Table 1.The physical properties of five bamboo species

Bamboo species	Culm part	Culm dia. (mm.)	Thickness wall (mm.)	Moisture content of sampling at test (%)	Specific gravity	Density (kg/m 3)	Shrinkage (%)		
							Core dia.	Thickness wall	Culm length
Dendrocalamus asper	Bottom	102.1	14.8	12 (9)*	0.67 (3) *	748 (3) *	4.3 (9) *	4.5 (9) *	0.1 (10) *
	Middle	97.5	10.8	11 (9)	0.69 (3)	773 (3)	5.4 (8)	6.5 (8)	0.0 (8)
culm length = 15.0 m	Top	77.9	7.8	11 (9)	0.70 (3)	779 (3)	3.9 (6)	2.2 (6)	0.0 (6)
sample size = 5.0 m	**Average**	**92.5**	**11.1**	**11**	**0.69**	**767**	**4.5**	**4.2**	**0.1**
Bambusa blumeana	Bottom	91.4	9.2	11 (9)	0.71 (3)	784 (3)	5.8 (3)	5.1 (8)	0.2 (8)
	Middle	78.6	7.9	10 (9)	0.85 (3)	935 (3)	4.5 (12)	4.4 (12)	0.2 (12)
culm length = 12.0 m	Top	55.4	6.7	11 (6)	0.75 (3)	837 (3)	4.2 (10)	3.8 (10)	0.0 (11)
sample size = 4.0 m	**Average**	**75.1**	**7.9**	**11**	**0.77**	**852**	**4.4**	**4.4**	**0.1**
Dendrocalamus strictu	Bottom	48.3	11.7	12 (6)	0.72 (3)	806 (3)	5.2 (10)	7.4 (7)	0.9 (10)
	Middle	45.3	7.3	11 (6)	0.75 (3)	843 (3)	3.6 (7)	3.2 (5)	0.3 (8)
culm length = 6.5 m	Top	39.6	6.2	10 (6)	0.75 (3)	833 (3)	4.7 (9)	3.8 (7)	0.0 (9)
sample size = 2.2 m	**Average**	**44.4**	**8.4**	**11**	**0.74**	**827**	**5.5**	**4.8**	**0.4**
Gigantochloa albocilia	Bottom	29.3	12.4	11 (6)	0.62 (3)	697 (3)	6.3 (11)	5.6 (10)	0.1 (11)
	Middle	28.8	8.0	11 (6)	0.68 (3)	750 (3)	3.5 (12)	4.2 (11)	0.2 (12)
culm length = 5.0 m	Top	26.1	6.2	12 (6)	0.66 (3)	737 (3)	4.7 (11)	5.6 (11)	0.3 (11)
sample size = 1.7 m	**Average**	**28.1**	**8.9**	**11**	**0.65**	**728**	**4.8**	**5.16**	**0.24**
Bambusa sp.	Bottom	59.6	12.3	12 (6)	0.75 (3)	848 (3)	4.1 (9)	2.9 (9)	0.1 (9)
culm length = 8.0 m	Middle	54.0	6.6	12 (6)	0.73 (3)	820 (3)	3.6 (6)	4.2 (6)	0.0 (6)
sample size = 2.7 m	Top	43.8	5.4	11 (6)	0.67 (3)	744 (5)	5.0 (12)	3.3 (12)	0.1 (12)
	Average	**50.8**	**8.1**	**12**	**0.72**	**804**	**4.2**	**3.5**	**0.12**

Note : ( )* number of samplings
test according to INBAR 2000

Table 2. The mechanical properties of five bamboo species

Bamboo Species	Culm part	Bending (Mpa)	MOE (x100 Mpa)	Compression (Mpa)	Shear (Mpa)		Tension (Mpa)	
					Internode	Node	Internode	Node
Dendrocalamus asper	Bottom	92 (10)*	702 (9)*	66.0 (3)*	9.7 (3)*	11.1 (3)*	385 (10)*	87 (6)*
	Middle	59 (11)	564 (11)	70.0 (4)	10.0 (2)	8.4 (2)	348 (9)	101 (6)
culm length = 15.0 m	Top	100 (12)	520 (12)	70.0 (3)	8.4 (2)	9.9 (3)	342 (9)	100 (8)
sample size = 5.0 m	**Average**	**84**	**595**	**68.5**	**9.4**	**9.8**	**359**	**96**
Bambusa blumeana	Bottom	93 (12)	634 (12)	66.5 (9)	11.1 (4)	11.4 (4)	421 (2)	103 (3)
	Middle	104 (12)	878 (12)	68.0 (6)	12.2 (4)	12.3 (3)	353 (2)	134 (2)
culm length = 12.0 m	Top	79 (11)	221 (11)	65.0 (14)	13.5 (6)	12.7 (4)	389 (2)	123 (3)
sample size = 4.0 m	**Average**	**92**	**578**	**66.5**	**12.3**	**12.1**	**388**	**122**
Dendrocalamus strictus	Bottom	81 (12)	191 (12)	54.5 (7)	12.8 (5)	12.0 (4)	394 (7)	142 (8)
	Middle	78 (12)	177 (10)	57.5 (6)	15.1 (4)	13.0 (3)	322 (3)	124 (8)
culm length = 6.5 m	Top	90 (10)	197 (10)	56.0 (8)	11.5 (3)	13.4 (2)	331 (2)	53 (1)
sample size = 2.2 m	**Average**	**83**	**189**	**56.0**	**13.1**	**12.8**	**349**	**106**
Gigantohloa albociliata	Bottom	130 (12)	280 (12)	41.0 (2)	10.1 (6)	9.4 (5)	358 (9)	164 (10)
Munro	Middle	114 (12)	264 (12)	53.0 (4)	9.8 (5)	10.3 (7)	447 (9)	168 (9)
culm length = 5.0 m	Top	108 (11)	381 (10)	41.0 (3)	8.9 (7)	9.2 (5)	438 (6)	199 (7)
sample size = 1.7 m	**Average**	**117**	**308**	**45.0**	**9.6**	**9.6**	**414**	**177**
Bambusa sp.	Bottom	71 (12)	224 (12)	62.5 (9)	11.5 (6)	11.4 (4)	271 (1)	127 (1)
	Middle	79 (12)	210 (12)	68.5 (12)	13.1 (5)	12.7 (6)	-	-
culm length = 8.0 m	Top	94 (12)	257 (12)	72.5 (10)	13.6 (4)	13.6 (6)	-	-
sample size = 2.7 m	**Average**	**81**	**234**	**68.0**	**12.7**	**12.6**	**271**	**127**

Note : ( )* number of samplings
test according to INBAR 2000

CONCLUSION

There are no significant differences in physical and mechanical properties among 5 bamboo species. Pai Liang and Pai Tong demonstrate the good potentials to be used for various building parts of bamboo housing as compared to that of the Dipterocarps.

ACKNOWLEDGEMENT

I would like to extend my sincere thanks to ITTO for the support to the project PD 56/99 Rev.1 (I) as well as to Mrs. Wanida Subansenee for her close coordination. I am also pleased to express my thank to Prof. Dr. Walter Liese for his hospitality and invaluable advise.

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IMPROVEMENT OF BAMBOO CHARCOAL TECHNIQUES

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Bamboo charcoal experiment was conducted at Charcoal Research Center in Saraburi province. Nodes and inter-nodes of 3 years old Pai See Suk (Bambusa blumeana) were used for the experiment. The techniques of 20-hour pre-drying at 200°C and without pre-drying were compared for charcoal making in different types of kilns, i.e., pit kiln, single drum kiln, and brick beehive kiln with the capacity of 1.0 m^3 and 2.0 m^3. Chemical components of the bamboo charcoal were analyzed. The results of the study indicated that charcoal production from brick beehive kiln was better than those from single drum and pit kilns. The quantity of charcoal production without pre-drying was higher than those from the pre-drying ones, but vice versa as far as the quality of charcoal was concerned. Fixed carbon of bamboo charcoal from brick beehive kiln with pre-drying was better than those from single drum and pit kilns. Naturally, volatile matter depends on temperature, viz. volatile matter decreases under high temperature. The volatile matter of bamboo charcoal without pre-drying was higher than that with pre-drying. Ash content of bamboo charcoal without pre-drying was lower, while sulfur contents varied with site and moisture contents of bamboo charcoal fluctuated. Heating value of charcoal from inter-nodes was higher. The raw bamboo vinegar from brick beehive kiln was condensed on an average of 12.1 liters and 34.7 liters from kiln capacity of 1.0 m^3 and 2.0 m^3, respectively.

Key words *: Bambusa blumeana* Schultes , bamboo charcoal

INTRODUCTION

Charcoal

When wood or biomass is burnt in the open air, it is transformed to an ash. However, if it is heated in a closed vessel or air-tight environment, it is pyrolyzed, or transformed through the action of the heat, leaving behind charcoal during this process of carbonization, smoke is emitted. If this smoke is cooled, a liquid can be collected. This liquid will separate into three distinct layers. An oily liquid occupies the top layer while thick wood tar settles on the bottom. The middle layer consists of a transparent, yellowish brown liquid which is commonly called raw wood vinegar or pyroligneus liquor.

Until recently, charcoal and wood vinegar have been used mainly in the areas other than in agriculture. Charcoal has been used as a fuel, as well as in sewage treatment and metal polishing. Wood vinegar has been used in various ways, *e.g.* as an ingredient in medicines, an additive to animal feeds, a deodorizer, a mordant in the dying process, a facilitator in the fermentation process, a filler in sewage treatment and a raw materials in other industries.

Recently, many farmers and researchers have also been looking into the use of charcoal and wood vinegar as chemical inputs for crop yield improvement and pest control. Toshiaki (1997) pointed out a number of the positive benefits of using charcoal and wood vinegar in agriculture.

Characteristics of Charcoal

1) Due to its porosity, charcoal improves the physical characteristics of soil, water permeability and water retention in particular.

2) Charcoal helps increase the quantity of useful microbes in soil, especially mycorrhiza, resulting in development of stronger root systems of plants and reduction of damages by insects.

3) In greenhouses, charcoal absorbs ammonia and other harmful chemicals.

4) Charcoal consists of a well-balanced variety of minerals including calcium and boron. Due to the effects of the carbonization process, these minerals exist in a form easily absorbed by plants.

5) The mixture of charcoal and manure reduces unfavorable odors and facilitates composting process.

Characteristics of Bamboo Charcoal

Carbonization Methods to Make Bamboo Charcoal

As in the case of wood charcoal, bamboo charcoal is made by not only charcoal kilns but also carbonization furnaces. In Japan, the bamboo species used are Mosochiku *(Phyllostachys pubescens),* Madake *(Phyllostachys bambusoides),* Hachiku *(Phyllostachys nigra)* and Nemagaridake *(Sasa kurilensis*).

Small-sized bamboos is used to make a round charcoal, while the larger and thicker ones are vertically cut into two or four pieces to make a flat charcoal. Bamboo charcoal is made in the same type of kiln, but different temperatures are used to make different types of bamboo charcoal for different purposes. The temperatures used are divided into 3 levels : low temperature (400^{o}C), medium temperature (600-700^{o}C) and high temperature (1,000 ^{o}C or higher).

The process of bamboo charcoal making is a circulation of the steam produced from the bamboo inside the kiln, bamboo drying, and water content adjustment over 3 - 4 days, a gradual increase of the kiln temperature, and carbonization of the bamboo in 40-50 hours. Refining work takes 4–5 hours.

Properties of Bamboo Charcoal

Bamboo charcoal has superior characteristics such as easy carbonization, low tar content, higher level of hardness due to its relatively high silicic acid content, and better filterability compared to wood charcoal. As the heat decomposition process initially produces many acid constituents, including formic acid, a carbonating kiln must be stainless steel or other acid-resistant materials.

Bamboo charcoal also has high porosity and large surface area, *i.e.*, 200-300 m^2 per gram. The absorption capacity of bamboo charcoal carbonized at 1,000^{o}C is approximately ten times higher than that of Bincho charcoal or Bincho-tan. Because of this excellent absorption performance, bamboo charcoal is used for deodorants and moisture absorbents. It is also used for bedding, soil improvement, and other purposes.

Pai See Suk (*Bambusa blumeana*)

Pai See Suk (Bambusa blumeana), is commonly found on farmland and household areas in central and southern regions of Thailand. The species is native to Indonesia naturally grown on Java, Sumatra, and Borneo islands.

Pai See Suk has an average culm length or height of 10-18 m with 8-12 cm diameter, 30 cm internode length, 3-5 kg young shoot weight. Leaves are hairy with lanceolated shape. Culms are used for construction, furniture, handicrafts, pulp raw material, and young shoot for food.

Objectives of the Study

1) To test charcoal production from nodes and internodes of bamboo without pre-drying and with pre-drying of bamboo charcoal from pit kiln, single drum kiln, and brick beehive kiln.

2) To analyse chemical components of bamboo charcoal such as fixed carbon content, volatile matter content, ash content, sulfur content and moisture content.

3) To compare heating value of charcoal from nodes and internodes of bamboo.

MATERIALS AND METHODS

Materials

1) Culms of 3-year-old Pai See Suk
2) Chaocoal kilns : Pit kiln, single drum kiln, and 1-m^3 and 2-m^3 brick beehive kilns
3) Thermocouple
4) Moisture oven
5) Oxygen bomb calorimeter
6) Iron screen
7) Balances
8) Furnace

Methods

Bamboo charcoal experiment was designed with an advise from the International Charcoal Consultant, Dr. Kenji Hosokawa, Mr. Winai Panyathanya (head of Wood Energy Sub–division, Royal Forest Department) and Mrs. Wanida Subanseenee (project leader), to test the nodes and internodes of bamboo in 2 different techniques.

1) Control : charcoal making in 3 kiln types (pit kiln, single drum kiln, and brick beehive kiln) without pre-drying.

2) Charcoal making with pre-drying in 2 kiln types (single drum kiln and brick beehive kiln) by indirect firing at firing hole at 200°C for 20 hours followed by 24-hour cooling before being charcoaled in the experiments.

Pit Kiln

The pit kiln was built by digging the earth to be the structure from the bricks with width x length x height of 2.0 x 3.0 x 0.5 m with 3 chimneys and 1 firing hole (Figure 1).

Figure 1. Pit kiln

The operation of the pit kiln was started with burning some firewood and dry grasses or leaves on earth or zinc plate at the bottom of the kiln in which bamboo raw materials were horizontally piled. The layer of grass or leaves must be thick enough to prevent a direct contact of bamboo pile to the earth. The piled bamboo was burned with completely free access of air until the bamboo was in flame. At this stage, the flaming end was covered with earth or zinc plate. This reverse draft and control of the supply of air to kiln was obtained through the chimney.

Near the end of the carbonization process, the chimney through which the red hot charcoal was observed was removed and the hole covered with the earth. When all chimneys were removed, the kiln was closed. The bamboo materials for pit kiln test were nodes and internodes of Pai See Suk (*Bambusa blumeana*) without pre-drying and with pre-drying at 200°C for 20 hours.

During the carbonization process, observation of the smoke color was made in the same manner as in case of brick beehive kiln. The cooling period of the pit kiln was approximately 2- 3 days. The weights of lump charcoal, incomplete charcoal (brands), fine charcoal (<1 cm), and ash were recorded.

Single Drum Kiln

Single drum kiln with capacity of 0.2 m^3 was made from a 200-liter metal tank with holes in 3 vertical lines (Figure 2).

Figure 2. Single drum kiln

The operation of this kiln was begun with combustion and gradually followed by carbonization with direct draft. The fire was set at the bottom of the kiln before loading the bamboo atop. The kiln air inlet holes were plugged when the bamboo transformation into charcoal as indicated by clear smoke from the chimney. The cooling period of the single drum was approximately 6 hours. Bamboo materials for the single drum kiln test were the nodes and the internodes without pre-drying and with pre-drying at 200°C for 20 hours. The weights of lump charcoal, incomplete charcoal (brands), fine charcoal (<1 cm), and ash were recorded.

Brick Beehive Kiln

The brick beehive kiln was used as typical commercial charcoal kilns, but small in size. The materials for constructing a brick beehive kiln were bricks, clay, and sand. Some simple instruments such as a shovel, spade, trowel, aluminum can, and leveler were used in construction. There were 3 steps in the construction : site preparation, preparation of cementing material, and kiln construction.

The location for the kiln must be far from flooding area. A land area of 4x4 m was cleared and leveled. And O-shaped ring for the kiln foundation was made from straight bamboo and rod and nail at the specified diameter. The foundation was dug out to the depth of 3 layers of the bricks.

The cementing material was prepared from a mixture soft clay and sand. The clay was soaked in water for a few days. The mixture of clay to sand was 1:2 for cementing the bricks and 1:3 for exterior coating of the kiln. The arrangement of the brick from the foundation to the top of the kiln was in the same manner as normal brick construction. For a local-design brick beehive kiln, 3-brick layers of foundation were constructed with spaces for four chimneys and a loading port and firing port were left before the base wall was begun. Each layer of brick must be vertically and horizontally leveled. At 0.8 m above the kiln floor, a space for an accelerating hole must be left in the wall. Opposite to the firing port, 4 chimneys were constructed after the kiln wall was completed. The original design placed the firing port at the loading port, but separated in the later design for the tunnel could be neatly and permanently built. A burning of 1–2 armfuls of firewood for 3–4 hours inside the kiln was carried out for drying and curing the binding materials (Figure 3).

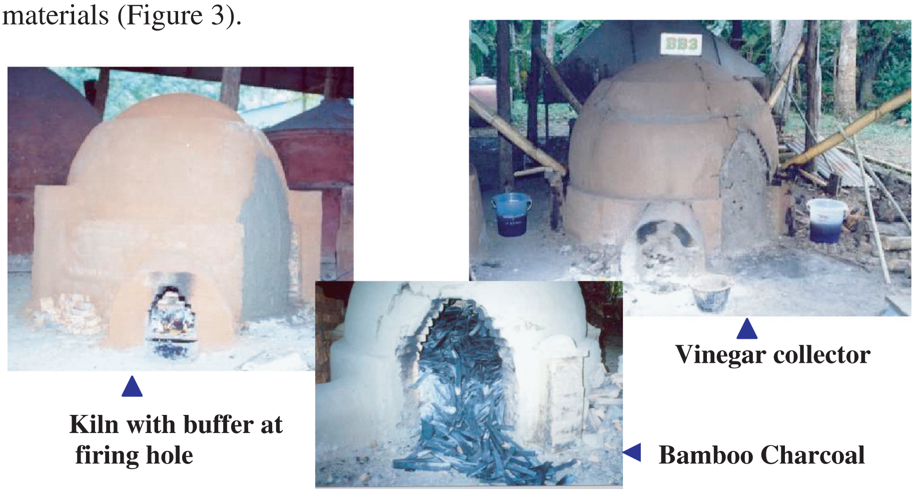

Figure 3. Brick beehive kiln

Raw materials for the experiment on bamboo charcoal making in brick beehive kiln were the nodes and the internodes of Pai See Suk (*Bambusa blumeana*) without pre-drying and with pre-drying 200°C for 20 hours. The operation was slow at the beginning because the loaded wood was not combusted. The kiln temperature was initially slowly increased by the hot air from the combusting firewood in the firing port. The hot air will got into the kiln through the accelerating hole and chimneys to replace the cool air inside. The accelerating hole was closed when the smoke temperature was approximately 120°C for the chimneys could fully perform their normal function. The kiln and the smoke temperatures were raised slowly until the kiln temperature reach 180–200°C. The smoke became thicker with white color and the smell of acid and methanol. This circumstance revealed that the spontaneous carbonization started to take place from the front and top of the kiln. The hot air from the firing port must then be terminated. The firing port was reduced to 6x6 cm and adjusted for proper cold inlet by smoke observation until complete carbonization took place. This operation is called "*initial firing technique*" and it is generally applied to mud beehive kilns by local charcoal makers. If the hot gas from firing is continued throughout complete carbonization, the operation is called "*continuous firing technique*". This technique is generally applied to commercial brick beehive kilns by local mangrove-charcoal makers. Near the end of carbonization, the smoke color turned to blue indicating that the kiln temperature was higher than 450°C, and clear when the temperature was higher than 500°C. The kiln was closed after the tar was dry and hardened at the chimneys outlet (tested by using a wood stick or finger to see if it was tainted with the tar). The hardened tar might take place by polymerization of phenolics with formaldehyde that was later produced by carbonization at 400-500°C (Kiatkrajai, 1986; Panyathanya, 2000).

Each chimney was closed one after another whenever tar inside was hardened. The kiln was left for 10-12 hours and any cracking walls were sealed with slurry mud. The mud suspension (10-30 % solid content) was used to bathe the kiln in order to completely seal any leaking wall and speed up cooling the kiln. The charcoal was unloaded when the kiln temperature decreased to 70°C. The weights of lump charcoal, brands or incomplete charcoal, fine (< 1 cm charcoal) and ash were recorded (Figure 4).


◀ **from nodes**

from internodes ▶


Figure 4. Bamboo charcoal of Pai See Suk (*Bambusa blumeana*).

Charcoal Production

Moisture content

$$\text{Moisture (\%)} = \frac{\text{Fresh weight} - \text{Oven} - \text{Dry weight}}{\text{Oven} - \text{Dry weight}} \times 100$$

Charcoal yield

$$\text{Yield (\%)} = \frac{\text{Charcoal weight}}{\text{Oven} - \text{dry weight} + \text{Firing oven} - \text{Dry weight Brand}} \times 100$$

Fresh weight	=	Fresh weight before being loaded into the kiln
Oven dry weight	=	Oven dry weight at moisture content 0 % under oven dry at 105°C for 24 hours
Charcoal weight	=	Total charcoal weight from the kiln
Brand (incomplete charcoal) weight	=	Total weight of wood charcoal not changed to complete charcoal
Firing oven dry weight	=	Oven dry weight of firing at 0% moisture content under oven dry at 105°C for 24 hours

Good performance of charcoal production *(Panyathanya, 1998)*

Production (yield)	> 30 %
Brand (incomplete charcoal)	< 5 %
Total firing fresh weight	< 10 % oven dry of firing weight

Chemical components

Chemical properties of charcoal were analyzed using the tools and instrument commonly available in the laboratory, *e.g.* oven, furnace, crucible, and balances. Following are the standards suggested by Kiatkrajai (1986).

1) Moisture content is fresh weight minus oven dry weight divided by oven dry weight and multiplied by 100.

2) Volatile matter content is part of oven dry charcoal which can evaporate in close crucible at 950°C in electric furnace for 6 minutes. Volatile matter contents are carbon, oxygen and hydrogen substances.

3) Fixed carbon content is organic substance appearing in crucible after minus volatile matter content and ash content. The majority of fixed carbon is carbon (may be 95%).

4) Ash content is inorganic substances which appear after charcoal was burnt in furnace at 750°C for 6 hours.

Simple random sampling without replacement (cf. Niyamanggoon, 1998) was employed in the selection of bamboo nodes and internodes as well as bamboo charcoal samples from pit kiln, single drum kiln and brick beehive kiln (Niyamanggoon, 1998).

RESULTS

Bamboo Charcoal Production

The Pit Kiln

Two replications of the nodes and the internodes of bamboo were used in bamboo charcoal production. The results are presented in Table 1.

Table 1. Charcoal production from the pit kiln

Item	Unit	Bamboo nodes		Bamboo internodes	
		Without pre-drying	Pre–drying at 200°C for 20 hrs	Without pre-drying	Pre–drying at 200°C for 20 hrs
Fresh weight	kg	200	200	200	200
Moisture	%	12.92	9.92	15.4	7.71
Firing fresh weight	kg	3	3	3	3
Moisture	%	12.92	9.92	15.4	7.71
Oven pre-drying weight	kg	177.11	181.95	173.3	185.68
Oven pre-drying weight of firing	kg	2.66	2.73	2.60	2.78
Charcoal	kg	32.3	31.5	31.2	33.0
Incomplete charcoal	kg	7.2	5.0	8.4	4.0
Hour per run	hr	38	33	40	34
Maximum temperature of middle kiln	°C	-	-	-	-
Charcoal production	%	18.71	17.53	18.63	17.89

The results presented in Table 1 indicate that the charcoal production from bamboo nodes without pre-drying and 38 hours per run was 18.71%, while 17.53% was obtained in case of pre-drying at 200°C for 20 hours and

33 hours per run. The productivity was 18.63**%** when charcoal was made from bamboo internodes without pre-drying and 40 hours per run, compared with that of 17.89 **%** in case with pre-drying at 200°C for 20 hours and 34 hours per run.

The Single Drum Kiln

The results of bamboo charcoal production are presented in Table 2. The results of the study show that 21.70**%** charcoal productivity was obtained from the bamboo nodes without pre-drying and burned at 458°C for 8 hours per run, compared with that of 24.65 **%** in case of pre-drying and burned at 465°C for 7 hours per run. In the other case, 22.43 **%** productivity was obtained from the internodes without pre-drying and burned at 479°C for 9 hours per run, while 19.42**%** was obtained from pre-drying internodes burned at 553°C for 7 hours per run.

Table 2. Charcoal production from the single drum kiln

Item	Unit	Bamboo nodes		Bamboo internodes	
		Without pre-drying	Pre-drying at 200° C for 20 hrs	Without pre-drying	Pre-drying at 200°C for 20 hrs
Fresh weight	kg	62	61	56	69
Moisture	%	13.95	5.4	16.22	4.58
Firing fresh weight	kg	1	1	1	1
Moisture	%	13.95	5.4	16.22	4.58
Oven pre-drying weight	kg	54.41	57.87	48.18	65.98
Oven pre-drying weight of firing	kg	0.88	0.94	0.86	0.95
Charcoal	kg	12	14.5	11	13
Incomplete charcoal	kg	-	-	-	-
Hour per run	hr	8	7	9	7
Maximum temperature of middle kiln	°C	458	465	479	553
Charcoal production	%	21.70	24.65	22.43	19.42

The 1.0-m^3 Brick Beehive Kiln

The results of bamboo charcoal production from 1.0-m^3 brick beehive kiln were presented in Table 3.

For raw material without pre-drying, 30.12% charcoal productivity was obtained from the nodes burned at 458°C for 31 hours per run, compared with 22.43 % from the internodes burned at 452°C for 34 hours per run. With pre-dried raw material, 24.65 % productivity was obtained from the nodes burned at 572°C for 28 hours per run, while that of 19.42 % was from the internodes burned at 651°C for 27 hours per run.

Table 3. Charcoal production from the 1.0-m^3 brick beehive kiln

Item	Unit	Bamboo nodes		Bamboo internodes	
		Without pre-drying	Pre-drying at 200°C for 20 hrs	Without pre-drying	Pre-drying at 200°C for 20 hrs
Fresh weight	kg	223.50	184.2	180	171
Moisture	%	13.93	4.58	14.78	5.04
Firing fresh weight	kg	25	14	15	14
Moisture	%	13.93	4.58	14.78	5.04
Oven pre-drying weight	kg	196.17	176.13	156.82	162.79
Oven pre-drying weight of firing	kg	21.94	13.38	13.07	13.33
Charcoal	kg	64.5	34.2	49	36.8
Incomplete charcoal	kg	4	-	11.5	-
Hour per run	hr	31	28	34	27
Maximum temperature of middle kiln	°C	458	572	452	651
Charcoal production	%	30.12	24.65	22.43	19.42
Raw bamboo vinegar	1		12.1		

The 2.0-m^3 Brick Beehive Kiln

The results of bamboo charcoal production from the 2.0-m^3 brick beehive kiln are presented in Table 4.

For material without pre-drying, 29.08% charcoal productivity was obtained from the nodes of bamboo burned at 537°C for 41 hours, compared with 28.48 % of that from the internodes burned at 545°C for 38 hours. In case of pre-dried material, 24.53% productivity was obtained from the nodes burned at 580°C for 38 hours, while 23.17 % productivity was obtained from the internodes burned at 637°C for 31 hours.

The 1.0-m^3 brick beehive kiln could produce 12.1 liters of raw bamboo vinegar whereas 34.7 liters of vinegar were received from the 2.0-m^3 kiln.

Table 4. Charcoal production from the 2.0-m^3 brick beehive kiln

Item	Unit	Bamboo nodes		Bamboo internodes	
		Without pre-drying	Pre-drying at 200°C for 20 hrs	Without pre-drying	Pre-drying at 200°C for 20 hrs
Fresh weight	kg	423	388	368	328.7
Moisture	%	13.95	6.40	13.8	5.25
Firing fresh weight	kg	44	34	35	30
Moisture	%	13.95	6.4	13.80	5.25
Oven pre-drying weight	kg	371.82	364.66	323.37	312.3
Oven pre-drying weight of firing	kg	38.61	31.95	30.75	28.5
Charcoal	kg	115.8	103.6	98.6	78.5
Incomplete charcoal	kg	12.2	-	8	2
Hour per run	hr	41	38	38	31
Maximum temperature of middle kiln	°C	537	580	545	637
Charcoal production	%	29.08	24.53	28.48	23.17
Raw vinegar	1		34.7		

Chemical Components of Bamboo Charcoal

Chemical Components of Bamboo Charcoal from Pit Kiln

It can be noticed from the results presented in Table 5 that the charcoal from bamboo nodes has higher moisture content and volatile matter, but lower fixed carbon, ash content, sulfur content, and heating value compared with those from the internodes.

Table 5. Chemical components and heating value of bamboo charcoal from pit kiln

Sample	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	S (%)	Heating value (kcal/kg)
Node	5.2	24.4	61.8	8.6	0.21	6,280
Inter-node	3.9	17	69.9	9.2	0.21	6,690

Chemical Components of Bamboo Charcoal from the Single Drum Kiln

The study results presented in Table 6 indicate that only higher volatile matter was found in charcoal from bamboo nodes without pre-drying, while higher moisture content, fixed carbon, ash content, sulfur content, and heating value were found in charcoal from the nodes with pre-drying. More fluctuations were found in the case of charcoal from bamboo internodes, *i.e.*, moisture content, fixed carbon, and heating value were higher in charcoal from the material without pre-drying, while volatile matter and ash content were higher in charcoal from pre-dried material.

Table 6. Chemical components and heating value of node and inter-node bamboo charcoal from single drum kiln

Sample	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	S (%)	Heating value (kcal/kg)
Nodes without pre-drying	4.4	28.9	58.7	8.0	0.22	6,120
Nodes with pre-drying	4.5	10.3	74.3	10.9	0.30	6,690
Internodes without pre-drying	4.6	12.5	74.8	8.1	0.19	6,840
Internode with pre-drying	2.9	14.6	68.6	13.9	0.19	6,410

Chemical Components of Bamboo Charcoal from Brick Beehive Kiln

Table 7 presents the results of the study on chemical components and heating value of charcoal made from bamboo nodes and internodes with and without pre-drying. Higher volatile matter was found only in the case of nodes without pre-drying, other higher values being found in the cases of charcoal from the pre-dried nodes. Moisture content and volatile matter were higher in charcoal from the internodes without pre-drying, while higher fixed carbon, ash content, sulfur content, and heating value were found in charcoal from the material with pre-drying.

Table 7. Chemical components and heating value of bamboo charcoal from brick beehive kiln

Sample	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	S (%)	Heating value (kcal/kg)
Nodes without pre- drying	5.0	18.4	70.6	6.0	0.25	6,730
Nodes with pre-drying	5.5	13.5	74.4	6.6	0.30	6,830
Internodes without pre-drying	4.0	25.0	64.8	6.2	0.10	6,480
Internodes with pre-drying	2.5	8.9	78.0	10.6	0.21	6,930

CONCLUSIONS AND RECOMMENDATIONS

The study on improvement of bamboo charcoal techniques was conducted at the Charcoal Research Center in Saraburi province. The results of the study can be concluded as follows.

1) The yield of charcoal from brick beehive kiln is higher than those from single drum and pit kilns. The charcoal from materials without pre-drying is better than that with pre-drying, while the quality of charcoal from the pre-dried nodes and internodes is better than that from materials without pre-drying.

2) The fixed carbon of charcoal made from pre-dried bamboo nodes and internodes is higher in brick beehive kiln.

3) The amount of volatile matter depends on temperature, *i.e.*, the volatile matter decreases under high temperature and the amount is higher in case of charcoal from the materials without pre-drying compared with those with pre-drying.

4) Ash content in charcoal from bamboo nodes and internodes without pre-drying is lower than those with pre-drying.

5) Sulfur contents range from 0.1 % to 0.3 % depending upon the site from which bamboo samples are taken.

6) The moisture contents of charcoal from bamboo nodes and internodes without pre-drying range from 2.5 % to 5.5 %, and the moisture contents do not depends on pre-drying of materials prior to charcoaling.

7) The heating value of charcoal from nodes and internodes range from 6,120 to 6,930 kcal/kg, higher value being found in charcoal from the internodes as compared with that from the nodes as well as in those without pre-drying, except in the case of charcoal from single drum kiln.

8) An average of 12.1 liters and 34.7 liters of raw bamboo vinegar is obtained from 1.0-m^3 and 2.0-m^3 brick beehive kiln, respectively. However, the determination of other characteristics and chemical components of the raw bamboo vinegar is not included in this study.

9) Brick beehive kiln developed by the International Charcoal Consultant is proved to be the best kiln for bamboo charcoal production.

The study includes only the materials from 3-year-old Pai See Suk (*Bambusa blumeana*). It is therefore recommended that other bamboo species be included in further study on bamboo charcoal making.

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BAMBOO FLOORING FROM PAI TONG

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The research covered the study on factors and floor-making methods affecting the properties of bamboo flooring from Pai Tong (Dendrocalamus asper). There were 2 types of adhesive used in the experiment with different pressing times. The first type of adhesive was polyvinyl acetate with cold pressing for 2, 4, 6, and 8 hours, the second one being urea formaldehyde with hot pressing for 21 and 42 minutes (1- and 2-minute pressing time per mm of flooring thickness). The samples were kept at room temperature for 7 days before mechanical properties were tested with B.S. 373:1957 method. The results of the study revealed that the average mean of modulus of rupture (MOR) ranged from 51.40 to 157.74 MPa, modulus of elasticity (MOE) from 515.76 to 1,353.33 MPa, and shear stress parallel to glue lines from 9.75 to 14.69 MPa. The solution of urea formaldehyde with hot pressing for 42 minutes was suitable for making Pai Tong flooring of satisfactory quality with MOR, MOE and shear stress parallel to glue lines of 157.74, 1,353.33, and 14.68 MPa respectively.

Keywords: Bamboo flooring, *Dendrocalamus asper* Backer, adhesive

INTRODUCTION

Bamboo has widely been used for housing in rural areas, particularly among the rural poor. However, bamboo timber has been processed for more value-added products for local and overseas markets, *e.g.*, furniture, handcrafts, charcoal, paper, house decorations. Timber of large-sized bamboo are processed as laminated bamboo used for different purposes. In Thailand, culms of Pai Tong (*Dendrocalamus asper*) have for a long time been used for construction, raw material for pulp industry. This bamboo species is characterized by large culm with long internodes, timber with white-yellowish color and straight grain. Lumber from trees becomes more expensive and there is a potential that bamboo flooring can be used as substitute of wood lumber.

The objectives of this study are to produce bamboo flooring from Pai Tong and to assess the factor affecting the quality of the product.

METHODOLOGY

The details of the study are as follows.

- Pai Tong (*D. asper*) culm with at least 7 mm thick and 2 m long.
- Split bamboo culm into minimum width of 25 mm.
- Soak the samples in Timbor 10% for 24 hours.
- 4-side plane of bamboo sheet to dimension of 2.5 cm by 7 mm and cut into piece of 40 cm long.
- Oven dry bamboo sheet to the moisture content of 8-12% for using urea formaldehyde glue and 18% polyvinyl acetate adhesive.
- Spare each adhesive on one side of bamboo sheet then side-laminate to get the width of 15 cm and pile-up laminate to get 21 mm in thickness (3 bamboo sheets per one laminated bamboo sample). Using 190 g of adhesive per $m.^2$
- Conditioning bamboo flooring at room temperature for 7 days before testing.
- Mechanical property test with B.S. 373:1957 method.
- Statistical analysis using one-way ANOVA analysis with combinations of 6 treatments under Completely Randomized Design (CRD).

Figure 1. Bamboo flooring manufacturing.

RESULTS

Modulus of Rupture (MOR)

The average mean of MOR ranged from 51.40 to 157.74 MPa. The results from one-way ANOVA analysis indicated that the type of adhesive for MOR test was significant at 1% probability level (Table 1).

Table 1. One-way ANOVA analysis for MOR

Source	df	SS	MS	F[1)]
Between groups	5	25,256.531	5,051.306	20.50**
Within groups	12	2,956.835	246.403	
Total	17	28,213.366		

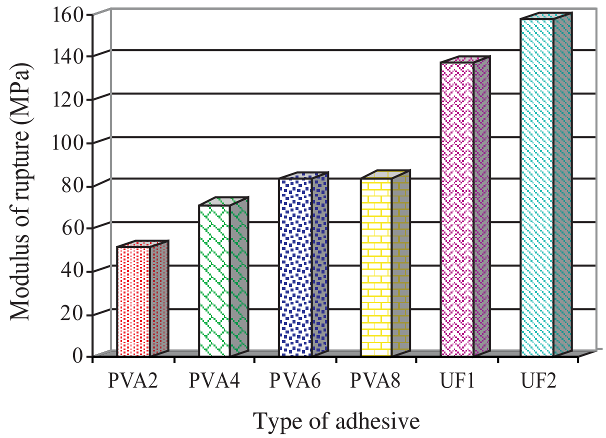
1) ** significant at 1% probability level

The results from Duncan's new multiple range test showed that the MOR of the samples using urea formaldehyde glue with hot pressing for 21 and 42 minutes and polyvinyl acetate adhesive with 4 different cold pressing times was significantly different at any level of pressing time (Table 2 and Figure 2). The highest mean of MOR, 157.74 MPa, was found in case of urea formaldehyde glue with 42-minutes pressing time, followed by 137.38 MPa with 21-minute pressing. The lowest mean of MOR, 51.40, was found in bamboo flooring using polyvinyl acetate adhesive with 2-hour pressing time.

Table 2. MOR of bamboo flooring (Duncan's new multiple range test at 1% probability level)

Type of adhesive	Average MOR, MPa[1)]
Polyvinyl acetate with 2-hr pressing	51.40 a
Polyvinyl acetate with 4-hr pressing	71.37 a
Polyvinyl acetate with 6-hr pressing	83.31 a
Polyvinyl acetate with 8-hr pressing	83.91 a
Urea formaldehyde with 21-min pressing	137.38 b
Urea formaldehyde with 42-min pressing	157.74 b

1) The difference between means with the same letter are not significantly different.



PVA2: polyvinyl acetate with 2-hr pressing
PVA4: polyvinyl acetate with 4-hr pressing
PVA6: polyvinyl acetate with 6-hr pressing
PVA8: polyvinyl acetate with 8-hr pressing
UF1 : urea formaldehyde with 21-min pressing
UF2 : urea formaldehyde with 42-min pressing

Figure 2. Average MOR of bamboo flooring.

Modulus of Elasticity (MOE)

The MOE of bamboo flooring ranged from 515.76 to 1,353.33 MPa. The results from one-way ANOVA analysis showed a similar trend as in case of MOR (Table 3).

Table 3. One-way ANOVA analysis for MOE

Source	df	SS	MS	F[1)]
Between groups	5	1,358,094.272	271,618.854	8.096**
Within groups	12	402,577.258	33,548.105	
Total	17	1,760,671.530		

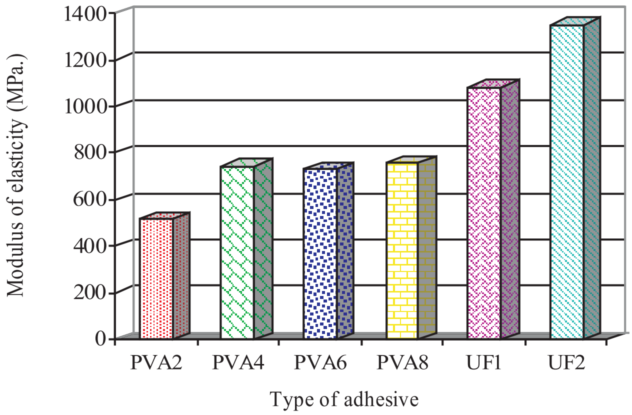
1) ** significant at 1% probability level

The results from Duncan's new multiple range test showed significant difference in MOE of bamboo flooring using two types of adhesive, UF and PVA (Table 4 and Figure 3). Highest mean of MOE, 1,353.33 MPa, was found in case of UF with 42-minute hot pressing, MOE of bamboo flooring using polyvinyl acetate adhesives were not significant at any level of pressing time.

Table 4. MOE of bamboo flooring (Duncan's new multiple range test at 1% probability level)

Type of adhesive	Average MOE, MPa[1)]	
Polyvinyl acetate with 2-hour pressing	545.76	a
Polyvinyl acetate with 4-hour pressing	745.02	ab
Polyvinyl acetate with 6-hour pressing	731.79	ab
Polyvinyl acetate with 8-hour pressing	756.64	ab
Urea formaldehyde with 21-min pressing	1,084.96	bc
Urea formaldehyde with 42-min pressing	1,353.33	c

[1)] The difference between means followed by the same letter are not significantly different.



PVA2: polyvinyl acetate with 2-hour pressing
PVA4: polyvinyl acetate with 4-hour pressing
PVA6: polyvinyl acetate with 6-hour pressing
PVA8: polyvinyl acetate with 8-hour pressing
UF1: urea formaldehyde with 21-minute pressing
UF2: urea formaldehyde with 42-minute pressing

Figure 3. Average MOE of bamboo flooring.

Shearing Stress Parallel to Glue Lines

The average shearing stress parallel to glue lines of bamboo flooring ranged from 9.75 to 14.69 MPa. The results from One-way ANOVA analysis showed the significant difference among adhesive types (Table 5).

Table 5. One-way ANOVA analysis for shearing stress parallel to glue lines

Source	df	SS	MS	F[1)]
Between groups	5	50.391	10.078	4.696*
Within groups	12	25.752	2.146	
Total	17	76.144		

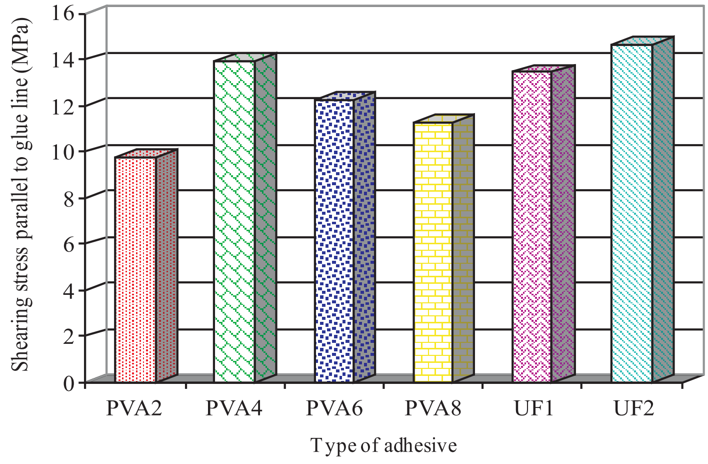
[1)] * significant at 5% probability level

The highest shearing stress was 14.69 MPa in bamboo flooring using urea formaldehyde with 42 minutes pressing time, followed by 13.93 MPa of polyvinyl acetate with 4-hour pressing (Table 6 and Figure 4).

Table 6. Shearing stress parallel to glue lines of bamboo flooring (Duncan's new multiple range test at 5% probability level)

Type of adhesive	Average shearing stress parallel to glue lines, MPa[1)]
Polyvinyl acetate with 2-hr pressing	9.75 a
Polyvinyl acetate with 4-hr pressing	13.93 bc
Polyvinyl acetate with 6-hr pressing	12.25 abc
Polyvinyl acetate with 8-hr pressing	11.31 ab
Urea formaldehyde with 21-min pressing	13.46 bc
Urea formaldehyde with 42-min pressing	14.69 c

[1)] The difference between means followed by the same letter are not significantly different.



PVA2: polyvinyl acetate with 2-hour pressing
PVA4: polyvinyl acetate with 4-hour pressing
PVA6: polyvinyl acetate with 6-hour pressing
PVA8: polyvinyl acetate with 8-hour pressing
UF1: urea formaldehyde with 21-minute pressing
UF2: urea formaldehyde with 42-minute pressing

Figure 4. Average Shearing stress parallel to glue lines of bamboo flooring.

CONCLUSIONS

Mechanical properties of bamboo flooring from Pai Tong (*D. asper*) by using 2 adhesives with different pressing times can be concluded as follows.

Bamboo flooring from Pai Tong using urea formaldehyde with 42 minutes pressing time showed highest MOR (157.74 MPa), highest MOE (1,353.33 MPa), and highest shearing stress parallel to glue lines (14.69 MPa).

The best glue used in manufacturing of bamboo flooring of Pai Tong is urea formaldehyde with 42-minute hot pressing, as far as the mechanical properties of the product are concerned.

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THE EFFECTS OF BAMBOO PRETREATMENT ON THE PROPERTIES OF BAMBOO CEMENT BOARDS

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The study included five bamboo species : Pai Tong (Dendrocalamus asper Backer), Pai See Suk (Bambusa blumeana Schultes), Pai Sang (Dendrocalamus strictus Nees), Pai Rai (Gigantochloa albociliata Munro), and Pai Liang (Bambusa sp.). Three pretreatment of bamboo flakes were applied, i.e., non-soaking, 12-hour, and 24-hour water soaking. The boards composed of 30 to 70 parts by weight of bamboo flake and Portland cement with 60% water and 3% calcium chloride. The boards were 12 mm thick with the density of 1,200 kg/m^3.

The results of the study revealed that the pre-treatment did affect the properties of bamboo cement boards, while the combinations of bamboo species and pretreatment showed an influence on physical and mechanical properties of the boards. Nonsoaking pretreatment of Pai Tong, Pai See Suk, Pai Sang, and Pai Rai demonstrated poor properties of the boards as far as poor setting and thickness spring back were concerned. On the contrary, pretreated bamboo flakes with 12-hour and 24-hour soaking showed a good improvement of the properties with slight difference. However, bamboo cement boards from Pai Liang with 3 pretreatment had no significant difference in properties. It is therefore recommended that bamboo cement boards from Pai Liang be made without any pretreatment, 12-hour soaking pretreatment being needed in case of other four bamboo species.

Keywords: *Dendrocalamus asper* Backer, *Bambusa blumeana* Schultes, *Dendrocalamus strictus* Nees, *Gigantochloa albociliata* Munro, *Bambusa* sp., pretreatment, bamboo cement board

INTRODUCTION

Since the logging ban launched in January 1989, Thailand has been dependent on the import of timber and wood-based products. Although the value of export of these commodities has been increasing and surpassing the import value during the past few years, local consumption is still dependent on a variety of imports. Promotion of commercial tree planting by the government aims to boost local wood-based industries and reduces the dependency on imports. Bamboo is one of 38 tree species listed in the promotion program. Bamboo has some advantages, *e.g.*, fast growing, easy maintenance, annual harvest; compared with other timber species. The most common bamboo species for utilization in Thailand are Pai See Suk (*Bambusa blumeana*), Pai Liang (*Bambusa* sp.), Pai Tong (*Dendrocalamus asper*), Pai Sang (*Dendrocalamus strictus*), Pai Rai (*Gigantochloa albociliata*), and Pai Ruak (*Thyrsostachys siamensis*). Major construction materials, steel and cement in particular, become more and more expensive. Utilization of processed bamboo timber as construction material will be less expensive and more environmentally friendly.

The objectives of the study are to select suitable bamboo species for the production of bamboo cement board and to test the quality of the boards under different conditions.

METHODOLOGY

Split-plot design was employed with 5 bamboo species as main unit (*D. asper, B. blumeana, D. strictus, G. albaciliata,* and *Bambusa* sp.) with 3 pretreatment, *i.e*., non-soaking, 12-hour and 24-hour water soaking, as sub-unit with 3 replications of Completely Randomized Design (CRD). Following are the details of bamboo cement board preparation and testing. (Figure 1)

Composition of bamboo cement board :

Bamboo flake : Portland cement	30 : 70 by weight
Calcium chloride	3 % by portland cement weight
Water	60 % by portland cement weight

Dimension	:	12 mm thick and 1,200 kg/m^3 density
Board making	:	Cold pressing for 24 hours.
Pretest condition	:	Room temperature for 28 days.
Testing methods	:	D 1037-96a and TIS 878-1989

Bending Test

Figure 1. Preparation and testing of bamboo cement board.

RESULTS

The test of cement boards made from five bamboo species with 3 different conditions of non- soaking (control), 12-hour and 24-hour soaking can be summarized as follows.

The average thickness of bamboo cement boards with non-pretreatment and pretreatment was 13.68 mm, while the average density ranged from 914.72 to 1,308.71 kg/m^3.

The moisture contents of bamboo cement boards without and with pretreatment ranged from 6.01 to 8.86%. The lowest water absorption, 14.46%, was found in non-pretreated bamboo cement board made from Pai Liang, 15.15% in case of that from Pai Tong with 24-hour soaking (Table 1 and Figure 2).

Table 1. Water absorption of bamboo cement boards after soaking for 2 hours (Duncan's new multiple range test at 1% probability level)

Species	Pretreatment[1)]					
	Control		Soaking period			
			12 hours		24 hours	
Dendrocalamus asper	39.65	a	16.00	b	15.15	b
Bambusa sp.	14.46	b	17.63	b	17.59	b
Gigantochloa albociliata	35.87	a	17.63	b	16.93	b
Bambusa blumeana	39.41	a	16.66	b	19.46	b
Dendrocalamus strictus	37.13	a	19.75	b	16.79	b

[1)] The difference between means followed by the same letter are not significantly different.

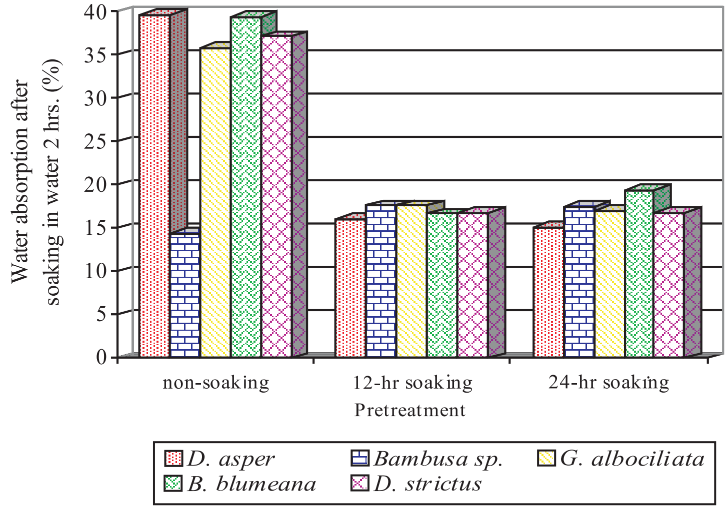

Figure 2. Average water absorption of bamboo cement boards after soaking for 2 hours.

The lowest water absorption, 17.13%, was found in bamboo cement boards made from Pai Liang (*Bambusa* sp.) without pretreatment, compared with 19.10% in case of Pai Tong (*D. asper*) boards with 12-hour soaking (Table 2 and Figure 3).

Table 2. Water absorption of bamboo cement boards after soaking in water for 24 hours (Duncan's new multiple range test at 1% probability level)

Species	Pretreatment[1]					
	Control		Soaking period			
			12 hours		24 hours	
Dendrocalamus asper	42.22	a	19.10	b	19.27	b
Bambusa sp.	17.13	b	20.95	b	21.35	b
Gigantochloa albociliata	37.35	a	20.79	b	20.49	b
Bambusa blumeana	40.39	a	20.11	b	23.10	b
Dendrocalamus strictus	38.23	a	19.65	b	20.36	b

[1] The difference between means followed by the same letter are not significantly different.

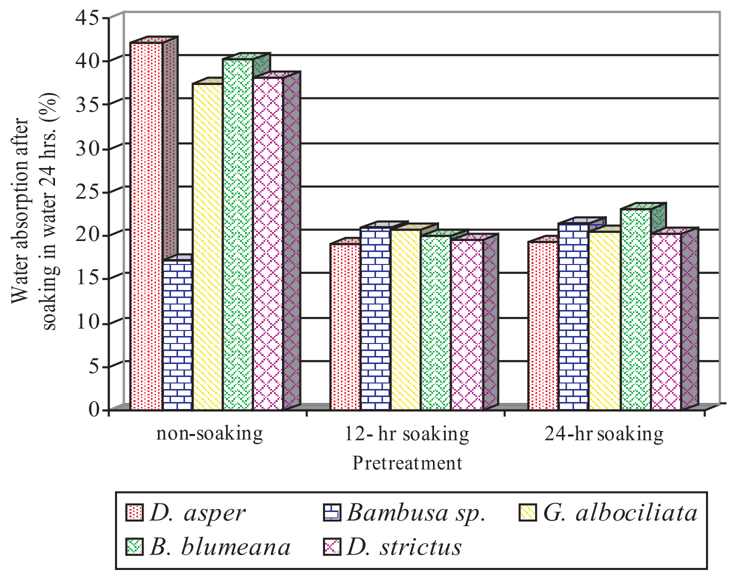

Figure 3. Average water absorption of bamboo cement boards after soaking in water for 24 hours.

After 2-hour soaking, bamboo cement boards made from Pai See Suk (B. blumeana) with 12-hour pretreatment showed lowest thickness swelling, 0.70%, followed by 0.80% of Pai Sang (D. strictus) of the same treatment (Table 3 and Figure 4).

Table 3. Thickness swelling of bamboo cement boards after soaking in water for 2 hours (Duncan's new multiple range test at 1% probability level)

Species	Pretreatment[1)]					
	Control		Soaking period			
			12 hours		24 hours	
Dendrocalamus asper	8.08	a	1.32	c	0.99	c
Bambusa sp.	1.32	c	1.08	c	1.36	c
Gigantochloa albaciliata	7.73	a	1.03	c	1.15	c
Bambusa blumeana	7.51	ab	0.70	c	1.38	c
Dendrocalamus strictus	5.42	b	0.80	c	1.28	c

1) The difference between means followed by the same letter are not significantly different.

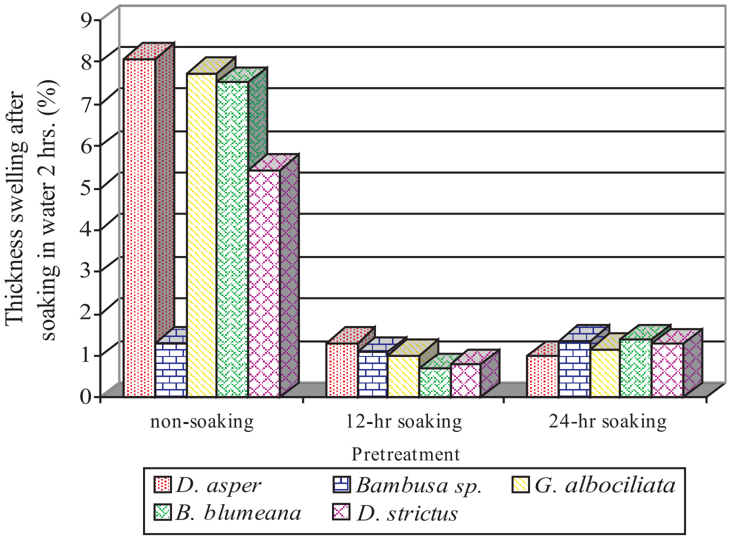

Figure 4. Average thickness swelling of bamboo cement boards after soaking in water for 2 hours.

The lowest thickness swelling after soaking in water for 24 hours was found in bamboo cement boards of Pai Sang (D. strictus) with 12-hour pretreatment, 1.07%, followed by 1.14% of Pai Tong (D. asper) with 24-hour pretreatment (Table 4 and Figure 5).

Table 4. The thickness swelling of bamboo cement boards after soaking in water for 24 hours (Duncan's new multiple range test at 1% probability level)

Species	Pretreatment[1)]		
	Control	Soaking period	
		12 hours	24 hours
Dendrocalamus asper	9.05 a	1.59 c	1.14 c
Bambusa sp.	1.69 c	1.41 c	1.64 c
Gigantochloa albociliata	9.08 a	1.44 c	1.34 c
Bambusa blumeana	7.75 ab	1.19 c	1.53 c
Dendrocalamus strictus	6.04 b	1.07 c	1.63 c

[1)] The difference between means followed by the same letter are not significantly different.

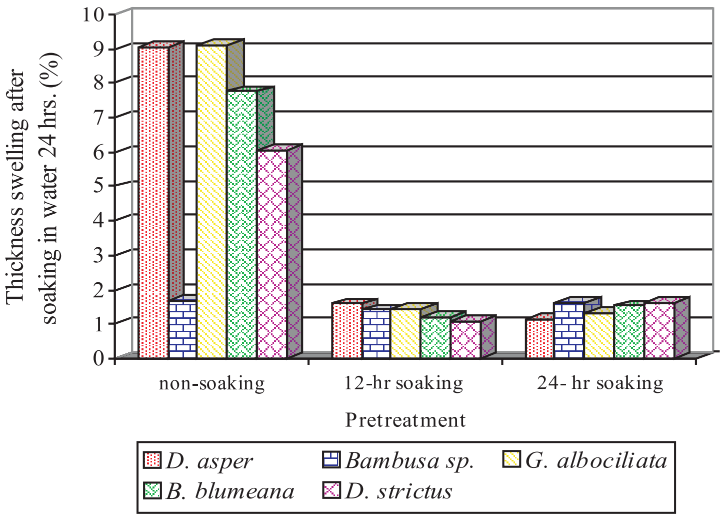

Figure 5. Average thickness swelling after soaking in water for 24 hours.

Bamboo cement boards made from Pai See Suk (B. blumeana) with 12-hour pretreatment had highest modulus of rupture (MOR), viz. 11.60 MPa followed by 10.86 MPa of non-pretreated Pai Liang (Bambusa sp.) as shown in Table 5 and Figure 6.

Table 5. Modulus of rupture (MOR) of bamboo cement boards (Duncan's new multiple range test at 1% probability level)

Species	Pretreatment[1)]					
	Control		Soaking period			
			12 hours		24 hours	
Dendrocalamus asper	1.34	e	9.25	abcd	8.19	bcd
Bambusa sp.	10.86	ab	7.84	bcd	8.26	bcd
Gigantochloa albociliata	1.03	e	9.56	abcd	9.17	abcd
Bambusa blumeana	1.17	e	11.60	a	10.45	abc
Dendrocalamus strictus	0.43	e	7.54	cd	6.71	d

[1)] The difference between means followed by the same letter are not significantly different.

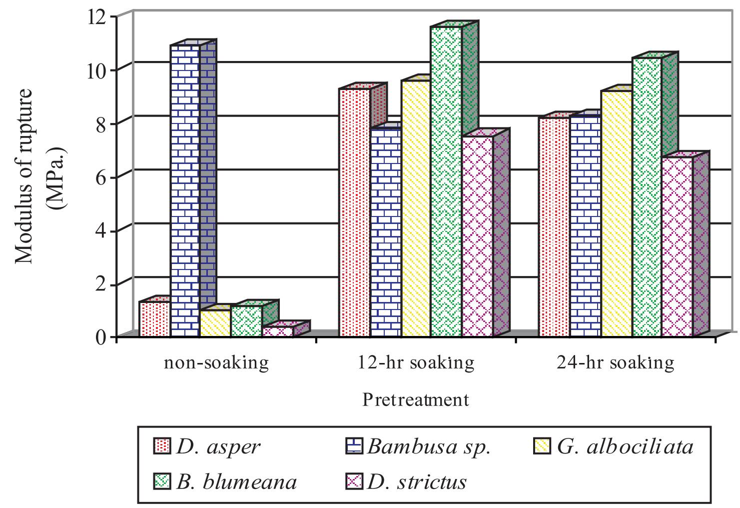

Figure 6. Average modulus of rupture (MOR).

The highest modulus of elasticity (MOE), 3,257 MPa, was found in bamboo cement boards of Pai See Suk (B. blumeana) followed by 3,127 MPa of those made from Pai Liang (Bambusa sp.) as shown in Table 6 and Figure 7.

Table 6. Modulus of elasticity (MOE) of bamboo cement boards (Duncan's new multiple range test at 1% probability level)

Species	Pretreatment[1)]		
	Control	Soaking period	
		12 hours	24 hours
Dendrocalamus asper	96 b	2,649 a	2,634 a
Bambusa sp.	3,127 a	2,342 a	2,602 a
Gigantochloa albociliata	185 b	3,029 a	2,956 a
Bambusa blumeana	205 b	3,257 a	2,969 a
Dendrocalamus strictus	90 b	3,014 a	2,374 a

[1)] The difference between means followed by the same letter are not significantly different.

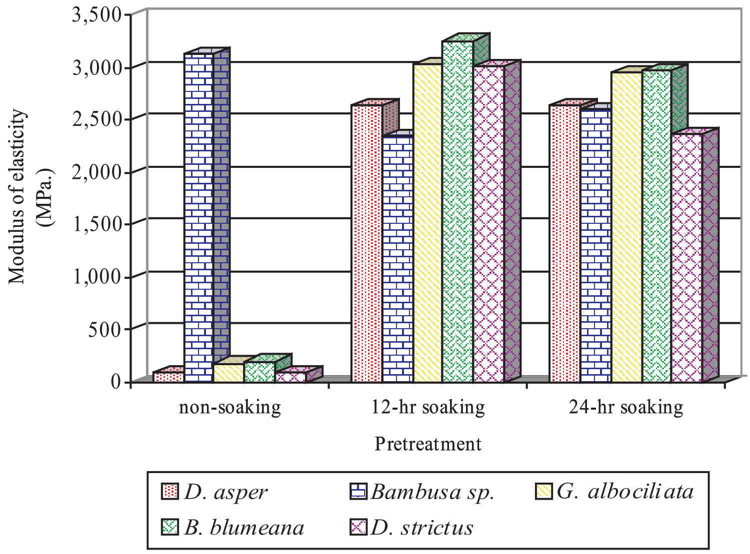

Figure 7. Average modulus of elasticity (MOE).

The highest internal bonding strength (IB), 0.77 MPa, was found in bamboo cement boards made from 12-hour pretreated Pai Sang (*D. strictus*), followed by 0.74 MPa of the boards from Pai See Suk (*B.blumeana*) with 12-hour pretreatment **(Table 7 and Figure 8).**

Table 7. Internal bonding strength (IB) of bamboo cement boards (Duncan's new multiple range test at 1% probability level)

Species	Pretreatment[1)]					
	Control		Soaking period			
			12-hours		24-hours	
Dendrocalamus asper	0.00	d	0.45	c	0.49	bc
Bambusa sp.	0.64	abc	0.55	abc	0.58	abc
Gigantochloa albociliata	0.00	d	0.54	abc	0.58	abc
Bambusa blumeana	0.00	d	0.74	ab	0.62	abc
Dendrocalamus strictus	0.00	d	0.77	a	0.52	abc

[1)] The difference between means followed by the same letter are not significantly different.

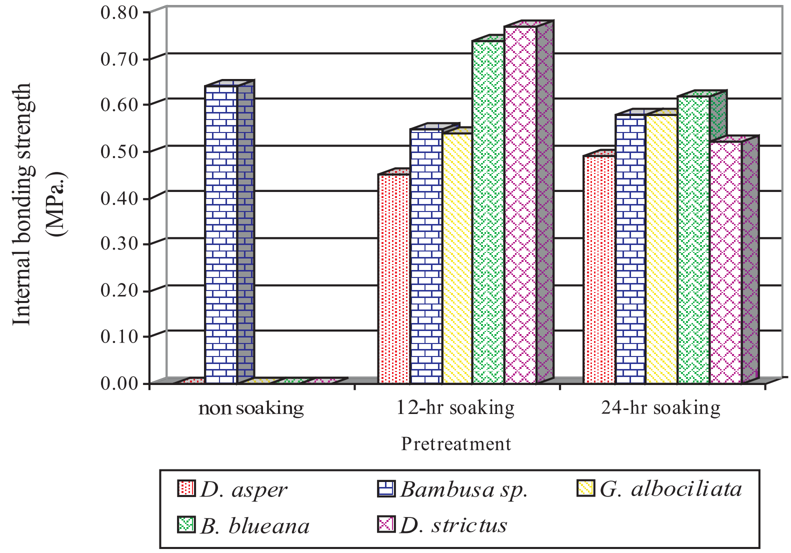

Figure 8. Average internal bonding strength (IB).

CONCLUSIONS

Five bamboo species showed a satisfactory quality as raw material to produce bamboo cement boards. Pai Liang (*Bambusa* sp.) was of the most outstanding properties for making bamboo cement boards even without pretreatment. The materials from other 4 species must be pretreated due to substantial amount of extractives such as starch and sugar that make poor cement bonding with bamboo flakes (Benjachaya, 1992). This phenomenon caused a poor setting and board thickness spring back. With pretreatment of 12-hour and 24-hour water soaking, bamboo cement boards showed non-significant difference in the properties. It is recommended that 12-hour soaking be an appropriate pretreatment to produce good quality bamboo cement boards.

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BAMBOO DYEING

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Three bamboo species, i.e., Pai See Suk (Bambusa blumeana), Pai Sang (Dendrocalamus strictus), and Pai Rai (Gigantachloa albociliata), were included in the experiment. The slivers of these bamboos were dyed using natural dyestuffs derived from heartwood of Acacia catechu Willd., heartwood of Artocarpus heterophyllus Lamk., heartwood of Caesalpinia sappan Linn., heartwood of Cudrania javanensis Trecul, root of Curcuma longa Linn., bark of Oroxylum indicum Vent, and leaves of Tectona grandis Linn f. with alum as a mordant. Dyeing of bamboo with natural dyestuffs makes the products more attractive and more preferable in terms of environmental conservation, whereas the local knowledge on natural dyestuffs harvesting and processing is preserved and promoted.

Key words: natural dyes, dyeing, bamboo

INTRODUCTION

High technology plays an important role in the change of human culture. Synthetic materials, plastic in particular, have been developed to replace the natural ones. Non-wood forest products (NWFP) are commonly used and related to the culture of rural people. Bamboo is one of the most important NWFP as it is multipurpose plant species from which the people enjoy various uses of it, *e.g.* shoot for food, culms for furniture, home decorates, handicrafts, utensil, musical instrument, construction material, as well as for windbreak and protection of soil erosion.

Natural dyes are NWFP derived from different parts of plants and animals and used as dyestuffs for dyeing of silk, cotton, wool, and other fibers. Natural dyestuffs are environmentally friendly and they represent the local knowledge on harvesting, processing, and utilization of natural resources. However, much natural dyes have been replaced by the synthetic ones since mid nineteen century. Synthetic dyes give more brilliant colors. Dyeing process with synthetic dyes takes much shorter time and better control of color shades. Moreover, commercial quantities of synthetic dyes are available in the market. Thus, synthetic dyes become more common in bamboo dyeing.

The objectives of this study were to conduct the experiment on dyeing of bamboo slivers with natural dyestuffs for wicker products and to promote the local knowledge on harvesting and processing of natural dyestuffs.

MATERIALS AND METHODS

Bamboo Slivers

Among 5 bamboo species selected for the studies in the RFD-ITTO Project, *i.e.,* Pai See Suk *(Bambusa blumeana)*, Pai Liang (*Bambusa* sp.*),* Pai Tong (*Dendrocalamus asper)*, Pai Sang (*Dendrocalamus strictus),* and Pai Rai (*Gigantachloa albociliata),* Pai See Suk, Pai Sang, and Pai Rai are commonly used for weaving. The culms of different species are used for different purposes. Culm age is the most important factors determining the use of bamboo, *e.g.*, culms of 3 years of age and older are good for furniture and construction works, while the younger ones are good for weaving. In other words, young culms of 1-2 years old are for delicate works and the older ones for heavy-duty products.

Natural Dyestuffs

The colors of different shades can be derived from barks, heartwoods, leaves, roots and flowers of plants and some from animal (Subansenee, 1995). Seven natural dyestuffs used for bamboo dyeing in this study were those derived from heartwood of *Acacia catechu* Willd., heartwood of *Artocarpus heterophyllus* Lamk., heartwood of *Caesalpinia sappan* Linn., heartwood of *Cudrania javanensis* trecul. root of *Curcuma longa* Linn., bark of *Oroxylum indicum* Vent, and leaves of *Tectona grandis* Linn f. with the following descriptions.

Acacia catechu Willd.

Family	:	Leguminosae
Trade name	:	Catechu tree, cutch tree
Local name	:	Bae, si-siad khean, si siad leung, si siad
General characteristics	:	Medium, spiny tree; cultivated in the dry habitats.
Usage	:	Wood is for short pole, agricultural tool's handles and furniture. Catechol of its extractives is for anti- tussives

		and brown coloring matter for dyeing (called calico printing and catechu brown, cutch brown). A catechu gum is used as masticatory in the betel-Quid, antidiarrhea, antidysentery and treatment of fingal diseases of foot; wood powder is used to stop bleeding.
Coloring part	:	Wood gives brown dye.

***Artocarpus heterophyllus* Lamk.**
***A. integrifolia* Linn. f syn.**

Family	:	Moraceae
Trade name	:	Jack Tree
Local name	:	Ka nun, ma ka nun, mak mea, nun, ka noo, pa yoi sa, na ko
General characteristics	:	It is a large tree, fast growing, with 18 - 21 m in height. Leaves are thick, rough, 4-7 in. long, glabrous above and hairy beneath. Male and female flowers are separated in the same tree. Female flower is green and bigger than male flower. The mature fruits appear after 8 months of breeding, spiny surface, yellowish-green, with many seeds.
Usage	:	Fruit is edible.
Coloring parts	:	Heartwood and root give yellowish-brown dye.

***Caesalpinia sappan* Linn**

Family	:	Caesalpiniaceae
Trade name	:	Sappan wood, False sandal wood
Local name	:	Fang, ngai, fang som
General characteristics	:	Small shurby, thorny tree; common in deciduous scrubs, occasionally cultivated as edges in the villages.
Usage	:	Decoction from wood is used as blood tonic, treatment of pulmonary diseases.
Coloring parts	:	Heartwood gives red color, mainly brazilia. Root gives yellow color.

Cudrania javanensis **Trecul**
Maclura cochinchinensis **Lour syn.**

Family	:	Moraceae
Trade name	:	Mai luang.
Local name	:	Kae lae, luang, kae kong, kae, nam kae, chang ga tog.
General characteristics	:	It is a large climber plant 20-80cm diameter 6-12 m in length, with long and hard thorn (up to 3 in. long). Bark is prone to be vertical debarked, non-resinous, brownish-gray. Leaves are 1 in. wide, 2 in. long, obtuse apex, green above and pale beneath. Fruit is drupe, yellowish-red when ripe, as chicken egg size, many seeds and edible.
Usage	:	The economic size is between 35-50 cm in diameter of more than15 years old. It will be shortened into 1 - 2 m long, debarked. Only heartwood is used for yellow dye source and contains medicinal ingredient for diuretics and antidiarrhoea. Wood is also for small instruments. The calico yellow is bisulphite compound of morin for calico printing.
Coloring part	:	Heartwood gives yellow dye.

Curcuma longa **Linn.**

Family	:	Zingiberaceae
Trade name	:	Tumeric
Local name	:	Khamin, khamin-chun
General characteristics	:	Parennial herb, 30-90 cm. high. ellipsoid Rhizome, particular smell.
Usage	:	Root is a source of yellow coloring matter for dyeing and food coloring matter. Root is medicinal plant: carminative, treatment of peptic ulcer and dyspepsia; external use for itching and infected wound.
Coloring part	:	Root gives yellow color.

Oroxylum indicum **Vent**

Family	:	Bignoniaceae
Local name	:	Pe ka, lin fa, ma lid mai, mak lin chang
General characteristics	:	It is a small to medium tree with 4-20 m height, smooth and gray bark. Leaves are ovate, 3-9 cm wide. Flower is red-purple or blackish-brown. Fruit is pod, 6-10 cm wide and 45-120 cm long. Seed is flat, 2.5-4 cm wide and 5 -9 cm long.
Usage	:	Leaves, root, root bark, seed are ingredients for various medicines.
Coloring part	:	Bark gives khaki dye.

Tectona grandis **Linn f.**

Family	:	Verbenaceae
Trade name	:	Teak
Local name	:	Sak, sae ba yee, pa yee, per yee, kao yea o.
General characteristics	:	Large, deciduous tree; common in mixed deciduous forest in the North.
Usage	:	Wood is for the high-class structures, furniture, agricultural' stools, box, toys, musical instrument, high-grade plywood, and floors. Decoction from leaves and heart wood is used for antidiabetic; and decoction from heart wood only is used for antipyretic.
Coloring parts	:	Young leaves contain red color for paper and cloth dyeing. Heartwood gives khaki dye.

Dyeing Procedures

Preparation of the Materials

Dyestuffs were chipped into small pieces and dried in shade. Fresh bamboo culms were stripped into thin slivers, then scoured or bleached before dyeing. Both bamboo slivers and natural dyestuffs were obtained from the Non Wood Forest Products Research Experimental Station in Nakhon Ratchasima and Chiangmai provinces.

Scouring

Scouring and bleaching are either or both practiced for good results of dyeing. Gums, resins, oily or starch substance in bamboo slivers must be removed by scouring with alkali as 0.2% sodium carbonate or 0.2% sodium hydroxide. About 2-3 teaspoon of alkali were dissolved in 2 liters of boiling water in which 60 grams of bamboo slivers were boiled for 5-10 minutes before being cleansed with water.

Mordanting

The procedure to help fix color in the fiber is called mordanting (Carman, 1978). There are three methods of mordanting : pre-mordant – dye with mordant before dyeing; after-mordant – dyeing before and then mordanting; and adding mordant into the dyebath and then dyeing. Mordants are both chemical and non-chemical substances. There are a number of natural mordants used in the old times, such as clays, wood ashes, rock salts, vinegar, urine, etc. Even the metal dye pot acted as a mordant. Basic mordants are commonly known as alum (potassium aluminium sulphate), tin (stannous chloride), copper (copper sulphate), iron (ferrous sulpate), chrome (potassium dicromate). All of them are heavy metals, using must be with special care. Different mordants give different colors. Alum is normally used as safety mordant even dyeing on silk, cotton or wool.

The mordant in this study was prepared by dissolving 15 grams of alum in small amount of water before adding more water up to 2 liters. Sixty grams of bamboo slivers (or dyed bamboo sliver – for after mordant) were simmered in the mordanting bath for 10 minutes before being rinsed with water.

Dyeing methods

Natural dyeing is a traditional process. Basically, extraction the color can be made putting dyestuff chips in boiling water and simmering for 1-2 hours or soaking in water for 12 hours before being boiled and strained. Bamboo slivers were put into the dyebath and simmered for 20-30 minutes until desired color was obtained. Dyeing may be repeated if desired color had not yet be obtained. The materials were then rinsed clean water then dried. Dyeing duration and the color(s) obtained depend on concentration of dye solution and the thickness of bamboo slivers.

It is suggested that soft water or rain water be used for mordanting and dyeing. The hardness of water will affect the dyebath. The amount of water for dyeing depends on the weight of bamboo slivers, the standard ratio being 20 : 1.

RESULTS AND DISCUSSION

The results on dyeing of bamboo slivers are as presented below. Using of alum as a mordant to fix color, the reaction occurred while mixing alum in dye solution derived from *Artocarpus heterophyllus* Lamk., *Caesalpinia sappan* Linn, *Cudrania javanensis* Trecul, and *Curcuma longa* Linn. to bring about the increase in and/or the change of an intense color. Regardless of the results, pre-mordant, after-mordant, and combined mordant showed their light fastness as level 3-4.

Dyestuffs	Coloring part	Mordant	Color
Acacia catechu Willd.	Heartwood	Alum	Brown
Artocarpus heterophylls Lamk.	Heartwood	Alum	Yellowish-brown
Caesalpinia sappan Linn.	Heartwood	No mordant	Orange
Caesalpinia sappan Linn.	Heartwood	Alum	Red to reddish
Cudrania javanensis Trecul	Heartwood	Alum	Yellow
Curcuma longa Linn.	Root	Alum	Yellow
Oroxylum indicum Vent	Bark	Alum	Khaki
Tectona grandis Linn f.	Leaves	Alum	Khaki

CONCLUSIONS AND RECOMMENDATIONS

Bamboo dyeing is one the important processes to give the value-added to bamboo products, as well as to improve the quality of fungi-infected products. Although bamboo dyeing cannot be practiced with large quantity of raw material, the activity leads to income generation and employment opportunity in rural area. Products with natural dyes are of higher prices and represent the local knowledge on the use of natural resources.

Natural dyestuffs from different parts of the plants in natural forests, harvesting of these dyestuffs must be made with conservation measures. Local knowledge on harvesting and processing of dyestuffs should be preserved and incorporated with the principles of sustainable development.

ACKNOWLEDGEMENTS

The author is grateful to International Tropical Timber Organization (ITTO) for funding the project PD 56/99 Rev. 1(I). Special thanks are given to Prof. Dr. Walter Liese, Dr. Hwan Ok Ma, and Mrs. Wanida Subansenee for their valuable comments and suggestions. Sincere thanks are extended to Mr. Prachoen Sroithongkham, Mr. Suthep Chiablaem and all staff of Non Wood Forest Products Research Experimental Station in Nakhonratchasima province for their kind arrangements of dyestuffs and bamboo materials for this experiment.

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Sustainable Management

SUSTAINABLE MANAGEMENT OF BAMBOO

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The Promotion of the Utilization of Bamboo from Sustainable Sources in Thailand (PD 56/99 Rev. 1 (I)) set the experiment on bamboo management by carry on the internal technical report No. 1 "Review of Bamboo Management" by Kowit Sombun, the management consultant. Five bamboo species (Bambusa sp, B. blumeana, Dendrocalamus asper, D. strictus, and Gigantachloa albociliata) were included in the study of the effects of spacing, culm management and agroforestry system on culms and shoots production.

The results showed that B. blumeana has highest productivity and survival percentage at this stage followed by G. albociliata and D. strictus respectively.

With respect to test the appropriated spacing of bamboo for highest production, the result were difference in each bamboo species. The 8 x 4 m spacing was appropriate for Bambusa sp, B. blumeana and D. strictus, 8 x 8 m for D. asper, and 4 x 4 m for G. albociliata.

The sustainable management of B. blumeana and D. strictus for culm production should be done by harvesting all culms at age 3 years or older from the clump for optimum production and good culm quality. But for G. albociliata harvesting the culms must be done between 1 and 3 years old not older than those otherwise the productivity will be reduce and sustainable production can not be obtained.

Key words: *Bambusa* sp., *Bambusa blumeana* Schult., *Dendrocalamus asper* Back, *Dendrocalamus strictus* Nees, *Gigantachloa albociliata* Munro, sustainable management

INTRODUCTION

Bamboo is one of the most important plant species that Thai people in the rural areas mostly rely on for their daily life, and sometimes it can generate income to support their families. With lack of proper knowledge on propagation, planting and management by most local people, these resources once prosperous are now almost depleted. The natural bamboo growing areas is now considered being degraded, and causing low productivity. The proper knowledge for sustainable production is vital to the improvement of local living.

The study on sustainable management is one of the specific objectives of the RFD/ITTO Project aiming to developing the guidelines for sustainable management of bamboo. The main activities of the study are as follows.

1) Selection of 2 demonstration sites in the northern and northeastern regions.

2) Establishment of 2 demonstration plots for sustainable management of bamboo including site preparation.

3) Selection of 5 bamboo species for each plantation site according to the results of market studies, *e.g.*, local and national (as well as international) demand for basic consumption, production and marketing.

4) Conduct research on sustainable management of bamboo plantation in order to

- identify a proper spacing for cultivation of each commercial bamboo species,
- demonstrate the proper silvicultural systems basically needed for planting,
- find out a suitable proportion of shoot and culms harvesting for highest yield of sustainable production, and
- study the edible insect rearing in bamboo plantation as a value-added product.

The experiments are divided into 4 parts as follows.

Experiment 1	**:**	Species and spacing trials.
Experiment 2	**:**	The effects of selective culm harvesting by age class on the productivity of bamboo.
Experiment 3	**:**	Management trials for shoot and culm production.
Experiment 4	**:**	Trials on bamboo in agroforestry systems.

The experiments included 5 bamboo species, *i.e.*, Pai Tong (*Dendrocalamus asper)*, Pai Sang (*Dendrocalamus strictus*), Pai See Suk (*Bambusa blumeana*), Pai Liang (*Bambusa sp.*), and Pai Rai (*Gigantachloa albociliata*). These bamboo species are used for different purposes, *viz.* young shoots for food, culms for furniture, handcrafts, construction, and other uses.

This report is prepared based on the results of 2-year experiment on sustainable management of bamboo. More observations must be made before the final conclusions can be drawn after the bamboo plants have reached their maturity and the plantations are at full production of shoots and culms.