FINAL TECHNICAL REPORT

Project : PD 56/99 Rev. 1(I)
Promotion of the Utilization of Bamboo from Sustainable Sources in Thailand

Sustainable Management and Utilization from Bamboo

Royal Forest Department
International Tropical Timber Organization
Bangkok, Thailand

September 2004

 

Local Name : Pai Sang Mon
Scientific Name : *Dendrocalamus sericeus* Munro
Chiangdao District, Chiangmai Province

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PREFACE

The **Royal Forest Department** has the policy to promote the establishment and development of commercial plantations, which are regarded to be an important source of income for the rural people as well as a supply of raw material for local industries. This will lead to future development of our national economy.

Bamboo plays an important role in rural development of Thailand. Bamboo shoots provide the rural people with an income in rainy season during which no products are obtained from the major agricultural crops. Bamboo culms are commonly used as construction material of the households in rural area whereas bamboo handicrafts provide an important additional income. The wide uses of bamboo give more employment opportunities and better income distribution. Since bamboo is ubiquitous, people always harvest bamboo without any conservation measures. The natural bamboo resource has been diminished in relation to the depletion of forest area. The scarcity of bamboo resource will force the people to plant more bamboo for their household uses and sell the surplus, if any, for additional income, as well as to properly manage natural bamboo stands for sustainable uses. Thus, bamboo research and development are of vital important in this regard.

The **Royal Forest Department** has received the support from the governments of **Japan** and **the United States of America** through the **International Tropical Timber Organization (ITTO)** to undertake the research and development project on **Promotion of the Utilization of Bamboo from Sustainable Source in Thailand**. The project covers the period from the years 2000 to 2004. Technical reports, internal reports, and manuals are produced for extension purposes and as a basis for future research and development of bamboo resource in Thailand and elsewhere.

On behalf of the **Royal Forest Department**, I would like to express our sincere thanks to **ITTO** and the governments of **Japan** and **the United States of America** for the support. Special thanks are given to **Dr. Hwan Ok Ma**, ITTO Projects Manager, for his constant support during the entire course of the project.

Chatchai Ratanophat

Director General

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ABSTRACT

With the support of the International Tropical Timber Organization (ITTO) Project PD 56/99 Rev 1(I), Thailand conducted the research work on sustainable management and utilization of bamboo. Five economic bamboo, *i.e.*, Pai See Suk (*Bambusa blumeana* J.A. & J.H. Schultes), Pai Liang (*Bambusa sp*.), Pai Tong (*Dendrocalamus asper* Backer ex Heyne), Pai Sang (*Dendrocalamus strictus* (Roxb.) Nees), and Pai Rai (*Gigantachloa albociliata* (Munro) Kurz.) were selected and planted for demonstration, as well as for the studies on sustainable management and utilization. The Project activities included also the study on relevant and useful information along with the other objectives: charcoal making, natural dyeing and bamboo shoot processing.

The training on Bamboo Furniture Parts and Handicrafts, Charcoal Production was organized for the people of community forest in Chiangmai, Nakorn Rachsima and Karnjanaburi provinces. The pilot cottage industry on bamboo furniture parts and handicrafts was set up in Mae-Mae community forest, Chiangmai province together with the establishment of Women Association and Bamboo Cooperatives. Women's participation in Mae-Mae community forest was used as a case study for developing the additional income for the rural people.

The research work aims to produce the necessary information on cultivation and sustainable management of bamboo, protection, properties, dyeing, shoot processing, charcoal techniques, bamboo flooring, and bamboo cement-bonded board, as well as women's participation. The research results presented in this report as well as in the internal papers are also available on the Project's website: **http://www.forest.go.th/bamboo**.

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INTRODUCTION

Background

After logging was banned in Thailand in 1989, the products from the forest came mainly from non-wood sources. Bamboo is one of the important non-wood forest products (NWFPs) that generates additional income and creates an employment to the rural people at the subsistence level. Bamboo has traditionally been used as food, construction material, fuelwood, furniture, musical instruments, gun-handles, kitchen utensils, as well as for weaving and making handicrafts. The natural stands of bamboo in Thai forests have declined in recent years due to over exploitation, improper harvesting, and inadequacy of technical know-how for efficient utilization. Several private and public enterprises have tried to establish bamboo plantations on several occasions, but have been hampered from the lack of technical knowledge on management, utilization, processing, and marketing. Thus, there is a clear-cut need to develop a better quality of bamboo products and their marketability in order to generate more income for the rural people.

With the support of ITTO Project PD56/99 Rev.1(I) Thailand, the research team conducted the research on sustainable management and utilization of bamboo and disseminated the research results to some particular forest communities. The training courses on bamboo weaving and furniture parts, charcoal production techniques were organized for the people in community forests aiming to develop the skills of local people to make bamboo products with appropriate technology. The research findings can be used as an appropriate technology for the efficient and diversified utilization of bamboo leading to more alternatives for income generation in rural communities.

Project Objectives

(1) To study sustainable management of bamboo with a view to developing guidelines for improving sustainable management of bamboo.

(2) To promote efficient and diversified utilization of bamboo with a view to generating income sources for the rural communities.

Purpose of the Report

This report is intended to be used as a guideline for sustainable management and utilization of bamboo. It is expected that the knowledge gained from the studies will help develop means to produce value-added bamboo products. This report includes the results of the research and a synthesis of several internal technical reports and proceedings prepared during the project implementation. These internal reports are available on the Project's website : http://www.forest.go.th/bamboo.

This report is prepared by Mrs. Wanida Subansenee, the project leader, with the assistance of assistant project leader, Ms. Pannee Denrungruang, Mrs. Nuchanart Nilkamhaeng, the project staff and edited by Dr. Songkram Thammicha and Dr. Ladawan Puangchit.

Sustainable Utilization

BAMBOO PROTECTION

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The aim of this research was to solve the problem of insect damage and decaying of bamboo. The relationship between starch content and insect damage was also studied. Another objective was to investigate the possibilities for bamboo protection in rural area by simple methods which determine the effectiveness of various treatments for protecting bamboo culms, bamboo slivers and sticks by using non-chemical and chemical treatments. The project emphasized on low health hazardous chemical preservatives for furniture parts and alternative natural chemical preservatives for protecting bamboo slivers and sticks like Calotropin solution, neem seed solution and Stemona solution.

In case of non-chemical treatment, fresh bamboo culms were immersed in stagnant water for various periods of time. After 12 months exposure in field condition, the immersion for 2 months was adequate to prevent insect damage and fungi infestation. The starch content of bamboo culms depleted after immersing in stagnant water. However, the decrease in insect infestation was correlated with various factors such as species, moisture content and culm age.

For chemical treatment of dry bamboo culms, the immersion in 5% Timbor solution for 24 hours was the most effective for insect prevention while mixture of 0.05% Antiborer and 0.5% Antiblu could prevent deterioration by fungi.

In laboratory test, treatment of soaking bamboo slivers and sticks showed the effectiveness of some natural chemical preservatives against insect but they could not prevent fungi in moist condition.

Key words : bamboo, deterioration, discoloration, immersion, mold, natural chemical preservative, powder-post beetle, sap displacement, soaking

INTRODUCTION

Nowadays forest areas are decreasing, while consumption of timbers are increasing each year. Durable timbers are scarcely and no longer adequate, therefore the fast growing wood species are in replace. Bamboo is among the fast-growing wood species for multipurpose of rural people, and can be harvested continuously. As a source of human existence, bamboo has already become a valuable and excellent substitute for timber. In utilizing bamboo, one must have made approach to the considerations of their ecology and material properties of the respective bamboo. The role of bamboo as environmental material will increase more and more in the future.

There are 15 genera 82 species of bamboos in Thailand (Patanavibool *et al.,* 2001). The species commonly used belong to 5 genera, namely *Dendrocalamus, Bambusa, Thrysostachys, Cephalostachyum* and *Gigantochloa*. The species cultivated as plantation for edible shoots and wood utilization are Pai Tong (*Dendrocalamus asper*), Pai See Suk (*Bambusa blumeana*), Pai Rai (*Gigantochloa albociliata*), and Pai Ruak (*Thyrsostachys siamensis*). Pai Tong (*D. asper*) is widely planted in eastern Thailand for edible shoots, as well as for timber. Pai Ruak (*T. siamensis*) is naturally grown in the forest and planted by rural people in their home-yard for many purposes and it has been exported to Europe for plant supports. There are more useful bamboo species in forest area which are valuable for daily life of the local people.

The utilization of bamboo in Thailand can be traced back to an ancient time. Bamboo has involved a great deal in the lifestyle and close relationship with local people. It is the raw material easy to find and made into usable inexpensive items. In the Thai society, bamboo plays an important role from birth till death, and each piece of bamboo handicrafts reflects the aspiration and local culture (Lisuwan, 1994).

Despite its rapid growth, bamboo consumption is not in balance with the lavish use of the existing number. This has been due to over cutting and improper harvesting, even though there is illegal cutting, therefore the scarcity of bamboo has occurred. Nowadays, the bamboo industrial entrepreneurs and local people whose products are in the market have realized the value of bamboo and its importance as raw material. They have tried to promote replanting of bamboo for sustainable use. Furthermore, the villagers still like to produce profitable bamboo handicrafts, the arts of which have been adopted from their former generations. Bamboo has been proved to be a potential source of cash. The development and utilization of bamboo in Thailand are demonstrated in "One Tambon One Product (OTOP)". These products become high value-added export products.

In tropical countries, destroying of bamboo by insect has been a serious problem. During storage and usage, bamboo timbers and woven products are perishable to insect and fungi. Liese (1997) pointed out that lacking of knowledge of bamboo protection, inadequate treatment facilities and improper chemical preservatives still exist so the problem of biological degradation could not be solved. The consumption of bamboo in the country is increasing every year, while the preservation methods are not appropriate. The increasing demand for bamboo will put more pressure on the resource in the future.

According to Liese (1980, 1997), Sulthoni (1987), and Jayanetti *et al.* (1998), the preservation of bamboo have been described as follows.

Bamboo has low natural resistance, it is liable to attack by fungi and insects. Deterioration of bamboo by powder-post beetles starts as soon as the culm is felled. Damage by insect, especially the bamboo borer, *Dinoderus minutus*, depends on starch content of the culm. Fungi can only attack bamboo culms in a sufficient moisture content, generally over 20%, but air-dried bamboo is protected against fungal degradation. It is strongly recommended that, in bamboo houses construction, the basement be made of concrete work or stone, the bamboo be kept dry so that at least deterioration by fungi is prevented. Untreated bamboo culms may have an average service life of less than 1-3 years when exposed to atmosphere and soil. Split culms are more rapidly destroyed than un-split ones. The bottom part of culm has higher durability than the middle or top part and the inner part is usually attacked earlier than the outer one. Bamboo harvested during summer are more rapidly destroyed than those felled after the rainy period as the latter has less starch present (Sulthoni, 1996; Liese, 1997).

The traditional Asian preservation method is to simply soak the bamboo in water. The soaking method required minimal equipment and technical knowledge. Freshly cut culms are put into stagnant or running water for several weeks. Plank (1950) and Beeson (1961) observed that during the soaking period, the starch content of the parenchyma cell is reduced. Soaking method has been reported to be associated with starch depletion (Roonwall *et al.,* 1966; Kumar *et al.,* 1990) and the degree of powder-post beetle attack decreases as the amount of starch is reduced. This method is therefore said to improve the resistance against borers (Liese, 1980; Tamolang *et al.,* 1980). However, not all bamboo species respond well to the treatment, as *D. asper* improved its resistance while the treatment of other species that have high starch content does not work sufficiently (Sulthoni, 1990). Liese (1997) emphasized that soaking does not increase the resistance against termite and fungi, but may lead to staining and bad odor of the bamboo culms.

Using of chemical for bamboo protection is more effective. The effectiveness depends on the type of preservative and its concentration. Non-leachable preservatives are suitable for outdoor uses. The preservative should not contain components poisonous to human and animals. The treatment is economically effective with the service life of 10-15 years for outdoor and 15-25 years for indoor uses. Because bamboo is relatively cheap and abundantly available raw material, any preservation must be cheap, easy to perform and readily available (Liese, 1980).

Chemical preservation by the open-tank treatment is an economical and simple method with a good protective effect. Culms are soaked in a solution of a water soluble preservative for several days. The solution gets into the culm by diffusion through both ends and partly through the sides. The results of investigation carried out on the conditions for open-tank treatment can be summarized as follows.

- Immature bamboo allow much better penetration through both the outer and the inner skin than does mature bamboo.
- Both the outer and the inner skin are permeable to some extent to preservatives during long soaking; however, the inner skin is a little more permeable than the outer.
- Split culms can be treated more easily than round ones and the use of split bamboo could reduce the soaking period by as much as one-half.
- Penetration and absorption of water-soluble preservatives are lower in fresh culm than in air-dried material.
- In air-dried culms, diffusion in the axial direction has been found to be about 20 times that in the transverse direction and radial diffusion is slightly more than the tangential. Diffusion through the inner wall is faster than through the outer part.
- Fresh culm should be treated with the preservative solution of higher concentration.

Water absorption in bamboo is generally slow, the duration of treatment depends mainly on the kind of preservative, the bamboo species, age and culm conditions. The penetration of liquid into the culm takes place in the axial direction from both ends through the vessel. The long stretching vessels are thus perfect pathways for exchange of sap by the preservative solution. Liese (1998) reported that the vessels are very small at the periphery of a culm wall and become larger in the middle and inner part. The vessels of bamboo occupy only rather small about 5-8 % area of the whole cross section. For a satisfactory treatment of the tissue, it is necessary that the preservative diffuse from the vessels into the surrounding fibers and parenchyma cells. Even when the vessels are completely filled, the bamboo culm can be destroyed by fungi or insect if the preservative does not diffuse into the tissue enough, the main tissue of the culm being left untreated. The anatomical structure of bamboo culms, however, make it difficult to treat effectively as it is more resistant to chemical penetration than wood (Liese, 1985; 1997).

The modified Boucherie method (sap displacement treatment) was developed from Boucherie method of wood preservation described by Purushotham *et al*. (1954) and Liese (1959). This method has provided the most effective for freshly cut bamboo by applying the preservative at one end under a moderate pressure of about 1 bar. The moisture content of the culms must be as high as possible. The treatment should be done on the day of cutting, otherwise the culms have to be stored in water prior to treatment. The culms are tightly fastened by rubber cuffs. The preservative is forced axially through the culm by an air pressure in the container. The water-transporting part of the culm can be penetrated completely. The pressure has to be maintained until nearby vessels are filled with the preservative and this is influenced by the vessel area of the species. The penetration and absorption of the preservative depend upon several factors such as concentration, treatment time, pressure, nature of chemical used, dimension, species, age of the bamboo, culm length, wall thickness, moisture content, *etc.* The modified procedure reduces the period of treatment from several days to 1-2 hours for culm of 4-5 m long (Liese, 1997). Liese and Kumar (2003) suggested that the culms of 150 mm diameter and 6 m long be treated in 30-50 minutes and those of 9 m long in 60-70 minutes with a pressure of 1.0-1.3 bar (15-20 psi, 1 bar = 15 psi).

The best results of this method are obtained during the rainy season and after, while failures may occur during the dry season. Young culms with higher water content are more suitable for this method than those with less moisture.

Independent of the respective vessel area, the bamboo culms must be treated as fresh as possible because soon after their felling, the vessel are filled by a blockage due to cellular out growths are slime. Therefore both ends have to be cut off immediately before the treatment for a clean surface (Liese, 1998).

After the culms have been treated, they are allowed to dry in a covered place to avoid direct wetting and expose to sun rays which may cause a leaching of the preservatives. Drying in a very humid tropical climate generally take a lot of time. It is therefore recommended to have enough space between the bamboo pieces and a good distance from the wet soil (not less than 40 cm) for a good ventilation.

Reports of bamboo preservation in Thailand are scarcely found. However, local people know how to protect bamboo culms or products by simple traditional methods as soaking, boiling, curing with heat and smoke, fumigating with sulphur, coating with resin, and treating with natural chemical preservatives. Unfortunately some of these methods are not effective due to their restrictions.

The objective of this experiment is to establish the effective methods of bamboo protection in Thailand against degradation by insects and fungi for prolonging its service life. The emphasis is placed on low health-hazardous chemical preservatives, simple equipment and easy to apply in rural area.

MATERIALS AND METHODS

Part I : Treatment of Bamboo Culms for Furniture Parts

Bamboo Species

Three bamboo species were included in the study.

a) **Pai Liang** (*Bambusa* sp.): 3 years old, cut from Ubon Ratchathani province on 10 March, 2001.

b) **Pai Tong** (*Dendrocalamus asper*): 3 years old, cut from Prachinburi province on 23 March, 2001.

c) **Pai Sang** (*Dendrocalamus strictus*): 3 years old, cut from Chiangmai province on 18 March, 2001.

Bamboo culms were divided into 3 sections (bottom, middle, and top) each of 2 m long and 5 replications per treatment. These sections were made hollow by piercing the inner nodes with an iron bar.

Non–chemical Treatment

Fresh bamboo culm parts were immersed in stagnant water in the lake of Lum Ta Kong Dam for 1, 2, 3, 4, 5 and 6 months to reduce the starch from bamboo culm parts in order to improve the resistance against insects borer and fungi.

Chemical Treatment

Air-dried bamboo culm parts were immersed in the following chemical solutions.

a) Mixture of 0.05% Antiborer (insecticide) and 0.5% Antiblu (fungicide) for 1 hour.

b) Timbor solution (5%) for 1 hour.

c) Timbor solution (5%) for 24 hours.

Antiborer (cypermethrin) is stable, long lasting in wood, extremely effective against insects and can be mixed with Antiblu. Cypermethrin is highly effective of low mamalian toxicity, low persistence in soil and rapidly degraded by microorganisms and physico–chemical process in soil. Antiborer formulations are used at low concentration further reducing the hazard. Environmental contamination is therefore minimized.

Antiblu is a liquid flowable concentrate containing a combination of two fungicides: Chlorothalonil and Carbendazim. The range of products has been formulated to give effective protection against sap stain and mold.

Timbor is boron–based preservative of Disodium Octaborate Tetrahydrate. Boron compounds present low health hazard. Acute toxicity of Boron compounds is relatively low. They are non–fixed–type water–borne formulations recommended for indoor wood treatment and appear to exert insecticidal effect at low concentration with anti–fungal activity at higher concentration.

After treatments, all bamboo culm parts were air dried under shelter about 1 month. The treated bamboo samples and control were then placed horizontally on supports under shelter in field conditions to expose to natural infestation by insects and fungi. The results of insects and fungal attack were evaluated after 1, 3, 6 and 12 months in the field and then half split for inspection. The degree of insect damage on bamboo culm parts was assessed basing on the method of Beeson (1961) by counting the borer's hole per sample and the inspection of fungal attack was rated as :

0 – no damage,

1 – slight attack (1–25%),

2 – moderate attack (26–50%) and

3 – heavy attack (51–100%).

Part II : Treatment of Bamboo Slivers and Sticks for Weaving

Bamboo Species

a) **Pai See Suk** (*Bambusa blumeana*) : 1 and 2 years old, cut from Nakhon Ratchasima province on 2 April, 2001.

b) **Pai Rai** (*Gigantochloa albociliata*) : 1 and 2 years old, cut from Chiangmai Province on 18 March, 2001.

One and two years old culms were split, stripped and shaved into slivers of 1x10x300 mm and sticks of 10x10x300 mm before being air-dried. Ten pieces of each sample (sliver or stick) were prepared for each preservation treatment: five pieces for insect and the other five pieces for fungi tests in the laboratory.

Non – chemical Treatment

The following treatments were set up : boiling the bamboo in water for 1 and 2 hours and boiling the bamboo in palm oil for 1 and 2 hours.

Natural Chemical Treatment

a) Boiling the bamboo in Calotropin solution for 1 and 2 hours.

b) Soaking the bamboo in 0.25% and 0.5% commercial neem seed solution for 3 days.

c) Soaking the bamboo in 0.25% and 0.5% commercial Stemona solution for 3 days.

Calotropin solution was prepared by boiling 2 kg of fresh stems and leaves of Giant Indian Milk Weed (*Calotropis gigantea* Linn.; Fam. Asclepiadaceae) in 20 litres of water and boiled the bamboo slivers and sticks in the solution for 1 and 2 hours. Boiling in Calotropin solution is a kind of traditional preservation to protect bamboo slivers for weaving against insect attack.

Neem (*Azadirachta indica* var. *siamensis*; Fam. Meliaceae) is available in the market as powder and solution. It is used for insect repellent, molting inhibition of insect in juvenile stage and hatching inhibition. Neem is both fertilizer and insecticide.

Stemona (*Stemona tuberosa* Lour.; common name : Non Tai Yak; Fam. Stemonaceae) is available for use as traditional insecticide in village for killing worm in the wound of cattle, preventing maggot on top of the preserved salted fish container and using as pesticide on plant.

Labaratory Test on the Effect of Preservative Treatments against Powder–post Beetle and Fungal Attack

a) ***Test against powder–post beetle***. Specimens were set between the mass rearing of *Dinoderus minutus* in bamboo splits of 75% damaged for 4 months. The result was evaluated by the number of insect bites on the treated bamboo slivers and sticks.

b) ***Test against fungal attack.*** Specimens were tested for fungal attack by placing on the rack in the moist chamber for 2 weeks. The result was investigated after 1 and 2 weeks exposure time. The rates of fungal growth on surface of slivers and sticks were evaluated.

RESULTS AND DISCUSSION

Part I. Treatment of Bamboo Culms for Furniture Parts

Non – chemical Treatment

Field test on the effects of immersion on fresh bamboo culm parts in stagnant water

The results after 12 months exposure in field condition and then half-split inspection showed that the immersion of bamboo culm parts in stagnant water for 2 months was adequate and effective for preventing insect attacks (Tables 1 and 2). The number of holes caused by insect on bamboo culm parts showed the quantity of some entrance holes and majority exit holes of powder–post beetle (*Dinoderus minutus*) and long–horn beetle (*Chloroporus annularis*). The damage by insect was evaluated as a percentage by inspecting half-split bamboo culm parts after 12 months exposure. Pai Tong (*D. asper*) had the best resistance to insect (5.2%), while Pai Liang (B*ambusa* sp.) and Pai Sang (*D. strictus*) were susceptible to insect attacks with 16.6% and 14.0% damage respectively (Table 2). The damage by insect on untreated bamboo culm parts of each species (Table 1) was less on the bottom parts, the middle and top parts being more susceptible to insect infestation.

There was less growth of mold and stain fungi on the surface of bamboo culm parts which immersed for 1 month, and more growth was found on the bottom parts (Tables 3 and 4). This could be explained that longer immersion time resulted in higher moisture uptake in culm parts and the bamboo needed

Table 1. Damage by insects (in number of holes) on bamboo parts immersed in stagnant water after 1, 3, 6 and 12 months exposure

Bamboo species	Immersion time	Control				1 month				2 months				3 months				4 months				5 months				6 months			
	Exposure time	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12
Bambusa sp.	Bottom	2	29	47	54	13	16	21	21	5	15	55	70	3	3	4	4	0	1	1	3	1	2	2	2	0	0	0	0
	Middle	9	18	53	64	8	22	53	67	2	8	8	8	2	3	4	6	0	0	0	0	0	0	0	0	0	0	0	0
	Top	6	28	74	79	1	1	2	8	6	7	7	7	0	0	0	0	0	5	5	7	0	0	2	2	0	0	0	0
	Total	17	75	174	197	22	39	76	96	13	30	70	85	5	6	8	10	0	6	6	10	1	2	4	4	0	0	0	0
	Average	**1.1**	**5.0**	**11.6**	**13.1**	**1.5**	**2.6**	**5.1**	**6.4**	**0.9**	**2.0**	**4.7**	**5.7**	**0.3**	**0.4**	**0.5**	**0.7**	**0**	**0.4**	**0.4**	**0.7**	**0.1**	**0.1**	**0.3**	**0.3**	**0**	**0**	**0**	**0**
Dendrocalamu asper	Bottom	2	3	3	3	1	11	16	25	1	15	16	17	0	11	14	17	3	9	10	40	1	1	1	1	0	0	0	0
	Middle	32	105	108	109	3	7	15	20	2	3	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Top	16	69	79	82	15	24	25	32	0	3	3	3	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
	Total	50	177	190	194	19	42	56	77	3	21	23	26	0	11	14	17	3	10	11	41	1	1	1	1	0	0	0	0
	Average	**3.3**	**11.8**	**12.7**	**12.9**	**1.3**	**2.8**	**3.7**	**5.1**	**0.2**	**1.4**	**1.5**	**1.7**	**0**	**0.7**	**0.9**	**1.1**	**0.2**	**0.7**	**0.7**	**2.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0**	**0**	**0**	**0**
Dendrocalamus strictus	Bottom	4	6	17	28	3	15	15	21	1	2	2	2	0	0	0	0	3	4	4	4	0	0	0	0	0	0	0	0
	Middle	22	89	560	758	3	4	15	25	0	6	9	11	0	0	1	1	2	2	2	2	0	0	0	0	0	0	0	0
	Top	23	46	389	553	3	11	43	96	2	5	5	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	59	141	966	1339	9	30	73	142	3	13	16	23	0	0	1	1	5	6	6	6	0	0	0	0	0	0	0	0
	Average	**3.9**	**9.4**	**64**	**89.3**	**0.6**	**2**	**4.9**	**9.5**	**0.2**	**0.9**	**1.1**	**1.5**	**0**	**0**	**0.1**	**0.1**	**0**	**0.4**	**0.4**	**0.4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Note : Number of holes in 3, 6 and 12 months are accumulated

Table 2. Percent of insect damage by half-split inspection on bamboo parts immersed in stagnant water after 12 months exposure

Bamboo species	Immersion time	Control	1 month	2 months	3 months	4 months	5 months	6 months
Bambusa sp.	Bottom	11.0	11.0	4.0	0.3	3.0	0	0
	Middle	8.8	5.6	0	0.3	0	0	0
	Top	30.0	1.1	0	0.0	1.0	0	0
	Average	16.6	5.9	1.3	0.2	1.3	0	0
Dendrocalamus asper	Bottom	0	7.5	1.1	0	0	0	0
	Middle	3.2	4.0	0	0	0	0	0
	Top	12.4	7.0	0	0	0	0	0
	Average	5.2	6.2	0.4	0	0	0	0
D. strictus	Bottom	5.0	8.0	2.0	0	0	0	0
	Middle	29.0	2.0	0.1	0	0	0	0
	Top	8.0	11.0	0	0	0	0	0
	Average	14.0	7.0	0.7	0	0	0	0

longer drying time. The thick wall bamboo species such as *D. asper* was more susceptible to fungal attacks and the bottom parts were more destroyed than the other parts. The results from investigation of half-split bamboo culm parts (Table 4) indicated less fungal growth in the inner part of bamboo which immersed for 1, 2, and 3 months. The results were similar to these of untreated culm parts of each species, except the bottom parts of thick wall bamboo species, *D. asper*. Less growth of fungi was found in untreated bamboo (control) due to less moisture in the culm. The longer immersion time in stagnant water caused some disadvantage such as dirt and discoloration of bamboo surface, unsatisfied odor, and cracking along the thin wall. Therefore, a 2-month immersion of bamboo culm parts in stagnant water was suitable and effective for preventing from both insect and fungal attacks.

Effects of immersion on starch depletion and its relation to insect and fungal attack

The starch content of each bamboo species was reduced and related to the depletion of insect infestation as shown in Table 5. The ratio of starch content to the number of insect attacks in the untreated bamboo culm parts of *Bambusa* sp., *D. asper* and *D. strictus* was 1.88%:197, 0.68%:194, and 0.60%:1339, respectively. After six months of immersion in stagnant water, the ratio was decreased to 0.10%:0 for *Bambusa* sp., 0.03%:0 for *D. asper*, and 0.17%:0 for *D. strictus*. On the contrary, the starch content had no influence upon the fungal growth, as did the immersion time, humidity in rainy season, and ventilation during the exposure in field conditions.

Table 3. Rate of discoloration on bamboo parts immersed in stagnant water after 1, 3, 6 and 12 months exposure

Bamboo species	Immersion time	Control				1 month				2 months				3 months				4 months				5 months				6 months			
	Exposure time	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12
Bambusa sp.	Bottom (2.9)	0	0	1	1	2	2	2	2	1	1	2	2	3	3	3	3	2	2	3	3	2	2	3	3	2	3	3	3
	Middle (1.2)	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Top (0.9)	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3
D. asper	Bottom (4.4)	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3
	Middle (2.1)	1	1	1	1	1	1	1	1	2	2	2	2	1	1	2	2	2	3	3	3	2	2	3	3	2	2	2	3
	Top (1.2)	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	1	1	2	3	2	2	2	2	2	2	2	2
D. strictus	Bottom (2.3)	1	1	1	1	2	2	2	2	2	2	2	3	1	1	2	2	2	2	3	3	1	2	2	2	2	2	3	3
	Middle (1.5)	0	0	1	1	1	1	1	1	2	2	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2
	Top (1.0)	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3	3	3	3	2	2	2	2

Rate of discoloration on bamboo surface caused by fungi

0 - no damage (no discoloration)
1 - slight attack (discoloration for 1-25% of surface area)
2 - moderate attack (discoloration for 26-50% of surface area)
3 - heavy attack (discoloration for 51-100% of surface area)

Note : Figures in parenthesis are bamboo thickness (cm)

Table 4. Rate of discoloration by half-split inspection on bamboo parts immersed in stagnant water after 12 months exposure

Bamboo species	Treatment	Control	1 month	2 months	3 months	4 months	5 months	6 months
Bambusa sp.	Bottom	1	1	1	1	2	2	2
	Middle	1	1	1	1	2	3	2
	Top	1	1	1	1	2	2	3
	Average	**1**	**1**	**1**	**1**	**2**	**2**	**2**
Dendrocalamus asper	Bottom	1	3	2	2	2	2	2
	Middle	1	1	1	1	2	2	2
	Top	1	1	1	1	2	2	2
	Average	**1**	**2**	**1**	**1**	**2**	**2**	**2**
D. strictus	Bottom	2	1	1	1	1	1	1
	Middle	1	3	1	2	2	2	2
	Top	1	2	1	1	2	2	1
	Average	**1**	**2**	**1**	**2**	**2**	**2**	**1**

Rate of discoloration

0 – no damage
1 – slight attack
2 – moderate attack
3 – heavy attack

Table 5. Correlation between starch content and insect damage (in number of holes) on bamboo parts immersed in stagnant water

Bamboo species	Control		1 month		2 months		3 months		4 months		5 months		6 months	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Bambusa sp	1.88	197	0.63	96	0.42	85	0.31	10	0.41	10	0.51	4	0.1	0
D. asper	0.68	194	0.21	77	0.06	26	*	17	*	41	0.01	1	0.03	0
D.strictus	0.6	1339	0.52	142	0.56	23	0.26	1	0.33	6	0.18	0	0.17	0

Note : a - Starch content in percent
: b - Insect attack in number of holes after 12 months exposure
: All bamboo samples are 3 years old.
: * - missing data
: Data of starch content obtained from the research of chemical properties "Chemical Composition of Five Bamboo Species in Thailand"

Chemical Treatment

Field test on the effects of immersion of dry bamboo culm parts in chemical preservatives

The results of chemical treatment showed that the immersion of bamboo culm parts in 5% Timbor solution for 24 hours was the most effective treatment against insect infestation for 12 months (Tables 6 and 7). The treatment with mixture of 0.05% Antiborer (insecticide) and 0.5% Antiblu (fungicide) immersion for 1 hour could protect *D. strictus* for 6 months and 1 month for other species (Table 6).

For the infestation of fungi**,** there was less growth of mold and stain fungi on the surface of bamboo culm parts in each treatment and control (Table 8), but after inspection of half-split bamboo (Table 9), and there was more fungal growth in the inner parts than on the surface. The mixture of 0.05% Antiborer and 0.5% Antiblu was the most effective to each species. The immersion in 5% Timbor solution for 24 hours was effective treatment for *D. asper* and *D. strictus*.

The penetration of Timbor solution in bamboo culm parts was inspected by tumeric test**.** The result showed more absorption of Timbor in the inner part than in the outer part, and the thin wall than the thick wall part. However, the amount of Timbor was not enough to prevent the insects even with 24-hour immersion. The appropriate immersion time should be considered as far as the bamboo wall thickness is concerned.

Table 6. Damage by insects (in number of holes) on treated bamboo parts after 1, 3, 6 and 12 months exposure

Bamboo species	Treatment	Control				Antiborer + Antiblu 1 hr				Timbor 5% 1 hr				Timbor 5% 24 hrs			
	Exposure time	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12
Bambusa sp.	Bottom	2	29	47	54	11	34	36	43	2	24	49	175	0	0	0	0
	Middle	9	18	53	64	11	11	16	138	42	64	84	85	0	8	11	11
	Top	6	28	74	79	0	1	2	28	24	29	34	35	0	0	1	1
	Total	17	75	174	197	22	46	54	209	68	117	167	295	0	8	12	12
	Average	**1.1**	**5.0**	**11.6**	**13.1**	**1.5**	**3.1**	**3.6**	**13.9**	**4.5**	**7.8**	**11.1**	**19.7**	**0**	**0.5**	**0.8**	**0.8**
D. asper	Bottom	2	3	3	3	0	41	50	69	15	15	17	17	3	12	14	15
	Middle	32	105	108	109	16	36	37	52	2	6	6	6	1	7	7	7
	Top	16	69	79	82	8	17	19	19	6	9	11	13	10	13	18	18
	Total	50	177	190	194	24	94	106	140	23	30	34	36	14	32	39	40
	Average	**3.3**	**11.8**	**12.7**	**12.9**	**1.6**	**6.3**	**7.1**	**9.3**	**1.5**	**2.0**	**2.3**	**2.4**	**0.9**	**2.1**	**2.6**	**2.7**
D. strictus	Bottom	4	6	17	28	0	0	0	5	0	3	6	32	0	7	7	9
	Middle	22	89	560	758	0	0	0	7	0	4	4	4	0	0	5	16
	Top	33	46	389	553	1	1	1	17	20	29	32	32	5	13	24	27
	Total	59	141	966	1339	1	1	1	29	20	36	42	68	5	20	36	52
	Average	**3.9**	**9.4**	**64.4**	**89.3**	**0.1**	**0.1**	**0.1**	**1.9**	**1.3**	**2.4**	**2.8**	**4.5**	**0.3**	**1.3**	**2.4**	**3.5**

Note : Number of holes in 3, 6, 12 months are accumulated.

Table 7. Percent of insect damage by half-split inspection on treated bamboo parts after 12 months exposure

Bamboo species	Treatment	Control	Antiborer + Antiblu 1 hr	Timbor 5% 1 hr	Timbor 5% 24 hrs
Bambusa sp.	Bottom	11.0	2.7	34.0	0
	Middle	8.8	26.4	0.2	0.1
	Top	30.0	8.1	0.6	0
	Average	**16.6**	**12.4**	**11.6**	**0.03**
Dendrocalamus asper	Bottom	0	3.0	0	0.7
	Middle	3.2	8.0	0	0
	Top	12.4	6.4	0.7	0
	Average	**5.2**	**5.8**	**0.2**	**0.2**
D. strictus	Bottom	5.0	1.0	10.0	2.0
	Middle	29.0	20.4	0	0
	Top	8.0	1.1	0.2	0.04
	Average	**14.0**	**7.5**	**3.4**	**0.7**

Table 8. Rate of discoloration on treated bamboo parts after 12 months exposure

Bamboo species	Treatment	Control				Antiborer + Antiblu 1 hr				Timbor 5% 1 hr				Timbor 5% 24 hrs			
	Exposure time	1	3	6	12	1	3	6	12	1	3	6	12	1	3	6	12
Bambusa sp.	Bottom	0	0	1	1	0	0	0	1	0	0	1	1	0	0	0	0
	Middle	1	1	1	1	0	0	1	1	0	0	1	1	0	1	1	1
	Top	1	1	1	1	0	1	1	1	0	0	1	1	0	0	1	2
D. asper	Bottom	2	2	2	2	0	1	1	1	0	1	1	1	0	1	1	1
	Middle	1	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1
	Top	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0
D. strictus	Bottom	1	1	1	1	0	0	1	1	0	0	1	1	0	1	1	1
	Middle	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
	Top	1	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1

Rate of discoloration
- 0 – no damage
- 1 – slight attack
- 2 – moderate attack
- 3 – heavy attack

Table 9. Rate of discoloration by half-split inspection on treated bamboo parts after 12 months exposure

Bamboo species	Treatment	Control	Antiborer + Antiblu 1 hr	Timbor 5% 1 hr	Timbor 5% 24 hrs
Bambusa sp.	Bottom	1	1	2	3
	Middle	1	1	2	2
	Top	1	1	3	3
	Average	**1**	**1**	**2**	**2**
Dendrocalamus asper	Bottom	1	1	1	1
	Middle	1	1	1	1
	Top	1	1	1	1
	Average	**1**	**1**	**1**	**1**
D.strictus	Bottom	2	1	2	1
	Middle	1	1	1	1
	Top	1	1	1	1
	Average	**1**	**1**	**1**	**1**

Rate of discoloration
- 0 – no damage
- 1 – slight attack
- 2 – moderate attack
- 3 – heavy attack

Part II. Treatment of Bamboo Slivers and Sticks for Weaving

Bamboo Slivers

Laboratory test against insects

The results of the test indicated that natural chemicals could not protect the slivers from one-year-old culms of *B. blumeana* and *G. albociliata.* Higher concentra-tion is recommended. Boiling in Calotropin solution for 2 hours, soaking in 0.5% neem seed solution for 3 days, and soaking in 0.25% Stemona solution for 3 days gave an effective protection for two-year-old. *B. blumeana,* as did 3-day soaking in 0.5% Stemona solution for two-year-old *G. albociliata* (Table 10).

Table 10. Damage by insects (in number of insect bites) on treated bamboo slivers after 4 months exposure

Bamboo species	Age (year)	Treatment	Control	C1	C2	N1	N2	S1	S2	W1	W2
B. blumeana	1	Bottom	12	22	10	17	24	16	14	91	30
		Middle	17	7	9	5	83	16	16	22	17
		Top	16	23	15	13	30	3	21	9	28
		Total	45	52	34	35	137	35	51	122	75
		Average	**3**	**3.5**	**2.3**	**2.3**	**9.1**	**2.3**	**3.4**	**8.1**	**5.0**
	2	Bottom	11	13	2	8	5	3	2	10	7
		Middle	21	1	5	15	3	7	6	28	12
		Top	5	2	3	9	5	3	9	1	4
		Total	37	16	10	32	13	13	17	39	23
		Average	**2.5**	**1.1**	**0.7**	**2.1**	**0.9**	**0.9**	**1.1**	**2.6**	**1.5**
G. albociliata	1	Bottom	41	19	41	13	32	12	3	2	18
		Middle	34	13	16	10	24	5	14	8	8
		Top	36	7	17	10	17	16	3	11	14
		Total	111	39	74	33	73	33	20	21	40
		Average	**7.4**	**2.6**	**4.9**	**2.2**	**4.9**	**2.2**	**1.3**	**1.4**	**2.7**
	2	Bottom	20	49	7	9	5	8	5	13	13
		Middle	8	14	7	18	17	8	5	9	14
		Top	18	4	18	15	6	11	1	7	24
		Total	46	67	32	42	28	27	11	29	51
		Average	**3.1**	**4.5**	**2.1**	**2.8**	**1.9**	**1.8**	**0.7**	**1.9**	**3.4**

Note : C1 = Boiling in Calotropin solution (2 kg. : 20 liters water) for 1 hr
C2 = Boiling in Calotropin solution (2 kg. : 20 liters water) for 2 hrs
N1 = Soaking in 0.25% neem seed solution for 3 days
N2 = Soaking in 0.5% neem seed solution for 3 days
S1 = Soaking in 0.25% Stemona solution for 3 days
S2 = Soaking in 0.5% Stemona solution for 3 days
W1 = Boiling in water for 1 hr
W2 = Boiling in water for 2 hrs

Laboratory test against fungi

A high rate of attack on bamboo slivers in each treatment was obvious. It seemed that the natural chemical could not inhibit fungi. They could grow on treated slivers with high moisture content (Tables 11 and 12).

Table 11. Rate of discoloration on treated bamboo slivers with natural chemicals after 1 and 2 weeks exposure

Treatment	Time	*B. blumeana* 1 year						*B. blumeana* 2 years					
		Bottom		Middle		Top		Bottom		Middle		Top	
		1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks
Control		2	2	2	3	2	3	2	3	2	3	2	3
Calotropin	1 hr	2	3	2	2	3	3	2	3	2	3	2	3
	2 hrs	2	3	2	3	2	3	3	3	3	3	2	3
Neem	3 days (0.25%)	2	3	2	3	3	3	1	3	1	3	2	3
	3 days (0.5%)	2	3	2	3	2	3	3	3	2	3	2	3
Stemona	3 days (0.25%)	2	3	2	3	3	3	3	3	1	2	1	3
	3 days (0.5%)	2	3	2	3	2	3	2	3	2	3	2	3
Water	1 hr	2	3	2	3	2	3	3	3	2	3	2	3
	2 hrs	2	3	3	3	2	3	3	3	3	3	3	3

Rate of discoloration
- 0 – no damage
- 1 – slight attack
- 2 – moderate attack
- 3 – heavy attack

Table 12. Rate of discoloration on treated bamboo slivers with natural chemicals after 1 and 2 weeks exposure

Treatment	Time	*G. albociliata* 1 year						*G. albociliata* 2 years					
		Bottom		Middle		Top		Bottom		Middle		Top	
		1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks
Control		1	2	2	2	1	2	1	2	2	3	1	2
Calotropin	1 hr	2	3	2	3	2	3	2	3	1	3	2	3
	2 hrs	3	3	3	3	3	3	1	2	1	2	2	3
Neem	3 days (0.25%)	2	3	2	3	2	3	1	3	2	3	2	3
	3 days (0.5%)	2	2	2	2	2	3	1	2	1	3	1	3
Stemona	3 days (0.25%)	1	2	2	2	2	3	1	3	2	3	2	3
	3 days (0.5%)	2	3	2	3	2	3	1	2	1	2	1	3
Water	1 hr	2	3	2	2	3	3	2	3	2	2	2	3
	2 hrs	2	3	2	3	2	3	1	2	1	3	2	2

Rate of discoloration
- 0 – no damage
- 1 – slight attack
- 2 – moderate attack
- 3 – heavy attack

Bamboo Sticks

Laboratory test against insect

Boiling in Calotropin solution for 2 hours and soaking in 0.5% Stemona solution for 3 days were effective for one-year-old *G. albociliata*, whereas boiling in water for 1 hour and soaking in 0.5% neem seed solution for 3 days were effective for two-year-old *G. albociliata.* The high insect infestation was found on bamboo sticks treated with boiling in palm oil (Table 13).

Table 13. Damage of insects (in number of insect bites) on treated bamboo sticks after 4 months exposure

Bamboo species	Treatment	Control	W1	W2	C1	C2	N1	N2	S1	S2	P1	P2
B. blumeana	Bottom	75	24	17	12	5	11	-	33	0	54	17
	Middle	25	7	15	0	0	1	-	9	3	19	18
	Top	46	14	9	5	2	8	-	15	5	29	10
	Total	146	45	41	17	7	20	-	57	8	102	45
	Average	**9.7**	**3**	**2.7**	**1.1**	**0.5**	**1.3**	**-**	**3.8**	**0.5**	**6.8**	**3**
B. blumeana	Bottom	57	2	14	17	-	3	4	14	6	63	16
	Middle	47	3	21	10	-	1	0	3	7	49	13
	Top	30	2	5	4	-	6	4	17	5	34	17
	Total	134	7	40	31	-	10	8	34	18	146	46
	Average	**8.9**	**0.5**	**2.7**	**2.1**	-	**0.7**	**0.5**	**2.3**	**1.2**	**9.7**	**3.1**

Note : W1 = Boiling in water for 1 hr
W2 = Boiling in water for 2 hrs
C1 = Boiling in Calotropin solution (2 kg. : 20 liters water) for 1 hr
C2 = Boiling in Calotropin solution (2 kg. : 20 liters water) for 2 hrs
N1 = Soaking in 0.25% neem seed solution for 3 days
N2 = Soaking in 0.5% neem seed solution for 3 days
S1 = Soaking in 0.25% Stemona solution for 3 days
S2 = Soaking in 0.5% Stemona solution for 3 days
P1 = Boiling in 200^{o}c palm oil for 1 hr
P2 = Boiling in 200^{o}c palm oil for 2 hrs

Laboratory test against fungi

There was high fungal growth on bamboo sticks in each treatment. Denser fungal mycelia were found on bamboo sticks than those on slivers due to higher moisture content in the sticks. It may be concluded that some natural chemical preservatives could not protect bamboo sticks from the fungal infestation (Table 14).

Table 14. Rate of discoloration on treated bamboo sticks with natural chemicals after 1 and 2 weeks exposure

Treatment	Time	*B. blumeana* 1 year						*B. blumeana* 2 years					
		Bottom		Middle		Top		Bottom		Middle		Top	
		1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks	1 wk	2 wks
Control		3	3	3	3	3	3	3	3	3	3	3	3
Calotropin	1 hr	3	3	3	3	3	3	3	3	3	3	3	3
	2 hrs	3	3	3	3	3	3	3	3	3	3	3	3
Neem	3 days (0.25%)	3	3	3	3	3	3	3	3	3	3	3	3
	3 days (0.5%)	3	3	3	3	3	3	3	3	3	3	3	3
Palm oil	1 hr	3	3	3	3	3	3	3	3	3	3	3	3
	2 hrs	3	3	3	3	3	3	3	3	3	3	3	3
Stemona	3 days (0.25%)	3	3	3	3	3	3	3	3	3	3	3	3
	3 days (0.5%)	3	3	3	3	3	3	3	3	3	3	3	3
Water	1 hr	3	3	3	3	3	3	3	3	3	3	3	3
	2 hrs	3	3	3	3	3	3	3	3	3	3	3	3

Rate of discoloration
0 – no damage
1 – slight attack
2 – moderate attack
3 – heavy attack

Even though some natural chemical treatments for protection of bamboo slivers and sticks gave good results, they were not as effective as chemical preservatives. However, it is necessary for local people to use natural chemicals since natural chemicals are available in local area, easy to produce, cheap, and safe to animal, human and environment.

CONCLUSION AND RECOMMENDATIONS

1. The immersion of bamboo culm in stagnant water for 2 months is adequate to improve the resistance against insects and fungi. Longer immersion time can deplete the starch content and, as a result, a decrease in insect infestation. However, long immersion causes high moisture content in bamboo culm that induces the fungal growth. Therefore, drying bamboo after immersion should be done by placing bamboo culms upright in a place with good ventilation and not during rainy season.

2. Soaking air-dried bamboo in 5% Boron compound for at least 24 hours is recommended for thin wall bamboo species against the insects, and longer soaking period should be applied in case of thick-wall bamboo. In case of fresh bamboo, higher concentration of preservatives and longer immersion time are recommended. Soaking bamboo in the mixture of insecticide and fungicide for 1 hour is an effective method, longer soaking time being for insect prevention.

3. Neem seed and Stemona solutions are effective to protect both bamboo slivers and sticks against insect, but other methods show some fluctuations. However, natural chemical treatments cannot prevent fungal attacks in bamboo especially in moist condition. Consequently, further experiment on higher concentrations should be carried out in order to find out the potential natural chemical preservatives which are available in the rural area.

4. The appropriate harvesting time is one of the factors contributing to deterioration by insect and fungi. Bamboo harvested during winter will have less starch and low moisture content that help resist the insect and fungal attacks.

5. The study on sap displacement was conducted using 8% Boron compound as the preservative and found that a good result was obtained when fresh culms of 2-years old *D. strictus* with 50-65 mm in diameter and 3 m long treated in 90 minutes with a pressure of 1.5-2.0 bar (Table 15). The preservative could penetrate completely along the culm and showed the appropriate amount by turmeric test. These treated bamboo culms were used as some parts of the Project's bamboo house construction at Mae Mae community forest in Chiangmai province.

The major advantages of sap displacement treatment are inexpensive installation, rapid treatment procedure, and complete penetration with clean surface. The solution can be recycled for a certain time, despite further investigations are needed. The best results are therefore obtained during or shortly after rainy season using younger culms with a higher moisture content (Jayanetti and Follett, 1998). Sap displacement treatment should be introduced to small scale bamboo manufacturers.

Table 15. Percent BAE in treated bamboo and penetration of 8% Timbor in *D.strictus* by sap displacement method

Pressure (bar)	Time (mins)	Moisture content in the culm	Diameter (mm)	Thickness (mm)	% Penetration on the cross		% BAE in wood					
							> 0.3		0.3 -		< 0.1	
					B	T	B	T	B	T	B	T
1.5	45	67.4	54.5	13.8	100	31	/					/
	60	66.1	54.3	15.5	98	32	/					/
	90	68.3	54.4	10.5	100	100	/	/				
2	45	70.2	52.8	11.9	100	44	/					/
	60	72.3	59.2	15.3	100	68	/					/
	90	75.1	56.9	15.4	100	94	/	/		/		

Note : Specimens are 3 m long from 2-year-old bamboo
BAE = Boric Acid Equivalent
B = butt end
T = top end

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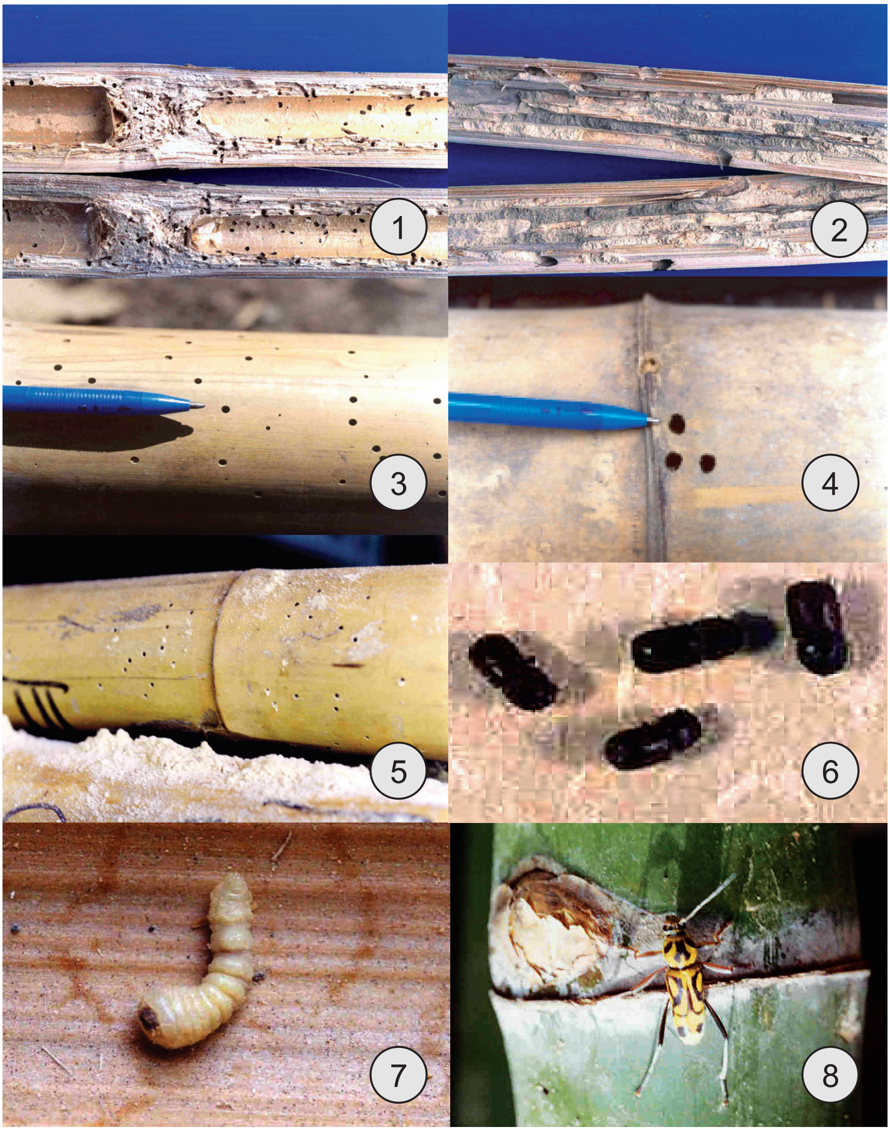
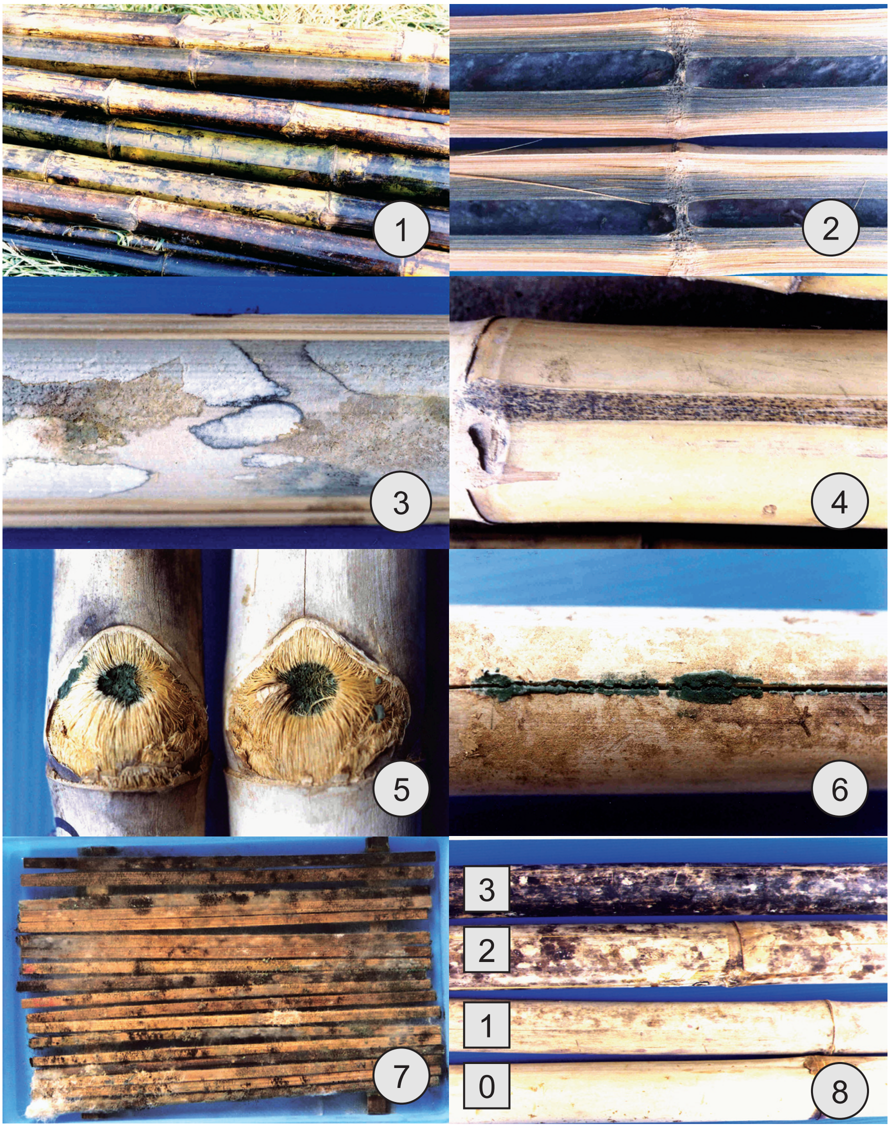
TAMOLANG et al., *Properties and Utilization of Philippine Erect Bamboos,* In "Bamboo Research in Asia", Proceedings of the International Bamboo Workshop, Singapore, May 28-30, 1980.

1 Bamboo culms were punctured by iron rod before treating.
2 Soaking bamboo culms in boron compound solution.
3 Stirred the solution occasionally while soaking bamboo culms in the mixture of insecticide and fungicide.
4 Specimens were placed upright in the container to let the solution in the culms out after soaking.
5 Specimens were tested for fungal attack by placing on rack in the moist chamber.
6 Bamboo culms were going to immersed in stagnant water at Lam Ta Klong Dam.
7 Specimens were placed on the support to expose to natural infestation by insects and fungi.



1 Insect infestation of powder post beetle (*Dinoderus minutus)*.
2 Insect infestation of long horn beetle (*Chlorophorus annularis)*.
3 Infestation of *D. minutus* (small holes) and *C. annularis* (bigger holes) on the same culm.
4 Exit holes of *C. annularis* .
5 Exit holes of *D. minutus.*
6 Adult of *Dinoderus minutus.*
7 *Larvae* of *Chlorophorus annularis.*
8 Adult of *Chlorophorus annularis*.



1 Dirty surface of bamboo culms after immersed in stagnant water.
2 Half spitted inspection showed staining fungi within the culm.
3 Mold and staining fungi in the culm.
4 Staining fungi on the wound of culm.
5-6 Mold on the bud scar and cracking culm.
7 Mold and staining fungi grow on the treated bamboo slivers.
8 Discoloration rating for fungi infestation.

1 Experiment on sap replacement method.

2 Air and fluid in the culms was pushed through the culms end during sap replacement process.

3-4 Tumeric testing on the treated culms showed good result of boron penetration on both butt and top end at pressure of 1.5 bar 90 mins.

5 Boron penetration of different treatments.

6 Tester A and B for tumeric test.

CHEMICAL COMPOSITION OF FIVE BAMBOO SPECIES IN THAILAND

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The chemical composition and starch content of five bamboo species, i.e., Pai Liang (Bambusa sp.), Pai Rai (Gigantochloa albociliata Munro), Pai Sang (Dendrocalamus strictus Nees), Pai See Suk (Bambusa blumeana Schult.), Pai Tong (Dendrocalamus asper Back) were determined. The inter-relationships of these species and their culm length for the properties were evaluated as a guide to their use potentials. The high cellulose and medium lignin contents of these species indicated their good potentials as a raw material for pulp and paper. The high alkali solubility may affect the yield in chemical pulping. The medium starch contents of the five bamboo species (1.88, 0.59, 0.60, 0.94 and 0.68 %) were already low and have been further reduced after immersion in water under field conditions.

Keywords : *Bambusa* sp., *Dendrocalamus strictus* Nees, *Bambusa blumeana* Schult., *Dendrocalamus asper* Back, *Gigantochloa albociliata* Munro, starch content, chemical composition

INTRODUCTION

Bamboo has for a long time played an important role in daily life of the rural people in Thailand. There are about 50 species of bamboo naturally grown, 32 species of which are commonly used for furniture, handicrafts, pulp and paper. The main purpose of this study is to assess the chemical properties and their variation along the culm length of 5 bamboo species as a guide to their use potentials.

The major components of bamboo culms are cellulose, hemicellulose and lignin, the minor ones being resins, tannins, waxes, and inorganic salts. Chemical composition may vary according to individual characteristics such as species, growing conditions, age, and the part of the culm (Liese, 1985). Cellulose and hemicellulose, also called holocellulose, are the solid residue of the total polysaccharide fraction that remains after extraction of minor components and lignin by mild oxidation. The water extract contains soluble carbohydrates such as monosaccharide, disaccharide, starch and soluble hemicellulose (Browning, 1978), while hot water extracts have more substances from bamboo culms, such as starch, tannin, sugar, pectin and phenolic compounds (Mohmod, 1997). Alcohol-benzene 1:2 (1/3 ethanol and 2/3 benzene) extracts almost all substances not belonging to the cellulose groups and lignin. The chemical composition of bamboo is of special interest to the pulp and paper industry. The following components and percentage are generally cited (in %, *i.e.*, percentage of the oven-dry weight; only for ash percentage of moisture-free weight): holocellulose (61-71%), lignin (20-30%), ash (1-5(-9)%), solubility in cold water (1.6-4.6%), hot water (3.1-7.0%), alcohol-benzene (0.3-5.3 (-7.8)%), and 1% NaOH (15-30 (-39)%). Greater alcohol-benzene and water solubility implies increased consumption of chemicals in pulping. The 1% NaOH solubility indicates the amount of low molecular weight carbohydrates consisting mainly of hemicellulose and degraded cellulose; as such, it may indicate the degree of decay, *e.g.* by fungi, heat and oxidation. Silica is the main constituent in ash and ultimately present problems for the pulp and paper-marking process. The silica content of bamboo culms is generally higher than that of wood, *viz*. 0.5-4.0% and mostly deposited in the epidermis. Since bamboo contains more impurities than wood, cooking is more costly and the pulp yield is less (Dransfield and Widjaja, 1995).

Plank (1950) and Beeson (1961) observed that during the soaking period in the water, the starch contents of the bamboo tissue are reduced. It is therefore said to be less attractive thereby improving the resistance level against borers and also blue-stain fungi (Tamolang *et al*., 1980; Liese, 1998).

Sulthoni (1987) studied the starch contents of the Indonesian bamboo: *Dendrocalamus asper*, *Bambusa vulgaris*, *Gigantochloa apus* and *G. atter*. The results indicated that the seasonal variations of starch content influence the natural durability of bamboo.

The objectives of the study are to find the chemical composition in different portions of the culm of 5 bamboo species and to determine the starch contents of the culm and split bamboo after water immersion.

MATERIALS AND METHODS

Materials

Three bamboo culms were collected form each of 5 bamboo species of 3 years old. Each bamboo culm was divided into three portions, bottom (b), middle (m) and top (t) of 2 m long. The samples were prepared at the Research Station in Nakhon Ratchasima province before being brought to the laboratory at Royal Forest Department in Bangkok. Following are the locations and dates of sample collection :

- Pai Liang (*Bambusa* sp.) from Ubon Ratchathani on 10 March 2001;
- Pai Rai (Gigantochloa albociliata Munro) from Chiangmai on 18 March 2001;
- Pai Sang (Dendrocalamus strictus Nees) from Chiangmai on 18 March 2001;
- Pai See Suk (Bambusa blumeana Schult.) from Nakhon Ratchasima on 2 April 2001;
- Pai Tong (Dendrocalamus asper Back) from Prachinburi on 23 March 2001.

Methods

Determination of Chemical Component

The methods for chemical analysis of bamboo culms were based on standard methods, TAPPI for wood analysis, with two replications, samples being randomly cut from each culm portion.

Determination of general chemical properties

The specimens were dried at 50°C in oven. After chipping and drying again, samples were ground in a hammer mill and screened. Material retained at 40 mesh sieve was used for the following chemical analyses.

Ash	: TAPPI T 211 (Anonymous, 1993)
Alcohol-benzene solubility	: TAPPI T 204 (Anonymous, 1997)
Cold water solubility	: TAPPI T 207 (Anonymous, 1993)
Hot water solubility	: TAPPI T 207 (Anonymous, 1993)
1% Sodium hydroxide solubility	: TAPPI T 212 (Anonymous, 1998)
Acid-insoluble ash	: TAPPI T 244 (Anonymous, 1999)
Lignin	: TAPPI T 222 (Anonymous, 1998)
Holocellulose	: Wiese (1946)
Alpha-, bata-cellulose	: TAPPI T 203 (Anonymous, 1993)

Determination of starch content

Starch is a normal constituent in sapwood of the hard- and softwood species, where it is frequently found in the parenchymatous tissue. Starch is readily recognized from the blue color formed upon staining with diluted solution of iodine.

The specimens were chipped, dried at 50°C in oven and ground before being passed through a 200 mesh sieve. They were dried for three days in a desiccator over concentrated sulphuric acid and used for starch analysis with the methods suggested by Browning (1978) and Humphreys and Kelly (1961).

Determination of Starch Contents in Bamboo Culms and Split Bamboo Soaked in Water

Bamboo culms

The samples of culm portions (bottom, middle, and top) were immersed in the Lam Ta Kong Dam for 1, 2, 3, 4, 5, and 6 months before being taken up and washed thoroughly and left sun-dried. Thereafter, the process followed the methods specified in the determination of starch content.

Split bamboo

The fresh culm portions (in previous section) of 2 m long were splitted into pieces of 1.0-2.5 cm and immersed in the Lam Ta Kong Dam for 7, 14, 21 days, 1, 2, and 3 months. After immersion, the samples were handled in the same manners as did for bamboo culms.

RESULTS AND DISCUSSION

Chemical Composition

Table 1 shows the chemical composition in different portions of culm of 5 bamboo species. The chemical compositions correlated insignificantly with culm length, except in cases of ash in Pai Liang and Pai Tong; 1% NaOH solubility in Pai Liang, Pai Sang and Pai See Suk; alcohol-benzene solubility in Pai Liang; acid insoluble ash in wood of Pai Liang and Pai Tong; lignin in Pai Liang, Pai Rai and Pai Sang; alpha- cellulose in Pai Tong; beta-cellulose in Pai Sang and Pai Tong. The average lignin content of about 25.3 to 27.7% was within the range of those found in 4 species of Indian bamboo widely used for paper making (Subash and Sathapathy, 1990). The holocellulose contents varied from 78.3 to 81.6% as compared with those in *Gigantochloa scortechinii*, *G. levis*, *Bambusa blumeana* and *Schizostachyum zollingeri* of Malaysia (Abd. Othman *et al.*, 1995), indicating a good potential for use as a raw material for pulping.

Table 1. Chemical compositions (%) of 5 bamboo species

Bamboo species	Portion	Ash	Cold water solubility	Hot water solubility	1% NaOH solubility	Alcohol-benzene solubility	Acid insoluble ash in wood	Lignin	Holo-cellulose	Alpha-cellulose	Beta-cellulose
Pai Liang (*Bambusa* sp.)	Bottom	1.4	8.9	11.3	24.2	4.6	0.4	25.9	78.5	65.7	17.9
	Middle	1.8	7.8	10.6	24.9	3.9	1.1	25.1	80.8	67.8	15.9
	Top	2.4	8.3	12.4	25.9	3.6	1.9	25.0	78.8	66.2	17.8
	Average	**1.8**	**8.3**	**11.5**	**25.0**	**4.0**	**1.1**	**25.3**	**79.4**	**66.6**	**17.2**
Pai Rai (*Gigantochloa albociliata* Munro)	Bottom	1.5	6.5	8.3	23.2	4.0	0.7	27.3	79.6	74.0	11.0
	Middle	2.4	9.8	12.4	27.9	6.2	1.2	27.2	80.8	74.5	10.7
	Top	1.5	7.4	8.93	26.3	4.1	0.8	23.4	79.6	71.2	14.1
	Average	**1.8**	**7.9**	**9.9**	**25.8**	**4.7**	**0.9**	**26.0**	**80.0**	**73.2**	**11.9**
Pai Sang (*Dendrocalamus strictus* Nees)	Bottom	2.1	6.6	11.6	26.0	6.2	1.1	28.0	77.9	72.2	13.2
	Middle	1.1	8.2	12.8	26.9	7.6	0.5	27.8	77.7	72.3	13.2
	Top	2.8	8.0	12.7	27.0	6.2	1.5	27.4	79.3	71.8	13.6
	Average	**2.0**	**7.5**	**12.8**	**26.7**	**6.6**	**1.0**	**27.7**	**78.3**	**72.1**	**13.4**
Pai See Suk (*Bambusa blumeana* Schult.)	Bottom	3.4	7.8	9.1	28.2	8.7	2.3	26.3	81.7	72.9	13.4
	Middle	5.8	5.2	6.9	28.7	6.7	5.0	27.6	81.2	72.2	14.4
	Top	4.9	6.1	8.6	28.9	7.1	4.1	27.6	81.9	73.8	12.9
	Average	**4.7**	**6.3**	**8.2**	**28.6**	**7.5**	**3.8**	**27.2**	**81.6**	**73.0**	**13.6**
Pai Tong (*Dendrocalamus asper* Back)	Bottom	0.9	7.4	9.1	21.8	8.5	0.4	28.2	79.7	73.4	12.8
	Middle	1.4	10.9	11.8	29.0	11.3	0.7	26.9	78.4	72.5	13.8
	Top	1.8	7.5	8.6	26.6	5.3	1.3	27.5	80.5	69.2	17.2
	Average	**1.4**	**8.6**	**9.8**	**25.8**	**8.3**	**0.8**	**27.5**	**79.6**	**71.7**	**14.6**

The extractive contents, particularly the cold and hot water soluble, are important in the predetermination of water soluble extractives such as tannin, starch, sugar, pectin and phenolic compounds within the woody materials (Janes, 1969). The results show the high concentration of hot and cold water soluble (8.2–12.8% and 7.5–8.6% respectively) which may influence the susceptibility to insect and fungal attacks (Plank, 1950).

The 1% NaOH solubility varied significantly with these species and culm length. The highest and lowest mean percentages were observed in the middle (29.0%) and bottom portions of Pai Tong (21.8%) respectively. Among the species, Pai See Suk possessed the highest average alkali soluble (28.6%) followed by Pai Sang (26.7%), Pai Rai (25.8%), Pai Tong (25.8%) and Pai Liang (25.0%). The high alkali solubility may affect the yield in chemical pulping (Mohmod et al., 1997).

Regarding the alcohol-benzene soluble of bamboo species, it was found that Pai Tong possesses the highest average value (8.3%) while Pai Liang was the lowest (4.0%).

The ash content of 5 bamboo species ranged from 0.9–5.8% falling within the ranges of those bamboos from India, Japan, Burma, Indonesia and Philippines (0.8 to 9.7%) which are used for machine-made products such as skewer and chopstick (Semana *et al.*, 1967).

Starch Contents

The starch contents of the 5 bamboo species were determined using colorimetric measurement of the color formed in the reaction of amylose in bamboo starch with iodine (Table 2). Tables 3 and 4 show the results of different immersion periods, *i.e.*, 7, 14, 21 days and 1, 2, 3 months for bamboo splits and 1, 2, 3, 4, 5 and 6 months for bamboo culms. The relation between starch content and immersion periods were also established.

The starch content of bamboo in this study changed significantly with immersion periods, those found in splits and culms after water immersion were less than 1%. Higher starch contents (more than 1%) were found in case of the splits of Pai Liang immersed for 1 and 3 weeks.

Bamboo species with less than 1% starch content is considered as good quality bamboo for construction (Sulthoni, 1985).

Table 2. Starch contents (%) of 5 bamboo species

Bamboo species	Vertical portion			**Average**
	Bottom	Middle	Top	
Pai Liang (*Bambusa sp.*)	1.30	1.78	2.55	**1.88**
Pai Rai (*Gigantochloa albociliata* Munro)	0.46	0.60	0.72	**0.59**
Pai Sang (*Dendrocalamus strictus* Nees)	0.63	0.65	0.52	**0.60**
Pai See Suk (*Bambusa blumeana* Schult.)	0.60	1.22	1.00	**0.94**
Pai Tong (*Dendrocalamus asper* Back)	0.14	1.03	0.86	**0.68**

Table 3. Starch contents (%) of bamboo culms after water immersion

Bamboo species	Portion	Duration					
		1 month	2 months	3 months	4 months	5 months	6 months
Pai Liang (*Bambusa* sp.)	Bottom	0.33	0.19	0.04	0.89	0.69	0.02
	Middle	0.06	0.35	0.41	0.24	0.33	0.08
	Top	1.50	0.71	0.48	0.09	0.52	0.19
	Average	0.63	0.42	0.31	0.41	0.51	0.10
Pai Rai (*Gigantochloa albociliata* Munro)	Bottom	-	0.21	0.15	0.18	0.05	0.11
	Middle	-	0.53	0.25	0.42	0.42	0.06
	Top	-	0.57	0.04	0.38	0.10	0.01
	Average	-	0.44	0.14	0.32	0.19	0.06
Pai Sang (*Dendrocalamus strictus* Nees)	Bottom	0.46	0.35	0.32	0.31	0.43	0.18
	Middle	0.76	0.40	0.33	0.29	0.06	0.13
	Top	0.35	0.93	0.14	0.41	0.05	0.20
	Average	0.52	0.56	0.26	0.33	0.18	0.17
Pai See Suk (*Bambusa blumeana* Schult.)	Bottom	0.35	0.34	0.22	0.08	0.07	0.03
	Middle	0.32	0.12	0.03	0.04	0.27	0.05
	Top	0.87	0.26	0.08	0.13	0.07	0.05
	Average	0.52	0.24	0.11	0.08	0.14	0.04
Pai Tong (*Dendrocalamus asper* Back)	Bottom	0.02	0.04	-	-	0.11	0.04
	Middle	0.05	0.08	-	-	0.02	0.02
	Top	0.55	0.08	-	-	0.14	0.03
	Average	0.21	0.06	-	-	0.01	0.03

Note : All bamboo samples are about three years old.
- denotes no analysis

Table 4. Starch contents (%) of bamboo splits after water immersion

Bamboo species	Portion	Duration					
		1 week	2 weeks	3 weeks	1 month	2 months	3 months
Pai Liang (*Bambusa* sp.)	Bottom	0.10	0.19	0.97	0.48	0.04	0.03
	Middle	1.27	1.20	0.93	0.47	0.17	0.09
	Top	1.96	1.24	1.16	0.62	0.70	0.13
	Average	**1.11**	**0.88**	**1.02**	**0.52**	**0.30**	**0.08**
Pai Rai (*Gigantochloa albociliata* Munro)	Bottom	0.18	0.51	0.24	0.30	0.09	0.05
	Middle	0.69	0.33	0.58	0.51	0.10	0.06
	Top	2.02	0.99	1.10	0.37	0.23	0.04
	Average	**0.97**	**0.61**	**0.64**	**0.39**	**0.14**	**0.05**
Pai Sang (*Dendrocalamus strictus* Nees)	Bottom	0.62	0.85	0.65	0.12	0.10	0.16
	Middle	0.84	0.48	0.98	0.40	0.10	0.03
	Top	0.86	1.10	0.62	0.36	0.10	0.08
	Average	**0.77**	**0.81**	**0.75**	**0.30**	**0.10**	**0.09**
Pai See Suk (*Bambusa blumeana* Schult.)	Bottom	0.73	0.44	0.51	0.26	0.10	0.06
	Middle	0.68	0.79	0.23	0.23	0.23	0.02
	Top	0.42	0.50	0.40	0.15	0.09	0.02
	Average	**0.61**	**0.58**	**0.38**	**0.22**	**0.14**	**0.04**
Pai Tong (*Dendrocalamus asper* Back)	Bottom	0.04	0.19	0.02	0.04	0.01	-
	Middle	0.66	0.74	0.18	0.03	0.01	-
	Top	0.21	0.23	0.23	0.18	0.01	-
	Average	**0.30**	**0.38**	**0.14**	**0.08**	**0.01**	**-**

Note : All bamboo samples are about three years old.
- denotes no analysis

CONCLUSIONS

There is a wide range of variations in chemical constituents in bamboo culms of the same age group. The considerably high holocellulose content of these bamboo species indicates their good potentials for use as a raw material for pulp and paper. The relatively high alkali solubility may, however, affect the yield of chemical pulp.

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PHYSICAL AND MECHANICAL PROPERTIES OF FIVE BAMBOO SPECIES IN THAILAND

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Five species of Bamboo were selected to test their physical and mechanical properties as the main species in the project. The species were Pai Liang (Bambusa sp.), Pai See Suk (Bambusa blumeana Schultes*), Pai Tong (Dendrocalamus asper* Backer*), Pai Sang (Dendrocalamus strictus* Nees*), and Pai Rai (Gigantochloa albociliata* Munro*) harvested from various provinces. The highest specific gravity and static bending are found in Pai See Suk and Pai Rai respectively. Pai Tong and Pai Liang are suitable for housing components due to their culm form and bending properties as compared to other building materials such as wood, while the other 3 species (Pai See Suk, Pai Sang, and Pai Rai) are suitable for flooring panel and other house parts. All bamboo species can be utilized for the various products depending on their characteristics such as thickness of culm wall.*

Key words: *Bambusa* sp., *Bambusa blumeana* Schultes , *Dendrocalamus asper* Backer, *Dendrocalamus strictus* Nees, *Gigantochloa albociliata* Munro, physical and mechanical properties

INTRODUCTION

The project "Promotion of the Utilization of Bamboo from Sustainable Sources in Thailand" has the goal to develop and disseminate the knowledge on management of bamboo and processing technologies to promote bamboo utilization in rural communities. The project places the emphasis on the feasibility of using bamboo for housing and furniture components.

The major properties to evaluate are physical and mechanical properties. All components of bamboo are also presented in wood. This means that nearly all factors affecting wood physical properties are similar to those of bamboo. The mechanical properties of wood or bamboo are an expression of their behavior under applied forces. This behavior is modified in a number of ways depending upon the kinds of force exerted on the bamboo and the way of application. The main testing on the strength of wood or bamboo is the bending strength. The bending stress are the result of a combination of all three primary stresses: compressive, tensile, and shear, which act together and cause flexure, or bending in the body. The bending strength of bamboo as an important factor in building construction has been studied by Limaye (1952), Sekhar *et al.* (1962), and Janssen (2000).

By the project PD 56/99 Rev. 1 (I), five bamboo species commonly grown and utilized in local communities of Thailand were tested to determine the use potentials.

MATERIALS AND METHODS

Five species of bamboo from four provinces were selected: Pai Liang (*Bambusa sp.*) from Sakon Nakhon; Pai See Suk (*Bambusa blumeana* Schultes) from Nakhon Ratchasima; Pai Tong (*Dendrocalamus asper* Backer) from Prachinburi; Pai Sang (*Dendrocalamus strictus* Nees) and Pai Rai (*Gigantochloa albociliata* Munro) from Chiangmai.

The samples, the number of which ranged from 3-12 pieces depending upon culm length, were prepared from 3-year-old culms. They represented 3 parts of the culm, i.e., bottom, middle, and top parts, and the average from these portions represented that of the whole culm.

The standard test of physical and mechanical properties was based on INBAR's manual by Janssen (2000).

RESULTS AND DISCUSSION

The physical and mechanical properties of the 5 species are presented in Tables 1 and 2. Table 1 shows the physical properties in different parts of culm of 5 bamboo species. There is no significant difference among five species. The highest specific gravity is found in Pai See Suk indicating the high hardness on the culm surface, those in other species being somewhat on the average density.

Table 2 shows the mechanical properties of 5 bamboo species. Pai See Suk has also the hightest modulus of rupture, but easily to break when high load has been applied on it. There are no significant different on the mechanical properties of five species.

Each bamboo species can be used as the construction material depending on the length, the size, and the thickness of the culm wall.