine tea flower, face soap and cosmetics made from tea amino acid, as well as washing bags made from tea powder, tea-based hand sanitizer, functional tea toothpaste, and other daily chemical products (Zhang et al., 2018; Alidu et al., 2025). Some progress has been made in functional terminal products, but the cultivation enterprise is insufficient, the production of high value-added functional terminal products is low, and the advantages of tea resources have not been brought into full play. In 2017, China consumed approximately 6% to 7% of tea raw material for deep processing—in Japan, it was over 40% in 2017. By extrapolating from this data, the potential estimated have tea deep-processing mass would be approximately 396.24 to 462.28 thousand tons in China in 2023. More if the deep processing in Yunnan increased to 40%, approximately an additional 222.8 thousand tons of tea could be used in that province alone, significantly alleviating the 507-thousand-ton primary tea surplus recorded in 2023. If deep processing occurred at the rate of 40% across the nation, it would yield the consumed approximately an additional 1416.44 thousand tons of tea produced (Wang, 2022; Wang et al., 2024; Zhang et al., 2023). Currently, only 6–7% of tea raw material in China is used for deep processing, compared to >40% in Japan. If Yunnan increased deep processing to 40%, approximately 222.8 thousand tons of tea could be absorbed locally, significantly reducing the 507 thousand-ton primary tea surplus recorded in 2023.

Conclusions

The results of this study demonstrate that while China's tea production has witnessed remarkable growth between 2018 and 2023—expanding by 924,700 tons nationally and 133,700 tons in Yunnan alone—the industry is facing mounting challenges due to inventory accumulation and supply–demand mismatches. Inventory levels of both primary and finished tea have escalated sharply, with finished tea stocks increasing by 289.31% to 3.196 million tons in 2023 and primary tea stocks reaching 507 thousand tons. These trends have been driven by a sustained rise in tea production outpacing consumption, which grew at an annual average rate of 5.95%. Meanwhile, China's export volume remains disproportionately low at 367.5 thousand tons, just 21.16% of the global total, highlighting weak international competitiveness. Overall, Yunnan's challenges are consistent with international experiences in major tea-producing countries, where oversupply and inventory accumulation have become common. However, Yunnan's specialization in Pu'er tea and potential for deep-processing and ecological branding provide unique comparative advantages in addressing these global challenges. Structurally, there exists a misalignment between the supply of certain tea categories, particularly green and black tea—and evolving consumer preferences, which are shifting toward yellow and dark teas and innovative new tea beverages. Despite promising developments in the new tea drink market, domestic consumption has not kept pace with supply, resulting in severe inventory pressure and product saturation. Especially for

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regions like Yunnan, prioritizing sustainable, diversified development strategies will be crucial to ensuring long-term resilience and value creation in the tea sector.

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