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Optimization of Key Parameters for a Tent-Type Mobile Tobacco Curing Barn and Its Associated Curing Process

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ABSTRACT

Traditional bulk curing barns face limitations such as immobility, difficulty adapting to shifting tobacco-growing regions and disaster prevention needs, and low curing efficiency. To address these issues, this study developed and optimized a tent type mobile tobacco curing barn and its associated curing process. Six tent-type mobile barns with different materials, specifications, and energy sources were compared regarding installation cost, thermal insulation performance, energy consumption, and curing effectiveness. The results indicated that the No. 2 biomass barn, constructed with polyurethane material and U-shaped edging, was selected as the optimal structure. This barn exhibited excellent thermal insulation, with a temperature drop of only 1.2°C after 2 hours from an initial temperature of 48.0°C. It also demonstrated low unit energy consumption (3.07 CNY/kg) and convenient installation. Furthermore, the heights of the air inlet and return air outlet were optimized to 400 mm and 380 mm, respectively, effectively improving the uniformity of temperature and humidity within the barn. Regarding the curing process, by refining the temperature and humidity control nodes and extending the yellowing and color-fixing stages, Curing Process 1 (Treatment Group 1) performed remarkably: the proportion of high-grade cured tobacco leaves significantly increased, the total content of aroma substances increased by 37.29%, and the protein content decreased by 5.46%.Compared to the traditional bulk curing barn, the tent-type mobile barn reduced curing costs by 18.75%, increased the proportion of high-grade tobacco by 87.50%, reduced the rate of green and mixed defective leaves by 26.67%, and also improved sensory quality. These results demonstrate that the tent-type mobile tobacco curing barn and its optimized associated curing process offer significant advantages in energy saving, cost reduction, and enhancing tobacco quality, making it suitable for promotion and application in tobacco-growing areas. effectively improving the uniformity of temperature and humidity within the barn. Regarding the curing process, by refining the temperature and humidity control nodes and extending the yellowing and color-fixing stages, Curing Process 1 (Treatment Group 1) performed remarkably: the proportion of high-grade cured tobacco leaves significantly increased, the total content of aroma substances increased by 37.29%, and the protein content decreased by 5.46%.Compared to the traditional bulk curing barn, the tent-type mobile barn reduced curing costs by 18.75%, increased the proportion of high-grade tobacco by 87.50%, reduced the rate of green and mixed defective leaves by 26.67%, and also improved sensory quality. These results demonstrate that the tent-type mobile tobacco curing barn and its optimized associated curing process offer significant advantages in energy saving, cost reduction, and enhancing tobacco quality, making it suitable for promotion and application in tobacco-growing areas.

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Introduction

China is the world's largest producer of flue-cured tobacco, with an annual production output consistently around 1.5 million tons [1]. Tobacco curing is a critical post-harvest process where factors such as temperature, humidity, and curing time directly influence quality indicators like color, aroma, combustibility, and physical properties of the tobacco leaves, ultimately affecting their final quality, economic value, and usability [2-6]. Curing barns are essential equipment for tobacco curing. Bulk curing barns have become a primary tool for tobacco curing and conditioning in China due to advantages such as high loading density, low energy consumption, and automated control of temperature and humidity during curing [7]. However, in some regions, bulk curing barns can be damaged by natural disasters, disrupting curing operations and causing significant economic losses. Furthermore, shifts in economic structures lead to the relocation of tobacco-growing areas, resulting in numerous idle bulk curing barns in some regions and causing substantial resource waste.

Mobile curing barns, as a novel type of barn, can be quickly installed and relocated multiple times, meeting the demand for shifting tobacco-growing areas. They serve as an important supplement to bulk curing barns and hold high application value. An appropriate curing process is crucial for improving tobacco quality [8]. However, current research on mobile curing barns is still in its early stages, with relevant construction parameters and curing processes often based on traditional barns, which hinders the promotion and application of mobile barns. The development of curing barns in China has progressed through several stages: from early open-flue barns, naturally ventilated common barns, hot-air circulation barns, retrofitted bulk barns, to the current bulk curing barns, which are now well-adapted to China's flue-cured tobacco production context [9]. Traditional bulk curing barns are primarily brick-and-concrete structures, requiring lengthy construction times and are immobile, failing to meet the current need for mobility in tobacco regions. Mobile curing barns offer advantages such as movability, energy savings, non-destruction of farmland, and convenient transport [10]. They also possess relatively strong earthquake resistance, making them suitable for use in seismic-prone tobacco areas. Nevertheless, the optimal construction design for mobile barns remains unclear. Current research on mobile barns primarily focuses on materials, structural design, layout optimization, energy consumption, environmental performance, economic benefits, and market demand and trends. Tan Xiaolei et al. compared the performance of container-type and polyurethane panel mobile barns with traditional bulk barns, finding that both mobile types had better sealing and higher precision in temperature and humidity control, effectively reducing curing costs and improving the quality of cured leaves [11]. Li Ang et al. found that polyurethane barns performed similarly to traditional bulk barns in terms of temperature differential and curing effect but were superior in economic benefits, energy savings, and labor cost reduction [12]. Li Shaode found that combined mobile barns were not inferior to conventional brick barns in terms of temperature differential and thermal insulation [13]. He Xue developed a novel movable air-source heat pump barn utilizing prefabricated panel construction for mobility [14]. The quality of cured tobacco is influenced by multiple factors, with barn type affecting both the appearance and intrinsic quality of the cured leaves, ultimately determining their value. Wang Ziwei et al. found that neutral and alkaline aroma components in tobacco cured with a new biomass barn were higher than in traditional bulk barns, indicating a significant influence of barn type on aroma substance content [15]. Luo Zhenbao et al. found that the average price of tobacco cured in an integrated biomass bulk barn was higher than in traditional coal-fired bulk barns, with slightly improved oil content and reduced off-odors [16]. Wu Shengjiang et al. studied the effect of energy source type in bulk barns on cured leaf quality, finding that integrated biomass barns yielded the highest proportions of high-grade tobacco, orange yellow tobacco, and the highest average price [17]. Zheng Yu et al. found differences in economic traits and appearance quality of cured leaves from different barn types; compared to open-type heat pump bulk barns, closed-type heat pump bulk barns increased the proportions of high-grade and lemon-yellow leaves in upper-stalk positions [18]. The curing method also affects tobacco aroma quality. Zhu Wenge et al. studied the differences between a hot-water air-source heat pump mobile barn and a coal-fired bulk barn, and the effects of different curing methods (loose-leaf vs. racked) on tobacco quality [19]. Results showed no significant difference in chemical components and sensory quality between tobacco cured in the mobile barn (using either method) and racked tobacco cured in the traditional barn, with the mobile barn offering superior comprehensive benefits. Kong Fangfang et al. showed differences in aroma components between traditionally racked and box-cured tobacco, highlighting the need to optimize barn equipment and associated curing processes to ensure tobacco aroma quality [20]. The barn type determines the temperature and humidity control performance of the curing equipment, and promoting new barn types requires research into matching curing processes to facilitate pigment degradation and substance conversion during curing, thereby improving the quality of cured leaves.

Given that bulk curing barns are immobile and cannot meet the needs of regional shifts and disaster resilience, and considering that the key construction parameters and associated curing processes for mobile barns are not yet well-defined, this study designed a tent-type mobile curing barn. By constructing tent-type mobile barns with different materials, specifications, and energy sources, the barn with the best overall performance was selected. Based on the traditional bulk curing process, the associated curing process for the tent-type mobile barn was optimized. The effects of different curing processes on the economic indicators, sensory quality, and biochemical indicators of cured tobacco were analyzed to identify the optimal associated curing process. Finally, the curing effectiveness of the selected mobile barn was compared with that of a traditional bulk barn. This research explores the key parameters of the tent-type mobile barn and its associated curing process, providing a theoretical basis for its promotion and application.

Materials and Methods

Structure of the Tent-Type Mobile Curing Barn

The tent-type mobile curing barn consists of a lightweight steel frame and multilayer insulating fabric, facilitating assembly and disassembly. It is equipped with a detachable ventilation system and moisture exhaust windows to ensure stable air circulation. Compared to bulk curing barns, the tent-type barn has thinner walls but incorporates composite insulation layers, effectively reducing heat loss, particularly under conditions of significant diurnal temperature variation. The barn comprises a heating chamber, barn frame, tobacco loading chamber, stacked state tarpaulin, tarpaullin fixing pressure bars, ground peg base, and other components, as shown in Figure 1.

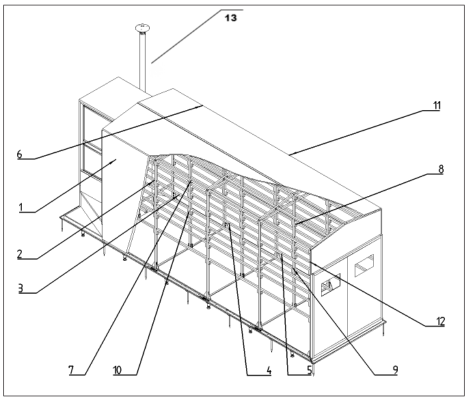

Figure 1: Tent Type Removable Bakehouse Structure Diagram

1. Combustion Chamber;
2. Support Framework;
3. Main Frame Base;
4. Longitudinal Support Rods;
5. Transverse Load-bearing Bar;
6. Roof of the Kiln;
7. Stiffener;
8. Tobacco Hangers;
9. Front Support;
10. Internal Intermediate Support Rods;
11. Insulation Layer;
12. Bakehouse Front-end Door and Window Construction;
13. Chimney

Determination of Key Construction Parameters for the Tent-Type Mobile Curing Barn

Experiments were conducted from May to November 2024 at a tobacco base in Longyan City, Fujian Province. The working principle of the tent-type mobile curing barn is shown in Figure 2. Six tent-type mobile barns with different materials and specifications were designed according to tobacco curing requirements, as listed in Table 1. Barns No. 1 and No. 6 were air-source heat pump barns, while Barns No. 2, 3, 4, and 5 were biomass barns. The insulation material for the tobacco loading chamber was polyurethane or polystyrene board, and the base materials included polyurethane, glass magnesium board, or wood and aluminum board. After construction, the tobacco loading capacity, average curing time, unit energy consumption, and thermal insulation performance of the different barns were measured and compared. Based on the selected optimal tent-type mobile barn structure, air duct regulating plates were installed at the air inlet and return air outlet to analyze the effect of their heights on barn performance.

Table 1: Materials and Specifications of Different Mobile Curing Barns

Number	Material of tobacco loading room	Material of undercover	Edge banding type	Size of tobacco loading room(mm)		
				Length	Width	Height
1	Polyurethane	Polyurethane	U-type	6000	2700	3500
2	Polyurethane	Polyurethane	U-type	6000	2700	3500
3	Polyurethane	Glass Mg Board	U-type	6000	2700	3500
4	Polyurethane	Glass Mg Board	U-type	6000	2700	3500
5	Polystyrene board	Wood, Aluminum	U-type	8000	2700	4150
6	Polyurethane	Glass Mg Board, Aluminum	U-type	6000	2700	2600

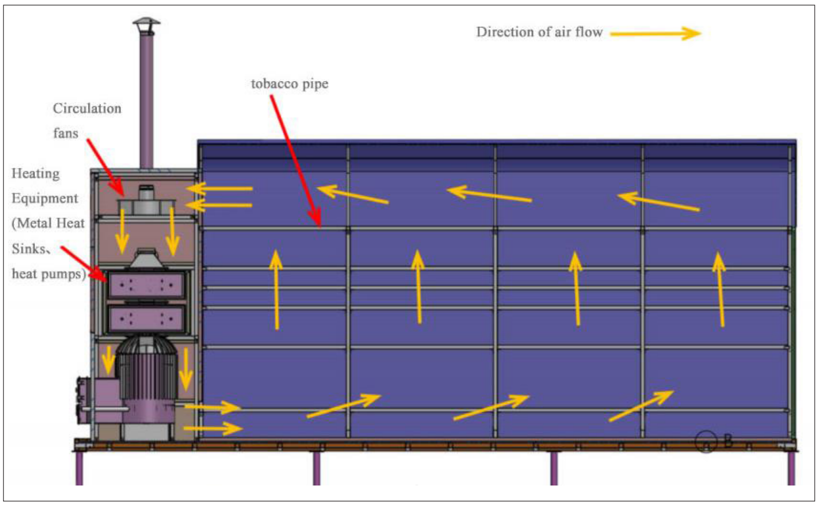

Figure 2: Schematic Diagram of the Working Principle of the Baking Room

Screening of the Associated Curing Process for the Tent-Type Mobile Curing Barn

The tested flue-cured tobacco variety was CB-1, a characteristic variety independently bred in Fujian Province known for its elegant, fleeting, and mellow aroma. It has a lamina yield 3%–5% higher than ordinary tobacco and requires one year less aging time, possessing high economic value [21]. The tobacco was managed according to local standardized cultivation practices for high-quality tobacco production. Middle-stalk, normally matured leaves were used for curing. Tobacco leaves were manually tied onto racks, with 8–9 kg per rack. The loading capacity was 280 racks. The traditional local bulk curing barn process served as the control group (CK). Based on this, the curing stages were refined by adding dry-bulb temperature setpoints and adjusting wet-bulb temperatures, appropriately extending the duration of the yellowing and color-fixing stages. Three different curing process treatment groups for the tent-type mobile barn were established. The specific temperature and humidity settings and curing times for each group are shown in Figure 3. Temperature and humidity within the barn were strictly controlled during curing. Cured tobacco leaves were collected for grade and quality evaluation. Each treatment group consisted of 3 replicate barns. All replicate barns were located in the same field (25° N, 117° E) with consistent soil fertility (organic matter content 2.8 g/kg) and stable microclimate (daily average temperature 28 ± 2°C, relative humidity 65 ± 5%). All curing operations were performed by the same team to ensure consistent control deviations (dry-bulb temperature ≤ ±0.5°C, relative humidity ≤ ±1%).

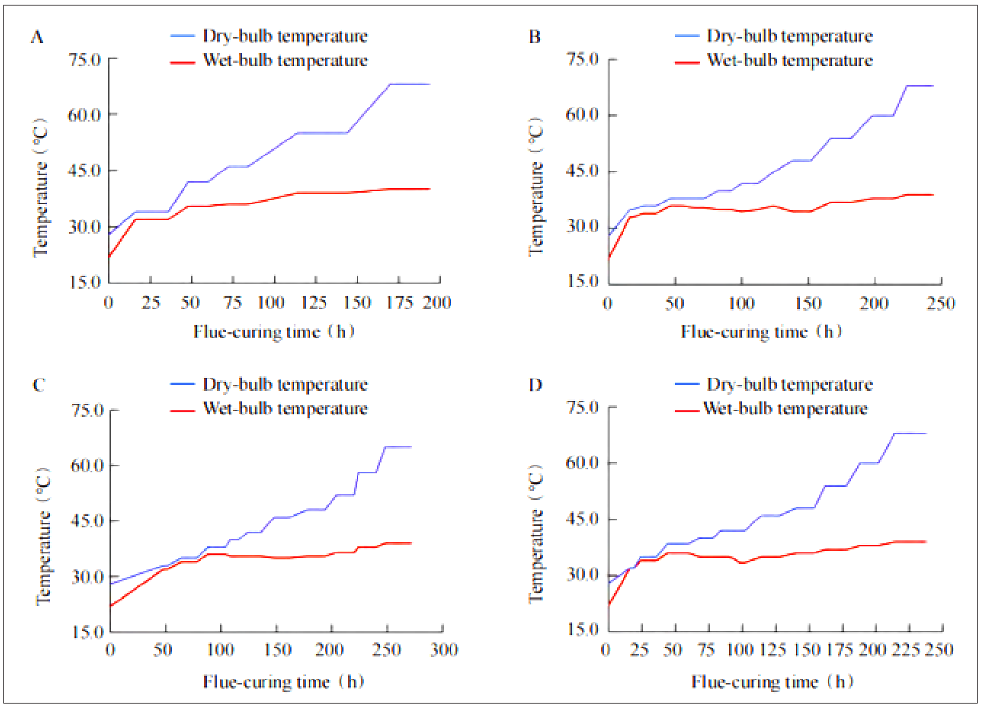

Figure 3: Curves of Flue-Curing Technology
A: Control Group; B: Treatment Group 1; C: Treatment Group 2; D: Treatment Group 3

Determination of Biochemical Indicators and Sensory Quality Evaluation of Cured Tobacco Leaves
The protein and free amino acid content of the cured tobacco leaves were determined following the methods described by Chen Yi et al. [22]. The aroma substance content was determined according to Wang Shaokun et al. [23]. These analyses were commissioned to Fujian Tiancheng Technology Co., Ltd. Simultaneously, the cured tobacco leaves were made into single-leaf tobacco samples and conditioned according to the method of Li Chao et al. [24]. Sensory evaluation of the cured tobacco was conducted by expert panelists from China Tobacco Fujan Industrial Co., Ltd., following GB 5606.4-2005 "Cigarettes—Part 4: Sensory Technical Requirements". The total score was 100 points, evaluating aroma characteristics (40 points), smoke characteristics (40 points), and taste characteristics (20 points). The specific indicator scores were: within aroma characteristics—tobacco base aroma (10 points), aroma quantity (15 points), aroma quality (15 points); within smoke characteristics—concentration (10 points), irritation (15 points), strength (5 points), off-odors (10 points); within taste characteristics—cleanliness (10 points), moistness (5 points), aftertaste (5 points). Each sample group was evaluated and scored by 5 experts, and the average score was taken as the final score for the sample.

Comparison of Curing Effectiveness Between the Tent-Type Mobile Barn and Traditional Bulk Curing Barn
The selected optimal tent-type mobile barn (No. 2 barn) was compared with a traditional bulk curing barn in terms of curing effectiveness. The traditional bulk barn used was a biomass barn constructed with brick-and-concrete, with a tobacco loading chamber size of 8000 mm (length) × 2700 mm (width) × 4150 mm (height). Fresh tobacco leaves (Cuibi 1) were cured using the selected associated process for the mobile barn and the traditional process for the bulk barn. Tobacco was manually racked (8–9 kg per rack). The loading capacity was 280 racks for the mobile barn and 480 racks for the traditional barn. The tobacco curing cost and quality grade of the cured leaves were measured, and sensory quality evaluation was performed using the method described in Section 2.4.

Data Processing and Analysis
Data processing and statistical analysis were performed using Excel and SPSS software.

Results
Results of Construction Parameter Measurements for the Tent-Type Mobile Curing Barn
Comparison of Installation and Construction Costs for Different Tent-Type Mobile Curing Barns
As shown in Table 2, among the six tent-type mobile barns, only Barn No. 5 required a crane for installation; the others could be installed using conventional equipment. In mountainous areas like Fujian, road conditions often cannot accommodate cranes, making installation with conventional equipment more practical. Regarding labor input and installation time, all barns except No. 5 required 4 workers. Barns No. 1 and No. 2 had the shortest installation times, followed by No. 3 and No. 4, while Barn No. 6 required the longest time. In terms of construction cost, Barns No. 2, 3, and 5 had similar costs, significantly lower than the other three barns and close to the construction cost of existing bulk curing barns, indicating high potential for promotion and application.

Table 2: Installation and Construction Cost of Different Mobile Curing Barns

Number	Installation equipment	Labor consuming	Time consuming/h	Construction cost (×104 yuan)
1	Conventional equipment	4	6.0	7.8
2	Conventional equipment	4	6.0	4.3
3	Conventional equipment	4	10.0	4.2
4	Conventional equipment	4	10.0	5.2
5	Crane	1	0.5	4.0
6	Conventional equipment	4	13.0	7.5

Comparison of Performance of Different Tent-Type Mobile Curing Barns

The performance of the six barns was further compared, as shown in Table 3. The tobacco loading capacity of all six barns met production requirements, with Barn No. 4 having a significantly higher capacity. Barns No. 1 and No. 6 were air-source heat pump barns with high electricity demands, while the others were biomass barns, more suitable for electricity-scarce mountainous areas. The average curing time for Barns No. 1, 2, and 3 was significantly lower than the others. Regarding unit energy consumption, Barns No. 1 and No. 6 had significantly lower unit energy consumption, indicating the advantage of air-source heat pump barns in reducing energy consumption. Among the biomass barns, Barn No. 2 had the lowest unit energy consumption. In terms of thermal insulation, Barn No. 2 performed well, with a temperature drop of only 1.2°C after 2 hours from an initial temperature of 48.0°C. Considering installation cost, barn performance, and the practical needs of tobacco-growing areas, the biomass barn constructed with polyurethane material and U-shaped edging (Barn No. 2) exhibited good sealing, convenient installation, relatively short average curing time, and low unit energy consumption, meeting the demands of tobacco curing production and demonstrating the best comprehensive performance. Therefore, Barn No. 2 was selected as the optimal tent-type mobile curing barn for subsequent research.

Table 3: Quantity of Tobacco Loaded, Flue-Curing Time, Energy Consumption, and Heat Retention in Different Mobile Curing Barns

Number	Quantity of tobacco loaded/kg	Average time of flue-curing/h	Unit energy consumption (yuan/kg)	Temperature after 2 h/°C
1	2420b	158.7c	2.32c	48.0
2	2580b	164.3c	3.14b	48.0
3	2570b	163.0c	3.68a	48.0
4	4540a	167.1b	3.12ab	48.0
5	2116c	161.0b	3.76a	48.0
6	2643b	173.5a	2.53c	48.0

Note: Different lowercase letters in the same column indicated significant difference ($P<0.05$). The same was applied in Table 5-Table 9.

Effect of Different Air Inlet and Outlet Heights on Temperature and Humidity Differences in the Curing Barn

The heights of the air inlet and return air outlet are important factors affecting vertical and planar temperature differences within the barn. Referring to the heights used in traditional bulk barns (400 mm and 400 mm), and after selecting Barn No. 2 as the optimal structure, the effect of different inlet and outlet heights on barn performance was analyzed due to differences in the tobacco loading chamber specifications compared to traditional barns, aiming to optimize the design. The effects are shown in Table 4. With a target temperature of 54.0°C, the maximum temperature difference and maximum relative humidity difference within the barn were minimized when the air inlet height was 400 mm and the return air outlet height was 380 mm, indicating effective improvement in the uniformity of temperature and humidity. These were therefore determined as the optimal heights for the tent-type mobile barn.

Table 4: Effects Of Different Air Inlet and Air Outlet Heights on Temperature and Humidity Differences in the Curing Barns

Number	Height of air inlet/mm	Height of air outlet/mm	Maximum temperature difference/°C	Maximum relative humidity difference/%
1	400	400	3.5	8.6
2	380	400	2.9	7.4
3	400	380	2.4	6.7
4	420	360	5.0	9.4
5	420	380	4.2	9.0
6	420	400	3.3	8.5

Screening Results for the Associated Curing Process of the Tent-Type Mobile Curing Barn

Effect of Different Curing Processes on the Economic Traits of Cured Tobacco Leaves

The appearance quality of cured tobacco leaves directly affects their economic value. The effects of different curing processes on economic traits are shown in Table 5. Treatment Group 1 (T1) achieved a high-grade tobacco proportion of 76.2%, a medium-grade proportion of 22.5%, and a low-grade proportion of only 1.3%. In contrast, the control group (CK) had proportions of 65.8%, 24.1%, and 10.1%, respectively. The high-grade proportion in T1 was significantly increased by 15.8 percentage points compared to CK, indicating a superior grade structure for T1 cured leaves. This increase led to a significantly higher average price for T1 leaves compared to other treatment groups and the control, with an increase of 4.2 CNY/kg over CK, suggesting that the T1 curing process yielded the best quality cured leaves and is suitable for use in mobile curing barns.

Table 5: Effects of Different Flue-Curing Technologies on Economic Traits of Flue-Cured Tobacco Leaves

Group	Top quality tobacco Proportion/%	Medium quality tobacco proportion/%	Low quality tobacco Proportion/%	Average price (yuan/kg)
Treatment group 1	76.2a	22.5c	1.3c	33.1a
Treatment group 2	72.9b	22.6c	4.5b	31.8b
Treatment group 3	72.3b	23.6b	4.1b	31.7b
Control group	65.8c	24.1a	10.1a	28.9c

Effect of Different Curing Processes on the Sensory Quality of Cured Tobacco Leaves

To further investigate the effect of different curing processes on sensory quality, cured leaves were made into single-leaf samples for evaluation. Results are shown in Table 6. The total sensory scores for T1, T2, and T3 were 82.1, 80.9, and 80.5, respectively, all significantly higher than the control's score of 79.2, with T1 achieving the highest score. Furthermore, for most specific sensory indicators, T1 scores were better than CK, showing improvements in tobacco base aroma, aroma quantity, aroma quality, concentration, and strength, along with reduced irritation and off-odors. These results indicate that using a reasonable associated curing process in the tent-type mobile barn can improve the intrinsic quality of cured tobacco.

Table 6: Evaluation Scores of Sensory Quality of Flue-Cured Tobacco Leaves Under Different Flue-Curing Technologies

Group	Fragrance characteristics			Smoke characteristics				Tasting characteristics			Total score
	Tobacco fragrance	Fragrance quantity	Fragrance quality	Viscosity	Irritation	Strength	Miscellaneous	Cleanliness	Wetness	Aftertase	
Treatment group 1	8.0a	13.0b	12.8a	8.2a	12.0d	4.6a	7.0c	8.7a	3.6a	4.2b	82.1a
Treatment group 2	7.8b	13.2a	12.1b	7.8b	12.4c	4.2b	7.6b	8.2b	3.5b	4.1b	80.9b
Treatment group 3	7.8b	12.2d	12.2c	7.6c	12.7b	4.1b	7.6b	8.3b	3.6a	4.4a	80.5c
Control group	7.5c	12.4c	11.4a	7.2d	12.9a	4.0c	7.8a	8.8a	3.6a	3.6c	79.2d

Effect of Different Curing Processes on the Biochemical Indicators of Cured Tobacco Leaves

To further study the effect on intrinsic quality, the content of aroma substances, proteins, and amino acids in cured leaves from different processes was measured. Results are shown in Table 7. The total aroma substance content in CK leaves was 151.21 μg/g, while for T1, T2, and T3, it was 207.60, 198.12, and 190.22 μg/g, representing significant increases of 37.29%, 31.02%, and 25.80%, respectively, compared to CK. Compared to CK, T1 showed significant increases in ketones (4.38%), alcohols (16.98%), aldehydes (92.68%), acids (66.00%), alkenes (39.80%), heterocyclics (242.86%), and esters (212.90%), indicating a richer aroma profile. This suggests that the curing process optimized for the mobile barn effectively promotes the conversion of tobacco aroma substances. Compared to CK, the protein content in T1 leaves was significantly reduced by 5.46%, while the amino acid content significantly increased by 10.61%, indicating that the optimized process promotes protein degradation and the formation of smaller molecule amino acids through more precise temperature and humidity control, contributing to improved intrinsic quality. In summary, the T1 curing process was identified as the optimal associated process for the mobile barn. Its key features include: adding dry-bulb temperature setpoints at 40.0, 48.0, and 60.0°C during the yellowing and color-fixing stages; in the mid-yellowing stage, curing at a dry-bulb of 38.0°C and wet-bulb of 36.0°C for 8–10 hours, then reducing the wet-bulb to 35.5°C without changing the dry-bulb; in the late yellowing stage, curing at a dry-bulb of 42.0°C and wet-bulb of 35.5°C for 10 hours to promote yellowing, then reducing the wet-bulb to 35.0°C to increase the water loss rate; and appropriately extending the duration of the yellowing and color-fixing stages.

Table 7: Effects of Different Flue-Curing Technologies on Biochemical Indexes of Flue Cured Tobacco Leaves

Group	Fragrance characteristics Smoke characteristics(μg/g)								Protein Content/%	Amino acid content/%
	Ketone	Alcohol	Aldehyde	Acid	Alkene	Heterocyclic	Ester	Total		
Treatment group 1	8.82b	16.33a	2.37a	3.32b	174.58b	0.24a	1.94a	207.60a	5.89d	24.81a
Treatment group 2	6.36d	9.01d	1.82b	1.78d	178.22a	0.15b	0.78b	198.12b	6.12b	23.99b
Treatment group 3	9.78a	15.52b	1.44c	3.78a	158.78c	0.16b	0.76b	190.22c	6.04c	24.52a
Control group	8.45c	13.96c	1.23d	2.00c	124.88d	0.07c	0.62c	151.21d	6.23a	22.43c

Comparison of Curing Effectiveness Between the Tent-Type Mobile Barn and Traditional Bulk Curing Barn

Curing Cost and Quality Grade

The selected optimal tent-type mobile barn (No. 2) was compared with the traditional bulk barn regarding curing cost and leaf quality grade. Results are shown in Table 8. Compared to the traditional barn, the tent-type mobile barn significantly reduced fuel cost by 18.18% and labor cost by 28.57%. The total curing cost for the mobile barn was 2.6 CNY/kg, significantly lower (18.75%) than the traditional barn's cost of 3.2 CNY/kg. This indicates that the mobile barn, with better sealing and more convenient operation, has clear advantages in saving energy and labor, resulting in good cost reduction effects. Regarding the grade structure of cured leaves, compared to the traditional barn, the mobile barn significantly increased the proportion of high-grade tobacco by 87.50% and significantly reduced the rate of green and mixed defective leaves by 26.67%. This demonstrates the superiority of the tent-type mobile barn in improving cured leaf grade and controlling leaf loss, thereby enhancing economic value.

Table 8: Comparison of the Flue-Curing Cost and Quality Grades of Tobacco Leaves Between Mobile Curing Barn and Traditional Bulk Curing Barn

Type of curing barn	Dried tobacco leaf amount/kg	Flue-curing cost(yuan/kg)				Top quality tobacco Proportion/%	Green and mixed Rate/%
Traditional bulk curing barn	552.6a	2.2a	0.3	0.7a	3.2a	8.0b	15.0a
Mobile curing barn	401.3b	1.8b	0.3	0.5b	2.6b	15.0a	11.0b

Sensory Quality Evaluation of Cured Tobacco Leaves

Fresh tobacco leaves were cured using the selected optimal mobile barn (No. 2) and the traditional bulk barn. The appearance of the cured leaves is shown in Figure 4; the color and appearance of leaves from both barns were generally similar. Subsequently, sensory evaluation was conducted (Table 9). The total sensory score for leaves from the mobile barn was 81.0, significantly higher by 1.4 points than the score for leaves from the traditional barn (79.6). This indicates that the tent-type mobile barn can significantly improve the intrinsic quality of cured tobacco, favoring high-quality tobacco production.

Figure 4: Comparison of Tobacco Cured in the Tent-Type Mobile Curing Barn and the Traditional Bulk Curing Barn (Left: Traditional bulk Curing Barn; Right: Tent-Type Mobile Curing Barn)

Table 9: Scores of the Sensory Quality Evaluation of Flue-Cured Tobacco Leaves between Mobile Curing Barn and Traditional Bulk Curing Barn

Type of curing barn	Fragrance characteristics			Smoke characteristics				Tasting characteristics			Total score
	Tobacco fragrance	Fragrance quantity	Fragrance quality	Viscosity	Irritation	Strength	Miscellaneous gas	Cleanliness	Wetness	Aftertaste	
Traditional bulk curing barn	8.0a	12.1b	12.5	7.4b	12.3	4.4b	7.4a	7.3a	4.1	4.1a	79.6b
Mobile curing barn	8.3b	12.5a	12.5	7.7a	12.4	4.7a	7.6b	7.4b	4.0	3.9b	81.0a

Discussion

The curing barn, as essential equipment in flue-cured tobacco production, directly determines the value of the cured leaves. Cuibi 1 is the most widely planted flue-cured variety in Fujian Province, holding an important position in tobacco industry production due to its orange-yellow color, full hue, high oil content, rich smoke, and sufficient aroma. However, during curing, the upper leaves of Cuibi 1 are prone to scald (grey or black spotting), damaging their economic value and industrial usability. Concurrently, with the shift in tobacco-growing areas, many bulk barns lie idle. The development of tent-type mobile barns helps improve equipment utilization efficiency and avoid asset idleness. Therefore, developing mobile barns meets the practical needs of current tobacco production, and optimizing the associated curing process can improve cured leaf quality and enhance the industrial usability of upper leaves, giving tent-type mobile barns significant application value [25].

By comparing the effects of different construction parameters, this study identified the material requirements and edging method for the tent-type mobile barn. The No. 2 barn, constructed with polyurethane material for both the loading chamber and base using U-shaped edging, exhibited the best comprehensive performance, with excellent thermal insulation (1.2°C drop in 2h from 48.0°C). Based on the No. 2 barn structure, the heights of the air inlet and outlet were optimized to 400 mm and 380 mm, respectively, based on minimizing temperature and humidity differences, further improving performance. Additionally, the No. 2 barn can be installed using conventional equipment, enhancing its applicability. He Xue designed a movable air-source heat pump barn that saved curing costs compared to conventional heat pump barns while greatly improving cured leaf quality [14]. In this study, both the traditional bulk barn and the selected optimal mobile barn were biomass-powered. Using the same energy source, the mobile barn reduced curing costs by 18.75%, increased the highgrade tobacco proportion by 87.50%, and reduced the green/mixed rate by 26.67% compared to the traditional barn, indicating that the mobile barn can effectively improve cured leaf quality while saving energy. Tan Xiaolei et al. reported that compared to traditional bulk barns, tobacco from mobile barns had more harmonious contents of reducing sugars, total sugars, total alkaloids, total nitrogen, potassium, and chlorine, indicating better leaf quality [11]. In this study, the total sensory score for leaves from the mobile barn was significantly higher (by 1.4 points) than from the traditional barn, indicating that besides appearance quality, the mobile barn also improves intrinsic quality, consistent with Tan Xiaolei et al.'s findings. The significantly reduced fuel cost for the mobile barn compared to the traditional barn indicates its advantage in energy consumption control, reducing curing energy use while ensuring leaf quality, consistent with the results of Li Shaode et al. [13]. The comparisons of curing cost and cured leaf quality demonstrate that the tent-type mobile barn can reduce curing costs while improving tobacco quality, showing good potential for promotion and application.

The curing process significantly impacts the sensory quality of cured leaves. Changes in chemical composition during curing are crucial for improving aroma quality and quantity [26]. Cuibi 1 tobacco often suffers from insufficient yellowing and residual greenness under conventional three-stage curing processes. Additionally, Cuibi 1 leaves are relatively thick, yellow somewhat slowly, and have average curing tolerance, easily leading to scorched lower leaves and scalded upper leaves, resulting in more yellow-green and defective leaves after curing. Based on the curing characteristics of Cuibi 1 and the features of the mobile barn, this study optimized the associated curing process. The optimal process (T1) refines the curing stages to promote yellowing and dehydration, improving their coordination, effectively avoiding forced or excessive yellowing, and greatly reducing the probability of scald and scorched leaves. By appropriately extending the yellowing and color-fixing stages, the process promotes the conversion of intrinsic substances, forming more aroma compounds, thereby enhancing intrinsic quality. The cured leaves from the optimal process had significantly higher total sensory score, high-grade proportion, and average price than those from the traditional process, indicating that the optimized process is better matched to the tenttype mobile barn, allowing it to fully utilize the barn's performance and effectively improve cured leaf quality. Simultaneously, the total aroma substances increased by 37.29% and protein content decreased by 5.46% compared to the traditional process, indicating more sufficient conversion of intrinsic substances during curing.

Conclusions

This study successfully developed a structurally sound and high-performance tenttype mobile tobacco curing barn and systematically optimized its associated curing process. The main conclusions are as follows:

- **Optimal Barn Structure Selection:** Among the six designed tent-type mobile barns, the No. 2 barn (constructed with polyurethane material and U-shaped edging) exhibited the best comprehensive performance. It demonstrated good thermal insulation (temperature drop of only 1.2°C after 2 hours from an initial 48.0°C), low unit energy consumption, and could be installed using conventional equipment, enhancing its adaptability in mountainous, electricity-scarce tobacco areas.
- **Optimization of Air Inlet and Outlet Heights:** By adjusting the heights, the optimal air inlet and return air outlet heights were determined to be 400 mm and 380 mm, respectively. This optimization significantly improved the uniformity of temperature and humidity within the barn, ensuring stable curing quality.
- **Optimization of the Associated Curing Process:** The optimized process (Treatment Group 1), by refining temperature and humidity control nodes (adding drybulb setpoints at 40.0°C, 48.0°C, and 60.0°C during yellowing and color-fixing) and appropriately extending the yellowing and color-fixing duration, effectively promoted protein

degradation (reduced by 5.46%) and aroma substance accumulation (increased by 37.29%) in the tobacco leaves. This significantly enhanced the economic traits (high-grade proportion reached 76.2%, average price 33.1 CNY/kg) and sensory quality (sensory score reached 82.1 points) of the cured leaves.

- **Comparison with Traditional Bulk Barn:** Compared to the traditional bulk curing barn, the tent-type mobile barn reduced curing costs by 18.75%, increased the highgrade tobacco proportion by 87.50%, reduced the green/mixed rate by 26.67%, and improved sensory quality by 1.4 points. This fully demonstrates the advantages of the tent-type mobile barn in energy saving, cost reduction, and quality improvement, providing a theoretical basis and technical support for its promotion and application in tobacco production.

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