Effect of Reducing the Smoking Time for Bamboo Strips on Physical and Mechanical Properties

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Abstract: This research project aims to create a bamboo strip smoking kiln for coloring bamboo strips used to weave sticky rice baskets. The goal of this study is to shorten the time necessary to smoke bamboo strips while guaranteeing that the smoked strips have the correct properties and may be smoked in accordance with the demands of the community. The study results show that the designed smoking oven has a unique characteristic in that it features a heat exchange mechanism that separates smoke and flames, preventing direct contact between the flames and the product and avoiding product damage. It is also portable and suited for smoking at a temperature of no more than 70°C for 72 hours. The smoked bamboo strips.

***Keywords*— Smoke-Drying Kiln, Bamboo Stripes, Sticky Rice Basket.**

I. Introduction

Bamboo is considered a crucial resource that can be utilized in various ways, ranging from shoots, culms, leaves, roots, bamboo membranes, and bamboo shavings. It offers diverse benefits, particularly in the field of handicrafts, where it is widely used to create numerous household items. Examples of these items include bamboo hats, baskets, mats, brooms, decorative covers, and bags [1]. Bamboo handicrafts are prevalent throughout all regions of Thailand and are commonly woven into tools and utensils for various purposes. They serve as household items such as hats, sieves, swings, and covers, as well as agricultural tools like baskets and fruit containers. Additionally, they are also used for capturing aquatic animals, such as traps and fishing nets. Bamboo handicrafts are simple traditional crafts that can be made and utilized independently or purchased at an affordable price.

Bamboo stripes, as a primary raw material in weaving crafts, are derived from bamboo plants and possess exceptional inherent properties [1]. They are well-suited for various weaving techniques and can be combined with different Thai artisanal methods to create intricate patterns on molded containers formed through cross-weaving techniques. The weaving of bamboo sticky rice steamers using bamboo stripes has gained popularity due to the desire for vibrant and beautiful colors on the steamer. Typically, the bamboo stripes are dyed before being woven to achieve desired hues. However, conventional chemical dyeing poses challenges in color fastness, and low-quality chemical dyes can be hazardous to the dyers, and the residual dye can be environmentally polluting. Natural dyeing methods offer an alternative for coloring bamboo stripes, with smoke curing being one such option. Smoke curing is a natural process that involves the use of fire from natural materials like rice husks, corn cobs, and lemongrass. The bamboo stripes used for weaving have a width ranging from 2–5 mm, and they undergo a color transformation from light brown to dark brown, eventually reaching black.

Fig.1 Characteristics of bamboo stripes: (left) not exposed to smoke and (right) that have been smoked.

The manuscript received May 28, 2024; revised June 18, 2024; accepted June 25, 2024; Date of publication June 30, 2024

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Smoke curing is a process that reduces the moisture content of bamboo stripes and typically takes approximately 5-7 days, resulting in a moisture reduction of 10-12 percent [2]. This reduction is due to the carbonization process that occurs during smoke curing. Consequently, the bamboo stripes that undergo smoke curing become stronger, as there are internal compositional changes within the bamboo cell structure [3]. Additionally, smoke curing acts as a protective measure against mold and insect infestations [4]. Smoke curing is also an integral part of artistic expression. In recent years, there has been a growing interest in dyeing bamboo stripes using smoke curing, particularly in environmentally friendly contexts that promote sustainable production. Research has focused on developing efficient and controllable natural dyeing methods using smoke curing, such as the use of smoke ovens to reduce time and energy consumption in the process while improving color consistency and quality [5]. These advancements have the potential to make smoke-cured dyeing a competitive alternative to chemical dyeing methods. Therefore, the application of technology to develop smoke curing processes for bamboo stripe dyeing contributes to the sustainable development of communities. Implementing such technology requires a multidimensional assessment of environmental resources, economic viability, societal inclusivity, and compatibility with the targeted community's lifestyle and activities. It should consider the suitability of renewable energy technologies across all four aspects, including technical feasibility, economic viability, policy alignment, environmental compatibility, and the ability to reduce community energy expenses, ensuring long-term sustainability.

The Sticky Rice Steamer Weaving Group in Ban Nard Village, Ban Klang Sub-district, Mueang Nakhon Phanom District, Nakhon Phanom Province, is a weaving group known for creating distinctive patterns on sticky rice steamers. They utilize bamboo stripes that have undergone smoke curing to craft these unique designs. The group has constructed their own smoke-drying kiln, as shown in Figure 2, which requires an internal fire to be lit. Each smoke curing session requires constant monitoring as the fire within the kiln is inconsistent and challenging to manage. The bamboo stripes are susceptible to damage during the process, and the smoke curing period takes approximately 7 days. Consequently, the group has acquired a suitable color of bamboo stripes that are ideal for weaving sticky rice steamers.

Therefore, the research aims to develop a smoke-drying kiln specifically for smoke-curing bamboo stripes used in weaving sticky rice steamers. The objective is to minimize damage, increase the value of the products, reduce the smoke-curing duration, improve usability, and further develop the bamboo stripe weaving craft into naturally dyed sticky rice steamer products using sustainable leftover materials. These advancements aim to enhance the aesthetic appeal of the new weaving designs and increase the value of each woven piece. Additionally, it offers an alternative for both weaving groups and individuals to acquire knowledge, improve their livelihoods, and develop materials used in weaving crafts while promoting beauty and reducing the use of synthetic chemicals. This approach not only helps reduce production costs but also contributes to environmental sustainability.

Fig. 2 Traditional smoke oven of the villagers.

II. MEDTHODOLOGY

A. Materials and methods

Smoking Kiln

The smoke-drying kiln (Fig. 3) has four components. First, the kiln (Kiln) is built of steel, with 5-millimeter-thick steel sheets covering both sides. It has a front door for fuel access and a 10x20-centimeter air vent on the upper side of the kiln, which connects to the heat exchanger and smoke output. Second, the heat exchanger and smoke exit (heat exchanger) are constructed of 1.5-millimeter-thick steel sheets. They consist of two sections: upper and lower, which house the combined smoke and heat pipes. Third, the smoke chamber (smoke chamber) has a capacity of 200 liters and two racks for storing the bamboo stripes. It has a smoke exit on the top cover to uniformly distribute smoke throughout the chamber. Finally, the foundation supports the kiln and smoke chamber and features sliding wheels for easy mobility and comfort during operation.

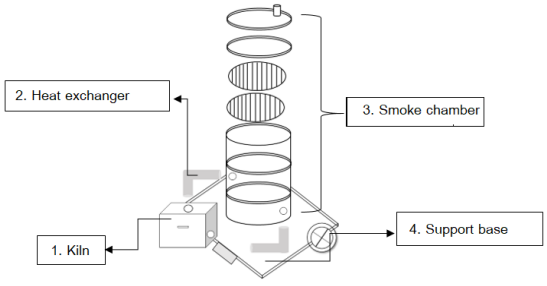

Fig. 3 Developed Smoking kiln model

The smoke-drying kiln designed for bamboo stripe processing has several remarkable characteristics, including a heat exchange system that efficiently isolates smoke and flames from direct contact with the goods. This protects product damage while also allowing for easy movement. The kiln chamber holds 200 liters, and a heat exchange system has been built to exchange heat utilizing rice straw

leftovers collected from the local population as fuel. The smoke-drying kiln's operation begins with the burning of rice straw fuel, which is the principal heat source for the smoke-curing process. When enough heat is created, hot air and smoke pass through the heat exchange mechanism, as seen in Fig.4. As hot air travels through the heat exchange device, it transmits heat to the surrounding environment, raising the interior temperature of the smoke-drying chamber. The heated air and smoke then move upward and exit out the chimney. The chimney is then closed, allowing air and smoke to circulate throughout the kiln. A part of the descending air enters the heat exchange device and undergoes heat exchange before being discharged into the incinerator. This technique will continue till the smoke-curing process for bamboo stripes is complete.

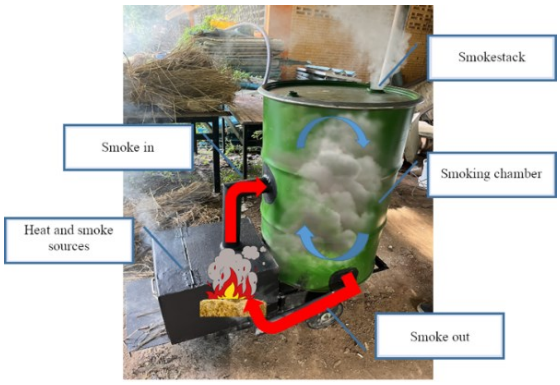

Fig. 4 Working process of smoked kiln

In this study (Fig. 5), bamboo strips measuring 400 mm in length, 50 mm in width, and 1 mm in thickness (obtained from the weaving group) will be utilized. In the section concerning smoke generated from 4 kg. of rice straw, the smoke will be cured at a temperature not exceeding 70 ˚C for 72 hours. This is done to compare the physical and mechanical properties of the bamboo strips used in the smoke-curing stove developed against the original smoke-curing stove of the local community.

Fig. 5 Process diagram

B. Evaluation of physical properties

The physical quality investigation was carried out using a Hunter Lab Lovibond SP 60 colorimeter, which uses the CIE LAB color space system to measure color values. The CIE LAB color space system quantifies color properties using the parameters L*, a*, and b*. L* denotes the lightness value, which ranges from 0 to 100.

C. Evaluation of mechanical properties

The tensile strength of the material was determined with a Mark 10 ESM 301L. The tests were performed at a speed of 300 mm/min at a distance of 250 mm.

D. Statistical analysis

The obtained data was analyzed using Analysis of Variance (ANOVA). If statistically significant, the differences in mean values were further computed using Duncan's new Multiple Range Test (DMRT) with the aid of the SPSS software package.

III. Results and Discussion

A. Physical properties

According to Table 1, the physical properties of bamboo stripes obtained from the smoke-curing process exhibited significant differences ($p \leq 0.05$) in terms of the lightness value (L*). The bamboo stripes that underwent smoke curing in the original smoke-drying kiln and the developed smoke-drying kiln showed distinct variations. The bamboo stripes subjected to smoke curing in the original smoke-drying kiln had a lightness value (L*) of 37.61f ± 1.13 after 168 hours of smoke curing. On the other hand, the bamboo stripes processed in the developed smoke-drying kiln exhibited a lightness value (L*) of 32.76^{ef} ± 0.63. It is evident that the bamboo stripes treated in the developed smoke-drying kiln had lower lightness values with a shorter smoke-curing duration. The color change occurred both internally and externally, resulting in more pronounced color variations. The bamboo stripes displayed shades ranging from brown to black (Fig.6), indicating reduced moisture content due to the smoke-curing process. This led to an increased amount of lignin [4,6], resulting in visually appealing color changes in the bamboo stripes after smoke curing [5].

Table 1 Physical and mechanical properties test of the bamboo strips with traditional smoked oven and the developed smoked kiln Time
Note: Vertical letters indicate statistically significant differences in means ($p \leq 0.05$). a means the highest mean, while f means the lowest mean

	Time (hr.)	Physical and mechanical properties test			
		Color characteristics			Tensile Strength (N)
		Lightness L*	a*	b*	
A	-	67.51^{a} ±1.01	8.01^{a} ±0.90	0.50^{a} ±0.04	104.03^{a} ±1.65
B	168	37.61^{f} ±1.13	1.61^{c} ±0.42	-0.58^{a} ±1.91	71.30^{e} ±2.16
C	72	32.76^{ef} ±0.63	3.68^{b} ±0.07	-0.50^{a} ±0.98	150.56^{e} ±0.81

Fig. 6: Color of Bamboo strip: A) Unexposed to smoke; B) Traditional smoke oven smoked; C) Developed smoking kiln smoked.

B. Mechanical properties

The tensile resistance values of both types of smoke-drying kilns were measured at $71.30^{e}\pm2.16$ and $150.56^{e}\pm0.81$ N. respectively. These tensile resistance values have implications for the utilization of bamboo stripes after the smoke-curing process, where they are used for weaving products. It was found that the original design of the smoke-drying kiln exhibited lower tensile resistance due to the direct contact between the bamboo stripes and the flames during the smoke-curing process. This contact resulted in a decrease in the structural integrity of the bamboo, particularly when longer dyeing durations were used [7]. The heat damaged the internal structure of the bamboo, causing a reduction in the moisture content of the outermost layer and increasing the brittleness of the bamboo [8]. On the other hand, the bamboo stripes that underwent smoke-curing in the developed smoke-drying kiln exhibited significantly higher tensile resistance, nearly twice as much compared to the untreated bamboo stripes. This improvement can be attributed to the absence of direct contact with flames in the smoke-drying kiln and the increased lignin content, which enhances the strength of the bamboo [9,10]. As a result, the smoke-cured bamboo stripes can be easily bent, twisted, and flexed while maintaining their strength and flexibility [2].

IV. Conclusion

Smoke-curing bamboo stripes is a process used to reduce moisture content and enhance the strength of bamboo stripes. The smoke-curing process not only increases the strength but also imparts a beautiful color to the bamboo stripes. The developed smoke-drying kiln has successfully reduced the smoke-curing duration from 7 days to just 3 days, providing convenience for the community. Moreover, the kiln allows for the desired color characteristics of the bamboo stripes to be achieved, meeting the specific requirements of the community. The bamboo stripes that undergo smoke curing in the developed kiln exhibit improved properties such as increased flexibility, ease of bending, and enhanced tensile strength compared to untreated bamboo stripes. These favorable properties make the smoke-cured bamboo stripes suitable for various handicraft applications, adding value to the products and generating sustainable income for the community.

Physical property testing of bamboo stripes using the new smoke-curing procedure with rice straw residues yields better color penetration and shorter processing periods than standard approaches. Furthermore, the bamboo stripes have a higher tensile strength while maintaining their integrity and quality. These findings demonstrate the ideal appropriateness of the developed smoke-cured bamboo stripes for weaving sticky rice steamers. To ensure high-quality bamboo stripes, they must have outstanding color penetration as well as be dry and durable enough to withstand long-term storage without breaking or losing flexibility throughout the weaving process. As a result, these bamboo stripes, created through the continuous smoke-curing process using rice straw residues, may be used to develop and manufacture new woven items.

ACKNOWLEDGMENT

This research project received funding support from the Research and Development Institute, Nakhon Phanom University. The authors would like to express their gratitude to the Department of Physics, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, for providing access to the Hunter Lab Lovibond color measurement instrument using the CLE LAB color system to measure L*a*b* values. The authors also thank the Department of Civil Engineering, Faculty of Engineering, Nakhon Phanom University, for their assistance with the Universal Testing Machine used for material tensile strength testing. Furthermore, the authors appreciate the support and provision of research facilities from the Department of Industrial Technology, Nakhon Phanom University, for this study.

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