Table 11. New culms formed in *P. pubescens* timber stand after fertilization

Treatment	Block 1	2	3	4	5	6	7	8	Mean	Percentage
1	62	52	58	27	28	38	51	35	44	141.9
2	59	53	49	31	27	31	40	39	41	132.2
3	65	64	56	29	32	30	41	44	45	145.2
4	50	39	35	22	24	29	33	39	34	109.7
5	33	48	38	15	15	30	38	37	31	100.0

3). It is also seen that applying compound commercial fertilizers at 375 kg/ha in furrow and of 750 kg/ha in stump in spring significantly increased the yield of *P. pubescens* (Tables 4,7-9).

The number of bamboo shoots and percentage of grown-up new culms are not the only factors determining yield. Yield also depends on the quality of culm such as culm circumference, length and thickness of culm wall. From a comparison of data in Tables 4, 10 and 11 it can be seen that culm yield in treatment 3 is lower than that in the other treatments, although the highest number of shoots and highest percentage of grown-up new culms were recorded in this treatment. The yields of fertilized plots were higher than in the unfertilized control plot.

The present study has shown that the application every spring of 375 kg/ha of compound fertilizer in furrow or 750 kg/ha in stump in the main productive regions of *P. pubescens*, such as in Zhejiang, Jiangxi and Fujian provinces gives the highest obtainable increment in bamboo timber yield of 46.9 percent and 54.3 percent, respectively. After deducting the cost of management (including fertilizer, loosening of soil, harvesting, weeding and other costs), the net profit can be as much as 842.20 yuan/ha and 797.70 yuan/ha, respectively. The application of 375 kg/ha of compound fertilizer in spring is recommended for timber stands of *P. pubescens*.

Acknowledgements

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A New Approach to the Management of Bamboo Stands

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Abstract

Experiments were conducted to determine the effect of soil working, application of fertilizer, inverted V-shaped thinning and irrigation on the productivity of Bamhusa al-undinacea. The improvement in productivity more than justi'es the cost involved for the above operations. The employment and income generated by bamboo cultivation by adoption of the above cultural practices are discussed..

introduction

About 50 years ago, the forests throughout Karnataka State were rich in bamboos. The availability of an abundant stock of this raw material prompted the forester to propose schemes for its economic utilization. One of them was the setting up of paper mills, and in due course, these were established at Bhadravathi and Dandeli. Today, there is a serious shortage of bamboo and the requirements of neither of the mills nor of the other users are being adequately met. Since natural regeneration of bamboo is slow and some bamboo species flower at very long intervals, efforts were made to raise plantations in the 1960s. However, the progress has been slow due to the prohibitive cost and paucity of funds. Between 1970 and 1980, the author made an attempt, on a small scale, to raise plantations through nursery- raised seedlings, stem cuttings and rhizome plantings. Although each of these methods has some advantages and gave good results, the area in which the attempt was made was small, the gestation period long and, therefore, could not, be sustained due to paucity of funds. Attempts to introduce *Bambusa vulgaris, B. polymorpha* and *B. brandisii* and a few other species by early foresters have met with success in so far as growth stocking and performance are concerned. Here again, the areas where the trials were conducted have been small. An alternative approach for a more effective and less expensive solution to the problem has been tried by the author by conducting experiments in the Chickmagalur and Shimoga districts. A brief account of this study is given here. The mean annual rainfall in the experimental site ranged from 800 to 1400 mm.

Methods

Three sets of experiments were done. The first set involved (a} soil working, (b) fertilizer application and (c) protection. The second set involved, in addition to the above three parameters, irrigation (40 1 water per clump once a month). The third set in addition to the parameters in set I, included inverted V-shaped thinning.

In experiment I, the soil around the bamboo clumps was dug to a depth of 35 cm and a width of 1 m. Fertilizer was applied to the clumps (0.5 kg of 15: 15: 15 NPK per clump) during the 1986 rainy season and observations were made at monthly intervals.

These treatments were carried out during the years 1986 and 1987. The size of each experimental set varied from 25 to 40 clumps. The trials were conducted over relatively small areas and the results suffer from this limitation (wherever more data are available, these are also furnished). Data on yield (number of clumps, length, girth and weight) were collected. For the purpose of comparison, the number of culms produced during 1985 was taken as control.

Results and Discussion

Experiment I

Soil working, application of fertilizer and provision of protection to the plants considerably increased productivity (Table 1). Whereas the new culm production was only 1 .O culm per clump during the control year 1985, after treatment, culm production went up to 2.1 culms per clump (in 1986).

Table 1. Effect of soil working, fertilizer application and protection on culm production

Name of forest division	No. of clumps	New culms produced 1985	1986	Increase over 1985 production
Bhadravathi	7400	4554	18958	12204
Shimoga	28815	32224	59924	27698
Koppa	30000	28934	60732	31798
Total	66215	677 14	138614	71700
New culms per clump		1.02	2.09	

Table 2. Rate of growth of new shoots (cm/24 h) observed in 1986

Treatment	No. of culms measured	25.8.86	26.8.86	Mean increase in height per day
Control	23	89.0	96.7	7.7
Treated	25	113.1	123.8	10.7

Table 3. Effect of irrigation, soil working, application of fertilizer and protection on culm production

Treatment	No. of clumps	No. of culms	No. of new culms	New culms/clump
Control	102	1714	132	1.3
Trial 1	40	472	150	3.8
Trial 2	40	543	117	2.9
Trial 3	40	651	173	4.3
Trial 4	40	495	162	4.1

Trial 1 *· 0.5 kg NPK; Trial 2 · 1 kg NPK; Trial 3 · 0.5 kg of urea and lack phosphate; Trial 4 · I kg of urea and rock phosphate*

The rate of growth of new shoots observed in a control plot and a treated plot is given in Table 2. In the control plot, the average rate of growth was 7.7 cm in 24 h, whereas in the treated plot it was 10.7 cm. It was further seen that the average height of culms was 89 cm in the control plot whereas it was 113 cm in the treated plot.

Experiment II

It can be seen from Table 3 that the control plot produced 1.3 culms /clump and the treated plots yielded 2.9-4.3 culms /clump. The yield was better when 0.5 kg of fertilizer was applied than when 1 .O kg was applied. Also, urea and rock phosphate gave a better performance than NPK.

Ten culms each were measured for their average girth and height in the control and treated plots. A notable improvement in both diameter and height was observed in the treated plots (Table 4). In their formative years, bamboo clumps grow taller at a rapid rate, but it is to be noted that in the present experiments, the bamboo clumps were over 20 years of age when these experiments were begun.

Bamboos were felled during 1988 to record their length, girth, weight, etc. The average weight of each green bamboo was 47.5 kg. If provision is made for 45 percent moisture content, the air dry

Table 4. Height and diameter of culms in control and treated plots (average of 10 culms)

	Treatment (m)	Girth (cm)
Control	4.7	7.4
Treated	6.9	11.1

bamboo will weigh about 23 kg. At the rate of 100 bamboos/ha during the control year, the yield is 2.3 tonnes. During the year in which treatments were given this increased to 4.6 tonnes/ha at the rate of 200 bamboos/ha.

Experiment III

Seventeen clumps of Bambusa arundinacea. and 25 clumps of *Dendrocalanus strictus* were treated with inverted thinning instead of the

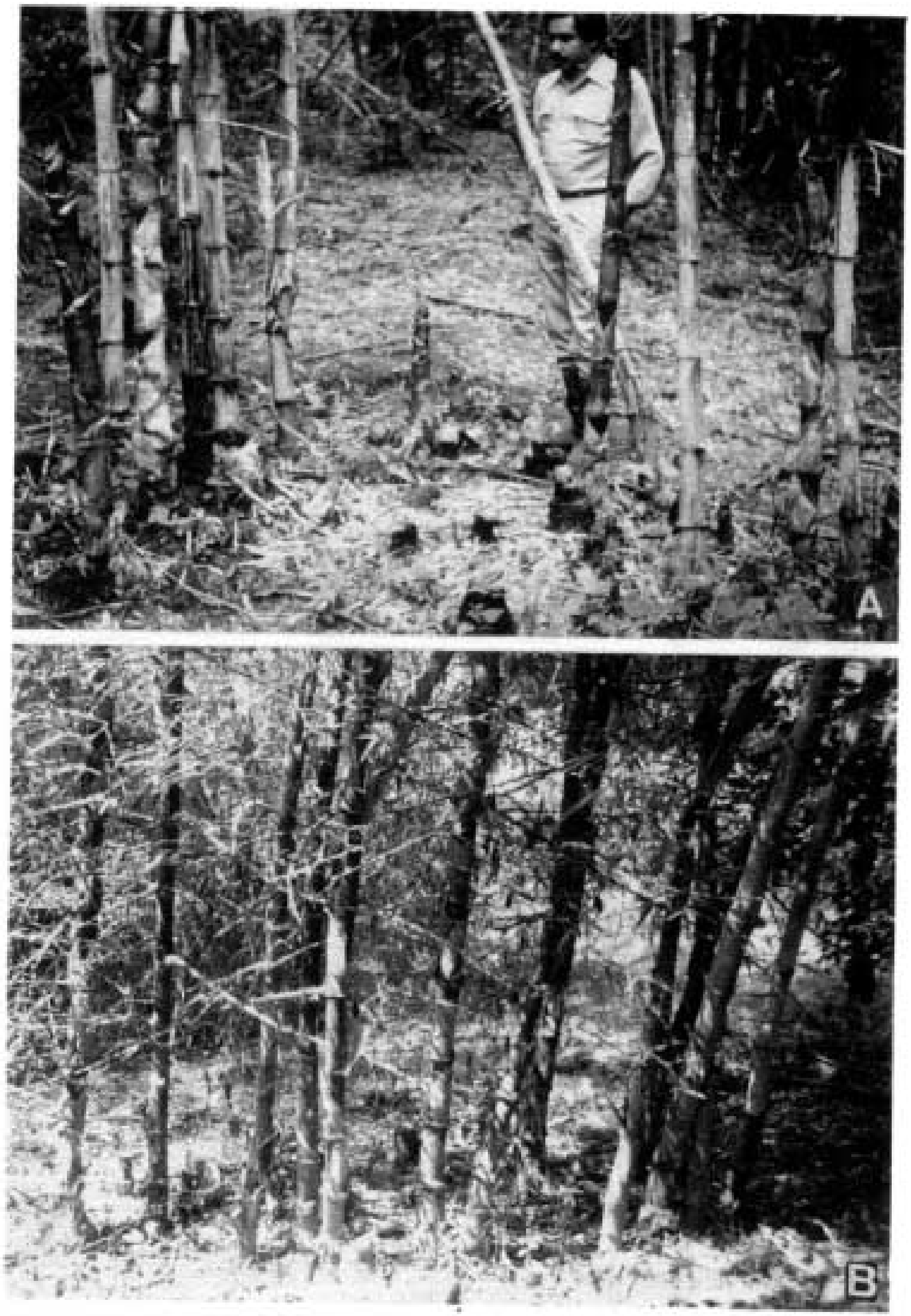

Fig. 1. Bambusa arundinacea clump one year (A) and two years (b) after treatment

Table 5. Effect of inverted 'V' thinning on culm production

	Control			Treated		
	Clumps	New culms	Culms clump	Clumps	NeW culms	Culm clump
Bambusa arundinacea	17	71	4.3	17	61	3.6
Dendrocalamus strictus	25	165	6.6	25	212	8.8

Table 6. Cost of treatment in rupees for a 20 ha plot with 100 clumps/ha

Item	Cost
Cost of 15: 15: 15 NPK fertilizer at 0.5 kg/plant for 2000 clumps	3 100
Digging the soil, fertilizer application for 2000 clumps at Rs. 3 per clump	6000
Fencing or cattle-proof trenching	29000
Watchers (3) for 6 months	7137
	43237 or Rs. 221 1/ha

traditionally practised horseshoe-shaped thinning. The inverted 'V' thinning is easier to execute in the field.

In the case of Bambusa arundinacea no improvement was observed {Table 5; Fig.lA, B). The clumps treated with inverted V-shaped thinning produced only 3.6 new culms/clump in comparison to 4.3 in the control. As the thinning intensity was not recorded, it is difficult to know the real effect of thinning on each clump, In the case of *Dendrocalamus strictus,* there were 6.6 culms/clump during 1986 and 8.5 culms/clump during 1987 after 'V' thinning was carried out (Fig.2).

A survey of the bamboo clumps revealed that dry, dead and damaged culms form a substantial portion of the total culms. In Chickmagalore district, the survey revealed that 28 percent of the total culms in a clump were dry, dead and damaged. During the process of thinning all such material will be extracted resulting in cleaning of the clumps. This operation will assist the clump in putting out new culms and at the same time give protection from fire. In addition, it gives an intermediate yield of bamboos.

Fig. 2. Dendrocalamus strictus clump showing V-shaped thinning.

Table 7. Mandays generated/ha

Item	Rs	Mandays
Soil working and fertilizer application, Rs 3/clump x 100 clumps	300	23
Inverted 'V' thinning and congestion removal, Rs 6/clump x 100	600	46
Digging cattle-proof trenches Rs 7/m^3 or Rs 1750/ha	1750	135
Watchmen (3) for 6 months, mandays 540/for 20 ha		27
Total		231

Table 8. Income generated in treated areas

	Rs.
a) 150 culms to Madars produce 150 mandays	2250
b) 50 culms to agarbathi workers produce	
1. For sticks 50x23kg=1150kg	
6 kg = 1 manday	
19 1 mandays at the rate of Rs 4/kg of sticks	4600
2. For application of gigatu to 1150 kg of stick	
1 kg = 1 manday = 1150 mandays	
At the rate of Rs 7/kg	8050
Mandays 1491	Rs. 14900

Investment

The cost of giving protection, soil working and fertilizer application to a plot of 20 ha is around Rs.44 237 as shown in Table 6. This works out to Rs. 22 12/ha.

Employment and Income Generation

Tables 7 and 8 give an idea of the employment and additional income that bamboo cultivation could generate. At the rate of two culms/clump and 100 clumps in one hectare the yield will be about 200 clums/ha. Out of this, if 50 clums are supplied to the agarbathi industry, and 150 bamboos to Madars, the income generated is given in Table 8.

The tending and other practices produced two culms/clump, which yields 4.6 tonnes/ha of air dry bamboo as against 2.3 during the control year. The tending and other practices generates 23 1 mandays of employment per hectare (Table 7). The income and mandays this generates through the agarbathi industry and application of gigatu is also surprisingly high and is 1491 mandays valued at Rs 14 900/ha. Thus, an investment of Rs. 22 1 l/ha (Table 6) is capable of generating within 36 months, far more mandays and income than most industrial investment returns can match.

These bamboo tending practices suggested improve the forest stand and also the whole ecosystem. They are capable of wiping out the bamboo shortage within a limited period. Increased bamboo yields support the Madar and other backward classes and tribal people who entirely depend on bamboos far their livelihood. In addition, bamboos support the agarbathi and silk industry which bring in foreign exchange.

Acknowledgements

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PROCEEDINGS OF
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PROPAGATION OF BAMBOOS

Techniques for Seed Storage of *Thyrsostachys siamensis*

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Abstract

The effect of seed moisture content and storage temperature on the viability of Thyrsostachys siamensis seeds was studied. The study showed that seed viability can be extended by reducing the initial moisture content before storing. Seeds stored at low temperatures (2-4 C and -5 C) maintained a high percentage of viability for up to 27 months.

Introduction

Thyrsostachys siamensis is a deciduous bamboo. Culms are 7-12 m tall, erect, not branching till high up, 4-8 cm in diameter and usually covered with persistent old culm sheaths. It is generally used for making umbrella handles, handicrafts, in house construction, the pulp and paper industry etc. In Thailand, it is one of the commercially important bamboos and the main raw material for the rural industries. It occurs in the dry forest areas in the North, North-east and central parts of Thailand. Sometimes it occurs as pure stands in the central highland forest especially in Kanchanaburi province.

T. siamensis is a sporadic flowering type bamboo, which usually flowers during November and February, depending on the location. Seeds can be collected during January to April. The quality of seeds is mainly dependent on their maturity and collection conditions. Seed germination is strongly correlated with moisture content (Anantachote, 1985). The size and shape of seeds also varies within species. Big seeds show a higher percentage of germination as compared to the smaller ones. Seed germination ranged from 7 to 86 percent (Anantachote, 1985). Seeds collected from Petchaburi province showed 86 percent germination while those from Lampang province showed only 7 percent germination.

Material and Methods

Seeds of *T. siamensis* were collected from Kanchanaburi province in February 1986. These were divided into five groups and the moisture content reduced to 10.2, 7.8, 7.5, 7.3 and 5.9 percent, respectively. The moisture content was calculated on a wet weight basis. The five groups of seeds were packed in sealed polyethylene bags for use in experiments.

Experiment I

This was set up to investigate the effect of room and low temperature on seed viability. The five groups of seed were stored for 27 months under three different conditions: at room temperature (25-30 C), cold room (2-4 C) and deep freezer (-5 C).

Experiment IX

This was carried out to differentiate the effect of low temperature on seed viability when stored under cold room and deep freezer conditions. The five groups of seeds were stored for 27 months under two different conditions: cold room (2-4 C) and deep freezer (-5 C).

For each treatment, four replications of 100 randomly selected seeds were tested for germination after 0,3,6,9,15,21 and 27 months of storage. All seed samples were separately sown in sterilized sand in plastic boxes in controlled environment germinators with 90 percent relative humidity, a 8 h daily photoperiod at 30 C and 12 h of darkness at 20 C. Results were expressed in terms of percentage of germination.

Results

The initial germination of the five groups was 89.0,92.3,92.8,88.5 and 95.5 percent, respectively

Table 1. Average germination percentage of *Thyrsostuchys siamensis* seeds of five different initial moisture contents (MC) stored under three different conditions for 27 months

Storage temperature	Initial MC (%)	Initial	Months 3	6	9	15	21	27
25-30 C	10.2	89.0	89.0	60.2	32.7	1.5	0	0
	7.7	92.2	84.7	85.2	74.5	17.0	0	0
	7.5	92.7	92.5	90.2	78.0	30.5	0	0
	7.3	88.5	87.0	88.5	82.5	26.2	0	0
	5.9	95.5	90.0	86.5	82.7	71.5	1.2	0
2-4 C	10.2	89.0	88.2	82.7	86.0	89.2	90.7	89.7
	7.7	92.2	87.5	91.2	90.0	92.7	92.2	89.2
	7.5	92.7	91.2	92.0	89.2	92.5	96.0	89.7
	7.3	88.5	91.0	91.5	86.5	94.7	94.7	92.5
	5.9	95.5	90.7	92.5	88.2	91.2	93.7	91.0
-5 c	10.2	89.0	93.2	88.7	89.0	90.2	90.0	89.7
	7.7	92.2	89.7	87.5	87.7	94.7	89.5	90.0
	7.5	92.7	86.2	90.2	92.0	93.7	92.7	89.5
	7.3	88.5	90.7	91.2	95.2	93.5	87.7	89.7
	5.9	95.5	89.2	94.0	83.7	89.7	92.2	91.2

Percentage germination of seeds stored at 2-4 C and -5 C were average of two sets of seed samples

Table 2. Analysis of variance of *Thyrsostachys siamensis* seeds stored for three, six and nine months under 15 treatment combinations

Source of variation	3 Months DF	F	6 Months DF	F	9 Months DF	F
Treatment	29	1.082	44	3.5 14**	59	10.625**
A	4	2.441	4	9.444**	4	24.22**
B	2	0.134	2	5.53**	2	41.655**
C	1	2.717	2	6.696**	3	27.002**
AB	8	0.42	8	2.115**	8	10.975**
AC	4	2.912	8	4.179**	12	5.502**
BC	2	0.134	4	3.674**	6	16.01 1**
ABC	8	0.42	16	1.708**	24	4.825**
Error	90		135		180	
Total	119		179		239	

A, initial moisture content; B, storage temperature; C, storage time

Table 3. Analysis of variance of *Thyrsostachys siamensis* **seeds stored for 3 and 27 months in the cold room and deep freezer**

Source of variation	3 Months DF	3 Months F	27 Months Df	27 Months F
Treatment	19	0.977	69	1.314
A	4	1.189	4	3.287*
B	1	0.002		0.03
c	1	1.097	6	2.707*
AB	4	0.43	4	0.943
AC	4	2.311	24	1.391
BC	1	0.002	6	0.899
ABC	4	0.432	24	0.778
Error	60		210	
Total	79		279	

A, initial moisture content; B, storage temperature; C, storage time

(Table 1). The germination of seeds with the highest moisture content and stored at room temperature was found to be lowest after six months. Seeds stored in the cold room and deep freezer remained viable at all moisture content levels until 27 months.

Experiment I

The results of the analysis of the variance of the seed viability data are presented in Table 2. This shows that with the increase in storage time, the influence of temperature and moisture content are marked.

Experiment II

The analysis of variance showed that the different treatment factors were not significant at three months (Table 3). The initial moisture content and storage time influenced seed viability when stored for 27 months.

Conclusion

Seeds of *Thyrsostachys siamensis* can be stored for about 27 months under controlled conditions. Seed viability can be extended by reducing the initial moisture content before storing, which helps in maintaining viability for up to nine months. Seed samples stored at room temperature lost their viability within 21 months. In comparison, seeds stored for 27 months under low temperature, such as in the cold room (2-4 C) and deep freezer (-5 C) can maintain a high percentage of viability (89.2-92.5) and were able to germinate within three to four days.

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Vegetative Propagation of *Ochlandra travancorica* and O. *scriptoria* by Culm Cuttings*

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Abstract

Experiments on vegetative propagation of the bamboo reeds, Ochlandra travancorica and O. scriptoriu, were curried out at monthly intervals from June 1981 to May 1982 by rooting culm cuttings. For enhancing the rooting response, four growth regulating substances, indoleucetic acid (MA), indolebutyric acid (IBA), nuphthuleneucetic acid (NAA) and coumurin were used. Observations on rooting, the number and height of shoots were recorded after six months. In both species, rooting occurred only between February and June. O. truvuncoricu was most responsive to coumarin 10 ppm and NAA 100 ppm in April, whereas O. scriptoriu was responsive to IBA 100 ppm in Murch. A field trial was conducted using O. truvuncoricu to compare the growth of clumps raised from seedlings and rooted cuttings. Observations after two years showed that the growth of cuttings treated wirh NAA 100 ppm was better in terms of number and height of culms per clump.

lntruduction

Ochlundru truvuncoricu (Bedd.) Benth. ex Gamble and 0. *scriptoriu* (Dennst.) C.E.C. Fisher are the two commercially important bamboo reeds found in the evergreen and semi-evergreen forests of southern India. *0. truvuncoricu* is an erect shrubby or arborescent species found in the plains and hills up to an altitude of 1500 m above sea level, whereas *0. scriptoriu* which is gregarious and shrubby in nature, is generally found on the river banks. Bamboo reeds form an important raw material for both traditional and modem industries. Mat-weaving and basket-making are the main source of livelihood for a large number of rural families. About 93 percent of the total yield is supplied to modem industries, especially the paper and pulp industry (Nair & Muraleedharan, 1983).

The annual yield of reeds in Kerala is decreasing considerably. In 198 1-82 the total production in the State was about 18 000 tonnes. This fell to a mere 6000 tonnes by 1983-84 (Anonymous 1982; 1984). To meet the ever-increasing demand for bamboo reeds it has become necessary to augment the production by both protecting natural regeneration and raising plantations. A regular seed supply is a major problem for bamboos because of their long flowering intervals. 0. *travancorica* is monocarpic and flowers at an interval of seven years. *0. scriptoriu* is reported to flower annually but no viable seeds have been obtained so far (Gamble, 1896).

Various methods of vegetative propagation like offset planting, layering, rooting of culm and branch cuttings are used for propagation of bamboos. The success and limitations of such propagation methods have been reviewed by Banik (1980) and Hasan (1980).

The present study was conducted with the objective of developing suitable methods for the propagation of bamboo reeds by rooting culm cuttings. Cuttings were treated with various growth regulating substances (GRS) and the experiments were repeated at monthly intervals for a period of one year to see whether the GRS or the season of extraction has any influence on rooting.

Materials and Methods

Preparation of Cuttings and Treatment with GRS

Approximately two to three-year-old culms of *0. travancorica* and *0. scriptoriu* were extracted from healthy clumps. The top thin part of the culm

* *KFRI scientific paper no. 18.5*

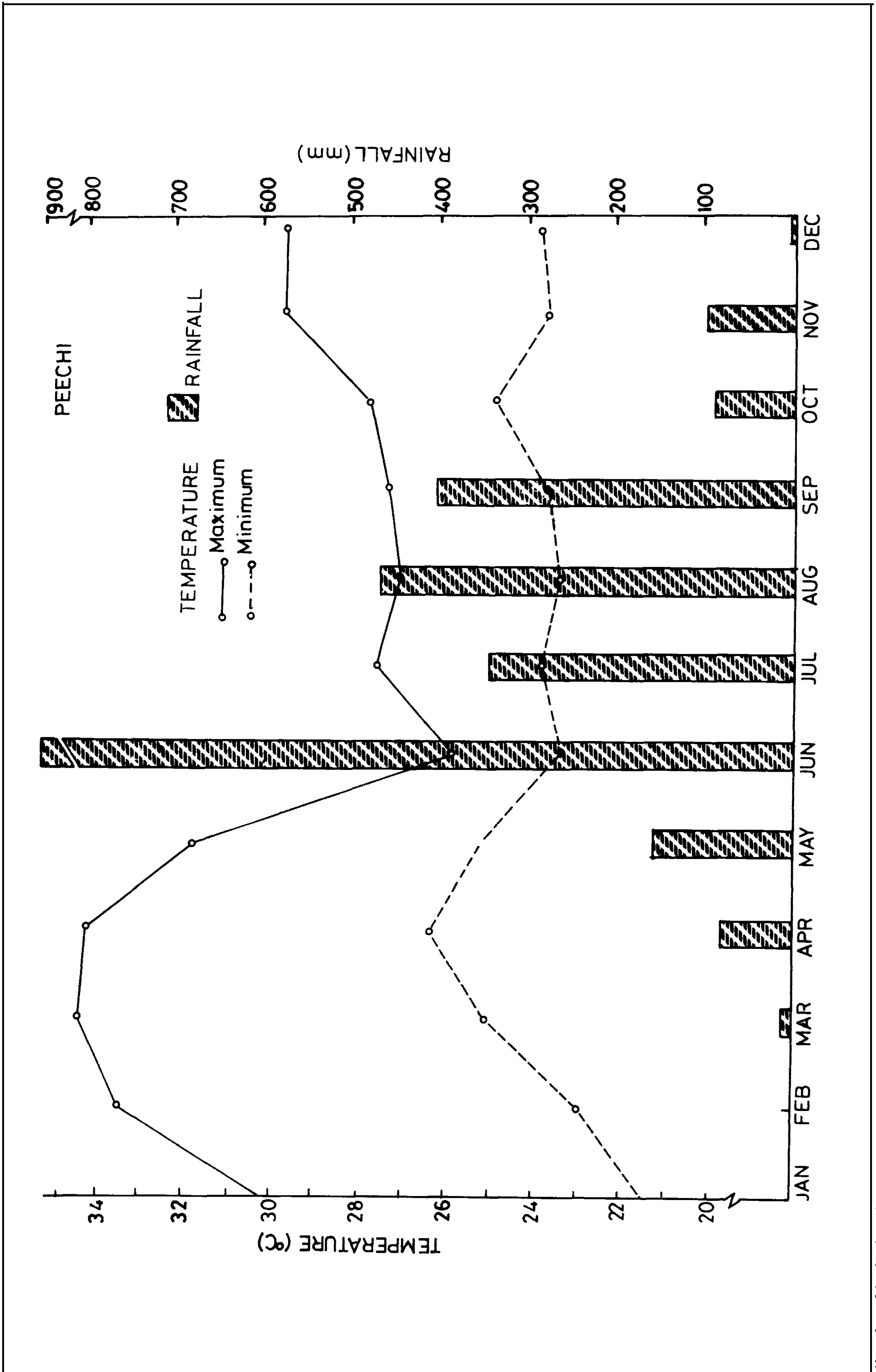

Fig. 1. Variation in temperature and rainfall from June 1981 to May 1982.

bearing leaves was discarded and the branches removed without damaging the axillary buds. Two-nodal cuttings were made leaving about 5-7 cm on each side beyond the node. Cuttings with healthy axillary buds were selected and an opening made in the centre of the internode into the cavity. The cuttings were divided into nine groups of ten each. Two concentrations (10 and 100 ppm) of four growth regulating substances, indoleacetic acid (IAA), indolebutyric acid (IBA), naphthaleneacetic acid (NAA) and coumarin were used for treating the cuttings, while one set was maintained as control (treated with water). About 100 ml of the solution was poured into the culm cavity and the opening closed by wrapping and tying with a polythene strip.

Nursery Preparation and Planting

One week prior to planting, the nursery beds (10 x I m) with garden soil were drenched with 0.01 percent (active ingredient) aldrex (National Organic Chemical Industries, Bombay) and 0.05 percent bavistin (BASF India Ltd., Bombay) to prevent termite and fungal attack, respectively.

Treated cuttings were placed horizontally on the nursery beds ensuring that the opening faced upwards and covered with a uniform layer of soil (2-3 cm deep). The beds were irrigated every morning and evening and provided with a thatch to prevent scorching by the sun. Fresh cuttings were collected at monthly intervals from June 1981 to May 1982, and the treatments repeated to study the effect of season on rooting.

Field Trial

Rooted cuttings of 0. *travancorica* were prepared in the nursery in March-April 1983 as mentioned earlier. Only two GRS, which appeared promising from the nursery experiments (IBA and NAA 100 ppm) and a control were used for the treatment of cuttings. Seedlings were also maintained in the nursery under similar conditions for about one year. About four hectares were cleared of undergrowth near the natural habitat of reeds in Vazhachal, Chalakudy Forest Division and planting done in a randomized block design. Each block had four treatments [cuttings treated with water (control), IBA 100 ppm, NAA 100 ppm and seedlings] with 20 plants per treatment at a spacing of 4x4m,

Observations

Observations on the percentage of rooting/survival, number and height of shoots per cutting were recorded after six months in the nursery and after two years in the case of field trials. The data were statistically analysed using analysis of variance and Duncan's new multiple range test (DMRT) after applying appropriate transformations (Keppel, 1973). The data on temperature and rainfall for the nursery experiments are given in Figure 1.

Results

Within two weeks of planting, the cuttings sprouted at the nodal region and slender roots appeared after a month at the lower portion of the

Fig. 2. Cuttings of O. travancorica in nursery beds after one year.

Table 1. Percentage of rooting in bamboo reeds Ochlandra travancorica and 0. scriptoria in response to various growth regulating substances (n = 10)

Treatment ppm	*Ochlundra travancorica*					*Ouch1andra scsiptoria*				
	Feb.	Mar,	Apr.	May	June	Feb	Mar	Apr.	May	June'
Control	20	30	40	40	50	10	10	-	10	.
IAA 10	10	40	-	30	30	10	20	-	-	10
IAA 100		30	30	10	40	20	30	10		10
IBA 10	20	30	30	40	20	10	20	-	-	30
IBA 100	10	20	40	20	20	40	50	-	-	
NAA 10	30	40	40	40	30	30	40	-	10	-
NAA 100	20	30	50	20	10	30	40	10	-	
Coumarin 10	30	50	50	40	10	-	10	-	20	-
Coumarin 100	20	40	40	50	20	-	10	-		-

*, *For both species no rooting was observed in any treatment from July to January*

Table 2. Analysis of variance (F-vaiue) of number and height of shoots (sprouts) in bamboo reeds *(Ochlandra travanconrica* and 0. scriptoria)

Source	*0. travancorica*		*0. scsiptoria*	
	Number	Height	Number	Height
Month	11.67**	5.74**	1.61ns	14.20**
GRS	5.26**	34.49**	2.41"'	6.76**
Concentration	0.55ns	0.05ns	0.51ns	I.44ns
Month x GRS	4.52**	2.65**	0.08"'	5.38**
Month x Concn.	2.19"'	10.33**	0.40ns	4.88**
Concn.x GRS	1.06"'	26.46**	0.18"'	5.03**
Month x GRS x Concn Control/	3.5 1**	10.80**	o.22ns	2.64**
treated Control/treated/ month	10.46**	85.3 1**	0.89"'	4.71**
Month	1.93ns	0.17""	1.43""	0.87""

**, *P* $\leq$ *0.01;* *P $\leq$ *0.05;* ns, not *significant*

sprouts. Generally, rooted cuttings took about three to six months for profuse rooting and rhizome formation followed by the emergence of numerous new shoots within a year in the nursery beds (Fig.2).

Percentage of Rooting

The rooting response of cuttings for various treatments is given in Table 1. Rooting was observed only in cuttings collected between February and June in both the species. In *O. travancorica,* four treatments (coumarin 10 ppm in March, NAA 10 and 100 ppm in April and the control in June) gave 50 percent rooting. However, in *O. scriptoria,* only IBA 100 ppm applied in March gave the best response.

Number of Shoots

In *O. travancorica* more shoots emerged from cuttings treated with the GRS (Fig. 3). The observed F values (Table 2) for various factorial effects showed that the interaction between month, GRS and concentration was significant indicating that the performance of GRS at the two levels used was not consistent over the various months. A large number of treatments were detected as superior by

Table 3. Growth of *Ochlandra travancorica* raised from seedlings and rooted culm cuttings

Treatment	% Establishment	No. of sprouts*	Height of sprouts (cm)
Seedlings	76.7	5.2	93.0
Control	81.7	7.9	111.9
IBA (100 ppm)	85.0	6.5	119.8
NAA (100 ppm)	85.0	9.2	160.2

*, Mean of 60 plants

DMRT and three of them which gave higher mean values are indicated in Figure 3. The maximum number of shoots obtained in the control was 12 while a treatment with IAA 100 ppm in March gave 21 shoots. But cuttings of *0. scriptoria* did not show any significant increase in shoot production with GRS.

Height of Shoots

The height of shoots was enhanced as a result of the GRS treatments in both bamboo reeds (Fig. 4). The results of analysis of variance indicated that the interactions were significant. The three superior treatments as indicated by DMRT for 0. *travancorica* were IAA 100 ppm in April and both coumarin 10 ppm and NAA 100 ppm in April and May. *0. scriptmia* gave the maximal response to IAA 100 ppm during March and June and IBA 10 ppm in February.

Since no treatment gave all the desired positive responses, a selection had to be made giving more preference to the percentage of rooting. For 0. *travancorica,* two treatments, coumarin 10 ppm and NAA 100 ppm gave 50 percent rooting in April with taller shoots than in the control. The same treatments also produced more shoots. Though none of these treatments were able to increase the percentage of rooting, these can be used to increase the vigour of rooted cuttings. In *0. scriptoria,* treatment with TBA 100 ppm in March, resulted in 50 percent rooting with taller shoots.

Field Establishment

All the four treatments showed a fairly higher rate of survival (75-85%) and the differences between treatments were not significant (Table 3). Clumps developed from rooted cuttings had a greater number of culms than those from seedlings (Fig.5). Of the three treatments, NAA 100 ppm produced the maximum number of shoots and also caused a significant increase in the height of the culms.

Discussion

The results indicate that like bamboos, bamboo reeds can also be propagated vegetatively using culm cuttings and used for establishment of plantations. Rooting and sprouting of cuttings of both species varied with the month of treatment and GRS. Rooting occurred only during the summer months (Feb-June) and cuttings treated with GRS showed enhanced vigour over the untreated ones. Earlier reports from the Philippines on *Bambusa blumeana* and B. *vulgaris* (Bumarlong & Tamolang, 1980) and our work on *B. arundinacea* and *B. balcoa* (Surendran *et al.,* 1983; Seethalaksmi *et al.,* 1983) have shown that GRS can be used for enhancing the rooting response of various bamboo species. Seasonal variation in rooting response has been earlier observed by White (1947) and Gupta and Pattanath (1976). This effect is more pronounced in bamboo reeds since in the control as well as in treated cuttings, rooting occurs only between February and June. During this period, higher temperature (between 23-34 C) and lower rainfall (0 to 900 mm) were observed. The other factors that influence rooting may be the endogenous levels of GRS and nutrients. Variation in the effect of auxins during different months have been observed earlier by Nanda (1970) who found that an auxin may stimulate rooting in one season but may be ineffective in another and at times, even inhibiting in yet another season.

The rooting response may also have some bearing on the growth phase of bamboo reeds. The reason why no rooting was obtained during the monsoons may be that the axillary buds remain dormant during this period when the new culms develop.

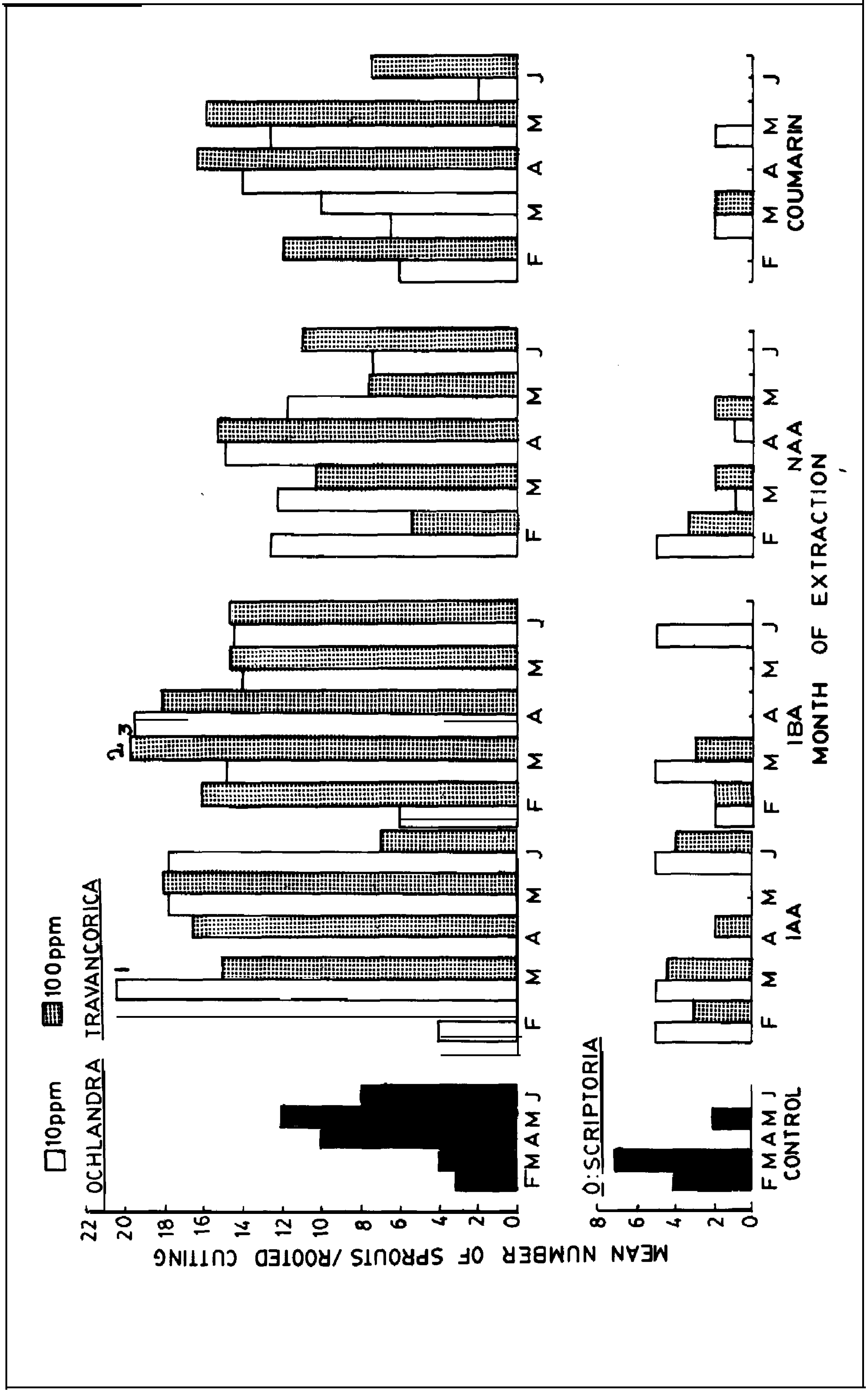

Fig. 3. Mean number of shoots per rooted cutting of O. travancorica and O. scriptoria. 1, 2 and 3 are superior treatments as selected by DMRT.

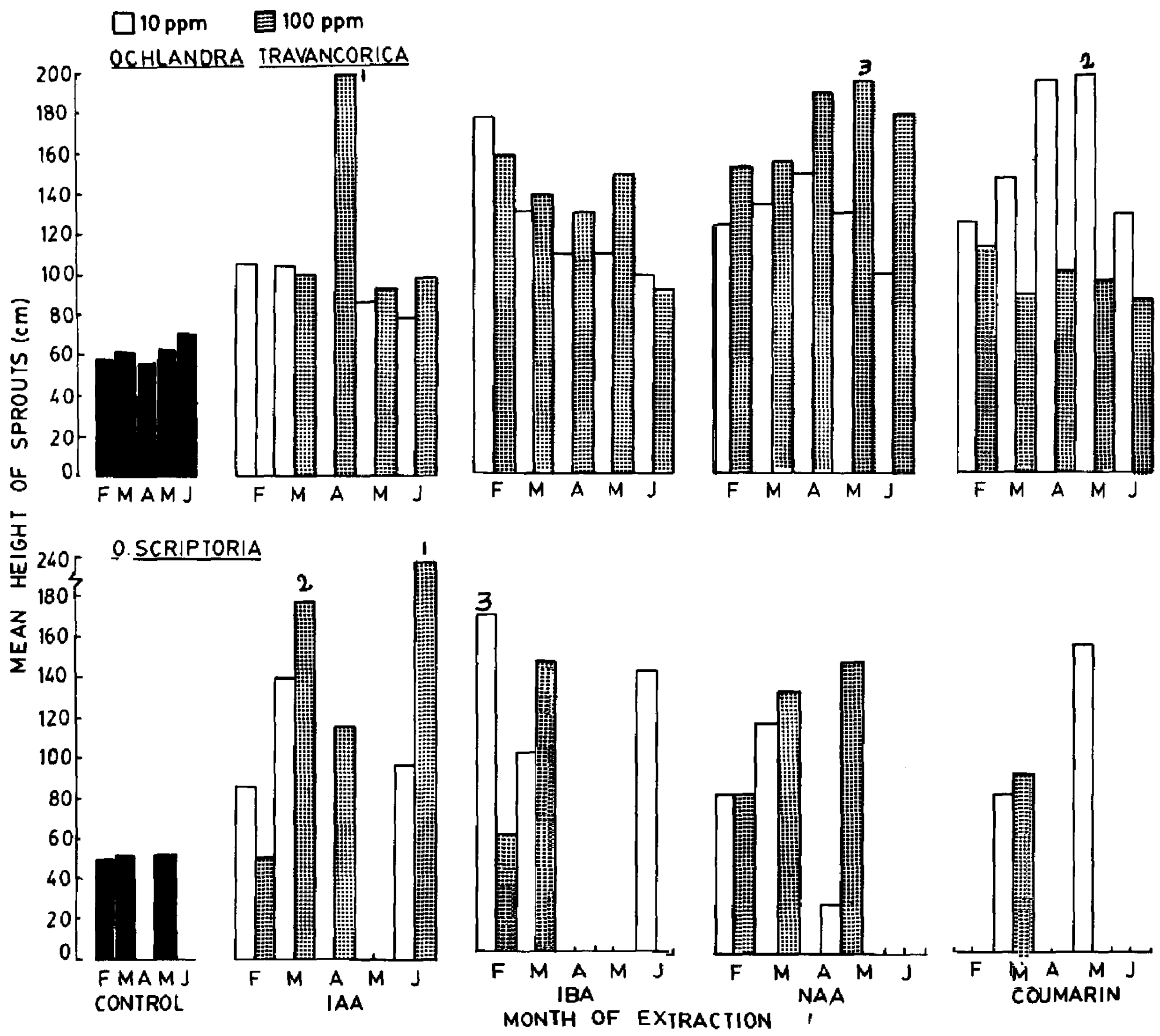

Fig. 4. Mean height of shoots per rooted cutting of O. travancorica and O. scriptoria. 1, 2, 3 are superior treatments as selected by DMRT

Fig. 5. Field established cutting of O. scriptoria after three years.

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Evaluation of Bamboo Regeneration Techniques

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Abstract

Regeneration of Arundinaria alpina, the only indigenous bamboo of Kenya, was tried through seeds, rhizomes, clumps and cuttings. Growth regulating substances were used to root the cuttings. only rhizomes and clumps gave a reasonable performance,

Introduction

The indigenous bamboo species of Kenya is *Arundinaria alpina* which is found distributed at altitudes ranging from 2200 to 3350 m above sea level. This limited ecological zone is a cause of concern because haphazard exploitation of bamboo can easily result in its extinction. Other favourable ecological zones are mainly located in the Aberdares, Mau ranges, Mt. Kenya and Mt. Elgon. These areas were used to support an extensive bamboo crop until the 1950s when most of these were replaced with fast growing, exotic, softwood trees. There, however, has been a major attempt during the recent years to revive the bamboo-based industries in Kenya. This would provide support to the weaker sections of the society.

Apart from its commercial value, bamboo is very effective in tying up the top soil thus preventing soil erosion. The indigenous species is quite suitable for fragile ecosystems such as swamps, canal banks, steep terrain and riverline areas. The increasing need for the use of bamboo in afforestation programmes mainly in the catchment and erosion-prone areas has called for a better understanding of bamboo management. An easy method of raising bamboo planting material would, therefore, greatly facilitate the rehabilitation programme.

Extensive studies on bamboo regeneration have been carried out in South-east Asia. However, little has been done systematically to study bamboo in Kenya and it is only recently that the Kenya Forestry Research Institute (KEFRI) has undertaken a project on the bamboos.

Regeneration Techniques

Bamboo regeneration in nature occurs through rhizomes and seeds. However, for raising nursery stocks, cuttings and clumps have also been tried with varying success. All the four methods have their merits and demerits which are indicated below.

Seed

Possibilities of raising bamboo plantations from seeds are not always practical because of the unusually long seeding cycles (Uchimura, 1980). In Kenya, most people do not even have a basic awareness of bamboo seeds. According to Dutra (1938), *Arundinaria alpina*, introduced in Brazil around 1804, flowered in 1836, 1868 and 1899, thus giving a seeding cycle of 31-33 years. Working with this as a reference point, it would be a lot less taxing to deduce the local seedling cycle. In natural stands the question of seeding cycle is not as easy as it may appear because of the physiological, genetical and ecological factors involved in this process and the out of phase flowering as reported by Prasad (1965). However, Banik (1980) observed that *Bambusa arundinlacea* flowers from February to June in three successive flushes with two dormant intervals and further reported that seeds from the first two flushes gave better germination than the third flush. He reported a seed germination rate between 26 and 52 percent in various bamboo species.

Clumps and Rhizomes

The use of clumps and rhizomes as planting material has proved quite successful. The former refers to dug-out clusters of bamboo stalks of the mother bamboo cut to a height of about 60 cm while the latter are underground offsets which are dug out. These are bulky, heavy, difficult to handle and transport, and are unsuitable for large-scale plantation (Hasan, 1980). Considerable work on the age, size and the number of rhizomes to be planted has been done by Uchimura (1980), Oh and Aoh

(1965) and Varmah and Bahadur (1980).

Cuttings

The use of branch cuttings instead of offsets, could provide a solution to the problems of scarcity, bulkiness and weight of planting material but success in propagation has been limited (Hasan, 1977). It was observed that branch specimens take 6 to 30 months to develop into good planting material. Experiments carried out in India have indicated that culm cuttings could be used for vegetative propagation and the month of April was found to be the best time for propagation by two-node cuttings. It was also observed that horizontal planting was superior to vertical and oblique methods (Varmah & Bahadur, 1980).

Study Area

The study was carried out at Moi University which is 35 km from Eldoret town located at an altitude of about 2100 m above sea level (latitude 0° 2' N and longitude 35° 5' E). The mean monthly temperature here is 14 C and ranges from 12 to 16 C. The mean annual maximum temperature range is from 6 to 10 C. The mean annual rainfall is around 1150 mm while the relative humidity ranges from 60 to 80 percent. The climate varies from humid to dry subhumid type. The basement rock is of volcanic type and the soils are red to deep brown friable clay. They are well-drained and deep.

Material and Methods

Seeds

Fresh flowers were collected from the bamboo stand at Kaptagat forest and hand-threshed. The seeds were planted in a 1 x 1 m plot and watered at regular intervals. No pretreatment was given.

Clumps

These refer to a dug-out cluster with five stalks of the mother bamboo chopped to a height of about 60 cm. Five such clumps were dug out and planted in pits 30 cm deep and 30 cm in diameter.

Rhizomes

These are underground offsets of 20 cm length. Five such rhizomes were completely buried in pits about 30 cm deep and 30 cm in diameter.

Cuttings

This refers to a cut branch stalk with two nodes. Three treatments were administered by dipping the lower portion including one node into rooting powder. Twenty such cuttings each were dipped into softwood rooting powder and hardwood rooting powder separately while twenty cuttings were left untreated. The cuttings were buried in a way such that the treated node was well below the soil. Standard nursery operations like weeding were carried out and watering was done as required.

The effectiveness of the four methods of regeneration was evaluated in terms of performance in the nursery based on survival counts, rate of growth, height and sprouting of new shoots. The experiment was carried out for a duration of four months.

Results and Discussion

Seeds

At the end of four months it was observed that the seeds did not germinate. This might be due to ecological difference, inefficient seed handling. freshness of the seeds sown or insufficient time allowed for germination. Variable results of seed germination have been reported in the literature. Sa and Joo (1970) reported that seeds performed well and provided the most economical method of raising bamboo; however, in our study, the experiment with seeds turned out to be a complete failure.

Clumps

The clump performance, in terms of height and number of shoots at the end of four months from the date of planting, is given in Table 1. An average height of 134 cm was recorded with a range from 111 to 153 cm. The number of shoots varied from two to four with an average of three shoots. The survival rate of clumps in this study was 100 percent.

Rhizomes

The rhizome performance recorded at the end of four months is seven in Table 2. The average height of the tallest shoot was I23 cm and it ranged from 115 to 132 cm. The average number of shoots obtained was five and ranged from three to seven shoots. Rhizomes also showed a 100 percent survival rate.

Cuttings

The performance of the cuttings in the nursery was very poor (Table 3). The average percentage survival rate varied from 10 to 15. The nature of rooting powder used did not result in a significant increase in survival. Similar results have been reported by White (1947) and Delgado (1949). At the end of four months, none of the cuttings had any aerial shoots, and hence were uprooted to look for

Table 1. Performance of clumps

Height of tallest shoot (cm)		No. of shoots
	121	4
	137	3
Replicate	153	4
	140	2
	111	4
Mean	134	3

Table 2. Performance of rhizomes

Height of tallest shoot (cm)		No. of shoots
	127	5
	132	3
Replicate	115	4
	119	7
	I22	6
Mean	123	5

Table 3. Performance of cuttings in nursery*

Treatment	No. showing survival	Height of new shoot	No. of new shoots
Softwood powder	3		
Hardwood powder	2		
Control	3		

*, 20 replicates used per treatment

root sprouts from the buried node and the cluster of shoots, which would emerge later as indications of potential shooting.

Conclusion

The study established that use of rhizomes and clumps was most suitable and effective for raising bamboo. Although there was no difference in the performance of both rhizomes or clumps it must be borne in mind that digging out of rhizomes is much more laborious. For a large scale operation, however, both rhizomes and clumps are not the best materials as they are bulky and difficult to transport.

Cuttings treated with rooting powder are unsuitable as propagules. Their survival rate was extremely low and there was no sprouting of new shoots. Nevertheless, if the survival rate of cuttings could be improved, this would provide a cheap and easy way to obtain bamboo propagules for small farm holders.

Propagation through seeds was disappointing as germination was not obtained in this study. However, if the exact year or age at which bamboos bear seeds could be predicted and seed handling techniques improved, these could prove to be a viable alternative.

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Traditional Vegetative Propagation and Tissue Culture of some Thai Bamboos

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Abstract

Vegetatille propagation of some Thai bamboos by traditional methods (offset planting, culm and branch cuttings) and by tissue culture was studied. Both offset planting and culm cuttings, were effective hut expensive. Propagation by branch cuttings was found to he ideal for Dendrocalamus asper-. The tissue culture study carried out showed that callus could he induced from nodes of aseptic seedlings of D. membranaceus. In addition, multiple shoots could also be produced from seeds.

Introduction

Bamboos are monocotyledonous plants, belonging to the Poaceae (subfamily, Bambusoidae). In Thailand, more than 12 genera and 42 species of bamboos have been recorded (Smitinand & Ramyarangsi, 1980). Several species are cultivated extensively for their edible shoots and mature culms. Some are also grown as landscape ornamentals. The economically important Thai bamboos are *Bamhusa arundinacea, B. blumeana, B. nana B. tulda, Cephalostachyum pergracile* and *C. virgatum, Dendrocalamus asper; D. brandisii, D. hamiltonii, D. membranaceus, D. strictus, Thyrsostachys siamensis* and *T. oliveri.* All these have the pachymorph or sympodial type of rhizome (McClure, 1966).

The most important area of bamboo growth in Thailand is in the Kanchanaburi province, 130 km west of Bangkok, while Prachinburi province, 135 km east of Bangkok is well known as the centre of bamboo farms. More than 4465 ha of *Dendrocalamus asper-* have been raised by private farmers for shoot production. Methods for the propagation of bamboo by culm and branch cuttings have been developed in this area. It has been observed that the farmers in Prachinburi obtain additional income by selling a large number of branch cuttings of *D. asper.* The price of a branch cutting is presently about 18-25 bahts each (25 bahts = 1 US $).

Several studies have been carried out on propagation of bamboos by conventional and tissue culture methods (Mehta *et* al.. 1982; Vasana, 1985; Yeh & Chang, 1986 a,b, 1987: Banik, 1987). In the present study, both traditional and tissue culture based methods have been investigated (Anantachote, 1984) for developing improved methods of propagation of bamboos.

Traditional Vegetative Propagation of Bamboo

Planting by Rhizome

Propagation of bamboo is known to occur asexually in the branching of rhizomes. The planting of culms with attached rhizomes (offset planting) is the best method. The most vigorous sprouting activity is seen in one-year-old culms (after budding). Cut culms with two to three nodal buds are planted in the soil, The underground nodal buds grow into rhizome and roots, while those above the ground develop into culms. This method is successful in bamboo species with thick walls such as *Thysostachys siamensis* and *Melocalamus compactiflorus.*

In the sympodial bamboos, growth of the culms occurs typically with the onset of the monsoon (June to October). The rhizome is usually short and the sprouts develop close together (within 30 cm), resulting in clump formation. The new rhizomes and new culms generally develop from a parent one-year-old culm. About three to seven large buds of the one-year-old parent culm tend to grow simultaneously but only one or two of them are able to grow completely. This is the limitation of rhizome plantings. Besides this method of propagation is too expensive for large-scale plantations. However, a rhizome can be enlarged by skillful cutting or fertilizing.

Culm Cutting

This is an effective method for propagating thick-walled and large-sized bamboos (8-12 cm in diameter) such as *Bambusa blumeana, B. vulgaris, Dendrocalamus latiflorus,* etc. One-year-old culms are suitable for culm cutting. The cuttings should have one or two nodal segments. For single node propagation, culms about 40 cm long with a node in the middle are used as explants. They are planted at an angle of about 45° and at a depth of 20 cm in the rooting medium. Node sections are placed at the same level of the rooting media with a bud exposed on the top side. Watering is done twice a day. Sprouting of new shoots can be seen after two to four weeks. Water, fungicide and insecticide are regularly applied for 6- 12 months before transplanting.

This method also is not popular because it is expensive. In addition, there is the limitation of using one-year-old culms which can otherwise be put to other uses.

Branch Cutting

Propagation by branch cuttings is a useful, practical and effective method that can be easily handled. It is also ideal for raising commercial large-scale plantations. This is normally done in the case of *Dendrocalamus asper,* the species which has aerial roots at the base of the lateral branch. Bigger branches have more potential for rooting than small ones. Rooting is abundant in rice husk charcoal medium; the roots are slender, thin and long, whereas those in soil are bigger and clustered. The rooting efficiency of each species is different and depends on culm size and wall thickness. Thick-walled bamboos possess a higher sprouting and rooting ability probably due to more food reserves. Branch cuttings and even culm cuttings of thin-walled bamboos such as *Cephalostuchyum pergracile* are mostly a failure. The species which have small branches at the top of the culm, such as *Thyrsostuchys siamensis* and *T. oliveri,* can hardly be propagated by this method.

Propagation by Tissue Culture Techniques

Tissue culture experiments on bamboos were carried out in the Central Laboratory of the Division of Silviculture, Royal Forest Department. The investigation can be divided into two parts, one dealing with callus induction and differentiation, and the other with multiple shoot induction.

Callus Induction and Differentiation

This study was conducted in order to determine means of callus induction from nodes of aseptic seedlings of *Dendrocalamus membranareus.* Mature seeds collected from Kanchanaburi province were surface-sterilized with 75 percent ethanol for one min, dipped into 10 percent sodium hypochlorite for 15 min and then rinsed thoroughly in sterile distilled water. Seeds were aseptically cultured on a medium containing MS components. Cultures were kept under fluorescent light of 2000 lux, in a 12/l 2 h day/night regime and at a constant temperature of 25 ± 2 C. Nodal segments of aseptically grown seven-day-old seedlings were cut to 2-2.5 cm and implanted on semi-solid MS media containing different concentrations of 2,4-dichlorophenoxyacetic acid (2,4-D) ranging from 0 to $8x10^{-5}$M and 6-benzylaminopurine (BAP) from 0 to $0.8x10^{-5}$M. Callus initiated from the nodal segments within six to eight weeks. It was moist, yellowish-white to brownish-yellow in colour and granular to nodular in texture. The callus could be maintained through unlimited subcultures in the same medium. Callus formed rapidly on medium containing 1 to $1.5x10^{-5}$M of 2,4-D and $0.2x10^{-5}$M of BAP. On media with higher concentrations of 2,4-D, the callus developed slowly with dark brown soft masses. After six to seven months, the white and fresh callus was transferred to a medium with a lower concentration of 2,4-D (0.5 to $1x10^{-5}$M). Embryogenic callus formed within three to four months.

Multiple Shoot Induction

The experiment was set up in order to investigate the sprouting possibilities of *Dendrocalamus membRanaceus* and *D. brandisii* seeds. The seeds of *D. membranaceus* were cultured in MS basal media supplemented with BAP at different concentrations ranging from 0 to $6x10^{-5}$M, with 1 percent agar and 3 percent sucrose. After 15 days it was found that the seeds had germinated and produced multiple shoots in all media containing BAP The best result was obtained with $2x10^{-5}$M BAP in which the seeds produced three to five multiple shoots, 1 to 3.5 cm in length. However, after three weeks the base of seedlings turned brown. Subculturing was done on the same medium. The maximum multiple shoots (25-30 shoots) were obtained in the medium supplemented with 0.5 to $2x10^{-5}$ M of BAP within three to four months. Concentrations of BAP higher than the optimum level produced a lower number of multiple shoots. However, rooting was not obtained in this medium. For rooting, MS medium with $1x10^{-5}$M NAA was used. The use of BAP in the root induction media inhibited root formation,

In the case of ***D. brandisii,*** vigorous multiple shoots (20-30) could be induced in MS medium supplemented with $2x10^{-5}$M of BAP. The multiple shoots showed sustained growth when subdivided and transferred to fresh medium of the same composition. Root formation occurred when the multiple shoots were transferred to MS medium containing lower BAP concentrations or to basal MS without any growth regulators. Rooting could also be induced in sterile vermiculite soaked with water. The plantlets were suitable for transplanting to soil and grew well under nursery conditions. Preparations for field planting are underway.

Another experiment to make use of small branches in culture was set up. Three species of bamboo, ***Thyrsostachys oliveri, Dendrocalamus asper*** and ***Bambusa nana*** were included in the experiment. Sections from young branches, about 3.5 mm in diameter and 1 S-3.0 cm long, were used as explants. MS basal medium supplemented with various concentrations of 2,4-D, NAA and BAP was used. Both auxin and cytokinin were required for optimal sprouting of the axillary buds.

BAP at $3x10^{-5}$ M induced the maximum formation of multiple shoots. A small number of sprouts survived for longer than two months but later turned brown and died. This experiment was repeated and the shoots were transferred to a rooting media before they turned brown. The problem of rooting is still under investigation.

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Tissue Culture Approaches to the Mass-propagation and Genetic Improvement of Bamboos

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Abstract

Bamboo is a critical natural resousce which has not easily lent itself to modern methods of mass-propagation and genetic improvement owing to its long vegetative phase and monocarpic flowering behaviour. Methods have been standardized in our laboratory to produce plants of Dendrocalamus strictus and Bambusa arundinacea through somatic embryogenesis from inflorescences and embryos, and from rhizomes, nodes and leaf sheaths of juvenile plants. Multiple shoots have been induced from seedlings, and plants have been raised from them through rooting. Plantlets have also been obtained from nodes of mature plants of B. vulgaris and D. strictus although only 4-10 percent of them form roots. Methodsfor the precocious induction of rhizomes have been developed to accelerate plantlet growth in the field. Using conventional breeding methods, the genetic improvement of the woody bamboos has till recently been difficult, because of the near impossibility of getting two desirable parents to flower simultaneously. Using tissue culture methods, in vitro flowering of somatic embryos has been achieved by us both in D. strictus and B. arundinacea within 8-10 weeks of culture. Using this method, it should be possible to produce bamboo hybrids. Protoplasts have been isolated from juvenile, embryogenic and mature tissues ofbamboos. This opens up the possibility of obtaining newer variants and somatic hybrids. Somaclonal variants have also been isolated. Greater variation, however, needs to be generated and assessed for the presence of desirable characters.

Introduction

Bamboo is a versatile multipurpose forest produce which plays a vital role in our domestic economy. In India, the lives of both urban and rural people are so dependent upon bamboo that it is hard to conceive living without this useful material. Elsewhere in the world and particularly in the South-east Asian region, bamboo is common as an article of daily use.

In India, the paper industry is largely dependent upon bamboo as raw material. India is the chief country in Asia which utilizes bamboo for manufacture of paper on a large scale. The principal sources of paper pulp of acceptable quality in India are *D. strictus* and *B. arundinacea*. It is estimated that out of an annual production of nearly 9.5 million tories of bamboo in India, about 4.9 million tonnes are presently being utilized for paper-making (Varmah & Bahadur, 1980). This yields around 600 000 tonnes of paper pulp per year which is very much short of the country's demand. The country's requirement in 1984 was 3.5 million tonnes which may rise to 4.5 million tonnes by the turn of the century (Varmah & Bahadur, 1980). In India, the large scale use of bamboo as raw material for paper has resulted in a situation where raising of new stands has fallen way behind the rate at which the clumps are being harvested. Unless these bamboo forests come under enlightened and scientific management, the future supplies of this material to the industry will be jeopardized.

Conventional Propagation of Bamboos

Bamboo propagation is by and large through seeds, offsets and culm cuttings. If the seed is viable, regeneration is normally easy, since their small size makes them easily transportable. The difficulty which arises in utilizing seeds is their low viability, poor storage characteristics and inbome microbial infestation. Also, seed availability is uncertain due to the long vegetative habit of bamboos and often depends on sporadic flowering. Vegetative propagation by offsets and culm cuttings has also proved to be of limited value. A drawback in this method is that the daughter clumps are prone to flowering at the same time as the parent clump.

Propagation of Bamboos through Tissue Culture

In vitro methods offer an attractive alternative to conventional methods for the mass-propagation of bamboos. The two principal methods that can be utilized for this purpose are somatic embryogenesis and micropropagation.

Somatic Embryogenesis

Somatic embryogenesis is defined as embryo initiation and development from cells that are not products of genetic fusion. Thus hundreds of plants can be obtained from somatic embryos. The following explants can be utilized for somatic embryogenesis:

Juvenile materials:

1. Zygotic embryo
2. Immature embryo
3. Seedling parts - node, leaf sheath, root, rhizome

Tissue-culture raised materials:

1. Somatic embryo
2. Parts of plantlets regenerated from somatic embryos

Adult (mature) materials:

1. Node
2. Shoot-tip
3. Leaf sheath base
4. Rhizome

With juvenile or tissue-culture raised materials of *Bambusa arundinacea* and *Dendrocalamus strictus*, callusing starts soon after inoculation on B_5+2,4-D (l0-30 μM; Mehta *et al., 1982;* Rao *et al.*, 1985, 1987; Fig. l A-E). The callus has both nodular (compact) and friable regions. On subculture, the compact callus gives rise to somatic embryos. These arise as protuberances on the surface of the callus. Several green embryos are observed in the compact callus. Germination of the embryoids takes place on the same medium. The scutellar region of the embryoids can be made to proliferate and give rise to a second generation of embryoids. Thus, the initial callus phase can be kept very short and reduced to the minimum. Once the initial crop of embryoids is obtained these can be made to 'bud' off several daughter embryoids and the process repeated ad infinitum. With each round of 'budding', there is a several-fold increase in the number of embryoids, each of which has the ability to give rise to a completely well-formed plant. It is important to remember that there is no callusing involved throughout and all daughter embryoids arise from pre-existing differentiated embryoids. Callusing is only in the very initial phase when the embryogenic compact callus is being formed.

Somatic embryogenesis has three major advantages:

1. The embryoids have pre-formed shoot and root poles thus eliminating the need for a rooting step as with shoots.
2. Multiplication of somatic embryos is very rapid. Whereas a nodal or a shoot culture may have a few shoots, an embryonic culture will have over a hundred embryos.
3. Maintaining and manipulating embryogenic cultures is easier and quicker, and hence less labour-intensive and costly than a shoot culture.

To date. somatic embryogenesis has been obtained in *Bambusa arundinacea* (Mehta *et* al , 1982); *Dendrocalamus strictus* (Rao *et* al., 1985). *B. oldhamii*, *B. beecheyana*, *Sinocalamus Iatiflora* (Yeh & Chang, 1986a. b, 1987) and *Phyllostachys viridis* (Hasan & Debergh, 1987).

There have been some initial successes with explants from mature bamboos. Work in our laboratory has shown that embryogenic compact callus can be obtained from cultured nodes (Fig. 2B). Zamora *et al.* (1989) have also obtained shoots from node and rhizome explants. The results are very promising and need to be investigated further.

Embryogenic Suspension Cultures

The raising of embryogenic suspension cultures is an area which deserves more attention than it is presently attracting. Once such suspension cultures are established and methods developed to differentiate embryoids in these, the way will open up for a truly mass-scale production of bamboo plantlets at minimum cost. It would also enable the production of artificial seeds (Redenbaugh *et* al.. 1988). The attempts made so far have not resulted in embryogenic suspensions but continuous efforts are being made in this direction (Huang *et* al.. 1988; Dekkers, 1989). In our laboratory also, continuously growing suspension cultures have been established.

Micropropagation - Nodal Explants

The technique of micropropagation or in vitro vegetative propagation can yield faithful duplicates of an original parent plant. In bamboos, the nodes bear axillary buds which remain dormant most of the year and generally sprout during the rainy

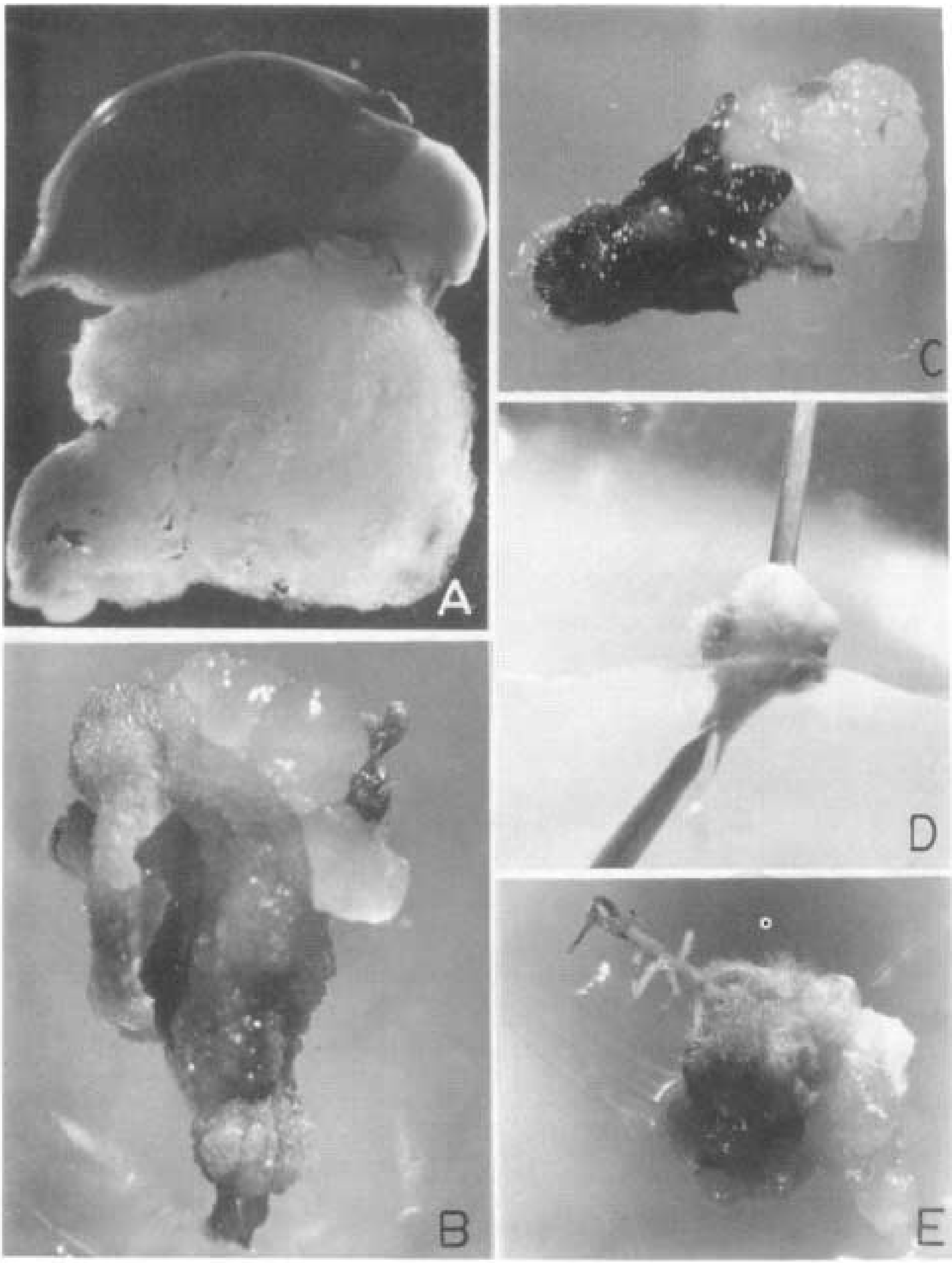

Fig. 1A-E. *Induction of embryogenic callus in Dendrocalamus strictus.*
***A**: Embryo, **B**: Leaf sheath, **C**: Rhizome, **D**: Node, **E**: Root.*

season; these buds have the capacity to transform into complete plantlets (McClure, 1966). There is even the possibility of inducing rhizomes in these buds, In such cases a separate root formation step is not required as the rhizomes are capable of producing both culms and roots, thus giving rise to complete plants. If successfully established, the use of the dormant axillary buds or nodes would make available a large presently unusable resource for propagation. Thus, the technique of micropropagation offers the potential ability to raise thousands of plantlets from the nodal regions of the existing clumps.

The results so far (Tikiya, 1984; Jerath, 1986) have shown that it is relatively easy to get the axillary buds in the nodes of *Bambusa vulgaris* and *Dendrocalamus strictus* to sprout (Fig. 2A). Multiple shoots can also be obtained. However, it has been difficult to get a sufficiently high percentage of them to root. Presently, depending on the species, between 4 to 10 percent of the nodal shoots can be rooted. This needs to be improved upon.

Micropropagation - Multiple Shoots From Seeds

Yet another approach is the formation of multiple shoots from seeds. The multiple shoots can be rooted or subcultured to obtain another set of multiple shoots. It has been observed that multiple shoots are easily induced from zygotic embryos and these can be rooted (work in our laboratory; Nadgir *et al.*, 1984; Dekkers, 1989). *In Bambusa arundinacea*, 58.4 percent of the seed cultures formed multiple shoots on B_5 medium supplemented with BAP (10^{-5}M) (Jerath, 1986).

Induction of Rhizome

Bamboo seedlings go through a juvenile phase with flimsy and short shoots (McClure, 1966). The seedlings attain maturity with the development of a rhizome which occurs towards the later part of the first year. The upward growing portions of the rhizomes develop into the tall mature bamboo shoots (culms). An evaluation of the published literature has shown that the physiology of rhizome formation and the factors leading to subsequent rapid growth, so often quoted as the prime asset of bamboos, are relatively unknown.

Methods have now been developed to precociously induce rhizomes in plantlets from somatic embryos and in seedlings (Fig. 2C). The induction of rhizomes helps in the early establishment of the plants in the field as well as enables earlier culm production (Fig. 2D). When done in vitro this provides an additional tool for plantlet multiplication through excision of the rhizome. The germinating rhizome produces both a shoot and a root, giving rise to a complete plantlet.

In Vitro Flowering of Bamboos

Flowering has been one of the most puzzling aspects of the biology of bamboos and the factors that trigger it are perhaps only recently getting to be understood. Bamboo hybrids have been obtained for the first time by Guangzhu and Fuqiu (1987). The opening of the bamboos to conventional methods of hybridization is a major advance indeed and should pave the way for breeding bamboos better suited to modern needs.

A method that has much promise in this regard is the induction of in vitro flowering. In our laboratory, somatic embryos of *Dendrocalanms strictus* and *Bambusa arundinacea* have been induced to flower in culture. This can be done at different stages of development and an embryoid can even directly give rise to a floret (Fig. 3A). For this purpose, compact callus with embryos developed on B_5+ 2,4 - D (3 x 10^{-5}M) + BAP(10^{-5} M) was transferred to B_5 + GA_3 (10^{-6}M) + ABA (5x10^{-6}M) + ethephon (10^{-3}M) and later subcultured on B_5 + 2,4-D (10 M) + BAP (1 0^{-5}M) + CW (5%). Flowering was obtained in 8-10 weeks of subculture. Normally spikelets are formed with a few florets. Although the plantlet can be very small, the florets are of the normal size. The spikelets and florets grow normally and the anthers and stigma emerge out. The induction of flowering in somatic embryos should make in vitro breeding for better bamboos possible. Alternatively, subsequent to flower induction, the bamboo plantlet could be potted out and experiments done under non-sterile conditions. We have found that it is possible to pot out bamboo plantlets at an initial stage of flowering and have the final expression of flowering in the growth chamber.

Protoplasts

Plant protoplasts offer a number of possibilities such as isolation of somaclonal variants, induction of somatic embryogenesis and above all of somatic hybridization. A number of technical problems still need to be solved to enable the development of an effective methodology for obtaining high yields of developmentally active protoplasts. The results of Tseng et *al.* (1975), Huang (1988). Dekkers (1989) and the work in our laboratory have shown that serious limitations exist in protoplast isolation and culture from both mature and juvenile tissues, and embryogenic calli. Progress in the development of embryogenic suspension cultures of bamboo will certainly

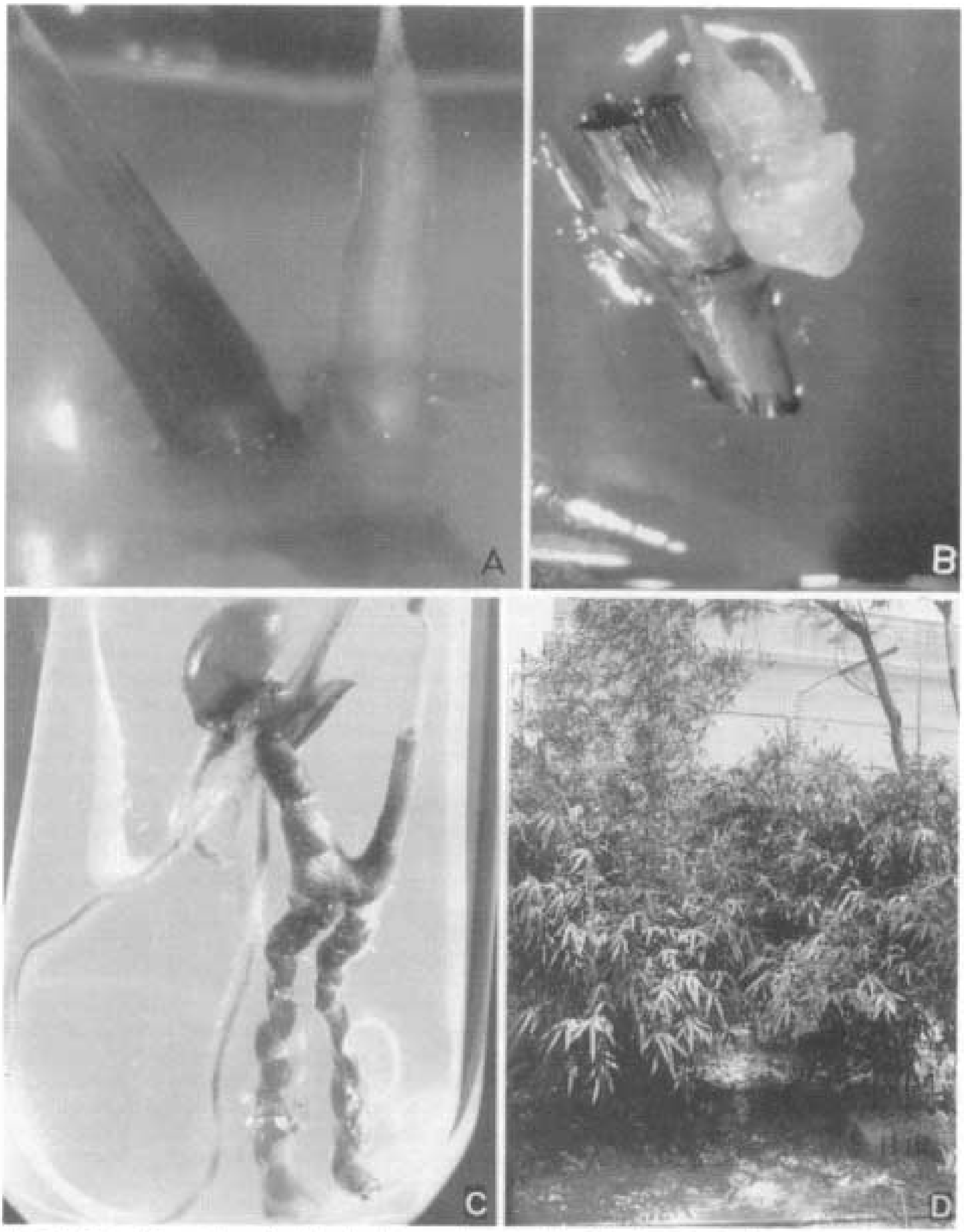

Fig. 2. A-D **A**. *Sprouting of axillary bud from cultured node of B. vulgaris.* **B**. *Formation of compact callus from mature node of D. strictus.* **C**. *Precocious induction of rhizome in seedling of D. strictus.* **D**. *Three-year-old tissue culture-raised plants of D. strictus in the botanical garden of the Department of Botany, University of Delhi.*

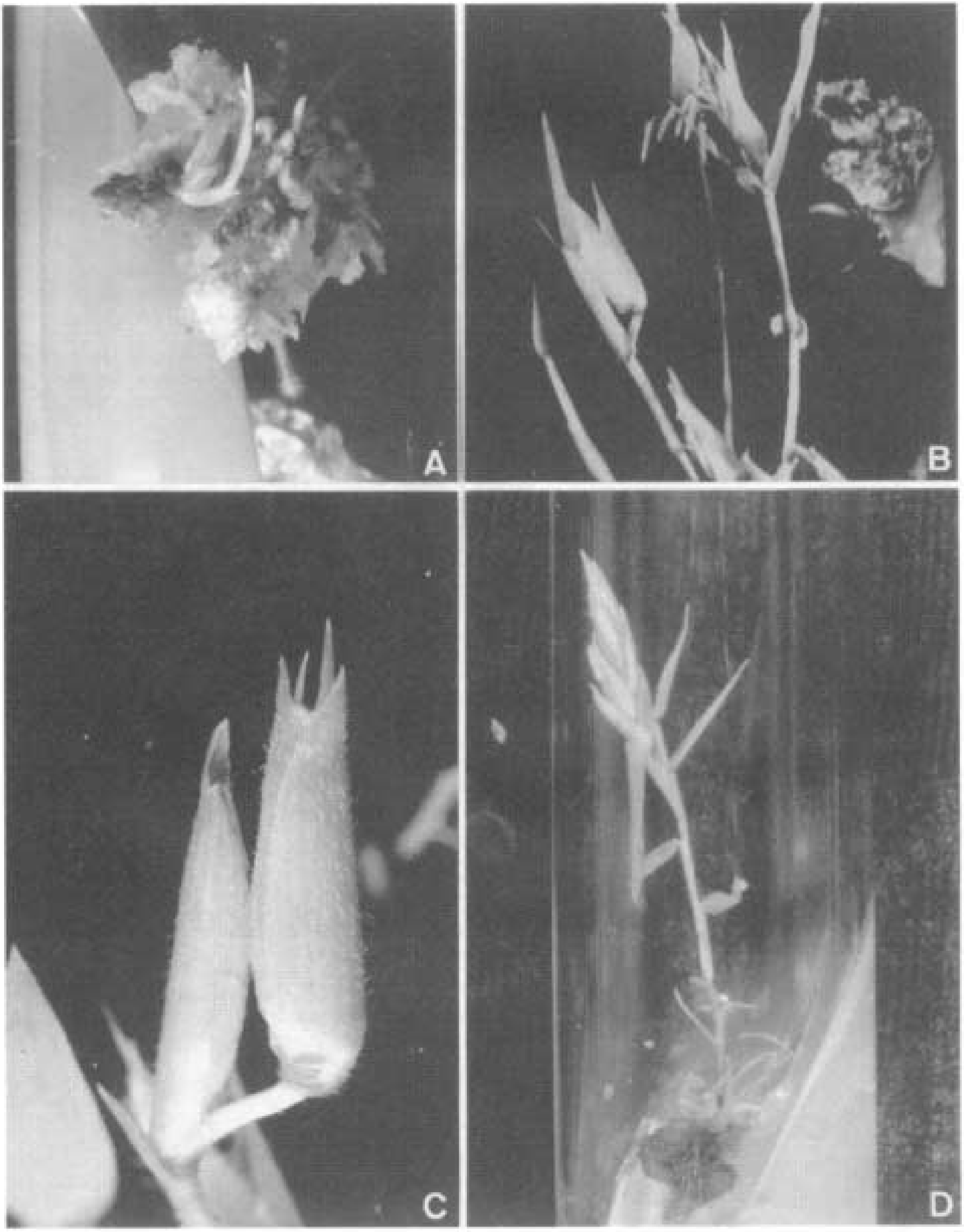

Fig. 3. A-D **A**. *An embryoid of D. strictus flowering soon after germination in culture.* **B**. *Flowering plantlet of D. strictus.* **C**. *Close-up of florets of in vitro-flowered plantlet of D. strictus.* **D**. *Flowering plantlet of B. arundinacea.*

lead to a breakthrough in protoplast culture as has happened in rice and other monocots.

Somaclonal Variants

Although the actual benefits from somaclonal variants have not matched expectations, this remains a promising area worth pursuing. Most somaclonal variants have not proved to be of value but a few have made it into breeding experiments. In the bamboos, it is necessary to generate a whole range of variation in order to work towards generating the bamboos of the future which will be more dedicated to modern applications.

A few somaclonal variants have been isolated in our laboratory. One of them is a plagiotropic mutant of *Bambusa arundinacea*. *We* have as yet not initiated experiments for screening for physiological mutants and have only picked up those that differ in morphological characters. Experimental induction of variation also needs to be done. It can be expected that once methods of protoplast isolation and culture are established for the bamboos, the work on somaclonal and experimentally generated variation will receive a fillip.

Conclusion

Tissue culture work on the bamboos is now coming of age with several groups working on it. It is heartening that nearly all are Asian groups in countries with a strong bamboo culture. Several areas of work in the tissue culture of bamboos are opening up and much progress can be expected in the future.

Acknowledgement

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Potential Application of Tissue Culture for Propagation of *Dendrocalamus strictus**

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Abstract

The propagation of most bamboo species is done through seeds, the availability of which is unreliable. Vegetative methods are also followed in some cases. Tissue culture could complement these vegetative procedures. This paper describes the conditions developed for- the rapid multiplication of Dendrocalamus strictus through organogenesis or embryogenesis using explants from seedlings and mature clumps. The results of the preliminary pilot scale field studies conducted on these plants are also presented.

Introduction

Bamboos have a very wide spectrum of applications in daily life (Varmah & Pant, 1981), but its most important use is in the paper and pulp industry. It constitutes nearly 70 percent of the raw material for this industry. The production of paper and pulp has risen from 0.13 million tonnes in 195 1 (17 mills) to 2.65 million tonnes in 1986 (271 mills). On the other hand, the capacity utilization of the paper and pulp mills has gone down from 90 to 58 percent in 1986 (Gupta & Shah, 1987), due to a steep fall in bamboo supply caused by deforestation, over-exploitation, cattle grazing and illicit trading.

Bamboos are mainly propagated by seeds. But seed propagation is unreliable due to the long and unpredictable flowering habit of the bamboos (from 25 to 60 yrs). Besides, the seeds have no dormancy period and are viable only for a short period (Anonymous 1948). Bamboo is also propagated vegetatively by culm cuttings and rhizomes. Each bamboo clump on an average, gives about 10 culms a year. Considering 30 years as the life span of a clump, one would get not more than 300 culms on the whole (Anonymous 1948).

An alternative method is that of micropropagation in vitro. This involves culturing of explants *in vitro* on defined media under sterile and controlled conditions and has been extensively utilized for the propagation of a large number of plants including forest trees (Bozzini, 1980). Being a clonal method, it reduces or eliminates the variations inherent in seed-raised plants and has the potential for large-scale propagation of 'candidate' or 'plus' or elite trees. In bamboos, 'plus' trees are selected on the basis of height, internodal length, sparse branching, number of culms per clump, interculm spacing and resistance to disease and pests. Some reports on tissue culture studies with different bamboo species are given in Table 1.

Dendl-ocalamus strictus is commercially in great demand as it is mostly a solid bamboo. The present paper describes studies carried out at the National ChemicaI Laboratory, Pune on micropropagation of *D. strictus* using explants from in vitro grown seedlings and embryogenic callus. The importance of tissue culture in the case of bamboo has been discussed based on preliminary pilot scale field studies.

Materials and Methods

Seeds of *D. strictus* collected from forests of Uttar Pradesh, Andhra Pradesh and Kamataka were used. For mature tissues, lateral branches were collected from identified elite trees growing in the forests of Andhra Pradesh and Karnataka. All

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Table 1. Reports on bamboo tissue culture

Species	Type of work	Media	Reference
Dendrocalamus strictus	Organogenic culture and plantlet regeneration	MS, KN, BAP, CM, IBA	Nadgir *et al.* (1984)
D. strictus	Embryo culture	White's medium	Alexander & Rao, (1968)
D. strictus	Somatic embryogenesis and plantlet regeneration	B_5, 2,4-D.IBA, NAA	Rao *et al.* (1985)
D. strictus	Callus differentiation	MS, 2.4-D, CM	Dekkers & Rao (1989)
Bamhusa arundinacea	Somatic embryogenesis	N_6, 2,4-D, BAP	Mehta et *al.* (1982)
B. beecheyana	Somatic embryogenesis and plantlet regeneration	MS, 2,4-D. KN	Yeh & Chang. (1986a)
B. ven tricosa	Organogenic callus	Basal, 2,4-D, BAP	Dekkers & Rao (1989)
B. oldhamii	Somatic embryogenesis	MS, KN, 2,4-D	Yeh & Chang (1986 b)
B. multiples X B. oldhamii	Protoplasts	MS salts, White's vitamins, malt extract & digestive enzymes	Huang (1988)
Bamhusa, Phyllostachys and *Sasa*	Callus cultures	No details	Huang & Murashige (1983)
Phyllostachys viridis	Somatic embryogenesis	MS (macro}, Nitsch (micro), 2.4-D	Anas et al. (1987)
Sinocalamus Iatifora	Somatic embryogenesis	MS, KN, 2,4-D	Yeh & Chang (1987)
Schizostachyum brachycladum	Organogenic callus	Basal, 2,4-D, NAA, CM	Dekkers & Rao (1989)
Not specified	Organogenic cultures	No details	Prutpongse & Gavinlertvatena (1989)
Not specified	Propagation of bamboo	No details	Gupta & Rawat (1988)

chemicals used were of analytical grade (British Drug House, E. Merck, Sigma and Difco) and glassware was of Borosil make.

Culture Conditions

All seedling and mature tree cultures were incubated at 25 ± 2 C with a 16/8 h photoperiod with a light illumination of 4.41 w/set^2 from cool-white fluorescent tubes.

Media Used

.MS Murashige and Skoog's basal medium (Murashige & Skoog, 1962)

MS-l - MS + 6-benzylaminopurine (BAP) (0.2%) + coconut milk (CM) (5%) + sucrose (2%)

MS-2 - MS/2 + sucrose (2%)

MS-3 - MS (only minerals) + thiamine-HCl (40) + inositol (1000) + 2,4-dichlorophenoxyacetic acid (2,4-D) (3.5)

MS-4 - MS + kinetin (KN) (0.5) + BAP (1.0) + CM (5%) + sucrose (2%) + agar (0.8 %)

MS-5 - MS+BAP(l.0)+KN(0.5)+CM (5%) + casein hydrolysate (CH) (200) + sucrose (2%)

Concentrations given in parentheses are in mg/l unless stated otherwise.

Seedlings

Organogenesis

After dehusking, the seeds were treated with 10 percent Savlon solution for five min followed by washing under running tap water to remove traces of this antiseptic detergent. Surface sterilization was carried out as described earlier (Mascarenhas *et* al., 1981) and the seeds inoculated on White's basal medium (White, 1963) with 2 percent sucrose and kept for germination in dark. After a week, the germinated seedlings were transferred to light for healthy development. When the seedlings had attained a height of about 40-50 mm (in 15-20 days). they were transferred to MS-1 liquid medium and agitated on a rotary shaker at 120 rpm for multiple shoot induction. Ten to 15 shoots developed in 30-40 days.

Subcultures were performed at intervals of 20 days by separation of the shoots, in groups of three to five and transferred to fresh MS-l liquid medium.

Rooting

For studies on in vitro rooting, shoots were excised and the cut ends dipped in liquid MS-2 medium containing auxins such as indole-3-acetic acid (IAA), indole-3-butyric acid (IBA), indole-3-propionic acid (IPA) and =-naphthaleneacetic acid (NAA) at different concentrations (0.05 - 5.0 ppm). Treatment with auxins was given for varying periods of time in dark. They were then shifted to the auxin-free MS-2 liquid medium for initiation of rhizogenesis and later incubated in light for l0-15 days for complete plantlet development. On attaining a height of about 50-60 mm, plantlets were transferred to polybags containing a mixture of sterile soil:sand:vermiculite (1: 1: 1). The plants were hardened in plastic trays enclosed with polythene sheet to maintain a humidity of about 90 percent. The humidity was maintained by removal of a portion of the polythene sheet and spraying water at regular intervals. After 30-40 days when new shoots emerged, they were transferred to the green house and then to the field.

Somatic Embryogenesis

Seeds of *D. strictus* were surface-sterilized by the method described earlier. Embryos from sterilized seeds were dissected out and cultured on MS-3 medium containing auxin. The callus obtained from embryos was transferred to MS-3 medium from which auxin had been omitted in order to induce somatic embryogenesis. The embryogenic callus was confirmed by staining with acetocarmine and Evan's Blue according to the procedure described by Gupta and Durzan (1987).

Mature Trees

Nodal segments, l0-15 mm in length, were collected from the secondary and tertiary branches. The surface sterilization method followed for seeds was not applicable for nodal segments, since it could not control the fungal and bacterial contamination. A two-stage sterilization process was developed which was effective in partly reducing the extent of infection. Segments were first treated with streptopenicillin and Benlate (100 ppm each) for 1h with agitation on a rotary shaker, followed by $HgCl_2$ as described for culture of seeds.

Segments with the nodal bud included were then inoculated on MS-4 semi-solid medium. The buds sprouted within 20-25 days and were then transferred to a liquid medium (MS-5) for further elongation and multiplication. Experiments on subculture and rooting of sprouted shoots are in progress.

Results

Seedling Culture

Seeds collected from the different agencies were used for obtaining in vitro seedlings by the procedure developed earlier. When these had attained a height of about 40-50 mm. they were transferred to solid and liquid (MS) media,both supplemented with different concentration and combinations of KN, BAP and CM. The maximum number of shoots (10-15) were obtained in MS-1 liquid medium when the cultures were agitated on a rotary shaker at 120 rpm under continuous illumination (Fig. 1). On agar media, growth was poor. Shoots growing on MS-l liquid medium were excised and subcultured to fresh media of the same composition. The capacity for shoot multiplication showed a variation among seeds. If transferred singly, the shoots failed to survive on subculture. Further growth and multiplication could be achieved at each passage only if the shoots were subcultured in groups of three to four each. By this procedure upto eight sub-cultures have already been done. A phenomenon we are unable to explain is the ability of some shoot cultures to survive repeated subcultures.

A small number of shoots grown in MS- 1 liquid medium in shake flasks also developed roots. These could be directly excised and transferred to

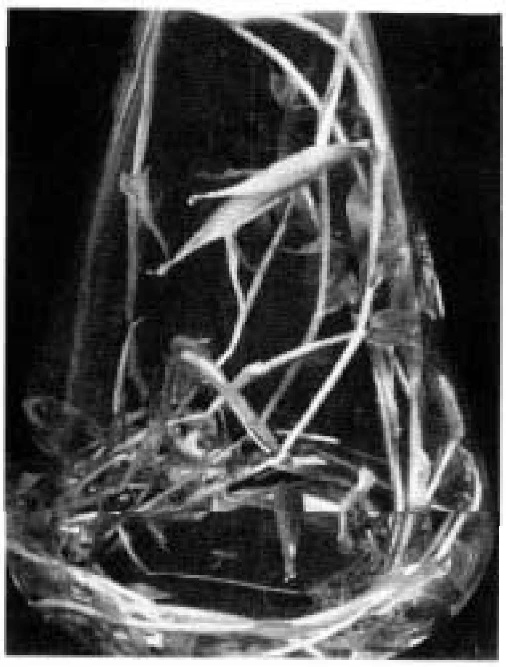

Fig. 1. Multiple shoots from a seedling.

polybags. Shoots which did not show rhizogenesis were excised and dipped in MS-2 liquid medium containing different auxins like IAA, IBA, IPA or NAA. Contact of the shoots with MS-2 liquid medium containing IBM (0.1 ppm) resulted in 80 percent rooting within two weeks (Fig.2); 80 percent of which kept 48 h in dark followed by transfer to auxin-free MS-2 liquid medium survived in the soil mixture (Fig. 3). Tissue culture-raised plants appeared similar to normal seedlings and showed no visible abnormalities. Several plantlets are now undergoing field trials.

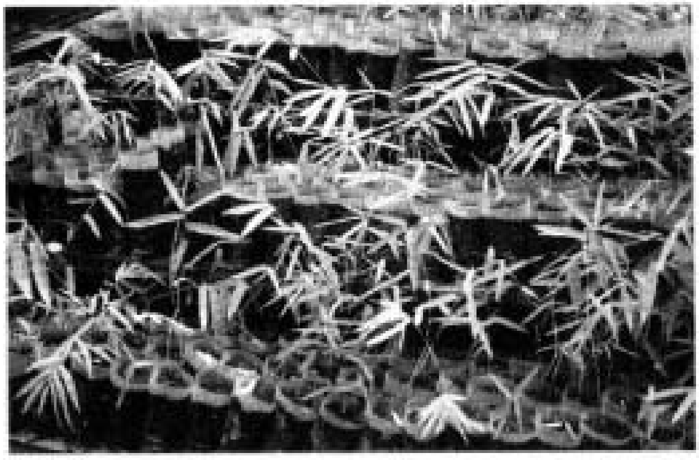

Fig. 3. Tissue culture plantlets in polybags.

Embryogenic Cultures

Sixty to 70 percent of the calli obtained from embryos on the auxin-containing MS-3 medium exhibited selective staining for embryogenic cells. On transfer of this callus to the auxin-free MS-3 medium, somatic embryos differentiated within two weeks (Fig. 4) and developed into plantlets after a further period of four weeks if left undisturbed on the same medium. Fifty percent of these plantlets survived after transfer to the soil mixture and are now undergoing field trials (Fig. 5).

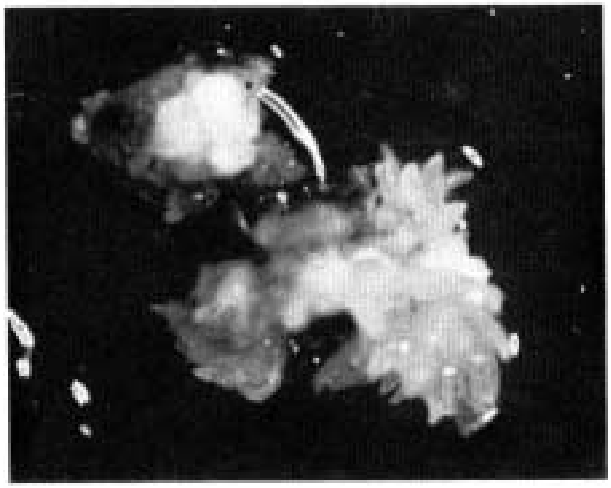

Fig. 4. Emblyogenic callus.

Fig. 2. Rootedplantlet.

Mature Tree Culture

Plant material from mature clumps was collected from 'elites' of *D. strictus* growing in the forests. Normal sterilization methods were unsuitable for controlling bacterial and fungal con-

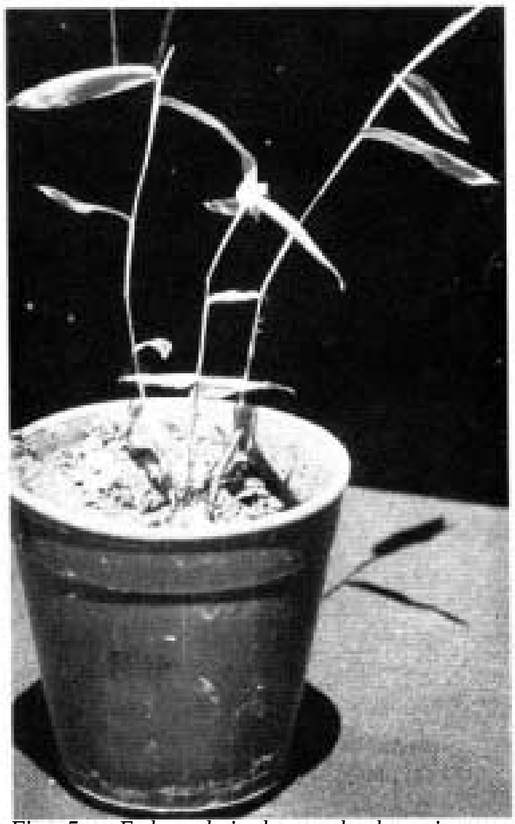

Fig. 5. Embryo-derived plantlet in pot.

tamination which obstructed further sprouting. Several anti-bacterials like streptopenicillin, rifamycin, tetracycline and chloromycetin were tried at different concentrations (50-500 ppm) and for different durations (30- 120 min) in combination with the anti-fungal agent, Benlate (50-500 ppm). A combination of streptopenicillin and Benlate (100 ppm each) for 60 min followed by $HgCl_2$ (0.1%) gave about 50 percent sterile cultures. In preliminary experiments, explants from mature clumps of *D. strictus* were inoculated on the same media used for seedling explants. These conditions were, however, ineffective. Different concentrations and combinations of growth regulators were, therefore, tested using MS medium. On an agar medium, MS-4 containing KN, BAP and CM, 80 percent of the nodal buds sprouted in three to four weeks (Fig. 6). This medium was good only for initial sprouting. Subcultures on this medium resulted in the browning and death of the sprouted shoots which could be overcome by transfer of the sprouted buds to MS-5 medium which was additionally supplemented with CH. Experiments are in progress to standardize optimal conditions for subculture, multiplication and rooting.

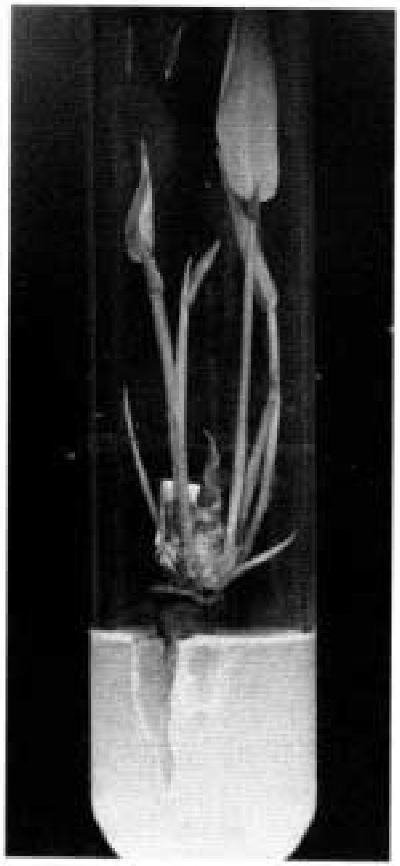

Fig. 6. Sprouted bud from nodal segment.

Field Evaluation

A preliminary pilot-scale field-trial was conducted in July 1983 with seven tissue culture and seven seed-raised plantlets, respectively. This was not a statistically designed trial but has yielded some interesting information,

The plants were transplanted from polybags to earthenware pots (17 x 20 cm) containing soil and sand (3:l) and grown in a glasshouse for nine months before planting in the field at a spacing of 1 m alternately with seedlings of the same age and height to serve as controls. All plants received the same irrigation and fertilizer doses.

The most striking difference observed between propagules and seedlings was in culm development. Culms formed on all propagules within 16 months of transplanting to the field, whereas this response was observed in only one of the seedlings during this period. Further increase in the number and diameter of culms and in the length of internodes was also found to be higher in propagules than seedlings. Comparative growth data for tissue culture propagules and seedlings after 16 and 62 months is given in Table 2.

The observations recorded over 62 months indicate that bamboo propagules, though derived from seedling explants, exhibit early culm formation and the annual increase in number of culms is higher than that in seedlings. These results are being confirmed at different locations with statistically laid out replicated field trials at 5 m spacing.

Cost Evaluation of Plants Raised by Tissue Culture

An important factor that influences the usefulness of a nursery process particularly for forest trees is the cost of the plants (Donnan, 1986). These can be considered secondary if the benefits compensate for the high initial costs. In order to determine the applicability of tissue culture for bamboo propagation, a cost evaluation of tissue culture plantlets was carried out by a procedure described earlier for *Eucalyptus* (Mascarenhas et *al.*, 1988). These costs were calculated for a production of 100 000 plants and included the operational expenses involving labour, power, chemicals, glassware, etc. The costs cover all operations from culture of primary explants to their planting in the nursery and does not include transportation costs from the nursery to the respective sites. All calculations are based on 80 percent survival of tissue culture plantlets when transferred to soil. These costs were determined by production of plants using a three stage process and through somatic embryogenesis. In the normal three stage process, the unit cost is Rs. 2.41. Attempts are in progress to reduce the three stage to a two stage process. Plantlets obtained through somatic

Table 2. Comparative field data of D. *strictus* plants

	No. of culm		Height of main culm (m)		No. of internodes in main culm		Girth of second internode from base (cm)		Average length of first 10 internodes from base (cm)	
	16M	62 M	16M	62 M	16M	62 M	16M	62 M	16M	62 M
Tissue culture plantlet	4.0 ± 0.597	12.0 ± 1.542	3.15 ± 0.308	9.7 ± 0.850	24.0 ± 0.616	45.0 ± 1.490	6.6 ± 0.784	16.1 ± 0.848	16.0 ± 0.846	20.7 f0.870
Seedling	1	5.0 ± 1.732	1.95	4.2 ± 0.456	19.0	28.0 ± 2.92 1	4.0	8.2 ± 1.038	11.0	15.6 ± 0.558

Results are the average data taken after 16 and 62 months of control and tissue culture raised plants.
± standard error was not relevant since culm formation occurred in only one control seedling within I6 months;
M, months.

embryogenesis cost Rs 0.50 per plant with a survival rate of 50 percent.

Discussion

Reports on the growth in culture of different bamboo species are now gradually increasing although success with *Dendmcalamus strictus* is still limited .

Our procedure via organogenesis differs from the other reports on D. strictus in that the cultures are isolated from seedlings without any callus phase. This could eliminate or reduce variability that often occurs in callus-derived plants and could be of major advantage for clonal propagation.

Although there are reports on somatic embryogenesis from the different bamboo species, success with ***D. strictus*** has been restricted to two main groups (Mehta et *al.*, 1982; Rao *et al.*, 1985; Dekkers & Rao, 1987). In the former report, induction of callus and embryoids was achieved on B_5 (Gamborg *et al.*, 1968) basal medium in the presence of 2,4-D. NAA and IBA added to the full-strength medium promoted embryoid germination and healthy plants developed by transfer to a half-strength mineral liquid medium containing the above auxins. Dekkers and Rao (1987) used a sequential method for plantlet development from callus. MS basal medium supplemented with 2,4-D resulted in callus induction. Transfer of this callus to a medium containing CM and later to a plain basal medium resulted in embryoid and plantlet development, respectively.

The present report for complete plantlet development via embryogenesis is simple and involves only two steps. The first step is on a medium containing the basal salts and 2,4-D for callus formation and the second on an auxin-free medium for further growth and development of the somatic embryos to plants.

The operational costs for producing tissue culture plants of bamboo from seedlings through our procedure was found to be about three times higher than the cost of *Eucalyptus* plantlets produced in our laboratory (Mascarenhas *et al.*, 1988). This increased rate is mainly due to the fact that the cultures are produced in shake flasks, involving a higher power and labour pool and an in *vitro* rooting step.

Plants raised through tissue culture, however, develop a substantial number of tillers within two to three months after transfer to soil. Similar rhizomes develop on seedlings after five to six months. These can be individually separated and transferred to the field within six to eight months. This routine could cut down considerably the initially higher cost of the tissue culture produced plant.

Conclusion

Based on the observations of our preliminary field trials we foresee several advantages in the utilization of tissue culture for D. *strictus.*

1. Year-round multiplication of plants by organogenesis even from seedlings. This would ensure a steady supply of seedlings unaffected by the unpredictable flowering behaviour. Seed-raised progeny show wide variations. This could be prevented by developing a suitable method from explants of elite clumps. The studies using somatic embryos still require confirmation regarding the clonal homogenenity of the plants since these are derived through an intermediate callus phase.
2. Early culm formation with a steady annual

increase in number and size of culms in tissue culture raised plants. This observation which requires confirmation could cut down the rotation cycle in bamboo where the culms are harvested two years after formation by the paper and pulp industry. It will be interesting to observe the influence of gregarious flowering in natural stands on the flowering behaviour of the tissue culture-raised plants at different ages.

3. Tissue culture would also enable wide hybridizations to be carried out using protoplasts (Huang, 1988). This would result in a planned breeding strategy so that useful traits can be combined. In *vitro* flowering could also similarly increase the importance of tissue culture in bamboo breeding which is complex and difficult due to the unpredictable and long flowering cycles in the different bamboo species.

We are presently conducting studies to develop a process using mature elite clumps whose rooting stage is being perfected. Success in this process and the growth performance in field would confirm whether plants raised by tissue culture from elites retain their parental characteristics.

Acknowledgements

The authors are thankful to the National Bank for Agriculture and Rural Development for financial assistance to carry out the work. Thanks are also due to the following agencies for assistance in collecting the material and supply of seeds : Andhra Pradesh Forest Development Corporation, Bhadrachalam Paper Boards Ltd, Harihar Polyfibers, Karnataka Forest Development Corporation and Uttar Pradesh and Maharashtra Forest Departments. We would also like to thank Mr Javed Khan, Mrs Achala Belsare, Miss P.K. Salma, Miss Nazifa Nagarwala for their technical assistance and Miss Shobha Nimhan for typing the manuscript.

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Mass-propagation of Bamboos from Somatic Embryos and their Successful Transfer to the Forest

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Abstract

Large numbers of somatic embryos of the bamboo Dendrocalamus strictus and Bambusa arundinacea were obtained by culturing mature embryos and explants from aseptically grown seedlings on B_5 (Gamborg's medium) + 2,4-dichlorophenoxyacetic. acid (2,4-D; 10 µM, 30 µM, 50 µM and 100 µM). The somatic embryos (embryoids) arise as protuberances on the surface of the embryogenic callus in three to four weeks of culture. Embryoids were subcultured on a multiplication medium (for mass-propagation) while the embryogenic callus was maintained on a 2,4-D supplemented medium. After three weeks the embryoids germinated on a germination medium. Rhizomes were induced and the plantlets transferred to a potting mixture in earthernulare pots (10 cm diameter). Fur the initial 21 days these plants were acclimatized in large indigenously fabricated growth chambers with controlled conditions before being transferred to the greenhouse or to the field. Over 14 000 tissue culture-raisedplants have been produced. Four to 18-month-old plants have been transferred to forests in several States in India for field trials. At all these locations the test tube plants have been growing well and are comparable to or better than the seed-raised bamboo plants.

Introduction

Bamboos are a critical natural resource. One of their major uses in India is as raw material for the production of paper, The mass-scale use of bamboo by the paper mills has led to a situation where replacement and raising of new stands has fallen way behind the rate at which the bamboo clumps are being cut. The peculiar characteristic of bamboos to flower after prolonged periods and then die collectively is another factor which has given added impetus to the already urgent need for its mass-propagation as much of these flowered forests are now bare. In addition, the tremendous grazing pressure and forest fires prevent the young seedlings from surviving.

Tissue culture methods offer a means of large scale production of plants in the shortest span of time. Although development of the tissue culture technology, its field-testing and the refinement of procedures may be a slow and time-consuming process, when once established, mass-production on a factory or industrial scale would become possible. With several groups in many countries applying themselves to the problem, it is only a matter of time before the desired results start showing. The work of Zamora *et al.* (1989) from the Philippines, Nadgir *et al.* (1984) and our own work are pointers in this direction.

To allow a valid comparison of costs, the actual cost of a plant raised from seed by the forest agencies needs to be computed taking into account costs of the general establishment and infrastructure, in addition to other inputs. This is very important since it would indicate to the tissue culturist the level of efficiency needed to be attained. With continuing improvement in the techniques being used, the cost of a tissue culture raised bamboo plant will get progressively reduced.

The plantlets produced in this laboratory are mostly through somatic embryogenesis from juvenile explants. Some plantlets have been produced from nodal explants, obtained from mature bamboos. This paper briefly outlines the progress of work so far in somatic embryogenesis of bamboo, the raising of plantlets, their acclimatization and transfer to the forests.

Materials and Methods

The procedure used for mature embryos of *Dendiocalamus strictus* and *Bambusa arundinacea* as explants was essentially similar to that described earlier (Rao *et al.*, 1985, 1987). Other explants such as the node, leaf sheath, root and rhizome were obtained from aseptically-grown seedlings.

The inductive medium consisted of the B_5 basal medium (Gamborg *et* al., 1968), sucrose (2%) and 0.8 percent agar agar (w/v) supplemented with 2,4-dichlorophenoxyacetic acid (2,4-D) at 10, 30, 50 and 100 μM. The pH of the medium was adjusted to 5.8 prior to autoclaving at 1.05 kg/cm^2 for 15 min.

Squash preparations of the embryogenic callus were made in one percent acetocarmine and photographed in a Zeiss ICM 405 microscope. Cultures with different stages of somatic embryos and plantlets were dissected and photographed in a Zeiss SV8 stereozoom microscope.

Results

Callusing starts soon after germination of the zygotic embryo in seeds inoculated on the inductive medium. The callus increased till day 30 and was nodular in appearance. Its colour was white to cream with both friable and compact (embryogenic) regions. The origin of the embryogenic callus was traced to the vascular bundles (Fig. 1 A,B). Several starch-filled multicellular structures are seen in the callus (Fig. lC,D). Embryogenic callus formed in 60 percent of the cultures (Fig.2A). Somatic embryos arise as protuberances on the surface of the callus. Several small, white to green embryoids with well-developed scutella were observed in the compact callus. An average of 14.6 embryoids at the chlorophyllous stage of the callus were observed after dissection of a 30-day-old culture. In most of the embryoids, the scutellar region proliferated and gave rise to several daughter embryoids, which initially appear as buds.

Embryoids induced on the 2,4-D medium were separated aseptically and subcultured on B_5 basal medium supplemented with or without a low concentration of 2,4-D (Fig. 2B). The embryoids multiply on this medium. Whereas some germination of embryoids is obtained, the cultures are mostly put through a separate germination step.

The somatic embryos are well-formed and have a bipolar structure with a shoot and a root pole. They germinate fairly easily to form plantlets (Fig. 3A). The plantlets are separated and allowed to grow until 8-10 cm tall (Fig. 2C). Once well-developed root systems have been formed, the plantlets are transplanted to soil. One method of ensuring 100 percent survival of the plantlets is to induce precocious rhizome formation. Alternatively rhizome induction can be done after potting.

The plantlets are removed from the agar medium and potted directly into a soil: fine sand: farmyard manure (1:l: 1) potting mix in 10 cm diameter earthenware pots (Fig. 3B). The plantlets which are transferred have an average height of 9.5 cm with two or three leaves. These are then maintained in the growth chamber at 90.80 and 70 percent RH for one week each (total 3 weeks) under 6000 lux from cool-white daylight fluorescent tubes. The temperature of the growth chamber is maintained at 29 $\pm$ 1 C. Plantlet survival ranges between 90 and 95 percent and even reaches 98 percent if adequate care is taken. As already mentioned, if the plantlets are potted after rhizome induction, 100 percent survival can be obtained. After hardening, the plantlets are transferred to greenhouses where these are maintained for two months before repotting into large polybags (Fig. 3C,D). The plantlets are normally field-planted when 8- 12 months old.

Over 14 000 tissue culture raised plantlets have been produced so far. Four to 18-month-old plantlets have been planted in different States for field trials. At all these locations, the test-tube raised bamboo plants have been growing well and are comparable to the seed-raised ones.

Discussion

Somatic embryogenesis and regeneration of plantlets was reported for the first time in the bamboos, *Bambusa aruudirracea* and *Dendrocalamus strictus* by Mehta et al. (1982) and Rao *et al.* (1985). Later Yeh and Chang (1986a.b. 1987) reported somatic embryogenesis and plantlet regeneration in *B. oldhamii, B. beecheyana* and *Sinocalamus latijlora,* and Hasan and Debergh (1987) in *Phyllostachys viridis.*

Tissue culture methods such as somatic embryogenesis and subsequent plantlet regeneration can be useful in raising plantations under circumstances where conventional propagation materials are limiting. If the costs are brought down to comparable levels, it could supplement current replanting efforts. Whereas the present methods are effective, further optimization and simplification of laboratory and acclimatization procedures is necessary.

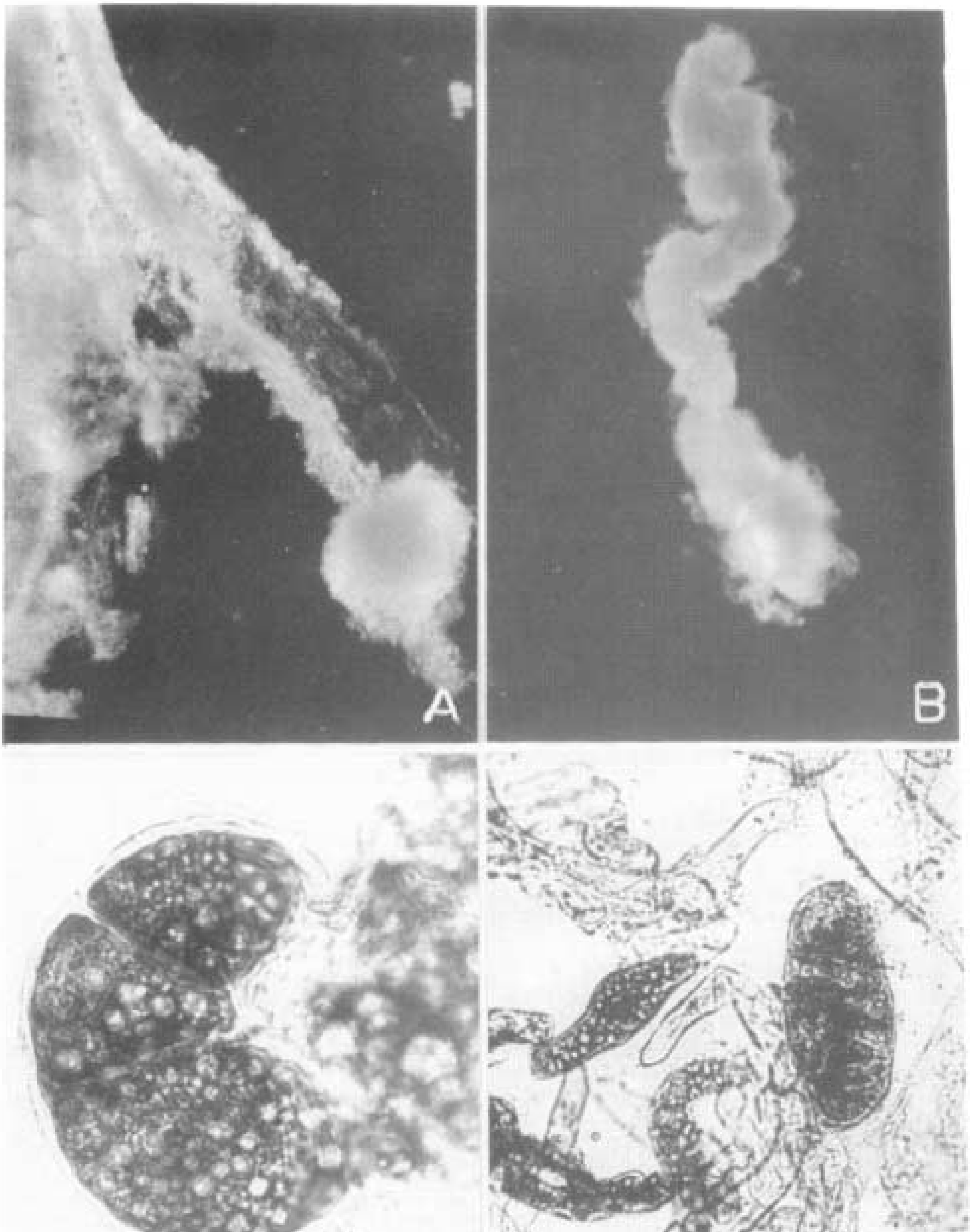

Fig. 1A-D. *A,B. Formation of compact callus along vascular bundle of leaf in D. strictus. C,D. Squash preparation of newly-formed callus showing starch-filled multicelled structures (D. strictus).*

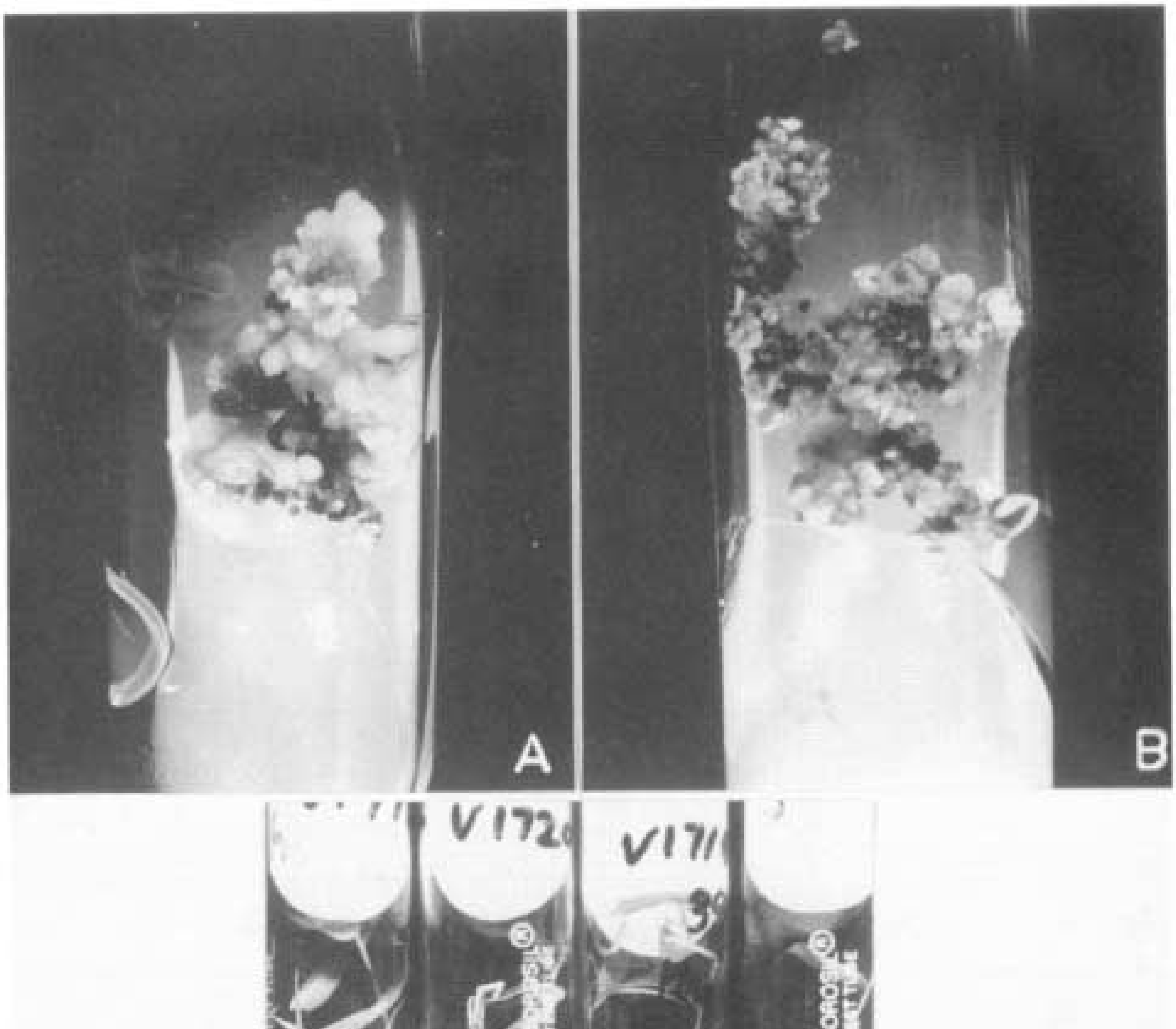

Fig. 2A-C. A. Embryogenic compact callus. B. Callus with differentiating embryoids. C. Mature plantlets ready for transfer. (All photograph of D. strictus).

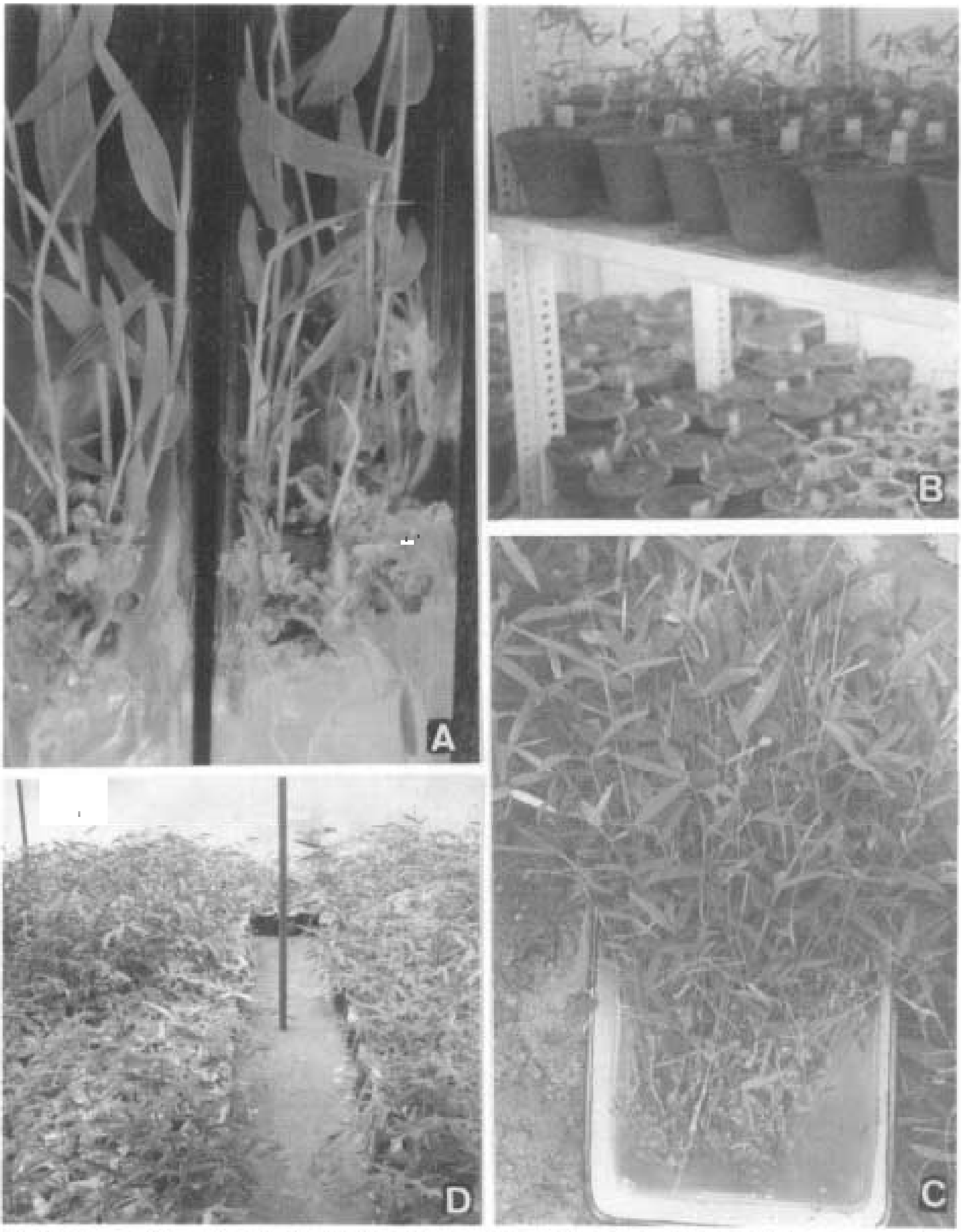

Fig. 3A-D. *A. Plantlets and germinating somatic embryos. B. Newly potted plantlets in the growth chamber. C. Plantlets ready for repotting into polybags. D. Plantlets in greenhouse before transfer to forests. (All photographs of D. strictus).*

The success of a tissue culture-based mass-propagation programme depends in addition to regenerating plantlets, on the development of efficient methods for their transplantation to soil. In bamboo, the present method is relatively simple and does away with pre-transfer preparatory steps such as reduction of salt and sucrose concentrations used in the culture medium and prior exposure to high light intensities. We are currently in the midst of experiments to do away with acclimatization in growth chambers. Direct transfer to the greenhouse is now being effected with an average survival rate of 78 percent. Even at this level, the benefit is that expensive acclimatization chambers can be done away with.

Acknowledgement

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PROCEEDINGS OF
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DISEASES AND PESTS OF BAMBOOS

Diseases of Bamboos in Kerala*

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Abstract

Commercially important bamboos, including reed bamboos, namely, Bambusa arundinacea, Dendrocalamus strictus, Ochlandra travancorica, O. scriptoria and O. ebracteata are found widely distributed throughout the State of Kerala, Recently, large-scale planting of a arundinacea and other bamboos has been taken up as pure stands or as under-plantings among teak plantations. The preliminary findings of the disease survey indicate that bamboos are susceptible to various diseases. A total of 36 fungal organisms werefound to be associated with diseases of leaf, culm and rhizome. As many as 21 pathogens were recorded for the first time in bamboos. In the nurseries, diseases caused by Rhizoctonia solani, Dactylaria sp, Helminthosporium sp. and Alternaria alternata were most prevalent. Basal culm decay cuused by Fusarium spp., culnr rot caused by F. equiseti, F. oxysporum, Fusarium sp., culm sheath rot caused by Glomerel- & cingulata and Pestaloziella sp., foliar infection by Drechslera sp., Exserohilum sp.. Colletotrichum sp. and leaf rust caused by Dasturella sp. were the important diseases encountered in plantations and natural stands. Large-scale mortality of young plants (1 to 2-year-old) due to rhizome bud rot and subsequent die-back of culms have emerged as the most serious disease in plantations warranting detailed investigation. The status of bamboo diseases in the State and the symptomatology and etiology of some of the important diseases are listed in this study.

Introduction

Of about 1250 species of bamboos belonging to 75 genera, nearly 136 species occur in India. In Kerala, bamboos are found distributed right from the sea coast to the high ranges; *Bambusa arundinacea* (Retz.) Willd., *Dendrocalamus strictus* Nees, *Oxytenantheru* sp., *Ochlandra truvancorica* (Bedd.) Benth. *ex* Gamble, 0. *scriptoria* (Dennst.) Fischer and 0. *ebracteata* Raizada & Chatterji, have been found associated with different forest types in the State (Varmah & Bahadur, 1980).

Considering the role played by diseases in decreasing the productivity of bamboos, a systematic survey spread out throughout the State was conducted in a total of 34 representative areas of natural stands and plantations where bamboos are raised either purely or inter-mixed with teak (Fig. 1). Several bamboo nurseries and a few trial plots were also surveyed. Observations on disease incidence and their severity were recorded at periodic intervals. Since the failure of bamboo nurseries was found to be due to poor emergence of seedlings, a seed pathological study was also undertaken. This paper provides the first tentative checklist of diseases along with their incidence and severity on various bamboo species in Kerala and also information on the role of spermoplane microflora of stored seeds of *I?. arundinacea* and *D. strictus.*

Current Status of Diseases in Nurseries

Raising vigorous and disease-free planting stock has a great impact on field-planting programmes. In Kerala, bare-root bamboo seedlings are raised by following the usual forest nursery prescriptions. About 1.5 kg of bamboo seeds are sown in a standard bed (12 x 1.2 x 0.25 m); shade regulation and watering were done as in the case of other forestry crops. After 40 days of growth, the seedlings were transplanted into polythene bags.

During the survey, various diseases occurring in bamboo nurseries were recorded in the different

* KFRI scientific paper no. 187

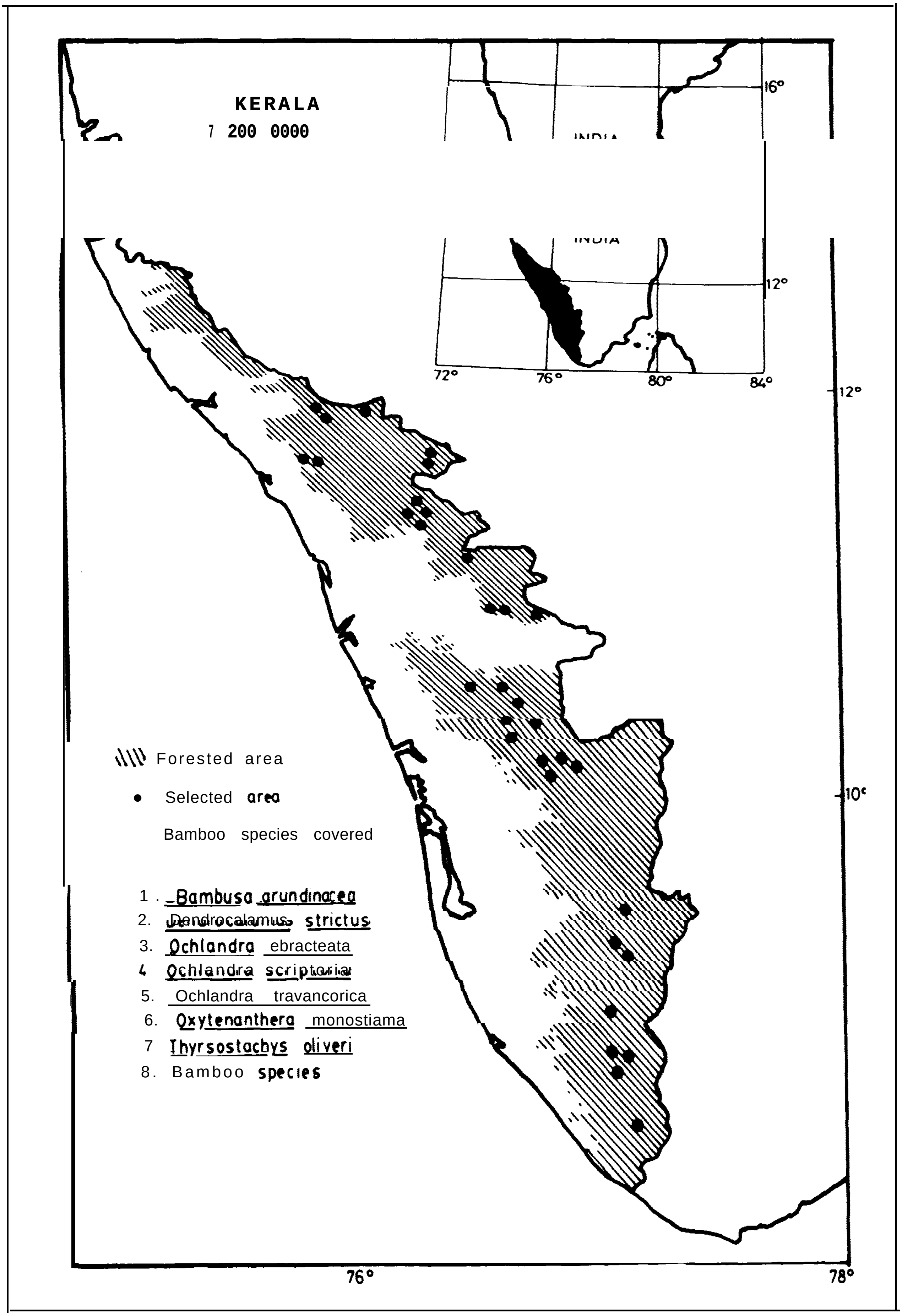

Fig. 1. Bamboo growing areas in Kerala selected for the disease survey.

Table 1. Tentative checkfist of nursery diseases of bamboos

Disease	Pathogen/s	Bamboo species affected
Damping-off	*Rhizoctonia* solani state of *Thanatephorus cucumelis*	BA. DS
	Fusarium sp.	BA, DS
	F. moniliforme	OS
Seedling stem infection	*R. soIani*	BA
Leaf blight	*Alternaria alternata**	BA, DS
	*Alrernaria sp.**	BA
	*Colletotrichum gloeosporioides**	BA, DS
	Coniothylium sp.	BA
	*Curvularia lunata**	BA
	*Dactylaria sp. **	BA, DS, PP
	*Exserohilum rostratum**	BA, PP
	Helmjnthosporium sp.	BA
Seedling rhizome rot	*Graphium* sp."	BA

*, New pathogen record for- bamboos; **BA,** *Bambusa arundinacea;* DS, *Dendrocalamus strictus;* **PP.** ***Phyllostachys pubescens;*** OS, *Ochlarzdra scriptoria*

localities of the State. Most of the diseases were prevalent in almost all the nurseries surveyed, but the severity of disease varied from nursery to nursery depending upon local climatic factors, seedling density, etc. A total of four diseases were recorded with which 12 pathogens were associated, Of these six pathogens are new records for bamboos (Table 1),

Damping-off and Seedling Rot

Poor seedling emergence is generally attributed to the poor quality of seeds. Failure of nurseries due to post-emergence damping-off is not uncommon. Damping-off was recorded in nurseries of B. *ar-undinacea* and *D. strictus. Rhizoctonia soIani* (Kuhn state of *Thanatephor-us* cucumeris (Frank) Donk), and *Fusarium* spp. were found to be associated with the disease. Seedling rot and stem rot were also observed in *B. arundinacea* nurseries; R. *solani'* was found to be associated with these diseases (Fig. 2A). Seedling infection and subsequent rot caused by *Fusal-ium moniliforme* Sheldon was also recorded in *O. scriptoria.*

Foliage Diseases

Leaf infection occurs either in patches or is scattered in the seed beds. The incidence and severity of the diseases depend on various factors. Foliage infection caused by R. *solani* occurred usually in patches, especially in heavily watered seed beds. The infection originated on the lower leaves and later spread to the stem and upper leaves resulting in heavy defoliation and seedling mortality. The other foliar pathogens associated with seedling diseases of *B. ar-undinacea* and *D. strictus* were *Helmin thospor-ium* sp., *Exserohilum rostraturn* (Drechsler) Leonard, *Alternaria alternata* (Fr.) Keissler, *Curvularia lurrata* (Walker) Boedijn, *Dactylaria* sp., *Coniothyrium, Colletotrichum gloeosporioides* (Penz.) Sacc., etc. The infection by these fungal organisms was found scattered in the beds. A severe foliar infection caused by *E. rostratum* leading to seedling blight was observed in *Phyllostachys puhescens.* The infection which appeared in the bare-root nursery seedlings often persisted in the transplanted polypotted seedlings. The apparently minor foliage infection of the bare-root seedlings resulted in severe leaf blotch and subsequent defoliation and death on transplantation.

Current Status of Diseases in Plantations

The planting of bamboos (B. *arrundinacea* and *D.* strictus) in old teak and soft wood plantations has been recently taken up in the State. One-year-old bare-root or container-grown seedlings are utilized for planting. This is usually done in pits made at a spacing of 10 x 10 m after the onset of the South-west monsoon (May/June). Top pruning of the shoots, about 30-40 cm from the seedling base is often done before planting.

Large-scale mortality was observed in the young (1 to 2- year-old) plantations throughout the State. Poor establishment of young plantations could possibly be due to various factors, which include cattle browsing, damage caused by rats,

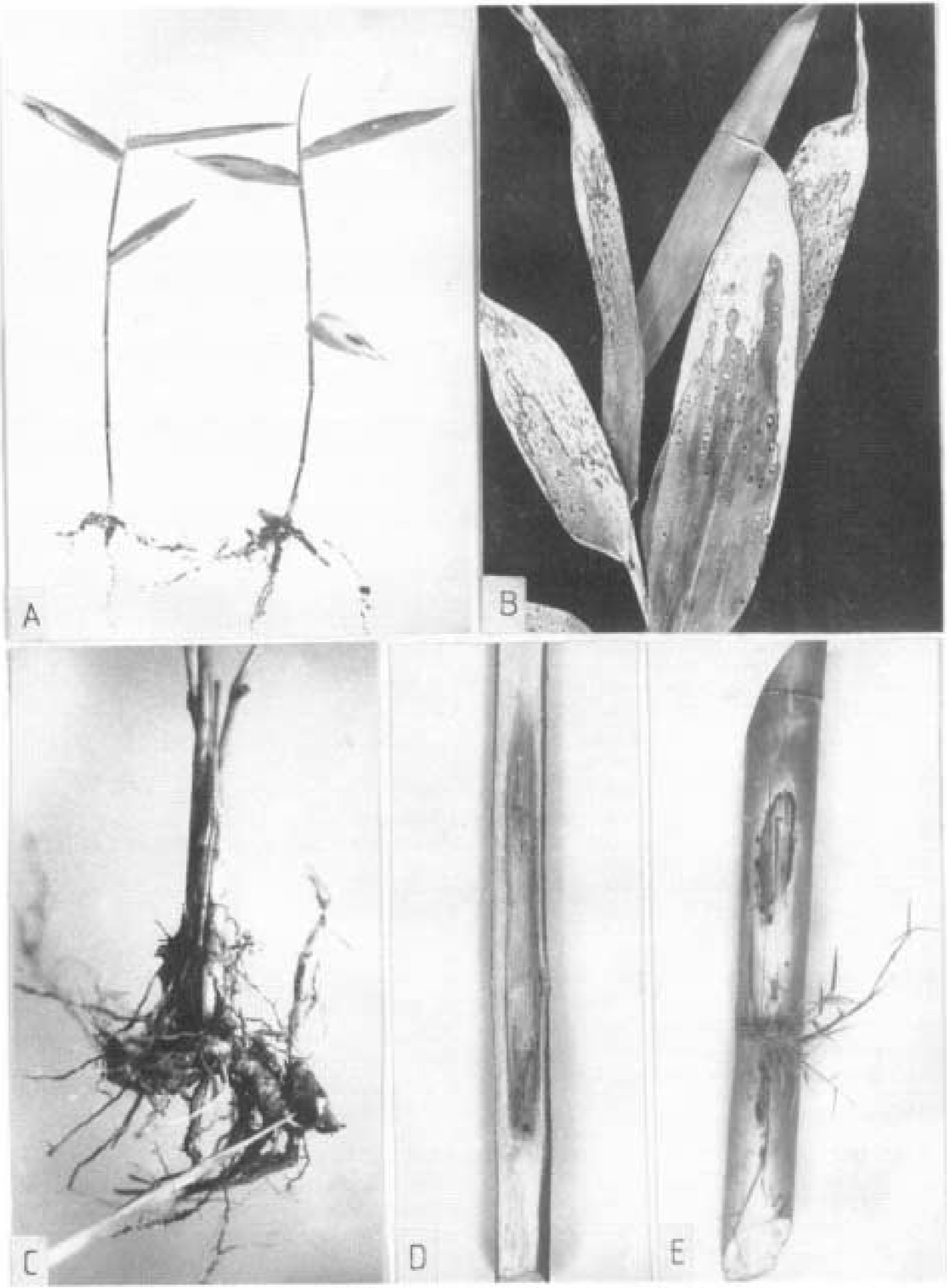

Fig.2. A-E. Seedling stem and leaf infection of B. arundinacea caused by Rhizoctonia solani. B. Leaf infection of D. longispathus caused by Helminthosporium sp. C. Rhizome bud rot of 1.5-year-old B. arundinacea plant caused by Pythium sp. and Fusarium sp. D. Stem infection of B. arundinacea caused by F. pallidoroseum. E. Stem infection of T. oliveri caused by Curvularia sp.

Table 2. Tentative checklist of plantation diseases of bamboos

Disease	Pathogen(s)	Bamboo species affected
Rhizome bud rot	*Pythium* sp.*, *Fusarium* sp.	BA
Rhizome decay	*Pseudomonas* sp.”	BA
Basal culm decay	*F. moniliforme*	BA, BV
Culm rot	*f. equiseti**	BA, BV, DL
	*F. oxysporum**	TO
	Fusarium sp.	BA, DL, DS
Culm sheath rot	*Glomerella cingulata**	BA, BV, DS
	Pestaloziella sp.	BA
Stem infection	*F. pallidoroseum**	BA
	Colletotrichum gloeosporioides	BA
	Curvularia sp.*	TO
Leaf rust	*Uasturella divina*	BA, BV, BVE, DS
	Puccinia sp.	BA, DL, DB, P, TO
Leaf spot	*Alternuria alternata**	BA
	Ascomycetes (unidentified)	BA, DS, P
	Chaetospermum sp.*	BA
	Colletotrichum crassipes”	BA
	*Curvularia sp.**	BA, P
	Dactylaria sp.*	BA, BV, DL, DS
	Drechslera sp.*	BA, B
	Exserohilum sp.*	BA
	*Glomerella cingulata**	BA, DS, DL, BV
	Helminthosporium sp,	BA, DS, TO
	Petrakomyces sp.*	BA
	*Septogloeum sp**	BA
	Stagnospora sp.*	BA, P
Sooty mould	*Spiropes scopiformis**,	BA
	Meliola sp.	BA

, New pathogen record for bamboos; BA, Bambusa arundinacea; BVE, B. ventricosa; BV, B. vulgaris; **DB, Dendrocalamus brandisii; DS, D. strictus; DL, D. longispathus; P, Phyllostachys sp.; TO, Thyrsostachys oliveri; B , Bambusa sp.*

pigs and porcupines which gnaw through rhizomes and bases of young culms. A total of nine diseases were recorded in the plantations with which 25 pathogens were found to be associated. Of these 20 are new records for the bamboos (Table 2).

Rhizome Bud Rot

Infection of both scaly and flat culm buds in the rhizomes of one to two-year-old *B. arundinacea* plants was observed in certain localities. Since the rhizomes were very hard and woody, the infection usually occurred in the tender rhizome buds which resulted in rotting and failure of culm production in the growing season; this also hindered the proliferation of the rhizome resulting in stunted growth of the shoots (Fig. 2C). *Pythium* sp. and *Fusarium* sp. were found to be associated with the rhizome bud rot.

Rhizome Decay

A disease causing discolouration and decay of the entire rhizome was observed in one-year-old plantations, especially in water-logged areas. A bacterium, *Psudomonas* sp., was found associated with this disease.

Basal Culm Decay

In growing culms, the ‘komali’ stage is considered highly susceptible to fungal infection (Kondas, 1982). It was often observed that the culm that had just emerged from the soil was more prone to infection. Infection appears as a violet or dirty brown discolouration on the culm sheath at the soil level. Tissues inside the culm sheath also show pronounced discolouration and the rotting is accompanied by a strong pungent smell. The diseased culm does not grow further and becomes entirely decayed in the course of time. F. *moniliforme* Sheldon was isolated from the diseased and discoloured tissues; in many cases no fungal organism could be isolated from the discoloured tissues.

Culm Rot

Rot in emerging culms was observed in many bamboo species. *Dendrocalamus strictus, B. arundinacea, B. vulgaris* Schr. and *D. longispathus* (Kurz.) Benth. were the severely affected species. The infection occurred at any spot in the emerging culm and was usually predisposed by wounds made by the sap-sucking insect *(Purohitha* sp.). The infection manifested itself in the form of small spindle-shaped brown lesions on the culm sheath, which later coalesced to form large necrotic areas. The infection also spreads both upward and downward inside the culm sheath causing browning and decay of the culm, resulting in various deformities (Fig. 3A-D). Two species of *Fusarium,* namely, *F. equiseti* sp. (Corda) Sacc. and *Furaisum* sp. were found associated with culm rot. In *Thyrsostachys oliveri* Gamble, culm rot initiated at the base of the culm and spread upwards resulting in the die-back of the entire culm. *F. oxysporum* Schl. was found linked with the disease.

Culm Sheath Rot

Infection of young culm sheaths caused by *Glomerella cingulata* and *Pestaoziella* sp. was recorded in *B. arundinacea, B. vulgaris* and *D. strictus. The* infection was often predisposed by injury caused by insects.

Stem Infection

Stem infections in the form of longitudinal necrotic streaks extending 1-2 m in length on mature culms with dark greyish-brown lesions on young green branches were commonly observed in young plantations of *B. arundinacea. Fusarium pallidoroseum* (Cooke) Sacc. was isolated from the infected tissues (Fig. 2D). Stem infection was also noticed in young fully grown culms of *T. oliveri.* The infection initiated as small dark brown or black lesions at the nodal region and spread rapidly both in the downward and upward directions, resulting in rotting (Fig. 2E). Such weakened culms were normally snapped by wind. *Curvularia* sp. was isolated from the infected tissues. In young plantations of *B. arundinacea,* the cut ends of pruned shoots were found infected with *Colletotrichum gloeosporioides*. The infection spreads towards the base, causing the die-back of the shoots.

Foliage Infection

Foliage infections were observed in all the bamboo plantations surveyed. Several fungal organisms were found associated with the foliar diseases. Leaf rust caused by *Dasturella divina* and *Puccinia* sp. was observed in most of the bamboo species surveyed. The foliage infections varied from small insignificant lesions to large necrotic areas which spread to the entire leaf lamina, thus causing leaf blotch and subsequent defoliation (Fig.2B). *Glomerella cingulata* (Stonem.) Spauld & Schrenk, *Exserohilum* sp., *Helminthosporium* sp., *Alternaria alternata* (Fr.) Keissler, *Curvularia* sp., *Dactylaria* sp., etc. were the important pathogens linked with the foliage infections of bamboos.

Current Status of Diseases in Natural Stands

The occurrence and distribution of various species of bamboos in the State vary greatly depending upon the locality and various other ecological factors. For example, *B. arundinacea* prefers rich moist soil and grows in moist deciduous and semi-evergreen forests, moist valleys and house compounds whereas *D. strictus* is found distributed in deciduous forests and dry localities. *Oxytenanthera* sp. occurs in semi-evergreen and evergreen forests. Out of nine species of reed bamboos, the commercially important species *Ochlandra travancorica* and 0. *scriptoria* are found in the semi-evergreen and evergreen forests of the State while *0. ehracteata* is confined to the semi-evergreen forests in Kottoor reserve (Trivandrum Forest Division).

Almost all the diseases recorded in the plantations were also observed in natural stands. In addition, diseases such as witch's broom and little leaf disease were also observed. A total of seven diseases were recorded in natural stands with which 22 pathogens were associated. Of these 12 are new records for bamboos (Table 3).

Basal culm decay was more prevalent in the natural stands *of B. arundinacea* as compared to that in the plantations. The disease was also recorded in natural stands of *Oxytenanthera* sp. *Fusarium* spp. were found to be associated with this disease. A high mortality of 17.1 to 2 1.6 percent due to basal culm decay was observed in natural stands at Noolpuzha (Wynad) whereas a comparatively low mortality (5.4 to 8.0%) was recorded at Muthanga (Wynad) in a two year observation period (Table 4).

Witch's Broom

This disease, observed in *Ochlamdra tralancorica, 0. scriptoria* and *0. ebracteata,* was

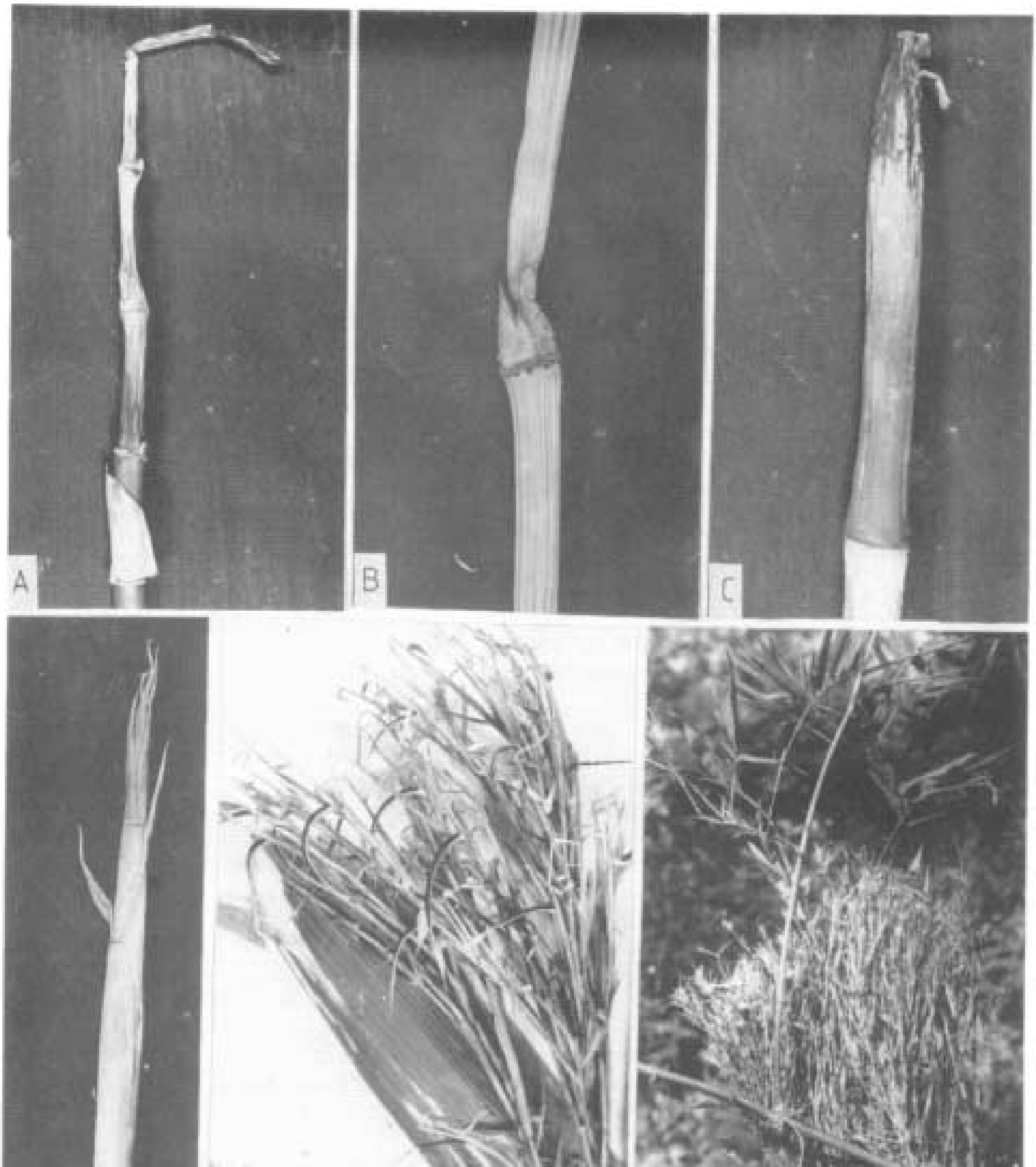

Fig. 3 A-E. A-D. Various stages of culm rot in B. arundinacea caused by Fusarium equiseti and Fusarium sp. E. Witch's broom disease of Ochlandra travancorica caused by Balansia linearis. F. Little leaf disease of D. strictus caused by MLO.

Table 3. Tentative checklist of diseases of bamboos in natural stands

Disease	Pathogen (s)	Bamboo species affected
Basal culm decay	*Fusarium* spp.	BA, OM
Juvenile culm rot	*Fusarium* sp., *Periconia* sp.	BA
Leaf rust	*Dasturella divina*	BA, DS. OM
	Puccinia sp.	DS
Leaf spot	*Alternaria* sp.*	BA, DS, A
	Ascomycetes @identified)	BA
	Curvulai-ia sp.*	DS, A
	Dactylaria sp. *	BA, DS, OE, OS,OT
	Drechslera sp.	BA
	Exserohilum sp,	OS
	F. pallidoroseum	BA, DS
	*Glomerella cingulata**	BA, OE, OS, OT
	Hehninthospo;ium sp.	BA, OM
	Phomopsis sp	BA
	Phyl1achora sp.	BA, DS
	Pythompces sp.	OS, OT
	Stagnospora sp.*	BA
Sooty mould	*Spiropes scopifoimis**, *Meliola* sp.	BA, OE, OS, OT
Witch's broom	*Balansia linearis**	OS, OT
Little leaf	Mycoplasma-like organism	DS

**, New pathogen record for bamboo; BA, Bambusa arundinacea; DS, Dendrocalamus strictus; OE, Ochlandra ebr-acteata; OD, Ochlandra scriptoria; OT, Ochlandr-a travancorica; A, Arundinaria sp; OM, Oxytenanthera monostigma*

widespread in most of the reed-growing areas. It caused profuse growth of axillary shoots and pronounced reduction of internodal length and size of the stem, sheath and leaves; the normal leaf of *0. travancorica* (40 x 10 cm) was reduced to 3-10 x 0.5-l cm due to infection. The fungus *Balansia linearis* (Rehm.) Diehl was seen associated with this disease. It produced dark brown to black fructifications on the affected leaves and usually spread lengthwise from the leaf base to the apex. Often the whole leaf appeared to be a fungal fructification with the exception of a small portion of the apex (Fig. 3E). The infection was recorded throughout the year.

Little Leaf Disease

The disease occurred only in a few clumps of D. *strictus.* It was characterized by the production of a large number of abnormal shoots from the nodal region giving rise to a bushy growth. The internodes and leaves were stunted (Fig. 3F). Usually, only a few diseased culms were observed in the clump bearing stunted shoots. Fluorescence microscopic studies employing Diene's stain (Deeley et *al.,* 1979) showed that the infection may be caused by mycoplasma.

Seed Microflora of Stored Bamboo Seeds

B. *arundinacea* and *D. strictus* flower sporadically and the flowering occurs in small patches or in a few clumps in certain localities. Sporadic flowering also occurs in 0. *travancorica* and O. *scriptoria.* Flowering occurs during November/ December and seed formation and ripening take place in April/May. Generally, the forest nurseries are raised during December/January and hence the bamboo seeds have to be stored for a considerable period of time before sowing is done. Under the humid tropical conditions of Kerala , the bamboo seeds are vulnerable to fungal infection during storage which reduces their viability and vigour.

Seeds of ***B.*** *arundinracea* stored for four months in closed containers at 15 C and 28 ± 2 C and seeds of D. strictus stored for the' same period at 28 ± 2C were used in the present investigation. In each treatment, 200 seeds were tested employing the standard blotter technique. A total of 19 fungal and two bacterial organisms were encountered on the seeds of both the bamboo species. Of these, seven were potential seed-borne pathogens capable of causing infection in nursery seedlings (Table 5).

Table 4. Basal culm decay of *B. arundinacea* in natural stands at four localities surveyed during 1987-1988

Locality	1987			1988		
	No. clumps observed	No. new culms	% culm mortality	No. clumps observed	No. new culms	% culm mortality
Anamari (Nilambur)	104	268	19.4	126	286	13.9
Noolpuzha (Wynad)	98	368	17.1	92	331	21.6
Muthanga	68	212	8.01	72	260	5.38
Thirunelly (Wynad)	114	317	14.5	83	323	19.2

Fungal species and their frequency of occurrence were more in the seeds of D. *strictus* than those of *B. ar-undinacea*. A comparatively low incidence of seed microflora was observed in seeds stored at low temperature (15 C) and a higher percentage of germination (82%) recorded as compared to those stored at 28 ± 2 C (63 %). A few of the germinated seedlings showed severe fungal infection on the radicle and coleoptile. Seedling deformity was also recorded in some cases due to severe fungal infection at the hilum region.

Table 5. Occurrence of spermoplane fungi on stored seeds of bamboos

Microorganism	Percent occurrence BA	DS
Alternaria spp.*	10.5	9.5
Aspergillus spp.	4	5.5
Beltraniopsis spp.	2.5	0
Cercospora sp.*	2	3.5
Chaetomium sp.	3	5.5
Cladosporium spp.	6	7
Cunvularia spp.*	11	16.5
Drechslera spp.*	23	24.5
Dactylaria spp.*	6	8.5
Epicoccum spp.	0	4.5
Fusarium spp.*	24	29.5
Memnoniella sp.	2	0.5
Mucor sp.	0.5	2.5
Nigrospora sp.	1.5	3
Penicillium sp.	4.5	6.5
Periconia sp.	0.5	1
Phoma sp,		2
Phomopsis sp,*	0	1
Pithomyces sp.	0	1.s

*Pathogen recorded on bamboos BA , Bamhusa arundinacea; DS, Dendrocalamus strictus

Discussion

Earlier, only a few diseases had been recorded from other bamboo-growing countries (Anonymous 1960; Beradze, 1972; Lan, 1980; Boa, 1985b). In Bangladesh, bamboo blight is an economically important disease (Boa, 1985a; Rahman, 1985). The growing culms of *Bambusa* sp. are affected by this disease. The sheath rot pathogen of rice (*Sarocladium oryzae)* and *Acremonium strictum* are both linked with bamboo blight, though the connection between fungi and disease has not been satisfactorily demonstrated {Boa, 1985a). In India, a few foliar rust diseases caused by *Dasturella divina, Puccinia* sp., and *Tunicospora bagchii* have been reported (Bakshi & Singh, 1967; Singh & Pandey, 197 1; Bakshi et *al., 1972;* Bakshi, 1976).

In the present investigation a total of 36 fungal organisms were recorded on bamboos of which 10 caused various diseases of seedlings in nursery, 25 in plantations and 22 in natural stands; five pathogens were common to nursery, plantation and natural stands and 13 were common to plantation and natural stands. As many as 2 1 pathogens were recorded for the first time on bamboos. However, the pathogenic nature of many of these fungal organisms has not been ascertained.

In bamboo nurseries damping-off caused by *R. solani* is the major disease as also reported in other forestry crops (Sharma et al., 1984; 1985). With the exception of *Exserohilum rostratum* and *Helminthosporium* sp., the other pathogens caused only very insignificant damage in nursery seedlings. As far as damping-off is concerned it can be effectively controlled by prophylactic fungicidal application as also by manipulating nursery operations such as shade regulations and watering frequency.

In young bamboo plantations, diseases of rhizome buds affecting both culm production and rhizome proliferation may pose a threat to the stand. Basal culm decay caused by *Fusarium* sp. in natural stands and also in plantations is another important disease which needs detailed investigation. In natural stands of *B. arundinacea* the per-cent mortality of emerged culms due to decay ranges from 5.4 to 21.6. The basal culm decay caused by *F. moniliforme, F. solani* and *Sclerotium rolfsii* has been recorded from other countries (Anonymous 1960; Lan, 1980; Chen, 1982). Culm rot and culm sheath rot are the other important diseases affecting most of the bamboo species in plantations. The culm sheath plays an important role in the development of new culms. The green culm sheath and the partially expanded internodes that are damaged by the sap-sucking insects, are rendered susceptible to fungal infection resulting in various deformities leading to the die-back of culms. The sap-sucking insects play a major role in inciting and spreading the disease within the culm and also between the clumps. Since most of the bamboo species surveyed are found to be susceptible to culm rot, a detailed study on various aspects of epidemology is warranted. The pathogens associated with the disease, *F. equiseti* and *Fusarium* sp., sporulate heavily on the discoloured and decayed culm tissues.

The witch's broom disease caused by *B. linearis* on *Ochlandra* spp. and little leaf disease of *D. strictus* were two diseases observed in natural stands. Earlier, witch's broom on various bamboo species had been reported to be caused by different fungal pathogens, namely, *Aciculosporium take, Epicloe bambusae* and *Loculistroma bambusae* from various countries (Shinohara, 1965; Chen, 1970; Kao & Leu, 1976). A disease similar to little leaf disease of *D. strictus*, observed in a few locations in Kerala has also been reported by Bakshi *et al.* (1972) as a disease of unknown etiology.

From the survey it is apparent that the disease situation observed in natural stands is not much different from that in plantations. This observation is at variance from a general belief that disease occurrence will be more in species under cultivation than in natural stands because of the long-term stability attained by the host and pathogen in a natural ecosystem. This may possibly be due to the greater pressure from man and domestic as well as wild animals on natural stands of bamboos.

Seed quality is known to have a great impact on the quality of planting stock. The mode of collection is vital for obtaining good quality bamboo seeds. Usually, bamboo seeds are collected from the forest floor and as a result are contaminated by plant debris and soil particles. The weather conditions during seed collection also influence seed health. Storage conditions also affect seed viability as seeds stored at a low temperature have higher germinability than those stored at a higher temperature. Improper seed cleaning and storage procedures are responsible for the incidence of storage microorganisms and low seed viability. The seed pathological studies have revealed a large number of potential pathogens on the seeds of *B. arundinacea* and *D. strictus.* Earlier, a detailed investigation on seed characteristics including seed germination and seed-borne fungi of several bamboo species grown in Thailand had been reported (Anantachote, 1985). From the preliminary studies on seed pathology of bamboos it may be concluded that there is an urgent need to standardize methods for seed collection, storage and seed certification to provide high quality seeds for future bamboo planting programmes.

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Some Common Diseases of Bamboo and Reeds in Kerala

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Abstract

A survey of common diseases of bamboos and bamboo-weds was conducted in certuin selected areas of Kerala during the year 1987-88. The sympromology and etiology of six diseases of bamboos and foul- diseases of reeds are described.

Introduction

Although a large number of saprophytic and parasitic fungi have been reported on dead and stored bamboo, the amount of information available on the pathogens of living bamboos and bamboo-reeds in India is very limited. Preliminary observations have shown that about 15-20 percent of the bamboos in natural groves are damaged or lost every year through various diseases and pests. Ravo (1962) reported the occurrence of *Ascochyta* sp. on bamboo from India. In 1984, Boa and Rahman from Bangladesh notified the possible danger of "bamboo blight", which is a serious disease of bamboo.

A detailed survey was conducted during 1987-88 in the natural groves of bamboos and reeds in certain selected plains and forest areas of the Kerala State. The results obtained so far are presented in this paper.

Materials and methods

The commonly occurring bamboo species both in the plains and forests of Kerala *are Bambusa al-undinacea* (Retz.) Willd; *B. vulgaris* Schrader ex Wendland and *Dendrocalamus strictus* Nees, and the main species of reeds *are Ochlandra travancorica* (Bedd.) Benth. ex Gamble and *0. rheedii* Dennst. These were examined in the field for the occurrence of diseases.

Disease Survey and Collection of Specimens

The disease survey was done over two monsoon and one summer season. Groves of bamboos and reeds in parts of the plains and forests of Trivandrum, Quilon, Kottayam, Idukki, Trichur and Palghat districts were periodically observed for disease. Appropriate specimens of diseased parts such as foliage, branches, culms, sheaths, etc. were collected and brought to the laboratory for isolating the causal organisms.

Isolation and Purification of the Casual Organisms

Isolation and purification of the organisms were done following standard laboratory techniques. In most cases tissue isolation on potato dextrose agar medium was done. Host extract agar was also tried in a few instances. The initial cultures that were obtained were purified further by hyphal tip transfer and single spore isolation techniques and through frequent sub-culturing.

Morphological Studies and Identification of the Organisms

Ten-day-old pure cultures were used for detailed morphological studies. For this purpose, slide cultures were prepared following the techniques of Riddel (1950). Small bits of the inoculum were inoculated on previously cut sterile agar blocks of 6 mm square and 2 mm thick and placed over a flamed glass slide. A flamed cover slip was put over the inoculated agar block and gently pressed. The slide was then placed in a sterile petridish over two glass rod pieces kept on a wet filter paper round, so that the slide with the inoculated agar block rested over the glass rod pieces. The dish was then incubated at room temperature. On the third day the slide was taken out and the agar block removed. The growth on the slide as well as on the cover slip was wetted with a drop of alcohol, mounted in lactophenol and sealed with nail polish to make them semi-permanent. The mounts so prepared were observed under a Microstar microscope with a photographic attachment. The morphological features were recorded, measurements made and microphotographs taken.

Pathogenicity Tests

Thepathogenicity of the isolates was confirmed by artificial inoculation of healthy bamboos and reeds. For this purpose, 15-day-old pure cultures of the organisms were used. Culture bits and spore suspensions in sterile distilled water were inoculated on both injured and non-injured plant parts. Wherever culture bits were used, the inoculated portions were covered with wet cotton. In other cases the inoculated portions were given a loose covering of polythene sheets. In the case of Taphrina, extracts of severely infected leaves in sterile distilled water were sprayed over the plant parts with an atomizer. Identical healthy control plants were marked and sprayed with sterile distilled water and otherwise treated similarly. Infection and development of symptoms were noted daily from the fifth day onwards.

Results

In bamboo, six diseases, namely, leaf and branch blight, grey-blight of culms, abnormal defoliation and withered culms, rotting of young culms, sooty mould, shrinking and withering of basal culms, and in reeds, thread blight and various types of leaf and culm blight were observed.

Among the bamboo diseases, leaf and branch blight and culm rotdiseaseswere commonly noted in all the three speciesand were particularly severe after the rainy season. Among the four diseases recorded on reeds, thread blight was a severe disease in both species of *Ochlandra.*

Bamboo

Leaf and branch blight

Three types of leaf and branch blight were commonly noted:

I. Symptoms: A large number of small longitudinal yellow lesions first appear on the leaves. These enla- rge in size and turn brown. The leaf margins become necrotic extending towards the centre. Such leaves are gradually blighted and abscise. The branches also become blighted with time. The disease can be designated as leaf and branch blight.

Etiology: Ascochyta phaseolarum Sacc. The culture which is at first white turns yellow with a black tinge from below. Pycnidia spherical to subglobose, light yellow and measure 60-200 pm. Conidia straight or slightly bent at one or both ends, hyaline, one-septate. The hyaline globose phialides measure 8-9 x 4-7 pm. Conidia measure 13.5 - 15.5 x 3-5.7µm.

2. Symptoms: Leaves turn brown in masses from the base to the tip of branches, and gradually become blighted and abscise. The disease may be designated as "brown blight".

Etiology: Fusarium semitectum Berk and Rav. The culture which is white at first and peach coloured from below, gradually turns buff brown. Sporodochia are absent. Macroconidia are found in aerial mycelium from loosely branched conidiophores. Conidia measure 2.5-7.5 x 17-40 pm with the foot cell being absent.

3. Symptoms: Large water-soaked patches appear on the leaves. Gradually the leaves fully turn papery white and become blighted. Severely affected branches are also seen. The nature of blighting is similar to that of leaf and sheath blight of rice. The disease may be designated as "leaf and stem blight" of bamboo (Fig. 1).

Etiology: Curvularia lunata (Wakker) Boedijn. Mycelium initially hyaline but gradually turns brown. When young the culture is white in colour and becomes darker at maturity. Conidia olive brown, curved or ellipsoid, 3-septate with round

Fig. 1. Leaf and stem blight of bamboo.

Fig. 2. Grey-blight of culms of bamboo.

apex and accuminate base. The two central cells are darker than the end cells. On an average, the conidia measure 2.6-14 µm. On inoculation the latter two organisms showed blight symptoms in rice plants.

Grey-blight of culms

This disease was observed in *Bambusa arundinacea* and *B.vulgaris.*

Symptoms: Patches of irregular grey coloured lesions ozene in the nodal regions of a few basal nodes. These extend gradually both upward and downward in strips finally covering the entire internode portion. The margins of these lesions become dark brown with necrotic centres (Fig. 2).

Etiology: Geotrichum (Link)sp. Myceliummilky white, conidiophores absent. Conidia arthrospores, hyaline, l-celled, cylindrical, formed by segmentation of hyphae and measure 13- 19.5 x 6.5 pm.

Abnormal defoliation and withered culms

Symptoms: Observed only in *Bambusa vulgaris.* A large number of raised lesions appear in almost all leaves which gradually become necrotic. The nearby lesions join together resulting in large blighted areas. Whole leaves dry up in certain branches and abscise. The branches may also dry up. The severely affected culms become discoloured and subsequently dry up (Fig. 3).

Etiology : Taphrina deformans Berk Tul. Transverse sections of the affected leaves showed septate intercellular mycelium which was sometimes deep-seated in the tissues. The hyphae beneath the cuticle showed ascogenous cells. The ascospores are globose and measure 3-4 pm in diameter. These undergo yeast-like budding within the ascus. Inoculation on turmeric leaves at first caused yellow lesions followed by large blotches.

Rotting of growing culms

This disease was found to occur in all bamboo species observed. Rotting occurs in the young culms at all stages of growth. The affected culms gradually die and the inner tissues along with the outer sheaths become rotted. In all cases, the associated organisms are more than one species of *Fusarium.* Rotting is promoted by certain borers and the presence of larvae was invariably noted inside the rotted culms (Fig. 4).

Sooty mould

Its occurrence is restricted to *Bambusa vulgaris.*

Symptoms : A black powdery fungal coating is seen on the upper side of the leaves of the affected branches and portions of culms. Such branches show withering.

Etiology: Capnodium (Mont.) sp.

Shrinking and withering of basal culms

The incidence of this disease was noticed in *Bambusa arundinacea. Ganoderma lucidum* (Fr.) Karst. occurs in large numbers at the basal portions of the living culms up to a height of about 1 m from

Fig. 3. Abnormal defoliation and withered culms ofbamboo.

Fig. 4. Rotting of growing culms of bamboo.

ground level. The repeated incidence in the same clump by this annual fungus causes discoloration, shrinking and withering of the basal portions of mature as well as young culms. The fungus also affects the root system which becomes retarded and malformed (Fig. 5).

Reeds

Leaf and culm blight (thread blight)
This disease is observed frequently at Palode and Ponmudi forest areas in both the *Ochlandra* species.
Symptoms: Large water-soaked irregular patches appear on the foliage with white centres and brown margins. The symptoms initiate at leaf junctions of the branches. The affected leaves rapidly dry up in bunches. In an affected clump almost all the branches show symptoms of branch blight. Closely sticking creamy white fungal threads are seen throughout the affected culms. All stages of culm growth are affected and the diseased culms gradually dry up (Figs. 6A,B).
Etiology: Pellicularia (Botryobasidum) salamonicolor (Berk & Br.) Dastur. On the host surface, the fungus appears as fine silvery-white mycelium or pustules. The mature mycelium turns pinkish-brown and is present on the culms and leaves. The asexual spores are hyaline, thin-walled, globose and measure 8-12 x 5-10 pm.

Rusty spots on leaves and culms
Symptoms: The incidence of this disease was noticed in both the reed species under study. Rusty irregular lesions in large numbers appear on leaves and culms and gradually turn necrotic. In severe cases, leaf and culm blight are seen (Fig. 7).
Etiology: Coniothyrium fuckelii Sace. Pycnidia are superficial, dark, numerous and measure 180-200 µm in diameter. The conidia are dark, globose to slightly elliptical and measure 2.5-5.6 x 2-35 µm.

Brown spot (blight) of leaves
Its incidence was noted in both the reed species under study.
Symptoms: Small irregular or oblong yellow spots appear superficially on the leaves. The spots gradually enlarge in size and later coalesce to form, larger blighted areas. The leaves become necrotic and brittle.
Etiology: Curvularia andropogoins (Zim.) Boedijn. The fungus culture which is initially white, turns dark at maturity. Conidiophores measure l00-190 pm long and are 9-10 pm wide. The conidia are terminal and lateral and are more or less straight, 3-septate, dark brown, thick-walled and measure 14-20 x 30-60 pm.

Leaf blight
Symptoms: Blighting of leaves is similar to that of *Pellicularia* blight. The only difference noticed is

Fig. 5. *Shrinking and withering of basal culms of bamboo by Ganoderma.*

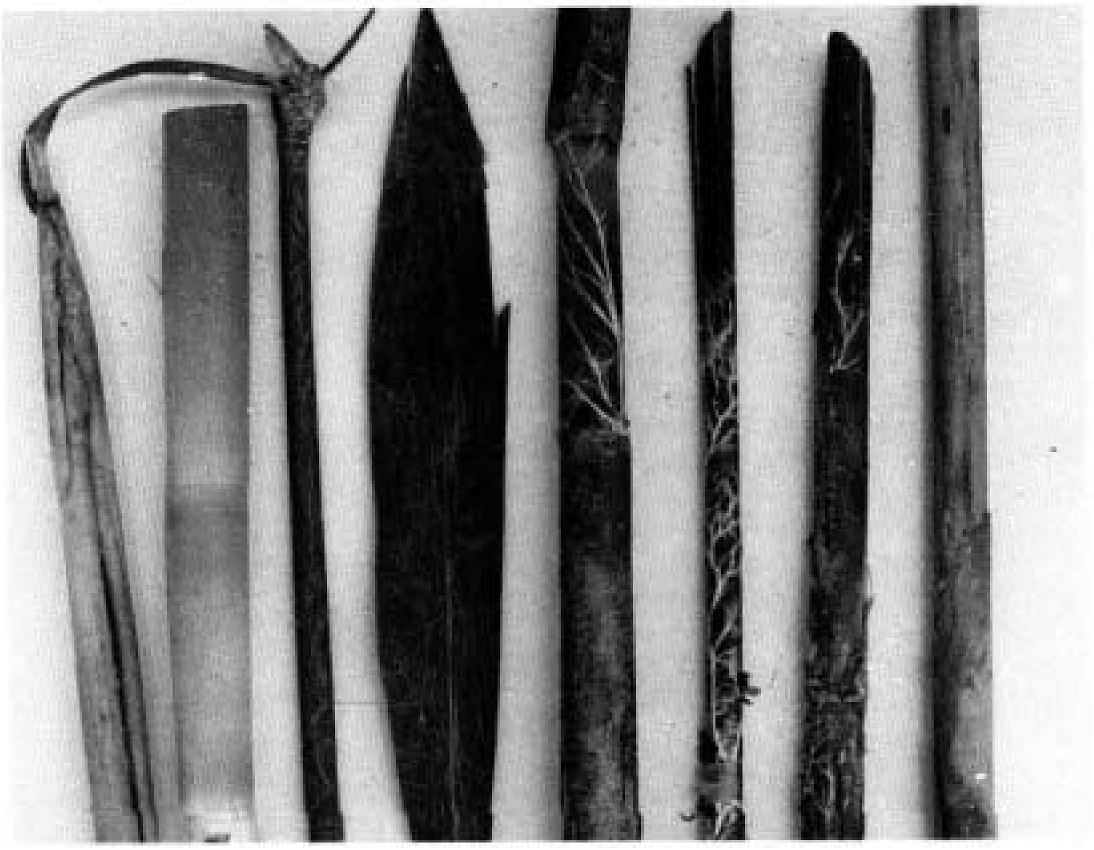

Fig. 6 A,B. Thread blight of reeds in lealIes (A) and culms (B).

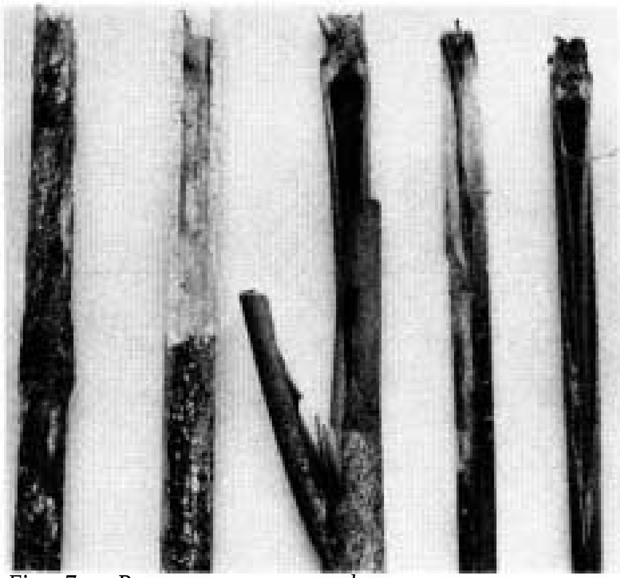

Fig. 7. Rusty spots on reeds,

the absence of any mycelial growth on the leaf surface. Instead a pinkish powder is seen on the blighted leaves at certain portions.

Etiology: Fusarium equiseti (Corda.) Sacc. The fungal culture is white in colour and later turns olive buff and becomes dark from below. The conidia are produced from lateral phialides and measure 10-12.5 x 2.5-3 pm. Sporodochia are absent.

Discussion

The production of blight symptoms through artificial inoculation in rice plants by *Fusarium semitectum* and *Curvularia lunata* showed that these are pathogens of other graminaceous crops also. The occurrence of *Ascochyta* sp. in bamboos was reported earlier by Ravo (1962). The present observations confirm its pathogenic nature in bamboo. Similarly the association of *Coniothyrium fuckelii* with bamboo blight has already been reported by Gibson (1975) from Bangladesh. In the present study a more or less similar incidence of the same fungus was seen in the reeds of Kerala.

The pathogenic nature of other organisms described in the present study have been reported in various other crops by earlier workers. Occurrence of *Fusarium equiseti* in leaves of *Eichhornia crassipes* by Banerjee (1942), the association of *Fusarium semitectum* with darkened young shoots of *Aegle marmelos* by Mitra (1935), *Pellicularia salmonicolor* in living stem of rubber, tea, coffee and citrus and other plants by Butler and Bisby (193 1) may be noted in this context.

The information obtained from the present study show that bamboos and reeds in Kerala are affected by several diseases which in certain localities and seasons occur in severe proportions, causing considerable yield losses and reduction of quality.

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Current Status of Pests of Bamboos in India

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Abstract

The different insect pests of standing and dry bamboo are described. Control measures are also suggested in the paper.

Introduction

Little information is available on the various insects feeding on bamboos and much less is known about their impact on the growth of bamboo. Chen (1928) presented notes on the bamboo borer, *Cyrtotrachelus longimanus* Fabricius. Beeson (1941) described the life history and control of weevil borers of bamboos, C. *dux* Boheman and C. *longimanus*. Mathur (1943) gave an account of defoliators of bamboos with a detailed account of the greater bamboo leaf roller, *Pyrausta coclesalis* Walker. Chatterjee and Sebastian (1964; 1966), and Singh and Sivaramakrishna (1976) recorded host plants and gave biological notes and control measures of the bamboo sap-sucker *Oregma bambusae* Buckton. Roonwal (1977) studied the life cycle of the bamboo stem beetle, *Estigmena chinensis* Hope. Dayun and Shao-jin (1987) provided brief information on pests of bamboos. Singh and Bhandari (1988) have also described important pests of bamboos and their control in India. As regards the ghoon borers of dried bamboos, a lot of work has been carried out in this country. Beeson (1941) outlined the life history and methods for the control of D. *brevis* Horn., D. *ocellaris* Stephens and *D. minutus* Fab. This paper gives a brief account of the current status of important pests of bamboos and their control.

Insect Pests

Standing bamboos are attacked by various insects belonging to the orders Coleoptera, Lepidoptera and Hemiptera. According to their food habits, these insects can be grouped into defoliators, borers of standing culms and sap-suckers of stem, leaf and seed. Felled and dried bamboos are attacked by ghoon and other borers.

Defoliators

Defoliation epidemics in bamboo forests and plantations are not quite frequent, Sometimes, during the rainy season, large-scale defoliation by the greater bamboo leaf roller *Pyrausta coclesalis* Walk is noticed. The species is distributed throughout the Indian subcontinent and South-east Asia. Mathur (1943) has described the life-history of the greater leaf roller in detail. It is quite injurious to bamboos with four generations a year. The leaf roller is parasitised by the tachinids *Carcelia octava* Bar., *Pales puvida* Meign and *Prosopodopsis fasciatus* Wd.; *Cedria paradoxa* Wlkn. (Hymenoptera: Braconidae); *Microgaster kuchingensis* Wlkn. (Hymenoptera: Braconidae) and *Xanthopimpla cera* Cam. (Hymenoptera: Ichneumonidae). The predators of the leaf roller include the carabids *Calleide pellipes* Andr., *C. rapax* Andr. and *C. splendidula* Fabricius, and the mantid *Hierodula ventralis* Gig. (Chatterjee & Misra, 1974). But quite often, these natural enemies are unable to control the pest and epidemic buildup of pest populations occurs during the rainy season leading to foliage loss. The damage is more in plantations than in forests. A solution of 0.2 percent fenitrothion or 0.1 percent carbaryl in water with a surfactant effectively controls the pest. It is not easy to use insecticides during the monsoons for controlling the pest. In Jawa, Kalshoven (1950-5 1), reported that the species has a high reproductive potential but is adequately controlled by parasites. In China, *P. coclesalis* Walker damaged more than seven million hectares as a result of which more than four million stock of *Phyllostachys pubescens* died. Aerial spraying and injection of insecticides into the cavity at the bottom of the plant reduced the extent of infestation (Shi, 1980).

Besides the greater leaf roller the other lepidopterous defoliators are *Pyrausta bambucivora* Moore, *Pionea flavofimbriata* Moore and *Massepha absolutalis* Walker (Lepidoptera: Pyralidae).

All these defoliators are pests of minor importance. A foliar spray of 0.1-0.2 percent fenitrothion or 0.1 percent carbaryl in water is used to control these pests.

Hieroglyphus banian Fabricius (Orthoptera: Pyrgomorphidae), a green or dry grass coloured grasshopper, is a major pest of rice, maize and wild grasses. It has an annual life cycle. The eggs remain in soil from November to June. *Scelio hieroglyphi* Timb. (Hymenoptera: Scelionidae) parasitizes eggs of this grasshopper. Beeson (194 1) reported an outbreak of this species in June, 1933 in bamboo forests from Hoshiarpur Forest Division.

Poecilocerus pictus Fabricius (Orthoptera: Acrididae) is a bright bluish green and yellow coloured grasshopper. Though primarily an agricultural pest, it is also injurious to bamboos, especially *D. str-ictus*. This was responsible for causing heavy defoliation in bamboo forests in Hoshiarpur Division in 1923 (Beeson, 1941). It has an annual life cycle and hibernates in the egg stage. Sporadic outbreaks of the grasshopper are sometimes reported in *D. str-ictus* forests from various forest divisions.

Dusting hoppers and adults with five and ten percent BHC, respectively, gives effective control of the above two grasshoppers (Anonymous 1989).

Shoot and Culm Borers

The most important shoot and culm borers are the two bamboo weevils, *Cyrtotrachelus dux* Boheman and *C. longimanus* Fabricius (Coleoptera: Curculionidae) and the bamboo hispine beetle, *Estigmena chinesis* Hope.

C. *dux* has an annual life cycle. The adults are active at the onset of the South-west monsoon and they bite deep holes in the tender culm shoots to obtain the sap, thus adversely affecting the growth of the culms. The eggs are laid in pits similar to those made for the purpose of feeding. The larva bores into the culm, leaving it when fully grown to pupate in the soil. Damage is characterized by a long larval tunnel starting beneath or near the culm sheath and passing internally through several internodes perforating each node and ending in a hollowed and dead terminal shoot. Culms may be killed outright and the development of multiple shoots of little commercial value is induced. The presence of a single larva is sufficient to destroy a culm. Infestation is usually heaviest where the density of culms is high. The other species, C. *longimanus* in both adult and larval stages, is also an important pest of D. *strictus* and other bamboos. The general habits of this species are similar to those of C, *dux* (Chen, 1928; Stebbing, 1914; Beeson, 1941'). Beeson (194 1) recommended capture of the beetle at the beginning of the monsoon. Dayun and Shao-jin (1987) recommended digging out of damaged culms and shoots for control. As damage is less in well-thinned and exploited areas than in stands with numerous dense clumps, the density of clumps should not be allowed to increase.

The bamboo hispine beetle, *Estigmena chinensis* (Coleoptera: Chrysomelidae) is the most important pest of standing bamboos in natural forests and plantations in India. Sometimes, all the culms in a clump are attacked. The over-wintering adult becomes active before the onset of the South-west monsoon and the female lays eggs in small groups in early rains on the internode of the stem, covering them with masticated fragments of leaves. The young larvae feed for some time between the culm sheath and the surface of the culm, eating patches of tender outer tissues, but later bore into the internode and tunnel both upwards and downwards. Pupation occurs in the tunnel in September and lasts for a month. The young adults remain in the tunnel during the winter and hot summer months. Damage appears to be most frequent in solid bamboos of small thickness and the solid parts of thick walls of hollow bamboos. Attack is either mild or absent in the walls of hollow bamboos. The injury is done during the first few months of growth of the culm. In the second year, the culms are rarely attacked (Beeson, 1941: Roonwal, 1977). This borer is one of the causes for the bending of bamboos. Congestion in bamboo clumps, dense clumps and split culms provide the beetle with shelter during the dry hot season. Thus, the cultural measures prescribed for the treatment of congestion can also take care of control of the pest. In a year when *Estigmena* damage increases abnormally, severely afflicted culms should be cut in those coupes where extraction is going on. Attacked culms should be sorted from the sound ones and exposed to sunlight which will kill the beetles (Deogan, 1937; Beeson, 1941).

Sap Suckers

There are a large number of sap-suckers of the Coccidae, Aleyrodidae, Aphidae and Memberacidae that attack bamboos (Beeson, 1941; Roonwal & Bhasin, 1954; Bhasin *et al., 1958;* Mathur & Singh, 1959 a, b, 1960 a, b, 1961 a, b). Of these, *Oregma bambusae* Buckton and *Ochrophara montana* Distant are important. The seed sucker pentatomid bug 0. montana occurs in epidemic form only at the time of flowering of bamboo.

Oregma bambusae Buckton (Hemiptera: Aphidae) is a serious pest of bamboo shoots when outbreaks occur. In most cases, these aphids cover the small and medium shoots entirely from bottom to top. Due to excessive drainage of sap, the vitality of the growing shoot is affected and it gets reduced in size, bent and twisted or may even die. The aphid has been recorded feeding on 16 species of bamboos (Chatterjee & Sebastian, 1964,1966; Singh & Shivaramakrishna, 1976). Sometimes they occur in such large numbers that the plant is smothered with a black mould which grows on the honey dew secreted by the aphid. The sweet secretion is also visited by hordes of flies, ants and other insects. Chatterjee and Sebastian (1964) recommended a spray of kerosene oil in soap emulsion to control it. Singh (1988) recommended foliar spray of 0.04 percent dimacron or rogor or 0.2 percent fenitrothion for control of the aphid.

The pentatomid bug *Ochrophara montana* Distant (Hemiptera: Pentatomidae) attacks flowering bamboo. It feeds on bamboo seeds on the flowering branches and after these have fallen to the ground. Because of the abundant food supply that results from the large scale flowering of bamboos, innumerable bugs are produced. It is only the exhaustion of food supply and the occurrence of heavy rain that kill these swarms. Epidemics of the bug have been reported from central India where large scale flowering of D. *strictus* occurred in Chandrapur and adjoining areas in 1982-83. Foliar spray of 0.25 percent fenitrothion or endosulfan were recommended for its control.

Witch's Broom of Bamboo

Witch's broom of the bamboo Dendrocalamus *strictus* has been observed in many areas. An unidentified phytophagous chalcid causes the broom symptoms. It attacks the branches at the node which become a little swollen at the base and remain stunted.

Borers of Felled or Dried Bamboos

The most important borers of felled bamboos are three species of *Dinoder-us* (Coleoptera: Bostrychidae): D. *ocellaris, D. minutus* and *D. brevis.* These ghoon borers or shot hole borers occur all over the country and cause immense damage to the bamboos during the process of drying. The most important period of borer attack is from March onwards. The ghoon borers have three to five generations a year. Although there are other species of borers attacking dry bamboo, these are not of economic importance. For protection against ghoon borers, both prophylactic methods and preservative treatments have been developed.

The habits and life histories of the three species of *Dinoderus* are similar. The beetles bore into the cut bamboo at spots where the external rind is severed or removed. They also bore into the exposed transverse sections of the cut ends and into the internal walls of the terminal internodes of hollow bamboos. Pairing takes place inside the tunnels and eggs are laid in exposed pores in the walls. There are three or four larval instars. Pupation occurs in a cell at the end of the larval tunnel and the pupal stage is of very short duration. Immature beetles may bore out through the rind immediately above its pupal cell or emerge from one of the original entrance holes. The first generation starting in March is completed in 11 to 12 weeks. The second generation starting in June is also completed in 11 to 12 weeks, with a pupal period of four days. The third generation starting at the end of September overwinters as the larvae pupate in March. This takes 22 to 24 weeks from boring in of beetles to emergence of brood. Under favourable conditions, there may be four generations. All the three species of bamboo ghoon borer are parasitised by *Spathius bisignatus* Wlkn. and S. *vulnificus* (Hymenoptera: Braconidae). Larvae, pupae and beetles of ghoon borers are preyed upon by *Tillus notates* Klug., *T. succinctus* Spin. (Coleoptera: Cleridae) and *Hectarthrum heros* Fabricius (Coleoptera: Cucujiidae) (Beeson, 194 1; Chatterjee & Mishra, 1974).

A spray treatment of bamboo culms with one percent lindane, three percent boric acid + borax (1:l) or three percent boric acid + zinc chloride (1:2) gives satisfactory results as a prophylactic measure. Dipping is more effective than spraying. The prophylactic measures should be undertaken before the monsoon begins (Mathur, 1964). Kumar *et al.* (1985) have suggested two different chemical compositions for prophylactic treatment of bamboos: (a) one percent sodium pentachlorophenate and (b) sodium pentachlorophenate: boric acid: borax (0.5:1: 1). Recently, Singh and Thapa (unpublished) studied prophylactic treatment with endosulfan, cypermethrin and fenvalerate which has given protection for approximately four months after felling.

Results of investigations carried out at the Forest Research Institute, Dehradun indicate that methods such as diffusion, soaking, steeping, sap displacement of preservatives, apart from being simple and cheap also give quite satisfactory results, provided a suitable schedule is worked out. Ponding of bamboos prior to treatment results in increased absorption of the preservative both by diffusion and pressure processes.

For preservative treatment of bamboos, soaking in a five percent aqueous solution of Copper-Chrome-Arsenic composition (CCA) gives good absorption (Singh & Tewari, 1979). The steeping method or immersion of green bamboo in five and ten percent aqueous solution of copper sulphate and zinc chloride has also given satisfactory results. Immersion in a ten percent aqeuous solution of copper sulphate, arsenic pentoxide, zinc chloride, boric acid-borax, ACC, CCA have provided good absorption of chemicals. Similarly diffusion and open tank immersion have proved effective (Singh & Tewari, 1981a-c; Tewari, 1981). Dry bamboos are refractory to treatment with preservatives (Tewari, 198 1).

Conclusion

So far very little attention has been paid to the pest management of bamboo forests in the country. Despite the fact that large scale defoliation as well as borer attack occur in the green culms, there have been no studies on their impact on the growth of bamboos. On a conservative estimate at least 25 percent of the standing culms of *D. strictus* are damaged by stem-boring beetles.

Heavy defoliation by the greater leaf roller leads to the weakening of culms. Similarly, a heavy incidence of sap-sucking bamboo aphids also weakens the culms, sometimes even killing them. Large amounts of seed are destroyed by the bamboo seed bug. In order to increase the productivity of bamboo forests and plantations, pest management is quite essential and the biology, life history, population dynamics and growth impact of pests need to be studied. Integrated pest management practices with emphasis on cultural, biological and genetic control should be evolved for natural and man-made bamboo forests. Safer insecticides like synthetic pyrethroids need to be tested for their prophylactic efficacy, and their environmental impact studied for their safety.

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Occurrence and Pest Status of some Insects Attacking Bamboos in Newly Established Plantations in Kerala*

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Abstract

The occurrence and pest status of insects that attack young plantations of bamboos have been studied. A total of II species of insects belonging to Lepidoptera, Hemiptera, Coleoptera and Hymenoptera have been collected and identifed. Of these, Myllocerus sp. (Coleopter-a: Curculionidae), Phymatostetha deschamps (Hemiptera: Cercopidae), Notobitus sp. (Hemiptel-a: Coreidae), Purohita cervina (Hemiptera: Fulgoridae) and Ceraphron sp. (Hymenoptera: Ceraphronidae) reported in this study are new pest records for bamboo in Kerala. In general, the severity of damage due to various insects was very low However, the damage done by shoot borers and sap suckers is of concern.

Introduction

Extensive plantations of bamboos, mostly of *Bambusa arundinacea,* have recently been raised in several parts of Kerala to meet the increasing demand for long-fibre pulping material. Although natural bamboo stands are relatively free from any major pest incidence, the new plantations were found to be affected by various insect pests (Table 1). About 20 insects have been reported as pests of bamboo in India (Browne, 1968; Singh, 1988; Chakrabarti & Maity, 1980; Sohi *et al.,* 1980) (Table 2). No systematic data have been gathered on the occurrence as well as pest status of various insect pests of bamboo in Kerala. With the recent setting up of extensive bamboo plantations in Kerala, several reports of pest problems were received which prompted the present study.

Materials and Methods

Data presented in this study are mostly based on observations in two plantations: (1) 1988 plantations under teak at Kombazha in the Pattikkad range (Trichur Forest Division) and (2) 1987 plantation under teak at Palappilly in the Chalakudy Forest Division. In both the plantations, a transect was taken across the plantation and observations made on the incidence of insect pests and nature of damage. In addition, casual observations were also made in natural stands of bamboo at Vazhachal (Chalakudy Forest Division) and at Mukkali (Palghat Forest Division).

Observations and Discussion

The insects collected in this study are listed in Table 1. Altogether 11 species belonging to Lepidoptera, Hemiptera. Coleoptera and Hymenoptera were collected and identified. Excepting the beetle *Estigmena chinensis* which was collected from natural stands, all the other species were collected from the new bamboo plantations. The most common damage noted in young plantations was shoot-boring, although other types of damage such as leaf-feeding, sap-sucking and gall-forming were also observed. In both the plots. the severity of damage caused by the insects was well below 10 percent.

Shoot Borers

Two Lepidopteran shoot borers were observed to cause damage in young plantations. One of them was a top shoot borer and the other was found to

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Table 1. Insects attacking bamboo plantations in Kerala

Species/Family	Locality	Remarks
Order Lepidoptera		
Unidentified lepidoptera	Peechi, Mukkali, Palapilly	Top shoot borer
Unidentified lepidoptera	Palapilly, Mukkali	Shoot borer
Pyraausta coclesalis (Pyraustidae)	Peechi, Mukkali, Palapilly	Leaf webber
Order Coleoptera		
Myllocerus sp, (Curculionidae)	Peechi	Leaf feeding
Estignena chinensis (Chrysomelidae)	Vazhachal	Shoot borer
Unidentified chrysomelid	Peechi	Foliage feeder
Order Hemiptera		
*Phymatostetha deschamps** Lin. (Cercopidae)	Peechi	Sap sucking
Oregma bambusae Buckton (Aphididae)	Mannuthy	Sap sucking
Purohitha cervina Distant* (Fulgoridae)	Kombazha, Nilambur	Sap sucking often causing die-back of affected culms
Notobitus sp. (Coreidae)	Kombazha. Nilambur	
Order Hymenoptera		
Ceraphron sp.*	At several places	Gall forming

*, *Recorded for the first time on bamboo*

feed mostly in the internodal area. The attack by the former resulted in the formation of 'brown heads'. The identity of the two borers is yet to be determined.

Leaf Feeders

This included the leaf roller *Pyrausta coclesalis,* the caterpillars of which webbed the top shoots. Each folded leaf contained only a single larva. Its attack often resulted in the damage of the apical bud resulting in formation of several side branches. Another foliage feeder collected during the study was the weevil, Mylocerus sp., which fed irregularly along the leaf margin, occasionally causing extensive damage.

Sap-sucking Insects

Four species of sap-sucking insects were collected during this study. A heavy buildup of two species, *Purohita crevina* and *Notobitus* sp., was found in some patches at Kombazha. *Purohita cervina* was found to be tended by the ant *Crematogaster* sp. which might be playing a role in its dispersal. The infested culms were also affected by a fungal disease (C. Mohanan, 1988, personal communication) and the role of these insects as vectors of this disease needs confirmation. *Purohita crevina* is already reported as a pest of bamboo in Darjeeling (Distant, 1916).

The bamboo aphid, *Oregma hambusae,* although not recorded from the areas under study, was observed on bamboo growing in nearby homesteads. Infestation by this insect caused yellowing of the leaves. Ghosh (1980) has reported that about 15 species of aphids attack bamboo in eastern India.

Occurrence of *Phyanrtostetha deschamps,* a well known pest of banana, was also observed on bamboo at Peechi although there was no visible damage.

Gall-forming Insects

Gall formation was very commonly observed in both the study plots. The gall-forming insect which was identified as *Ceraphron* sp. (Hymenoptera) lays its eggs on the growing tip of the main culm or side shoots. The insects that develop inside lead to swelling of the shoot resulting in retardation of growth. Nearly 50 insects were collected from a single gall on one occasion. These are minute and when ready for emergence, escape through a small slit formed in the middle of the swollen part of the

Table 2. Insect species recorded from bamboo

Order Lepidoptera	
Pyraustidae	*Aleurodidae*
Pyrausta hambucivora Moore	*Aleurotulus arundinacea* Singh
P. coclesalis Wlk.	
Tortric idae	Coccidae
Olethreutes par-agramma Meyr.	*Asterolecanium bambusae* Boisd.
	Odonaspis canaliculata Green
	0. inusittata Green
	0. secreta Cockcrell
	Poliaspoides simplex Green
Nymphalidae	
Lethe drypetis Hew.	
Order Coleoutera	
	Coreidae
	Notohitus sp.[4]
Curculionidae	Aphididae
Myocalandr-a exarata Boh.	*Oregma bambusae* Buckton
Myllocerus sp.	*Indoregma bambusae* Chakrabarti & Maity
	Aleulodaphis antennata Chakrabarti & Maity
Chrysomelidae	
Estigmena chinensis Hope	*Kalkiana bambusa*[3] Sohi Viraktamath& Dworakowska
Order Hemiptera	Order Orthoptera
Flattidae	Acrididae
Salurnis marginella Guer. Men.	*Poerilocer-us pictus* Fb.
	Schistocera gregaria Forskal
Fulgoridae	
Purohita cervinu Dist.	
Cercopidae	
Phymatostetha deschamps Lin.	
Order Hymenoptera	Order Diptera
Unidentified Chalcid	Tephritidae
Ceraphronidae	*CheIyophora striata* Bezzi
Ceraphron sp. [4]	

1. Singh (1988); 2. Chakrabarti & Maity (1980); 3. Sohi et al (1980); 4. Recorded for the first time on bamboo in Kerala; the remaining insects were recorded by Browne (1968)

shoot. The apical ends of the shoots that develop into galls subsequently dry up.

Of the various insects recorded, Myllocerus sp. (Curculionidae), *Phymatostetha deschamps* (Cercopidae), Notobitus sp. (Coreidae), *Purohita cervina* (Fulgoridae) and *Ceraphron* sp. (Ceraphronidae) are new records for bamboo from Kerala. The total number of insects thus recorded on bamboo comes to about 26 (Table 2).

On the whole the bamboo plantations in Kerala do not face any serious problem from insect pests. Of the various insects recorded, only the shoot borers (yet to be identified) and the sap-suckers *(Purohita* sp. and *Notohitrrs* sp.) are likely to affect the young plants either by interrupting shoot growth or causing shoot die-back due to sap drain.

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PRESERVATION OF BAMBOOS

Preservative Treatment of Bamboo for Structural Uses

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Abstract

The work carried out in the Forest Research Institute, Dehradun on bamboos in relation to their- structural use is reviewed. Different methods available for- treating green and dry bamboo with preservative chemicals are described.

Introduction

Bamboos are the fastest growing plants which yield a large biomass as a short rotational forest crop in the tropical regions. They are a unique group of grasses which can be used for a variety of purposes. The modem processing techniques have further extended their use.

In India, bamboo is densely distributed in Arunachal Pradesh, Assam, Manipur, Meghalaya, Tripura, West Bengal, Andhra Pradesh, Madhya Pradesh, Maharashtra, the Western Ghats, and Andaman & Nicobar islands, the estimated area under bamboo being 10 million hectares. There are 63 genera and about 700 species growing in the world (McClure, 1966) of which 30 genera and about 136 species occur in India (Suri & Chauhan, 1984). The most important economic species from the point of view of easy availability are *Bambusa arundinacea* Willd., *B. nutans* Wall., *B. polymorpha* Munro, *B. tulda* Roxb., *Dendrocalamus hamiltonii* Nees and Am., *D. strictus* Nees and *Melocarina bambusoides* Trin.

Physical and Mechanical Properties

The density of bamboo varies between 500 and 800 kg/m^3 depending mainly on the anatomical structure, such as the quantity and distribution of fibres around the vascular bundles. Accordingly, it increases from the central (innermost layers) to the peripheral parts of the culm and this variation could be 20-25 percent in thick-walled bamboos like *Dendrocalamus strictus* (Sharma & Mehra, 1970). In thin-walled bamboos, the differences in density are much less (Sekhar & Bhartari, 1960).

Bamboos possess a very high moisture content which varies from the bottom to the top and from the innermost layers to the periphery. Green bamboo may have 100 percent moisture (oven-dry weight basis) and the variation reported is 155 percent for the innermost layers to 70 percent for the peripheral layers (Sharma & Mehra, 1970). The variation from the top (82%) to the bottom (110%) is comparatively less. The fibre saturation point of bamboo is around 20-22 percent (Kishen et *al.*, 1956).

Bamboo possesses excellent strength properties, especially tensile strength. Most of the properties depend upon the species and the climatic conditions under which they grow (Sekhar & Gulati, 1973). An increase in tensile and compressive strength up to six years and bending strength up to eight years is known to occur. Strength properties are reported to decrease in older culms (Zhou, 1981). They also increase from the central to the outer part and from the bottom to the top. According to Bauman (Narayanmurti & Bist, 1947), there is more than 100 percent variation in strength from the inner to the outer layers (Table 1.)

Although several studies on strength properties have been conducted, the information on strength behaviour and its correlation with various factors such as moisture, anatomical structure. growth

Table 1. Bendingand tensile strength (kg/cm^2) of inner and outer layers of bamboo

Property	Inner	Outer
Bending strength	950	2535
Tensile strength	1480-1620	3 100-3300

Table 2. Strength of some Indian bamboo species in green and dry conditions vis-a-vis *Tectona grandis* (teak) and *Shorea robusta* (sal) adapted from Limaye (1957)

Species	Moisture content (%)	Strength property (kg/cm') Modulus of rupture	Modulus of elasticity	Maximum crushing stress
Dendrocalamus strictus	58	958	156409	423
	12	1310	180364	624
Bambusa balcoa	22	1015	170500	450
Bambusa nutans	12	662	111318	
Bambusa tulda	12	880	123295	
Tectona grandis (teak)	52	803	117659	412
	12	1057	132455	620
Shorea robusra (Sal)	60	958	128091	497
	12	1318	162045	641

characteristics, drying and preservative methods is still wanting. Even methods for evaluating strength properties have not been standardized and the available results are based on inadequate data obtained under different methods of testing and with widely varying dimensions. The limited data show that bamboo is as strong as timber and that some species exceed in strength over the strongest timbers like sal (Limaye, 1957; Table 2).

Variation in moisture content, density and strength along the wall thickness of bamboo is probably responsible for the adverse behaviour of bamboo in use. Green bamboo experiences irreversible and excessive shrinkage well above the fibre saturation point with only partial recovery at the intermediate stages. This behaviour is linked to collapse. Below the fibre saturation point the behaviour is similar to wood (Kishen et *al.*, 1956). Bamboos dry best under air dry conditions. Rapid drying in kiln may lead to surface cracking and splitting due to excessive shrinkage.

Both round and split bamboos are used as structural components for building houses and other structures. Half-split bamboos, after carefully scooping out the inner nodal portion, have been used as corrugated roofing. Bamboo has been used as a reinforcement for mud walls in rural and tribal areas in many developing countries such as India and Mexico. Glenn (1950) demonstrated its use as reinforcement of cement concrete. Bamboo is reported to yield a strength of 1400 kg/cm^2 in tension as compared to steel which is 4980 kg/cm^2 in cement concrete reinforcement (Purushotham, 1963).

Natural Durability of Bamboo

Although bamboo is one of the strongest structural materials available, it often succumbs prematurely to fungal and borer attack resulting in heavy damage to structural units. Most of the durability estimates are based on full-sized structures. There is not much systematic test yard data available on the natural durability of different bamboo species. The natural durability of bamboo is low and varies between 1 and 36 months depending on the species and climatic condition (Liese, 1980). In tropical countries the biodeterioration is very severe. Bamboos are generally destroyed in about one to two years' time when used in the open and in contact with ground while a service life of two to five years can be expected from bamboos when used under cover and out of contact with ground (Tewari, 1981). Systematic experiments carried out in the test yard indicate that untreated round bamboos belonging to *Bamhusa polymorpha* and *Dendrocalamus strictus* species were destroyed in 19 months by termites and fungi.

Decay in Bamboo

The strength of bamboo deteriorates rapidly with the onset of fungal decay. Enormous quantities of bamboo get degraded during transportation, storage in the forest depots as well as in mill yards due to stain fungi, wood rotting fungi and insects. White rot and soft rot cause more serious damage to bamboo than the brown rot. Split bamboo is more rapidly destroyed than round bamboo (Liese, 1980). The sclerenchymatous fibres of

Table 3. Penetration pattern of different of chemicals in *Dendrocalamus strictus* structural components

Treatment	Metaxylem (vessels)	Protoxylem (vessels)	Metaxylem fibre cap	Phloem fibre cap	Median xylem fibre cap	Parenchyma
Creosote	+++	+++	+++	+++	+++	+++
Wax dye	++	+		+	+	+
$AgNO_3$	++	+++	+++	+++	++	++

+++, heavily penetrated, more than 66% cells show penetration; ++, moderately penetrated, 30-66% of the cells penetrated; +, scarcely penetrated, only 10-30% cells penetrated; -, no penetration, less than 10% of thr sells penetrated

bamboo are attacked by fungi and its strength gets reduced considerably. These fibres are responsible for the mechanical strength of bamboo.

Prophylactic Treatment of Bamboos during Storage

Laboratory and field trials have demonstrated that losses due to fungi and insects can be easily cut down by at least 50 percent if proper treatments are carried out at the time of stacking, even under open storage. The cost of protection varies from Rs. 5 to 10 per tonne (Kumar et *al.*, 1980; 1983).

The following chemicals were found suitable for the prophylactic treatment of bamboos at the coverage rate of 24 litres per tonne.

1. Sodium pentachlorophenate, 1 percent solution.
2. Boric acid + borax (1: 1), 2 percent solution.
3. Sodium pentachlorophenate + boric acid + borax (0.5: 1: 1), 2.5 percent solution.

Sodium pentachlorophenate was not very effective against borer attack, whereas treatment with boric acid and borax resisted the attack of borers but was not as effective against stain fungi. A mixture of these compounds yielded the best results. For protection of structural bamboos (if stored outside), repetition of the treatment after four to six months is desirable for better protection.

Treatability of Bamboo

Bamboos are anatomically different from both hardwoods and softwoods in their mode of growth and tissue organization. The tissue of bamboos is built up of parenchymatous cells and vascular bundles (vessels and thick-walled fibres). The vascular bundles are not uniformly distributed inside the culm. Numerous smaller ones are present towards the outer portion while larger but fewer bundles are found towards the central part of the culm. Bamboo has no radial cell elements like the rays in wood. The outer wall is covered by a thin and hard layer and is less permeable than the inner layer. Due to these differences in anatomical structure, bamboo behaves entirely differently from wood during treatment with preservative.

The vascular bundles play an important role in preservative treatment. The axial flow is quite rapid in green bamboos, because of the end to end alignment of vessels. The degree of penetration decreases as the distance from the conducting vessel increases. The larger vessels (metaxylem) tend to get a larger amount of preservative than the smaller vessels (protoxylem).

Although the anatomical structure of some bamboos has been well-studied, there are not many studies on the flow channels and distribution and location of the preservative chemicals in the different structural parts. Recently, a study was conducted in *Dendrocalanms* strictus using organic and inorganic chemicals to determine the flow paths. The penetration results showed that creosote was better distributed than water soluble inorganic chemicals (Table 3).

Preservative Treatment of Bamboos

Treatment processes found suitable in case of timber (both in dry and green conditions) can also be applied to bamboos. A variety of processes like water leaching, application of paint coating, brushing, swabbing, spraying, dipping, smoking, baking, etc. are practised for the protection of bamboo. These only have a limited effect on the performance. Water leaching and baking result in partial removal of starch which attracts insects. The other treatments do not impart much toxicity because of poor penetration and retention of chemicals.

Table 4. Treatment of green bamboo *Dendrocalamus strictus* by different non-pressure methods (Singh & Tewari, 1979; 1981)

Specimen type	Method	Preservative	Duration	Absorption kg/m^3
Round	Diffusion	ACC 6%	10 days	7.76
Half-split	"	,,		11.16
Round	,,	,,		I0.65
Half-split	,,	,,		IS.53
Round	,,	,,	30 days	IS.65
Half-split	,,	,,		19.77
Round	,,	Boric acid Borax 6%	10 days	7.73
Half-split	,,	,,		11.32
Round	,,	,,	20 days	10.86
Half-split	,,	,,	..	20.16
Round	Osmo-paste diffusion	CCA paste	30 days	10.74
Half-split	,,	,,		14.66
Round	,,	,,	60 days	20.38
Half-split	,,	,,		31.76
Round	,,	ACC paste	30days	12.04
Half-split	,,	,,		18.51
Round	,,	,,	60days	26.25
Half-split	,,	,,		3 1.56
Round	Steam/ quenching	CCA 20%	4 h/OS h	5.26
Half-split	,,	,,		5.84
Round	,,	,,	4 h/48 h	18.34
Half-split	,,	,,	..	30.46

*. *ascertained by chemical analysis*

Methods of Treatment of Bamboos

A comprehensive study on the treatability of bamboo by steeping, sap-displacement, diffusion, open-tank and pressure processes and improvement of treatability by artificial methods was carried out in India. Details of the method of treatment by hot and cold process and pressure process are well known and illustrated in the Indian Standards (Anonymous 1982). In addition, the diffusion process and the modified Boucherie process are most suited for the treatment of green bamboos. The choice of preservative and the method of treatment depends upon the use to which the treated material is to be put and the condition (dry or green) of the material.

Treatment of Green Bamboo

Earlier studies on a number of bamboo species indicated that the treatability of green bamboos with non-pressure methods varied with the species and the modified Boucherie process was the only one which could be recommended with confidence (Narayanmurti & Bist, 1947). The best and simplest process for the treatment of green round and split bamboo is by the diffusion process, wherein the material is submerged in the preservative solution for a sufficiently long time to obtain adequate absorption and penetration. Singh and Tewari (198 1) treated green round and split bamboo *(Dendrvcalamus stric'tus)* by dip diffusion and osmosis processes with ACC and CCA and found that absorption and penetration of chemicals were more in half-split bamboo than in round. Obviously, the higher retention resulted from side penetration rather than through the inner wall which has been reported to be resistant to it by earlier workers (Narayanmurti & Bist, 1947). Moreover. move-

Table 5. Open-tank treatment (hot and cold process) of bamboos with creosote:fuel oil mixture (1:l) (Singh & Tewari, 1979)

Species	Heating time (h)	Absorption (kg/m^3)	
		Round	Half-split
Dendrocalamus strictus	3	54	57
	4	69	72
	6	72	74
Bambusa polymolpha	3	42	45
	4	49	57
	6	67	71

Table 6. High pressure treatment of air-dried bamboo *(Dendrocalamus strictus)* with cresote:fuel oil mixture (1:l) and CCA (Singh & Tewari, 1979)

Preservative	Pressure (kg/cm^2)	Pressure period (h)	Absorption (kg/m^3)	
			Round	Half-split
Creosote	14	1	88	92
	28	1	107	110
CCA 6%	7 (Empty cell)	1	14	18
	7 (Full cell)	1	16	16

ment of ionic solutions has been found to be faster in the tangential direction than in the radial direction across the wall thickness. The results obtained for treatment of green bamboos with different compositions by different diffusion-type treatments are summarized in Table 4. Whereas normal diffusion takes about 10 days to get the required absorption (absorption can be increased by increasing the concentration to 10 percent in case of ACC or CCA type preservatives), osmo-diffusion is quite slow. Moreover, there is wastage of chemicals in the form of paste.

Steam-quenching is perhaps the quickest method to get high retentions in shorter periods. Unfortunately, there is limited data with respect to quenching time on different species of bamboo. However, the trend indicates that it should be possible to get adequate retentions within a short treatment cycle. There is also the possibility of combining pressure treatment with pre-steaming to further reduce the treatment period. The effects of steaming with subsequent preservative treatment on strength reduction in case of bamboo needs to be established.

If the structural requirement needs round bamboos, the Boucherie process is perhaps the best suited method that can be adopted. The bamboos, however, have to be freshly felled (not more than two days old), and for the treatment to be satisfactory, it should be undertaken in the period of the year when the culms are full of sap (Purushotham, 1963). In order to make the treating equipment compact, handy and also for reducing the period of treatment, the modified Boucherie process could be used as given in the Indian Standards (Anonymous 1979). A plant to treat 30-40 bamboos at a time can be easily erected using suitably designed piping, end fittings and a pressure pump. Better distribution of preservative can be achieved if a higher concentration (10%) is used for the initial three to four h followed by a low concentration solution (3-4%) for an equal period, as has been found in the treatment of green poles (Shukla & Gaur, 1976).

Treatment of Dry Bamboos

Dry bamboos can also be treated using non-pressure and pressure methods. However, round bamboos having thin walls are highly susceptible to cracking even when subjected to low pressures of 5-7 kg/cm^2 (Singh, 1976). Since cracking results in strength loss, it is advisable to treat such bamboos by the hot and cold process. A heating period of three to four h with overnight cooling gives

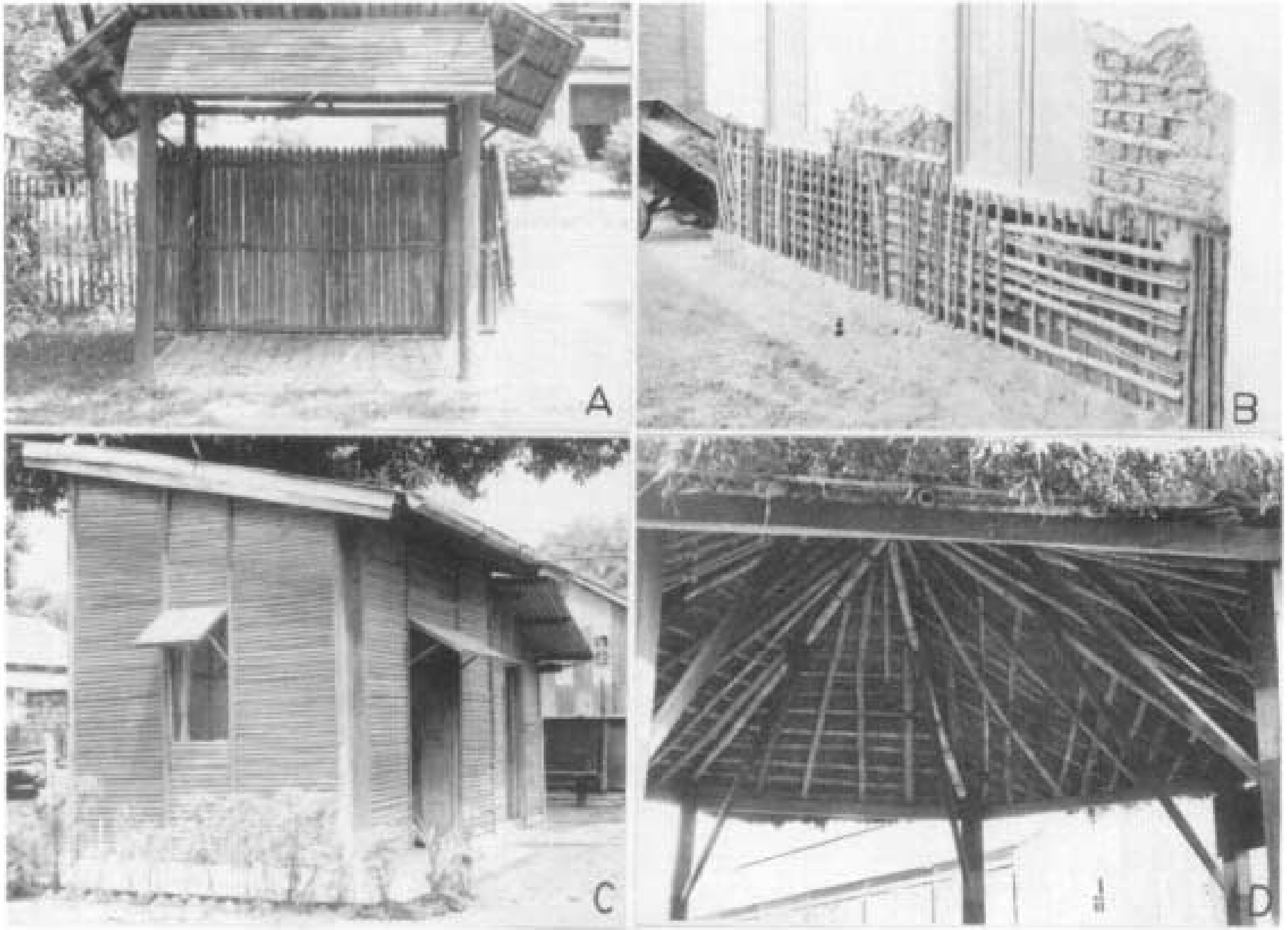

Fig. 1. A-D *A. Half-split bamboo roofing. Treatment with CCA prolonged the life to about 15 years. B. CCA-treated bamboo used for mud reinforcement in the walls failed up to nearly 45 cm from plinth after 20 years. Upper layers were sound even after 27 years. C. CCA-treated half-split bamboo used as exterior cladding for mud walls (present life 33 years). D. CCA-treated round bamboos framework for thatched shed (present life 33 years).*

Table7. Absorption of preservative in air-dried bamboos treated by steeping in 5% CCA (Singh & Tewari, 1979)

Species	Specimen	Duration (days)	Absorption (kg/m^3)
Dendrocalamus strictus	Round	6	9.8
	Half-split	9	11.4
Bambusa polymorpha	Round	6	6.9
	half-split	12	17.9

sufficient loadings for above ground use such as roofing supports, rafters, etc. For higher absorptions as required for ground contact, higher heating periods are necessary (Table 5). Gross absorption in this case falls a bit short of the requirement (Anonymous 1979). Pressure treatment using pressures of the order of 14 kg/cm^2 may be used for treatment of thick-walled bamboos to get adequate loading (Table 6).

For treatment with water-borne preservatives, the steeping method is more suited for round bamboos although the time taken to achieve the desired retention levels is about seven days (Table 7).

Performance of Treated Bamboos

Trials with treated bamboos have indicated varied durability depending upon the actual location of use. CCA-treated bamboos in exposed conditions showed signs of decay after 15 years (Fig. IA). The life span of treated bamboos used for reinforcement in mud was also found to be the same. Interestingly, such damage was noticed up to about 50 cm from the ground level (Fig, 1 B). The upper layers were sound and the damage is attributed to moisture ingress from the ground. The performance in partially exposed and under covered conditions is much better. Practically no damage to CCA-treated bamboo used as exterior claddings in low cost huts and as roofing support for thatched huts was noticed even after 33 years of service (Fig. 1 C, D).

Systematic research work on the durability of preservative treated bamboos was started some years back at the Forest Research Institute, Dehradun. Two species, namely, ***Bambusa polymorpha*** and ***Dendrocalamus*** strictus treated with Copper-Chrome-Arsenic (CCA), Acid-Copper-Chrome (ACC), Copper-Chrome-Boric (CCB) and creosote: fuel oil (50:50) were installed in the test yard in 1985. The results-to-date show the superiority of creosote over other preservatives, although it is too early to comment on the comparative performance of the preservatives on bamboo species as most of the samples are still sound.

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A Workable Solution for Preserving Round Bamboo with ASCU (CCA Type Salts)

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Abstract

It is known that bamboo can be preserved with ASCU (a CCA preservative) using the sap-replacement and pressure treatment methods. The former has the disadvantage of having to complete sap-replacement within a few hours of felling the bamboo. With regards to the latter method, reports from Taiwan suggest that if the septa are drilled through, round bamboos can be treated quite effectively. The disadvantage of doing so is the weakening of the bamboo structure as also considerable loss of preservative that remains trapped in betwteen the septa. This paper reports how hollow bamboo can be preserved quite easily and effectively under pressure if notched in a pattern. This neither reduces the bamboo's strength when used in compression or bending nor does it pose any problem in the proper distribution of ASCU.

Introduction

The use of bamboo in construction of buildings has for long been established in tropical countries. Bamboos have been used either in the round form or split and matted form. The biggest limitation so far has been that bamboos are destroyed very easily by fungi and termites. This paper examines a preservative system, which we have established as being workable and which retains the strength of round hollow bamboos.

In most parts of the world where bamboo is being used for buildings, such as India, Sri Lanka and in the far-eastern countries, treatment with CCA salts has been shown to be most effective. However, owing to the difficulty in penetration of the preservative through the outside surface, there has been a problem in the treatment of round bamboo whereas splits or half-rounds can be easily treated by dipping or by pressure treatment using CCA salts. Round bamboos are usually treated by the sap-replacement method which has the limitation that treatment has to be done within a few hours of felling. In many cases, this is neither practicable nor possible.

Pressure treatment of round bamboo has been done in Taiwan and other places by drilling the septa right through. It then accepts preservative chemicals both from inside and outside quite readily. However, this method also has its limitations. Drilling through the septa is possible only to lengths of 2 to 2.5 m and sometimes up to 3 m. After careful testing of retention and penetration of the preservative, this method has been found to be largely acceptable.

The Notched Method

The notched method is carried out by drilling holes or notches between septa. It allows the wood preservative to enter into the bamboo between the septa when under pressure. After pressure treatment is over and if the bamboos are left for some timein the cylinder, the trapped preservative solution drains out of it. These notches or holes are so small that there is no decrease in the strength of bamboo. They are made with power saws or electrical drills. There is also no restriction on the length of the bamboos used.

The bamboos were treated with 5 percent ASCU solution (CCA salt) using a vacuum/pressure cycle of 30 minutes and pressure of 10 kg/cm'. The final vacuum was allowed for about 30 minutes to remove as much drip as possible. The bamboos were weighed before and after treatment to arrive at the amount of loading of preservative. It was observed that loading could be controlled between 12 and 27 kg/m^3. The entire cross-section was preserved.

Conclusion

A simple and effective method to treat hollow bamboo with ASCU in the round form using a pressure/vacuum cycle has been tested and found to be suitable.

A Simple and Cheap Method of Bamboo Preservation

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Abstract

The utilization of bamboos for constructing houses is about 30 percent in the rural areas of the provinces of Yogyakarta, Central and Eust Java. and Bali. Most of' the people preserve bamboo by immersing them in their fish ponds or water canals. This method effectively prevents powder post beetle infzfestation in bamboo species with lower starch contents such as Ginantochloa apus and G. utter. In comparison, Banrbusa vulgaris with its high starch content, requires preservation treatment. Simple and cheap preser- ovation methods were studied and the results are discussed in this paper.

Introduction

Bamboo is one of the important constructional materials used in Indonesia, mainly in the rural areas of Java and Bali. It is grown by the people in their homeyards as a component of their "pekarangan" or agro-forestry system. The utilization of bamboos for construction is about 30 percent in the rural villages of the provinces of Yogyakarta, Central and East Java, and Bali. It is mostly used for rafters and ceiling frames (Anonymous 1977, 1982).

Compared to timber, bamboos are highly susceptible to bio-deteriorating agents and preservation treatment is necessary (Liese, 1980). The powder post beetles, *Dinoderus minutus* and D. *brevis* are the most important insect borers which attack bamboo products (Sulthoni, 1988). Since bamboo is cheap and easily available in the villages, the preservation treatment should also be simple and inexpensive. The rural Javanese simply immerse the bamboo in fish ponds or water canals (traditional preservation) for several weeks before it is put to use. This method is effective with bamboo species such as *Gigantochloa apus* and G. *utter* that have lower starch contents. For *Bambusa vulgar-is* which has a high starch content, the traditional method is ineffective (Sulthoni, 1985, 1988). To increase the resistance of B. *vulgaris* to borers and extend its service life, effective preservation methods need to be developed.

Studies on Bamboo Preservation

Simple methods such as immersing the dry bamboo in water, copper sulphate or diesel oil and adopting the modified Boucherie or "capping method" for freshly cut round bamboos were examined.

Traditional Treatment

In this method the bamboos are immersed in water for a period of one, two and three months. After this, they are kept outdoors under cover for one year to evaluate the extent of damage brought about by the powder post beetle. Two bamboo species with considerably high starch contents, *Bambusa vulgaris* and *Dendrocalamus asper,* were studied. Two culms each from three different monthly fellings were used as samples with 16 test specimens per culm for the treatment. The results showed (Table 1) that immersion of B. *vulgaris* in water did not eliminate borer attack.

Cold Soaking and Stake Test

This experiment was conducted to study the effect of soaking bamboo in seven percent copper sulphate solution or in diesel oil. The treated small stakes were of 5 x 46 cm split air-dried bamboo specimens. Fifteen samples each were made from 10 culms representing the whole length of each culm. The cold soaking period was seven days. The treated samples were put in ground contact in the open for one year.

Table 1. Intensity of damage by powder post beetle on water-immersed bamboo after keeping outdoors under cover for one year

Immersion treatment	Bore holes per 25 x 5 cm test specimen.					
	B. vulgaris			*D. asper*		
	Months of immersion			Months of immersion		
	1	2	3	1	2	3
Control	37.4	37.4	37.4	6.4	6.4	6.4
Running water	8.0	1.0	0.7	0.0	0.0	0.0
Stagnant water	9.0	2.7	4.7	0.0	0.0	0.4
Mud	17.0	4.6	4.9	0.7	0.6	0.6

Table 2. Intensity of damage (in % volume) by termite attack on 7 percent copper sulphate and diesel oil treated bamboos after one year in ground contact

Preservation treatment	*B. vulgaris*	*D. asper*
Control	72.3	30.8
Copper sulphate	0.0	0.0
Diesel oil	0.0	0.0

Table 3. Intensity of damage by powder post beetle attack on treated split and round bamboos

Preservation treatment	Average borer attacks per test specimen (number of holes)			
	B. vulgaris		*D. asper*	
	Split	Round	Split	Round
Control	9.77	119.30	2.17	19.74
Copper sulphate (7%)	0.40	20.74	0.04	1.20
Diesel oil	0.64	0.0	0.30	0.0

It is clear from Table 2 that both copper sulphate and diesel oil effectively prevented termite attack. Diesel oil treatment, however, proved to be much cheaper. It costs only about 16 000 rupiahs (about US$ 10) to treat 1 m^3 of bamboo as compared to 96 000 rupiahs (US$60) for copper sulphate treatment.The cost can even be lower if the preservatives are re-used.

Cold Soaking and In-service Test

Cold soaking for one week of the air-dried bamboo samples was carried out to study the efficacy of seven percent copper sulphate and diesel oil treatment for protection against borer attack.

Four culms each of B. vulgaris and D. asper were cut for each treatment and then air-dried in their round form. Fifteen pieces of 25 cm length each of split and round forms were prepared from each culm of the two bamboo species. The split test specimen was of 5 cm width. The treated samples were then installed randomly on stacks in the open but under roof cover and the borer incidence recorded after one year. From Table 3 it can be seen that both copper sulphate and diesel oil have a considerable effect on controlling the beetle attack.

In the present study diesel oil is more effective and significantly cheaper than copper sulphate. since the cost of treatment per m^3 is 38 234 rupihas as compared to 137 800 rupiahs for copper sulphate.

Capping Method

This method was tried on freshly cut round bamboo. In the Boucherie method, the penetration of preservative is by low pressure, while in capping it is by gravity. The bamboo samples were hung

Table 4. Intensity of damage caused by termite attacks on capping method-treated bamboos after eight months (July 1987-February 1988) in ground contact

Preservative treatment	Average damage (% volume) per test specimen	
	B. vulgaris	*D. asper-*
Control	20.9	10.7
Copper sulphate (7%)	0.0	1.2
Diesel oil	0.0	0.0

upright, bottom up, and the upper end of the bamboos connected with a tube to the preservative liquid tank. Gravitational pull forces the preservative liquid to penetrate the bamboo tissues through its lower end thereby replacing all the aqueous cell contents in seven days. To evaluate the retention of the preservative in the treated bamboos, spectrophotometric analysis of the residual drips which came out from the exit end was done. The treated bamboo test specimens were then placed in ground contact for one year to assess the efficacy of the treatment against termites. The preservatives used in the study were seven percent copper sulphate solution and diesel oil.

Six culms each of B. ***vulgaris*** and *D. asper-* were converted into test specimens of 46 cm length. The 45 test specimens of each bamboo species were randomly chosen and represented the bottom, middle and top of the culms.

In the capping method, both copper sulphate and diesel oil treatment were effective in controlling termite attack. Copper sulphate worth 81 200 rupiahs was used per cubic meter of the treated bamboos. This method would, however, be more difficult to use by the people.

Discussion

The traditional method of preservation is useful for certain bamboo species with low starch contents against attacks from insect borers. However, it is not recommended against termites.

The soaking method using diesel oil seems to be the most viable alternative, as it effectively prevents both borer and termite attacks and is cheaper than copper sulphate. This preservation method is recommended for improving the quality of furniture and handicrafts made from bamboo species by preventing attack by insect borers or termites.

Acknowledgements

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Storage Pests of Bamboos in Kerala*

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Abstract

About 12 species of insects, mostly beetles were recorded to cause damage to stored reeds and bamboos in Kerala. Among the various insects recorded, an unidentified subterranean termite and two species of beetles, Dinoderus minutus and D. ocellaris (Bostrychidae), were the most serious borers. Observations on the seasonal incidence, general characteristics as well as the nature of attack caused by these beetles are given.

Introduction

Bamboos are extensively used in Kerala as poles, for making mats, baskets and handicrafts as well as in the paper and rayon industries. Besides the large-diameter bamboos, the bamboo reed *(Ochlandra travancorica)* is extensively used in the paper and rayon industries. However, infestation by various storage pests render the storage of bamboo and bamboo products rather difficult. Although several studies have been conducted on the storage pests of bamboos in India and methods for controlling them outlined (Beeson, 1941; Gardener, 1945; Joseph, 1958), specific information on their relative pest status as well as seasonal occurrence in different regions is not available. This information is essential for the development of appropriate pest management strategies for protecting stored reeds and bamboos. The several requests for the protection of stored reeds and bamboos in the storage yards of several industrial units, particularly of the Kerala Newsprint Project (KNP), Mavelloor, prompted us to undertake the present study. Since reeds constitute a major part of the raw materials stored in KNP, this study was mostly centered around the storage pests of bamboo reeds, although information was also collected on the insect pests of stored bamboos.

Materials and Methods

Information on the storage pests of reeds was collected by making monthly observations at the KNP storage yard at Mavelloor from August 1981 to September 1982. Large stocks of reeds were being stored in this yard since June 198 1. Regular observations were also made on small bundles of reeds stacked in the Kerala Forest Research Institute (KFRI) campus at Peechi every month over 18 months (from October 198 1 to March 1983). In addition to these regular observations, stocks of reeds and reed products were examined wherever possible.

Observations and Discussion

Altogether 12 species of insects were found to attack stored reeds and bamboos in Kerala (Table 1). This included an unidentified species of subterranean termite and 11 species of beetles. During this study several species of termites were found to damage stored reeds and bamboos in many places. Usually the feeding takes place inside the culm leaving the outer layer intact. Termite damage must be considered as a major threat that affects the successful storage of reeds and bamboos in Kerala.

The beetles recorded in this study include three species each of the families Bostrychidae, Curculionidae and Brenthidae and one each of the families Cerambycidae and Lyctidae. All the beetles recorded, excepting *Dinoderus minutus* and *D. ocellaris,* caused only minor damage. The curculionids and anthribids mostly tunnelled through the inter-nodal septa as well as the walls of the bamboo culms. The weevils, namely, *Sipalus hypocryta*, *Sipalinus gigas* and the anthribid *Phloeobius alternans* and *Eucorynus crassicornis* caused the maximum damage. Although infestation by these insects resulted in extensive cavities. it rarely affected its structural stability. These in-

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Table 1. List of insects associated with stored reeds and bamboos in Kerala

Insect	Reed/bamboo	Locality	Nature of damage
Order Isoptera			
1. Unidentified termite	Reed	Mavelloor	Feeds from within the culm leaving the outer layer intact. Occasionally causes major damage.
Order Coleoptera			
Family Bostrychidae			
2. *Heterobostryrhus aequalis* Wat.	Reed	Mavelloor	Attack initiates through the cut ends. Galleries longitudinal. Minor pest.
3. *Dinoderus minutus* Fb.	Reed & bamboo	Several places in Kerala	Cause complete deterioration of affected culms. Major pest.
4. *D, ocellaris* Steph.			
Family Lyctidae			
5. *Minthea rugicollis* Walk	Reed	Mavelloor	Minor pest occasionally causing damage to various finished products.
Family Curculionidae			
6. Myocalandra exarata Boh.	Reed	Mavelloor	Reported as a pest of bamboo. Not likely to attack stored bamboos.
7. *Sipalus hypocryta* Boh.	Bamboo	Several places in Kerala	Minor pest in culms.
8. *Sipalinus gigas* Fb.	Bamboo		
Family Byrenthidae			
9. *Eucorynus crassiconis* Fb.	Bamboo		
10. *Phloeobius lutosus* Jord.	Bamboo		
11. *P alrernans* (Wied.)	Bamboo		
Family Cerambycidae			
12. *Diboma posticata* Gah.	Bamboo		

sects were never found to cause any serious problem in the storage yards. *Myocalandra exarata,* another weevil recorded here is known to be a pest of green bamboos (Beeson, 194 1), although on one occasion it was collected from stored reeds at Mavelloor. It is probable the infestation might have occurred prior to their extraction and the beetle might have developed in the extracted culm. *Diboma posticata,* the cerambycid collected in this area, was found to make longitudinal tunnels in the walls of culms, but the damage caused was negligible.

Among the small borers, the population of *Heterobostrychus aequalis* (Bostrychidae) was found to build up in stored reeds at Mavelloor. However, no major build up was noticed during the period of study. Infestation by *Minthea rugicollis* (Lyctidae) was observed mostly in finished bamboo and reed products where they occasionally caused serious damage.

Among the various storage pests recorded here. *Dinoderus* spp. (Bostrychidae) was the most prevalent as well as the most harmful to reeds and bamboos. Detailed observations were made on this insect since build up of this species was frequently encountered on the reed stacks at Mavelloor.

Of the three species of *Dinoderus* known to attack bamboo in India, D. *minutus* was by far the most common and was found in stacked reed as well as reed products throughout Kerala. While *D. minutus* was encountered every year during 1977-1983, D. *ocellaris* was found only in 1982 at Mavelloor in June-July in stacked reeds harvested from Konni. The infestation was mainly on comparatively fresh stacks of reed and both *D. minutus* and *D. ocellaris* were seen to occur as a mixed population with D. ocellaris outnumbering the former. The infestation was heavy and it appeared like a major outbreak. Adult beetles of both species could be seen boring on reeds along the sides of the stack, Dead beetles were noticed in the accumulated dust.

General Characteristics of *Dinoderus* Infestation

The most striking feature of *Dinoderus* infestation brought out by observations over several years *is* that the incidence of their infestation is highly unpredictable. Infestation has been noticed practically in all the months of the year, at one place or the other, but not continuously in the same place. The most intense build up of their populations was recorded in 1982 during the months of May, June and July, at Mavelloor. This was partly due to the availability of large stocks of reed in the yard and the involvement of both species of Dinoderus. This incidence was apparently not related to season, but rather to the quality of the reed. It has also been observed that infestation in a given locality is prevalent only during certain periods. For example, no infestation occurred in reed stacked at Nilambur during February 1981 when a similar project was underway (Gnanaharan et *al.*, 1982), although previously infestation had been noticed in the same yard.

Often within a storage yard, infestation was confined only to some of the stacks. Some of the infested stacks contained fresh cut reeds, yet older stacks were also attacked, thereby showing that the freshness of the material was not the sole factor. The bottom ends of the reeds were more heavily attacked than the other portions. Heaps of dust accumulated around the infested stacks particularly along their sides. Often, the intensity of infestation was greater towards the periphery of the stacks, especially the cut ends, through which the beetles bored their way, but declined sharply towards the interior. It was generally observed that infestations at particular sites declined in intensity and almost disappeared in about two to three months after their first appearance, although this was not always the case.

Kinds of Finished Products Attacked by *Dinoderus*

In addition to stacked whole reed culms. finished products made of reed or bamboo were often damaged by Dinoderus. These included reed mats stored in godowns (Angamaly) and reed or bamboo baskets stored in retaiI shops and houses (Trivandrum, Pudukkad, Peechi, Trichur). Reed culms cut and stored at the site of extraction were not generally infested although a few instances of light attack by *D, minutus* were observed in some places (Kollathirumedu, Sholayar). Split-bamboo roofing of an outdoor Orchidarium within the KFRI campus at Peechi was found heavily damaged by *Dinoderus* in January 1983. Bamboo or reed poles used in construction of field sheds were often found infested. All infestations recorded in the case of finished products were caused by D. *minutus.*

Conclusion

Although a number of insects are found to attack stored reeds and bamboos, the subterranean termites and *Dinoderus* beetles are capable of causing serious damage. Control of these insects will give sufficient protection to stored reeds and bamboos in Kerala.

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PROCEEDINGS OF
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PHYSICAL PROPERTIES OF BAMBOOS/ BAMBOO PRODUCTS

Why the Sudanese of West Java Prefer Slope-inhabiting *Gigantochloa pseudoarundinacea* to those Growing in the Valley

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Abstract

The physico-mechanical properties of the culm such as specific gravity, hending and tensile strength, anatomical properties such as fibre dimensions and the fibrovascular bundle frequency of Gigantochloa pseudoarundinacea growing on hill slopes and valleys in West Java were compared. The results show that the preference of' the Sundanese for- slope-inhabiting bamboo is scientifically justified because the specific gravity, bending and tensile strength of the former are higher than those growing in the valley.

Introduction

The use of bamboo as housing material is well established in the rural areas of many tropical countries where bamboos grow abundantly. In West Java (Indonesia), *Gigantochloa pseudoarundinacea* (Steud.) Widjaja is the most useful species of bamboo for making pillars, roofings and walls of village houses. The Sundanese who live in the area believe that the best quality bamboo for housing purposes should be harvested from the slope inhabiting groves rather than those growing in the valley. Ueda (1960) reported that the quality of bamboo was influenced by environmental factors, especially, the soil condition.

The present study was undertaken to determine the interrelationship between the physico-mechanical properties of *Gigantochloa pseudoarundinacea* growing in different habitats to determine whether the Sundanese practice had any scientific justification.

Material and Methods

The present study was conducted on populations of G. *pseudoar-undinacea* growing in Cibitung village near Bogor in West Java. This hilly area lies at an altitude of 500 m with an annual rainfall of about 4200 mm and has groves of G. *pseudoarudinacea* both on the hill slopes and in the valleys.

Representative sections of the basal (3rd and 4th internodes), middle (13th and 14th internodes) and top (23rd and 24th internodes) parts of the culms were sampled. The standard test procedure as laid down by the American Standard for Testing and Materials (ASTM) D 143-52 (1972) was followed with some modifications for determining the physical and mechanical properties of the culms using the Baldwin instrument (to measure tensile strength) and Amsler 6000 (to measure bending and tensile strength). The fibre length and wall thickness were determined by examining microscope slide preparations obtained by macerating pieces of culms in 50 percent $HN0_3$ at 50 C for 10 minutes. After washing, the preparations were stained with 1 percent methyl green in 10 percent acetic acid and mounted in glycerine.

Results and Discussion

Physical and Mechanical Properties

It can be seen from Table 1 that the specific gravity of the slope inhabiting bamboo is higher than the ones growing in the valley and is inversely correlated with the moisture content (Panshin & de-Zeeuw, 1970). Also, the results showed that

Table 1. Average physical, mechanical and anatomical properties of *G. pseudoarundinacea*

Locality	Position of the culm	Fibre length (mm)	Fibre Wall thickness (mm)	Frequency of fibrovascular bundle (%)	Internode sp.gr.	Node sp.gr.	Modulus of rupture (kg/cm^2)	Modulus of elasticity (kg/cm^2)	Tensile strength (kg/cm^2)
Hill slope	Basal	3.17	24.55	42.12	0.547	0.75	1824.0	269380	1705.58
	Middle	3.27	26.35	46.56	0.607	0.78	1934.1	285940	1929.33
	Top	2.78	37.97	52.06	0.675	0.78	2072.7	273620	1702.33
Valley	Basal	2.75	26.21	40.85	0.500	0.65	1716.0	194400	1288.35
	Middle	3.22	29.09	43.92	0.580	0.69	1790.2	195220	1673.08
	Top	3.00	34.55	47.07	0.617	0.74	2019.2	199680	1521.02

Table 2. Correlation matrix of physical, mechanical and anatomical properties

	Fibre length (mm)	Fibre wall thickness (mm)	Frequency of fibrovascular bundle (%)	Internode sp.gr.	Node sp.gr.	Modulus of rupture (kg/cm^2)	Modulus of elasticity (kg/cm^2)	Tensile strength (kg/cm^2)
Fibre length	1.000							
Fibre wall thickness	-0.478	1.000						
Frequency of fibrovascular bundle	-0.197	0.860	1.000					
Internode sp.gr.	-0.010	0.819	0.977	1.000				
Node sp.gr.	0.286	0.357	0.727	0.773	1.000			
Modulus of rupture	-0.118	0.809	0.937	0.936	0.809	1.000		
Modulus of elasticity	0.246	-0.029	0.434	0.434	0.841	0.440	1.000	
Tensile strength	0.706	-0.028	0.434	0.546	0.799	0.418	0.772	[illegible]

specific gravity increased from bottom to top, as recorded by Liese (1987).

There is also an increase in the modulus of rupture (MOR) towards the top of the culm (see also Limaye, 1952). However, MOR of bamboo culms from the two habitats did not differ significantly. On the other hand, the modulus of elasticity (MOE) and tensile strength of bamboo culms from one habitat were markedly different from the other (Table 1). The greater tensile strength of the slope-inhabiting bamboo may be due to the higher specific gravity they possess.

Anatomical Properties

Some anatomical characteristics of G. pseudo-***arudinacea*** are presented in Table 1. There is no appreciable difference in the fibre length in relation to the point of sampling along the length of the culm and those growing in different habitats. The wall thickness of the fibre is correlated with the height of the culm. Itoh and Shimaji (198 1) showed that lignification takes place from the bottom to the top of the culm. As the lignification is less at the top, the wall thickness is more. There is, however, no correlation of the wall thickness of the fibre with the habitat.

Our study shows that the fibrovascular bundle frequency increases towards the top of the culm as also observed by Espiloy (1987). However, there is no notable difference in the frequency of the fibrovascular bundles in relation to the habitat of the bamboo.

When these anatomical features were compared with the physical and mechanical properties of G. *pseudoarundinacea* it was noted that the wall thickness of the fibre, the modulus of rupture and the specific gravity show positive correlation with the habitat (r = 0.988, 0.936 and 0.841, respectively). Table 2 shows that the fibre length has a positive correlation with the tensile strength, whereas the wall thickness of the fibre is linked with the frequency of the fibrovascular bundle, specific gravity of the internodes and the modulus of rupture. The modulus of elasticity is positively correlated to the tensile strength and the specific gravity of the bamboo nodes.

Conclusions

The study showed that the slope-inhabiting *Gigantochloa pseudoarundinacea* has a higher specific gravity, modulus of elasticity and tensile strength than the one growing in the valley. The present study supports the Sundanese practise of prefering the slope inhabiting groves to the ones from the valley bottom. Further investigations are necessary to confirm whether the findings of this study are valid for other species of bamboo growing is different habitats.

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Comparative Strengths of Green and Air-dry Bamboo

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Abstract

A comparative study was conducted on the strength properties of six species of green and air-dry bamboo of Indonesia. The results show that like in woud, there is a general increase in strength when bamboo is dried from the green to the air-dry condition. An exception is Bambusa vulgaris, in which all the strength parameters tested decreased from the green to the air-dry condition. This seemed to be caused by an early attack oj this species by the powder post beetle, which weakened its strength. The increase in strength from the green to air-dry condition of bamboo was much lower than that of wood. For this reason there is not much risk in using green bamboo for construction purposes us far as strength is concerned.

Introduction

Bamboo is an important and cheap raw material abundantly available and widely utilized in Indonesia. It occurs in both natural and man-made forests. It is also planted in rural areas in the islands of Java and Sulawesi. Of the about 30 species of bamboo that grow in Indonesia, only 13 are cultivated in rural areas *(Bambusa bambos, B. multiplex, B. spinosa, B. vulgar-is, Dendrucalamus aspel; Gigantochloa apus, G. hasskarliana, G. nigrociliata, G. verticillata, Phyllostachys aurea, Schizostachyum blumei, S. brachycludum* and *S. zollingeri;* Hildebrand, 1954).

In the rural areas bamboo is often utilized in the green condition for construction purposes. The present study was conducted to determine whether there is any difference in strength between green and air-dry bamboo. For timber it has been established that below the fiber saturation point, the strength of wood increases with decrease in moisture content.

Materials and Methods

The following three-year-old bamboo species growing in the village of Degolan, near Yogyakarta were selected: *Bambusa arundinacea, B. vulgaris, Dendrocalamus asper, Gigantochloa apus, G. atter-* and *G. verticillatu.* Three culms of each species were selected and felled. Each culm was then cut into three equal parts: bottom, middle and top. These specimens were then tested in both green and air-dry condition for moisture content, bending strength, maximum crushing strength. tensile and shear strength.

Moisture Content

Moisture content was determined by oven-dry method on two sizes (see Janssen. 198 1) of the samples - unsplit round specimens of 2.5 cm length x diameter x thickness of the bamboo culm and split specimens of 10 x 5 cm x thickness of the culm.

Bending Strength (Modulus of Rupture)

Here also, specimens were tested in round and split forms. The length for round specimens was 76 cm if with nodes and 30 cm if without nodes. For split specimens, the size was 30 x 2 cm x culm thickness, with or without nodes. Tests were carried out using the Baldwin Universal Testing Machine (UTM) with a span of 70 cm and 28 cm for specimens of 76 cm and 30 cm length, respectively.

Compression Parallel to Grain (Maximum Crushing Strength)

Compression parallel to grain tests were made on two specimens; 10 cm length for the unsplit round bamboo with and without nodes and 3 cm x 1 cm x culm thickness for split specimens.

Tensile Strength

Tensile strength parallel to grain was determined using specimens of size 30 cm x 4 cm x thickness of the culm. The shape and size of the specimens prepared were such that they were narrowed at the center to a width of 1 .O cm. A special

Table 1. Average moisture content (%) of six bamboo species

s	Green				Air-dry			
	Pl	P2	P3	Mean	Pl	P2	P3	Mean
sl	48.5	38.5	31.6	39.5	15.7	15.6	15.2	15.5
s2	51.7	40.4	39.9	40.0	17.2	17.1	16.9	17.1
s3	76.0	53.3	36.0	55.1	14.7	16.8	13.6	15.0
s4	79.0	49.6	34.4	54.3	16.0	15.0	14.3	15.1
s5	94.2	71.8	50.9	72.3	14.1	14.5	14.7	14.4
S6	67.5	50.5	43.9	54.0	15.4	15.3	14.4	15.0
Mean	69.5	50.7	34.5	52.5	15.5	15.7	14.9	15.4

grip designed for this test was used in the UTM.

Shear Strength

Shear strength (parallel to grain) was determined on two different specimens of size 8 cm x diameter x culm thickness for round unsplit bamboo and 4 cm x 5 cm x culm thickness for split specimens. A special jig was used to carry out the tests.

Analysis of Data

The following notations were used in the study:
Species (S): Sl to 56 refer to *Bambusa arundinacea, B. vulgaris, Dendrocalamus asper; Gigantochloa apus, G. atter-* and *G. ver-ticillata,* respectively.
Position (P): Pl to P3 indicate bottom, middle and top portion of the culm, respectively.
Nodes (N): Nl indicates specimens with nodes and N2 to those without nodes.

A 6x3x2(x2) factorial experiment with three replicates under the completely randomized design was used.

Results and Discussion

Moisture Content

The moisture contents of green and air-dry bamboo are presented in Table 1. Analysis of variance of the data showed that the species, position of the specimen in the culm and dimension of the specimen, all have a highly significant effect on the moisture content of the bamboo.

The moisture content of green bamboo varies from 39.5 for Sl to 72.3 percent for S5 (Table 1). This variation might be due to differences in some inherent factors such as structure and chemical composition, and certain external factors such as site, climate, etc. The variation in air-dry moisture content between species, however, is small (Table 1).

Variation in moisture content from the bottom to the top of the culm shows a decreasing trend for green bamboo (Table 1). This could be due to the increased amount of parenchyma found at the bottom of the culm (Liese, 1980). In comparison, the air-dry moisture content does not vary greatly from the bottom to the top of the culm (Table 1).

Variation in moisture content is also seen between round and split green specimens (49.3 and 57.1 percent, respectively; Table 2). In the air-dry condition, the split specimens tend to have a lower moisture content.

Bending Strength

In this paper only data on the modulus of rupture (MOR) are presented (Table 3). Analysis of variance shows that moisture content (green or air-dry) and species have a highly significant effect on the bending strength of bamboos whereas the presence of nodes does not significantly affect bending strength.

Table 3 shows that, in general, there is an increase in bending strength from the green to the air-dry condition. However, this general trend does not hold good for all the species. Exceptions are *Bambusa vulgaris* and *Gigantochloa apus.*

Assuming that the fibre saturation point of bamboo is 20 percent (Liese, 1980), the increase in bending strength from green to air-dry condition is 0.05 percent per one percent decrease in moisture content. This value is lower than that of wood which is approximately four percent per one percent decrease in moisture content (Panshin & de Zeeuw, 1970).

Compression Parallel to Grain

The data on maximum crushing stress are pre-

Table 2. Variation in average moisture content (%) of round and split bamboo

Shape of sample	Moisture content	
	Green	Air-dry
Round	49.3	16.2
Split	57.1	14.5
Mean	53.2	15.4

sented in Table 4. Analysis of the data shows that moisture content (green and air-dry) and species have a marked effect on the maximum crushing stress and the presence of nodes does not significantly affect it. It can be seen from Table 4 that there is an increase in maximum crushing stress from the green to the air-dry condition with the exception of B. vulgar-is.

By assuming that the fibre saturation point of bamboo is 20 percent (Liese, 1980), the increase in crushing strength from green to air-dry condition is 4.9 percent per one percent decrease in moisture content. This value is lower than that of wood which is approximately six percent per one percent decrease in moisture content (Panshin & de Zeeuw, 1970).

Tension Parallel to Grain

Analysis of variance of the data on maximum tensile stress shows that moisture content and species do not have any significant effect on the tensile strength of bamboo. Table 5 shows that there is an increase in tensile strength of bamboo from an overall mean of 29776.1 N/cm^2 when green, to 3 1530.5 N/cm^2 when air-dry. An exception is, however, found in B. vulgaris.

By assuming that the fibre saturation point of bamboo is 20 percent (Liese, 1980), the increase in tensile strength from green to air-dry condition is 1.3 percent per one percent decrease in moisture content.

Shear Parallel to Grain

An analysis of the data in Table 6 shows that there is significant difference among species and the presence of nodes does not have a significant effect on shear strength. It can be seen that there is an increase in tensile strength from an overall mean of 800.5 N/cm^2 when green, to 824.0 N/cm' when air-dry (Table 7). An exception is found in B. vulgaris in which shear strength decreases when air-dry.

By assuming that the fiber saturation point of bamboo is 20 percent (Liese, 1980), the increase in crushing strength from green to air-dry condition is 0.65 percent per one percent decrease in moisture content.

Table 3. Average MOR (bending strength) of six bamboo species (N/cm^2)

N	S	Modulus of rupture							
		Green				Air-dry			
		Pl	P2	P3	Mean	Pl	P2	P3	Mean
	s1	8578.4	7661.1	11027.0	9088.9	9160.8	7949.2	9512.4	8874.1
	s2	10028.3	10969.1	10993.6	10663.7	10100.7	7 140.9	7759.0	8426.6
Nl	S3	6873.1	8097.8	9495.1	8155.3	10695.6	9433.9	10875.4	10336.0
	s4	10113.1	10824.0	9673.8	10203.6	8421.2	8326.8	9559.3	8750.8
	s5	8799.0	8809.3	10810.3	9472.9	11767.2	11328.4	12765.4	11953.7
	s6	8104.0	10946.7	8642.6	9231.1	8692.8	11217.1	8023.1	9411.3
	(Mean)				9469.3				9625.4
	s1	5893.5	7 158.9	9269.3	7440.6	7060.5	8329.1	90 13.4	8134.3
	s2	9737.9	9579.4	9466.8	9594.7	6673.3	8161.5	7693.9	7558.8
N2	S3	6392.9	9934.7	11577.6	9301.7	7214.5	7398.9	8917.0	7843.5
	s4	6148.8	8187.6	7103.8	7 146.8	6850.7	8435.0	7087.3	7493.4
	s5	6134.1	8054.5	9940.7	8043.1	7987.3	9686.5	10626.9	9433.6
	s6	6528.8	7203.7	6760.1	6830.9	7763.1	6881.8	6893.5	7 197.0
	(Mean)				8059.6				7943.4

Table 4. Average maximum crushing stress of six species of round bamboo (in N/cm2)

N	s	Green			Air-dry		
		Pl	P2	P3	Pl	P2	P3
	s1	2335.3	2874.5	3850.9	3879.8	3519.0	4988.9
	s2	2953.7	3 102.9	3411.7	2523.8	2868.8	2070.2
Nl	s3	1462.7	2453.3	2942.7	2 155.5	3043.4	4261.1
	s4	2173.6	2372.0	2650.4	2729.8	3654.8	4864.7
	s5	2477.0	2580.9	2797.7	3287.5	3912.6	3098.6
	s6	1675.2	2167.5	3309.2	2163.4	4136.0	4424.5
	s1	2 143.3	3036.4	3731.5	2838.3	3778.9	43 10.9
	s2	2969.3	3371.6	3340.1	2939.1	2660.9	1734.4
N2	s3	1801.8	2480.9	3232.2	2524.9	2955.3	4174. I
	s4	2 144.7	2299.6	2599.1	3417.0	3366.5	3389.1
	s5	2352.7	2723.2	3153.6	3469.9	3418.8	4023.1
	s6	1649.4	2233.2	3251.3	2202.4	3727.9	3732.0

Table 5. Average maximum tensile strength of six bamboo species (N/cm2)

S	Green				Air-dry			
	PI	P2	P3	Mean	Pl	P2	P3	Mean
s1	34731.9	32665.2	33913.2	33770.2	28156.3	25374.8	23495.4	25675.5
s2	29352.0	3 1853.7	43254.3	34820.1	28646.2	27316.1	30277.6	28746.7
s3	30224.3	26830.3	28434.3	28496.4	96555.2	29827.4	29365.5	51916.1
s4	28045.5	30258.2	29927.7	29410.5	30750.7	27907.7	3 1016.4	29891.7
s5	29989.8	27963.9	27309.5	28421.1	33151.6	29788.7	24706.2	292 15.6
s6	21009.5	2468 1.8	25523.1	23738.2	21913.7	24538.7	24760.7	23737.8
(Mean)				29776.1				3 1530.5

Conclusion

A comparative study on moisture contents and strength properties of six species of green and air-dry bamboo show that there is a general increase in bending, compression, tensile and shear strengths from the green to air-dry condition of bamboo. *Bambusa vulgaris* shows opposite results; all the air dry strengths measurements being consistently lower than when green. It is suspected that this may be related to an early attack of this species by powder post beetles during the drying of the specimens (see Sulthoni, 1988). The increase in strength from the green to air-dry condition was much lower than that in wood. For this reason there seems to be little risk involved in using green bamboo for construction purposes as far as strength is concerned.

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Table 6. Average shear strength of six species of round bamboo (N/cm')

N	S	Green			Air-dry		
		PI	P2	P3	PI	P2	P3
Nl	s1	886.7	924.7	1078.6	907.0	986.7	1260.1
	s2	333.8	1060.9	1036.5	727.4	727.8	536.6
	s3	581.2	642.1	864.1	599.2	609.3	967.5
	s4	671.9	803.6	827.5	649.7	661.6	929.4
	S5	581.3	682.3	1007.6	948.8	1126.7	1075.6
	S6	635.9	825.0	1128.1	795.4	825.2	957.0
N2	s1	843.8	872.1	876.1	792.7	910.8	1060.1
	s2	870.3	1959.4	1055.9	713.7	766.4	8 19.4
	s3	487.3	477.5	703.0	608.7	647.8	784.0
	s4	584.5	613.0	600.1	681.3	791.5	821.2
	s5	507.7	532.5	735.0	823.9	955.1	849.1
	S6	588.3	785.7	922.3	687.9	652.4	755.6

Table 7. Variation in average shear strength of six bamboo species in green and air-dry condition (N/cm^2)

Species	Green	Air-dry
Bambusa arundinacea	913.7	986.2
B. vulgaris	1136.1	723.5
Dendrocalamus asper-	625.9	736.1
Gigantochloa apus	683.4	755.7
G. attei	674.4	963.2
G. verticillata	769.2	779.4
Mean	800.5	824.0

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Wear Resistance of Two Commercial Bamboo Species in Peninsular Malaysia and their Suitability as a Flooring Material

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Abstract

The abrasive resistance of Bambusa vulgaris var: striata (Buloh gading) and Gigantochloa scortechinii (Buoh minyak) were assessed both at the longitudinal and the end grain surfaces. The results showed that both bamboo species are superior to Kempas (Koompasia malaccensis), the common flooring timber and rubber wood (Hevea brasiliensis), a light traffic flooring timber. The bamboos were suitable for- flooring purposes under medium traffic conditions.

Introduction

Bamboo, a member of the grass family Gramineae, is a fast growing and high yielding renewable resource. The uses of bamboo are unlimited, but proper utilization of this resource would be greatly beneficial especially to the rural population. In the industrial sector, it may be used as a substitute for timber in the near future.

In Peninsular Malaysia, bamboo covers an estimated area of about 329 000 ha of the forested land with an estimated standing stock of about seven million tonnes. Out of nearly 50 species available, only l0-15 species amounting to 60 000 tonnes with a market value of M$ three million are commonly used (Abd. Latif, 1987).

There are about 13 factories making bamboo products like skewers, blinds, chopsticks and toothpicks. It has been found that the waste derived during the processing of these products is in the range of 28-47 percent. This includes the upper parts of the culm and the nodal parts. These wastes could be utilized by manufacturing bamboo flooring material.

Abrasive resistance is a good criterion to assess whether bamboo is suitable for use as a flooring material. In the present work, the abrasive resistance of bamboo was compared with Kempas *(Koompasia malaccensis),* the common flooring timber in Malaysia.

Materials and Methods

Preparation of Materials for the Abrasion Test

The off-cuts of two species of bamboo, *Bambusa vulgar-is* (Buloh gading) and *Gigantochloa scortechinii* (Buloh minyak), obtained during the making of bamboo products, were used for testing purposes. These discarded poles were cut and sliced into blocks of size, 12.5 x 2.5 x 0.5 cm {thick) longitudinally and 2.5 x 0.5 x 0.5 cm (thick) from the end grain.

The splinters and slivers from the blocks were removed by slight burning and the blocks glued to a 50 x 50 cm plywood piece (Fig. 1 A,B). Planing and sanding were then carried out (Abd. Latif & Mohd. Rashid, 1986). Test pieces of size 76 x 51 mm (length and width, respectively) were cut from this parquet board for abrasive testing (Fig. 2 A,B). Thirty samples each of longitudinal (internode), longitudinal (node) and end grain surfaces were used for this test. Before testing, the specimens were conditioned to a moisture content of about 12 percent at 27.5 C.

Testing Procedure for Wear Resistance

The test procedure adopted in this study was similar to the ASTM D 1037-72a. The abrasion testing machine used for this purpose was similar to the U.S. Navy Wear Tester (Anonymous 1987). The abrasive medium used was 80 grit aluminium oxide.

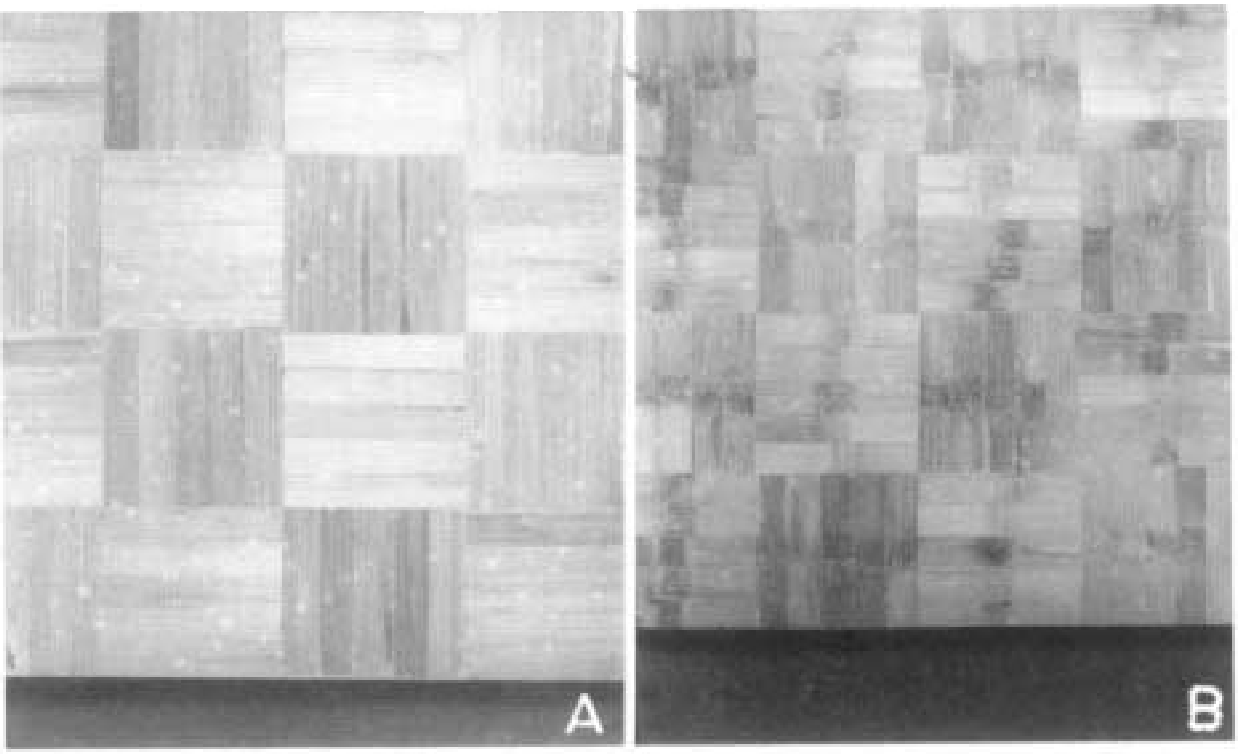

Fig. 1 A,B. *Finished product of bamboo parquet. A. with internode, and B. with nodal portion.*

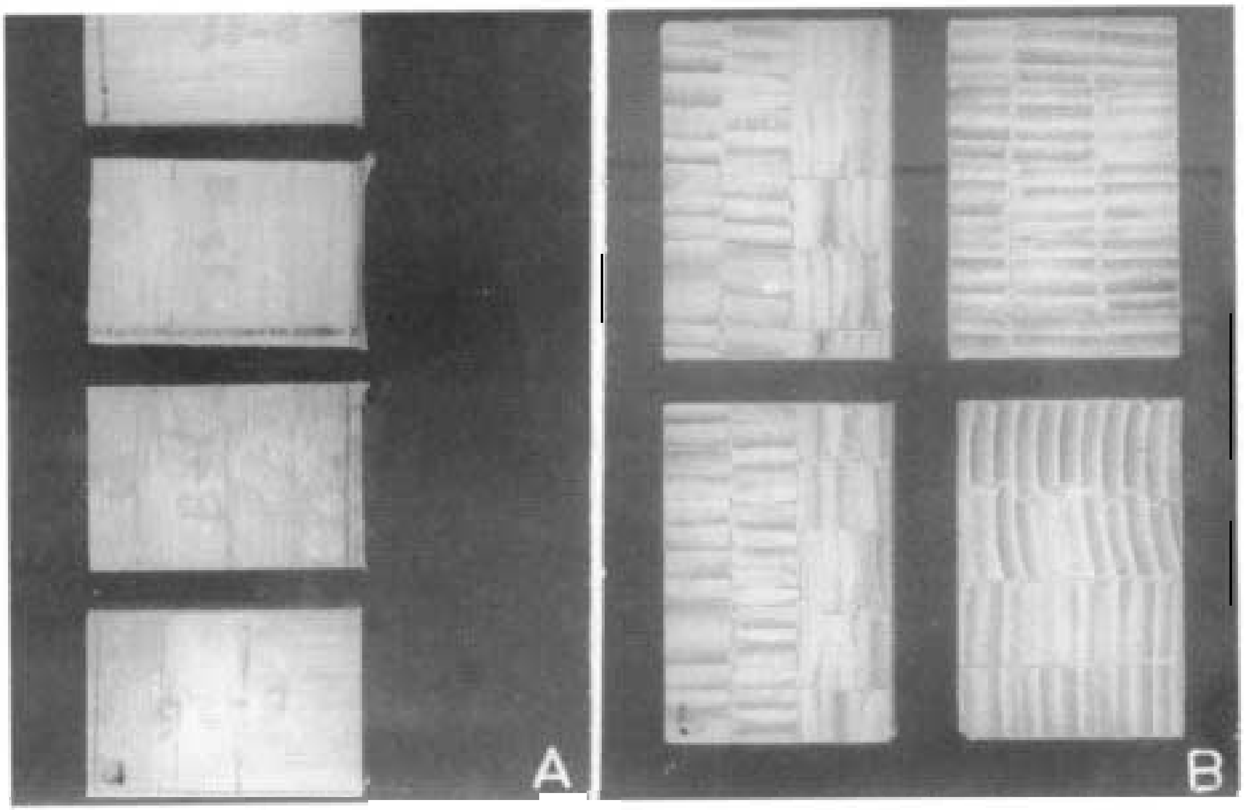

Fig. 2 A,B. *Samples of test board for abrasive test. A longitudinal, and B. end grain surfaces.*

Table 1. Loss in weight of *Bambusa vulgaris* var. striata and *Gigantochloa scortechinii* after abrasion test

Species	Density	Surface abraded	Revolutions										Percent weight loss after 1000 revolutions
			100	200	300	400	500	600	700	800	900	1000	
Bambusa vulgaris var. striata	630 kg/m^3	End grain (Internode)	0.0069	0.0099	0.0563	0.0702	0.0961	0.1164	0.1462	0.1713	0.1972	0.2151	0.1012
		Longitudinal (Internode)	0.0976	0.1486	0.2908	0.4054	0.4420	0.5511	0.6414	0.7159	0.8111	0.9024	0.5406
		Longitudinal (node)	0.0702	0.1208	0.1739	0.2237	0.2767	0.3280	0.3813	0.4464	0.4980	0.5517	0.3623
Gigantochloa scortechinii	680 kg/m^3	End grain (Internode)	0.0050	0.0941	0.0690	0.0910	0.1190	0.1413	0.1601	0.1771	0.1972	0.2163	0.1394
		Longitudinal (Internode)	0.1007	0.2190	0.3116	0.4041	0.4953	0.5854	0.6726	0.7617	0.8455	0.9192	0.6814
		Longitudinal (node)	0.0513	0.1064	0.1621	0.2547	0.3197	0.3897	0.4391	0.4836	0.5400	0.6140	0.4276
Kempas		End grain											0.21
		Tangential											0.84
		Radial											0.98
Rubber wood (Mohd. Shukari 1983)		End grain											0.75
		Tangential											1.80
		Radial											2.52

Table 2. Mechanical and morphological properties of bamboo species

Species	Density (kg/m^3)	Shear along the grain (MPa)		Compression along the grain (MPa)		Fibre length (mm)			Vascular bundle distribution per cm^2			Tangential/radial ratio of vascular bundle size			
		Min	Max	Min	Max	Butt	Middle	Top	Inner	Middle	Outer	Inner	Middle	Outer	
Bambusa vulgaris var striata	630	6.08	7.04	52.28	55.86	2.57	2.87	2.55	15	23	45	0.95	1.80	1.59	Butt
									13	23	43	0.51	0.81	1.93	Middle
									17	32	48	0.43	0.67	1.67	TOP
Gigantochloa scortechinii	680	4.30	7.53	30.10	42.45	2.75	2.73	2.65	16	18	28	0.77	1.50	2.00	Butt
									13	17	24	0.51	1.41	1.63	Middle
									20	24	28	0.78	1.38	1.74	TOP
Kempas (Lee et al., 1979)		9.93	47.5												
Rubber wood (Lee *et al.*, 1979)		9.03	25.92												

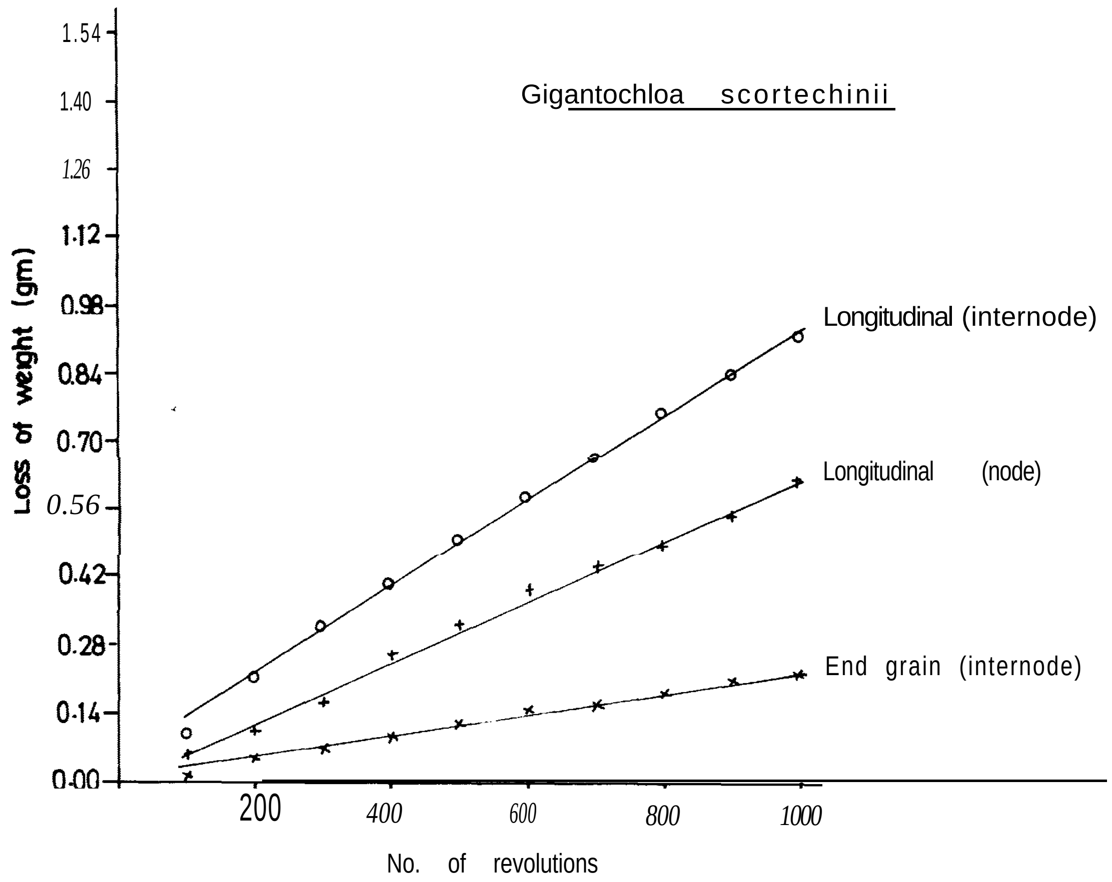

Fig. 3. Relationship between weight loss and number of revolutions (Bambusa vulgaris).

The test specimens were mounted onto the holder using epoxy adhesive. A fixed pressure was applied on the specimen by placing a 4.5 kg weight on top of the holder. The wear on the specimen was obtained by rubbing it against a revolving disk covered with the abrasive medium.

The holder revolved clockwise at a constant speed of 32.5 rpm. The specimen was lifted to a distance of 1.6 mm and dropped back into contact with the revolving disk twice during each revolution of the holder. The abrasive medium was applied through a mechanically agitated hopper at the rate of 46 g/min and was changed after 2000 revolutions. The weight loss of the specimens was calculated after every 100 revolutions of the revolving disk for a total of 1000 revolutions.

Fibre Length and Vascular Bundle Distribution

The distribution of the vascular bundles was determined within an area of 1 cm^2 of each sample (see Jane, 1933). For fibre length, 100 fibres were measured.

Results and Discussion

The weight loss data are presented in Table I. The average density, shear and compression along the grain, vascular bundle distribution and the fibre length measurement are presented in Table 2.

The results showed that the percentage of weight loss after 1000 revolutions for the end-grain samples was the lowest for both the bamboo species (0.1% for Bambusa *vulgaris* and *0.14%* for *Gigantochloa scortechinii).* The longitudinal surface which contained nodal portions was found to be more resistant than the one containing inter-nodal portions.

The linear relationship between weight loss and the number of revolutions as shown in Figures 3 and 4 for both the bamboo species has also been reported by Younguiste and Munthe (1948); Mohd. Shukari (1983) and Abd. Latif *et al.* (*1987).*

The weight loss of the two bamboo species is much lower than for both Kempas and rubber wood (Fig. 5) indicating that B. *vulgaris* and G. *scojtechinii* are more resistant to abrasion. The results

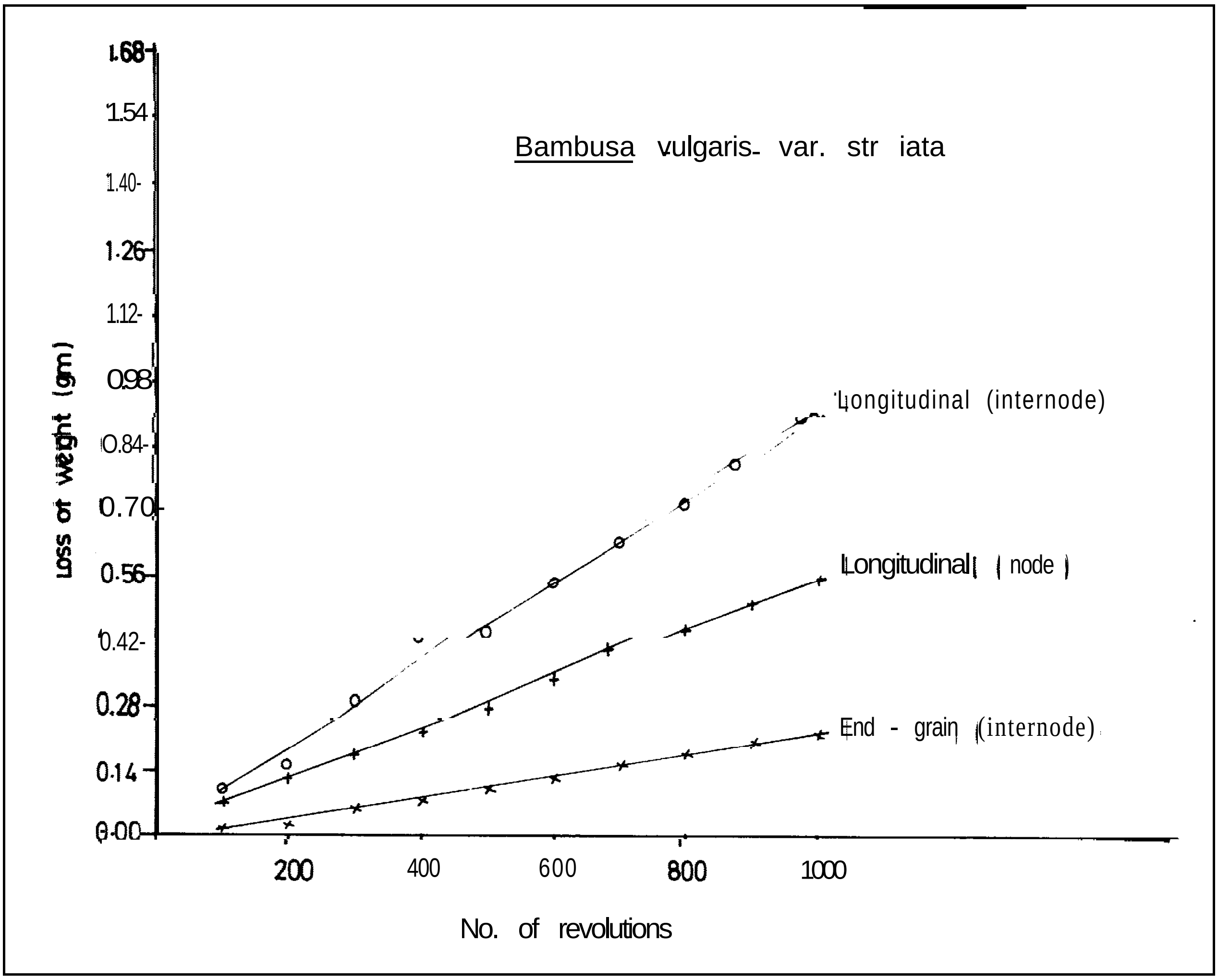

Fig. 4. Relationship between weight loss and number of r-evolutions (Gigantuchloa scortechinii).

also demonstrate that B. *vulgar-is* is more resistant to wear than *G. scortechinii.* When the cross-cut walls of both the species were examined, differences in the pattern of vascular bundle arrangement were noticed (Fig. 6). The fibre strand area in B. *vulgaris* was also found to be more than that in G. *scortechinii.*

Lim (1983) considered Kempas as suitable for heavy traffic flooring but more suitable under medium traffic conditions, and Mohd. Shukari (1983) suggested that rubber wood should only be used under light traffic conditions. The criteria used by both included abrasive resistance, density, strength group and texture of wood. Lim (1983) suggested that for light traffic conditions, an air-dry density greater than 650 kg/m3 is required. In addition, the shear value along the grain should exceed 1.4 MPa and 2.0 MPa for floorings used under light and medium traffic conditions, respectively. Table 2 shows that the values of shear along the grain were 6.1-7.0 and 4.3-7.5 MPa for B. *vulgaris* and G. *scortechinii,* respectively. Values for compression along the grain for B. *vulgaris var.* striata and G. *scortechinii* were 52.3-55.9 and 30. 1-42.5 MPa, respectively. As these values are higher than the suggested value of 17 MPa (Lim, 1983), B. *vulgaris* var. striata and G. *scortechinii* have high abrasive resistance and they are suitable for medium traffic flooring use.

Factors related to the anatomical structure, in particular the pore size and distribution, arrangement, and the fibre structure, and which could influence the resistance to wear (Youngquiste & Munthe, 1948) should also be examined while considering the use of bamboo for flooring purposes. Liese (1980) reported that the ultrastructure of most of the fibres was characterized by thick polylamellate secondary walls resulting in extremely high tensile strength. The strength was found to be in proportion to the fibre length and vascular bundle distribution in the material itself. The fibre length of these two bamboo species was higher (2.55-2.87 mm) than that of rubber wood (1.00-l. 10 mm) (Ashaari, 1980) and Kempas (1.00-l .60 mm) (Grant, 1958). This indicates that both bamboo species might be suitable for flooring purposes.

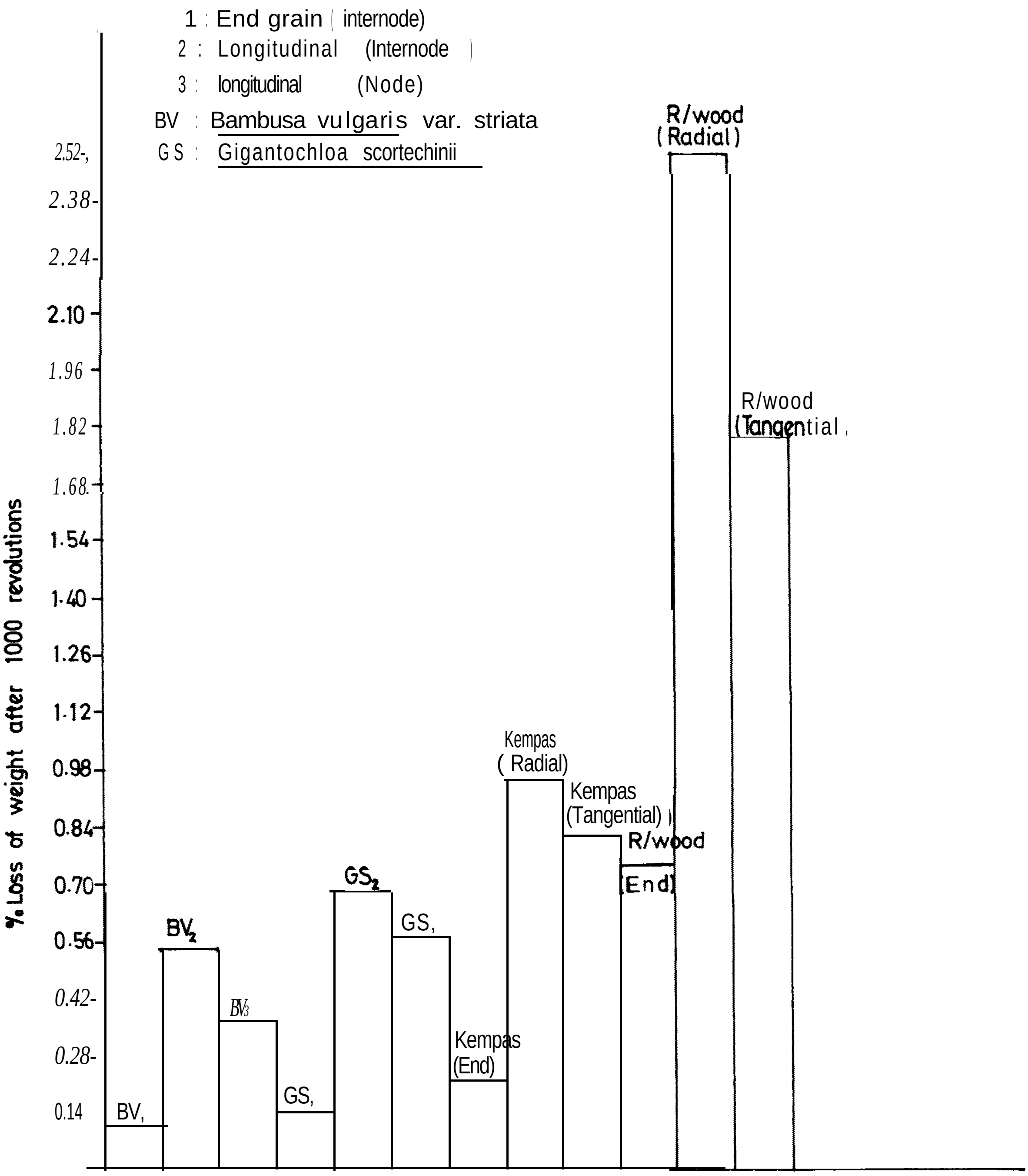

Fig. 5. Percentage loss of weight after 1000 revolutions of ahrasive disk on different surfaces as compared to rubber wood and Kempas.

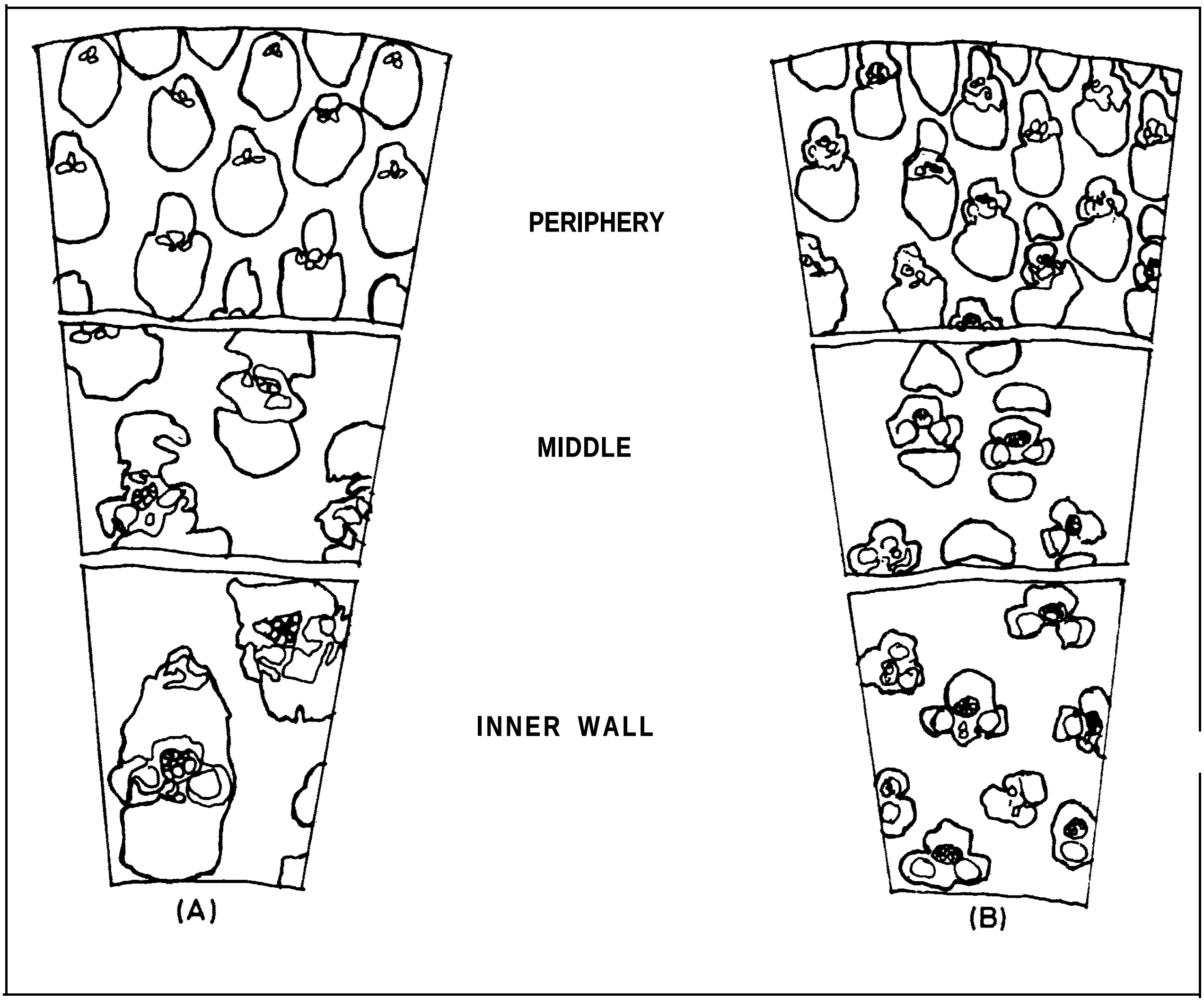

Fig. 6 A, B . Cross-section of the culm wall A. Bambusa vulgaris var striata. B. Gigantochloa scortechinii.

Conclusion

The results obtained from this study show that the abrasive resistance of *B. vulgar-is* var. striata and *G. scortechinii* was about 30 percent superior to Kempas and about five times more than rubber wood. Hence, these could be considered as suitable for flooring purposes under medium traffic conditions. The results also showed that *B. vulgaris* was more resistant to abrasive wear than G. *scortechinii*.

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Tensile Strength of Bamboo Fibre-reinforced Plastic Composites with Different Stacking Sequences

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Abstract

Although composites halle been developed in the past using natural fibres such as jute, shun, coin and banana, the maximum tensile strength achieved has heen only 104 N/mm^2. In the present work, multi-layered bamboo fibre-reinforced plastic (BFRPI composites with different stacking sequences have been successfully developed using a simple casting technique. These possess very high tensile strength but low ductility. At the same time, the density of these BFRP composites is much less: it is only about 50 percent of the density of the most commonly used glass fibre-reinforced plastic composites. The ultimate tensile strength of BFRP composites varies from 264 to 386 N/mm^2 depending upon their stacking sequence.

Introduction

Presently glass fibre reinforced plastic (GRP) composites are commonly being used in many industrial and commercial applications. These are, however, very costly due to the high cost of production of glass fibres and the high cost of polyester/epoxy resins. There is a dire necessity for the production of natural fibre-reinforced plastic composites as these are abundantly available at a low price. Varma *et al.* (1983) developed composites using coir fibres in polyester resin but the maximum tensile strength achieved was only 24 N/mm'. Satyanarayana *et al.* (1983) developed composites using natural fibres of jute, coir, cotton, etc. in polyester/epoxy resins with a maximum strength of 104 N/mm'. Bhantia et *al.* (1983) developed composites using jute and shan fibres in epoxy resin but again the maximum strength achieved was only 36.7 N/mm-. All these research workers did not make use of bamboo fibres for the development of composites.

Jindal (1984) studied the mechanical properties of *Dendrocalamus strictus* and found that the specific ultimate tensile strength of bamboo specimens is nearly six times that of mild steel, This led to the use of bamboo fibres for reinforced plastic composites (Jindal, 1986). In these composites, the bamboo fibres were all aligned only in one direction. Though the maximum ultimate tensile strength achieved was 425 N/mm', these composites had useful strength only in one direction. This paper outlines the results achieved with multilayered composites in different stacking sequences.

Sample Preparation

Bamboo fibres of thickness 0.5-0.8 mm in the form of woven mats were used. The fibres in the mat form were specially chosen because the longer bamboo fibres tend to curl and often overlap each other. But in the mat, each fibre is separated by weaving threads and hence remain in one plane.

The BFRP composites with different stacking sequence were prepared in two stages: (1) single-layered unidirectional laminae of bamboo fibres in araldite matrix and (2) multi-layered composites with a certain stacking sequence.

Preparation of a Single-layered Unidirectional Laminae

A 30 x 30 cm piece of woven bamboo mat (0.5-0.8 mm thick) was cut and placed on a Perspex plate, which had been degreased, cleaned and sprayed with a thin layer of mould-releasing agent. At the two edges (along the length of the fibres) of the mat, threads were removed, the fibres brought closer together and the epoxy resin with 10 percent by weight of hardener was applied with the help of a brush. After 24 h, when the araldite setting was complete, the threads in the central portion of the

Table 1. UItimate tensile strength of BFRP composites

Stacking sequence (in degrees)	Sample no.	Breadth (mm)	Thickness (mm)	Maximum load (on)	U1 timate tensile strength N/mm²	Mean ultimate tensile strength N/mm²
0,22.5,45, 67.5,90, -67.5, -45, -22.5,O (1)	1	10	11.02	42.728	387.73	
	2	10	10.84	37.926	349.87	386.14
	3	10	10.20	42.924	420.82	
0,30,60,90. -60, -30,O (11)	1	10	8.64	24.794	286.96	
	2	10	10.00	35.427	354.27	322 52
	3	10	10.20	32.634	326.34	
0, 45, 90 -45, 0 (III)	1	10	6.60	19.208	29 1 .03	
	2	10	7.20	20.482	284.47	263.9 1
	3	10	7.84	16.954	2 16.25	

Density of these composites varies from 980 to 1020 kg/m³

mat were removed with the help of a sharp blade and the fibres brought closer together, keeping a light dead weight in the form of a perspex plate, so that the fibres did not overlap. Also, the araldite mixture was applied at a few locations so that the fibres remained straight and close together. A square bit of 20 x 20 cm was removed from the central portion with the help of a hacksaw. This piece was dipped completely in araldite mixture placed in a specially prepared perspex mould and the top perspex plate carefully placed on the top of the wet mat. Dead weights were placed on the top plate and after 24 h of araldite-setting, a composite sheet of BFRP was obtained (for complete casting technique, see Jindal, 1986). A total of 12 sheets were cast. The thickness of these sheets varied from 0.9 to 1.1 mm.

Preparation of Multi-layered Composite with Different Stacking Sequences

From the single-layered unidirectional laminae of BFRP composite, rectangular pieces 16 x 110 mm were cut as shown in Figure 1 A. Composites were made with the following stacking sequences (figures in degrees):

I 0, 22.5,45, 67.5, 90, -67.5, -45, -22.5, 0 (9 layers),

II 0, 30, 60, 90 -60, -30, 0 (7 layers),

III 0,45,90 -45,O (5 layers).

The 0" is the direction of fibre along the direction of loading on the specimen. The rectangular pieces were placed sequence-wise one above the other and araldite mixture was applied on the surfaces in between all the pieces. The whole assembly was put in a hot air oven maintained at 60 C for four h, after which the oven was switched off and the composite allowed to cool in the oven itself. After 24 h, the composite was removed from the oven, machined to the dimensions of a tensile testing specimen shown in Figure 1B. Three samples each of stacking sequence I, II and III were made.

Results and Discussion

BFRP composite samples were tested under tension using the Instron machine. Load-extension curves were obtained on an automatic chart recorder for all samples. Figure 1C shows the load-extension curve for sample 1 with stacking sequence I. It can be observed that this is linear almost up to the breaking load, and over a gauge length of 25 mm the extension is approximately 1 mm, showing thereby that the mechanical behaviour of BFRP composites with different stacking sequences is more or less brittle.

In the composite sample, 0° ± 67.5' and ± 60" layers failed due to fibre fracture and the fibres pulled out from the matrix at the time of breaking, while the ± 45°, ± 30°, ± 22.5' and 90" layers failed due to matrix failure (Fig. 2). Sample delamination did not occur during the tensile loading.

Table 1 summarizes the results of ultimate tensile strength of the composites with different stacking sequences. The mean ultimate tensile strength of the composite with stacking sequence I is 386.1

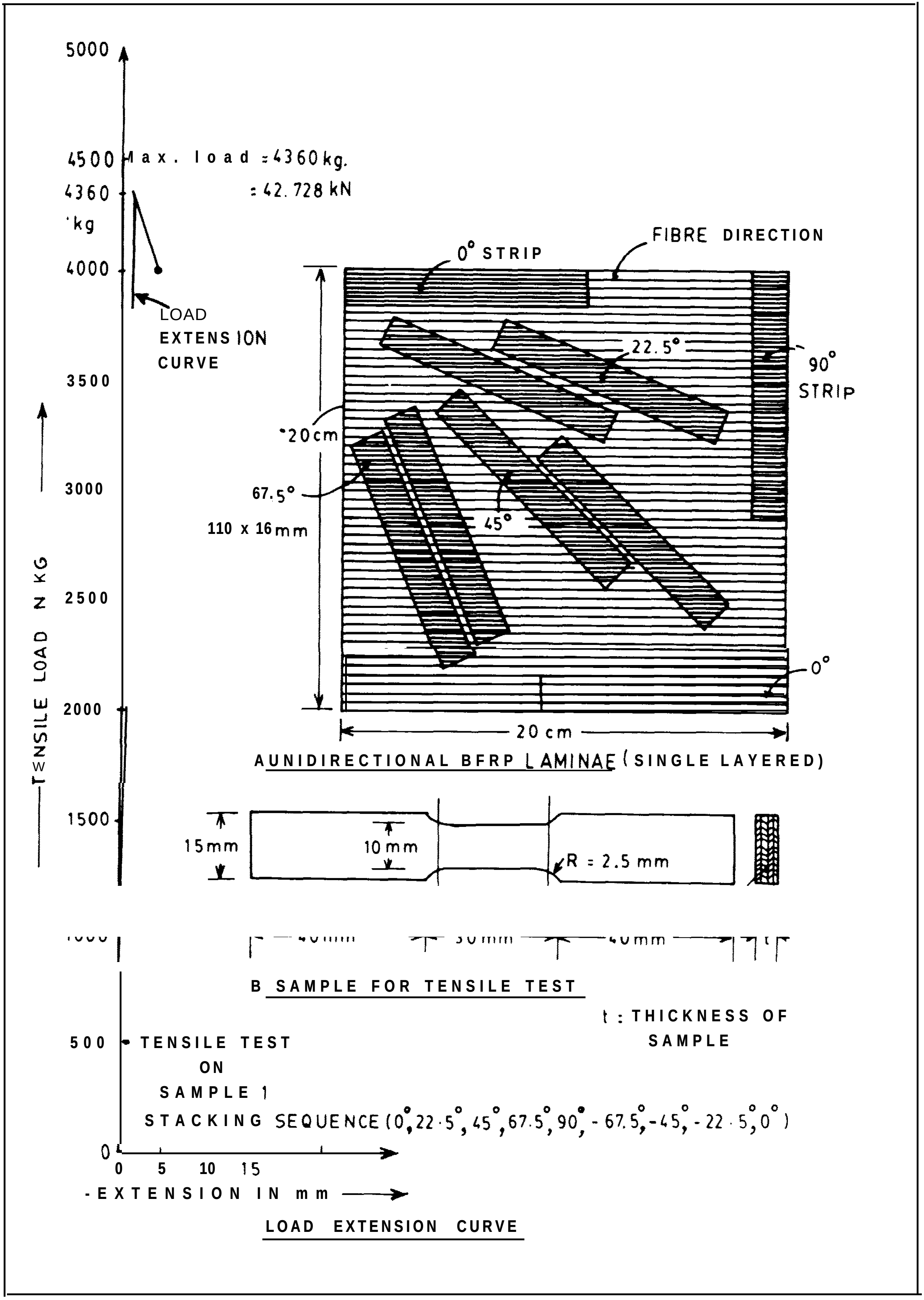

Fig. I A-C. A. Unidirectional BFRP laminae (single-layered). B. Sample for tensile test. C. Load extension curve

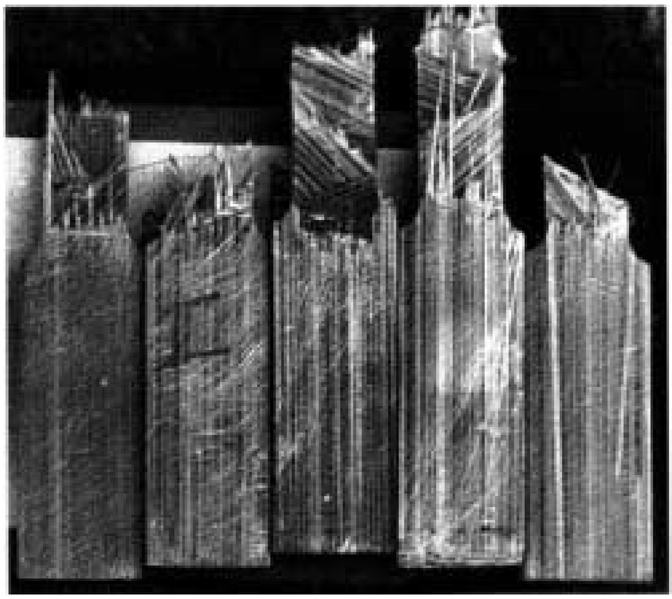

Fig. 2. Fractured samples of BFRP composites with different stacking sequences.

N/mm2, sequence II, 322.5 N/mm^2 and sequence III, 263.9 N/mm2. The mismatch between the ultimate tensile strengths of the three stacking sequences is due to the fact that in a multi-layered composite as above, some layers are strong and fail due to fibre fracture while others are weak and fail due to matrix fracture.

Conclusions

BFRP composites with different stacking sequences possess very high tensile strength ranging from 263.9 to 386.1 N/mm^2. The multi-layered composite with stacking sequence I (fibres in layers inclined at 0°, 22.5°, 45°, 67.5°, 90°, -67.5°, -45°, - 22.5°, 0° to the direction of loading) possesses the maximum ultimate tensile strength, with a mean value equal to 386.1 N/mm2. The mechanical behaviour of multi-layered BFRP composites with different stacking sequences is brittle but strong. The BFRP composites can be used for avariety of structural applications where strength and lightness are the important considerations.

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PROCEEDINGS OF
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BAMBOO AS A CONSTRUCTION/ HOUSING MATERIAL

The Importance of Bamboo as a Building Material

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Abstract

The importance of bamboo as a building material is outlined through an overview of the physical and mechanical properties as related to other building materials. However, in the building industry, bamboo is still not exploited to the full. Therefore, a proposal is made to raise an IUFRO/CIB-subgroup on 'Bamboo as a building material'. The paper outlines the state of the art on durability, mechanical properties, housing, larger industrial and social buildings, bridges, roads, bamboo-reinforced concrete, woven bamboo and split bamboo for ceilings and walls, bamboo-boards, and piles and rafts, and might serve as a starting point for the activities of the said sub-group.

Introduction

To increase the self-sufficiency of developing countries, indigenous materials must be exploited to the full. Among them bamboo is a familiar material with a long history of usefulness, and in building it has been employed in South-east Asia for housing and scaffolding. The question, whether bamboo could play a bigger part in building, especially in structural applications, was investigated through a comprehensive research programme on the mechanical properties of bamboo, particularly for structural uses in joints and trusses. This paper highlights the structural properties of bamboo, the use of bamboo in building and bridge construction, and a proposal to form a IUFRO subgroup on building with bamboo.

The Structural Properties of Bamboo

Compression Strength

The ratio between the ultimate compression and the mass per volume has been studied by several authors, both for wood and bamboo.
The ratios are:

- for dry bamboo (moisture content 12%): $\sigma = 0.094\ \rho$
- for green bamboo (moisture content 60% or more): $\sigma = 0.075\ \rho$, in which:
  σ = ultimate compression stress in N/mm^2 and
  ρ = mass per volume in kg/m^3 (see Janssen, 198 1).

The ratio gives dry bamboo a slightly higher compression strength of 0.094 as compared with 0.084 for dry wood. This might be caused by the higher cellulosic content of 55 percent in bamboo compared with 50 percent in wood. This comparison is a rough one since bamboo and wood consist of a number of different varieties, and this comparison deals only with mean values. However, such a comparison will make clear in which cases bamboo might be a good alternative, or even a better one, and in which cases the use of bamboo should be rejected.

Bending Strength

The ratio between the ultimate bending stress σ in N/mm^2 and the mass per volume ρ in kg/m' is:

- for dry bamboo (12% M.C.) $\sigma = 0.14\ \rho$
- for green bamboo $\sigma = 0.11\ \rho$ (see Janssen, 1981).

In the case of bending, the deformation is more usually important than the strength, and the Young's modulus should be discussed. For dry bamboo the Young's modulus values can be as high as 20 000 N/mm^2.

Referring to creep in bending, this is of no importance. The author has found that creep in bending is only 10 percent of the immediate deformation, and the remaining deformation after unloading is about 3 percent (M.C. 12%. initial strain level $2^{o}/_{oo}$, duration up to 14 months) (see Fig. 1).

Shear Strength

According to a common belief, bamboo should be weak in shear. This is simply not true. The shear strength of wood and bamboo correlates positively with the thickness of the cell walls and negatively

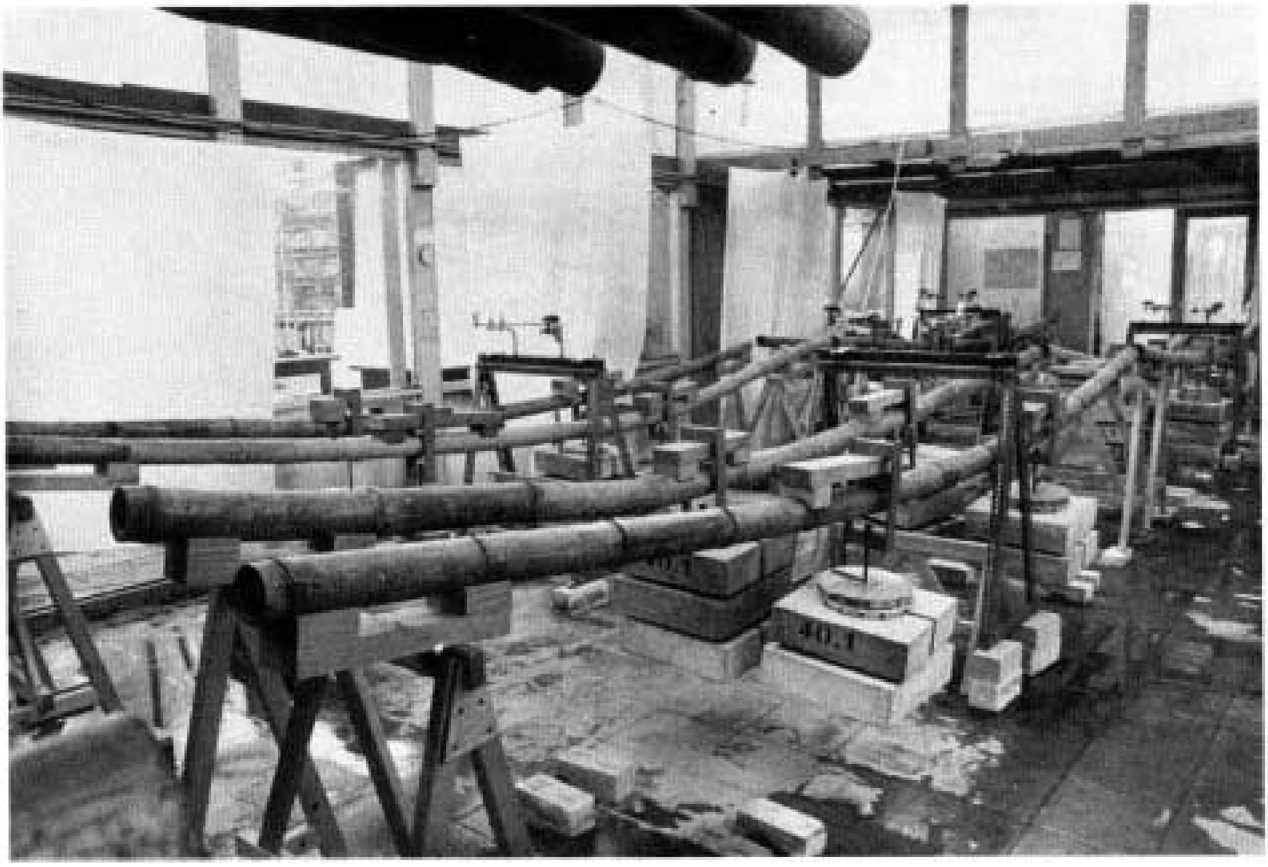

Fig. I. Long-term bending test on bamboo.

with the percentage of rays.

One can derive the following formula for wood:

$\tau = 0.027\ \rho - 0.22\ R$ in which τ = ultimate shear stress in N/mm*, ρ = mass per volume in kg/m^3 and R = percentage of rays (see Janssen, 1981). Data for ρ and R can be taken from several handbooks.

For bamboo, this formula becomes: $\tau = 0.021$ p instead of 0.027 ρ. Taking into account the standard deviations, 0.0044 for the mean value 0.021, and 0.0067 for the mean value 0.027, these mean values do not differ significantly.

In spite of this factor 0.021, which is lower than 0.027 for wood, bamboo appears to be strong in shear, not only due to the absence of rays, but also due to the high mass per volume.

However, in practice, shear in bamboo is a problem. We can understand this discrepancy if we compare a beam of bamboo with one of wood. For example, say bamboo has an outer diameter of 100 mm and a wall thickness of 6 mm. In order to have the same moment of inertia, the wooden beam has to be 41 x 82 mm. Consequently, the cross-sectional area in the neutral axis is 2 x 6 = 12 mm only in bamboo, and 41 mm in the wooden beam. This difference in size causes difficulties in shear in bamboo. In summary, therefore, bamboo is stronger in shear than wood, but its hollow form causes more problems in shear than in the case of wood.

Mass per Volume

For bamboo, data on the mass per volume have not been recorded as precisely as for wood. It is clear, however, that a common value for bamboo is at least 600 kg/m^3, and that values as high as 800 or even 900 occur quite often (all values for conditioned bamboo with 12 percent M.C.)

Price

A fair mean is one US dollar for a culm of 8 m length. This price is valid for many local markets all over the world. For preservation we add another \$0.50. Assuming an outer diameter of 100 mm and a wall thickness of 6 mm, we can calculate a price of \$ 105 per m^3. (The cross-section of the bamboo is $\frac{\pi}{4}(100^2-88^2) = 1770\ mm^2$.) Per length of 8 m this is 8 m x 1770 $mm^2 = 0.0142\ m^3$ from which a price of \$ 105/m^3 results.)

As stated before a wooden beam with the same moment of inertia measures 41 x 82 mm, with a cross-section of 3360 mm^2, equal to 1.90 times the cross-section of the bamboo. In order to be as economical as the bamboo, the price of the wood should be as low as only \$ 105/l .90 = \$ 55/m^3.

In the case of a column, a square wooden column with the size 70 x 70 mm has the same moment of inertia in all directions. Evidently, the cross-section is 4900 mm^2 or 2.77 times that of the bamboo. In order to compete in this case the price of the wood should be only $ $38/m^3$. From this point of view, bamboo is rather economical.

The. Use of Bamboo in Building and Bridge Construction

With respect to the use of bamboo in building, a summary of advantages and disadvantages is given below.

Advantages

- it grows very rapidly and can be cultivated by the population with a quick and continuous return of capital,
- good mechanical properties,
- only simple tools are needed,
- the outer skin contains much silica, which protects the bamboo.

Disadvantages

- bamboo needs preservation in order to obtain a reasonable lifetime,
- the form of a bamboo culm is not exactly a cylinder, but is tapered,
- fire is a very great risk.

Fig. 2. Detail of a test on a bamboo truss.

Lastly, the hollow form is an advantage from the mechanical point of view, but for joints it is a disadvantage.

Use in Building

The use of bamboo in building is limited by a lack of knowledge of how to make joints in bamboo. Usually, joints in bamboo structures are complicated and labour-intensive, and the structural safety is unknown. Only a few references have been published (Fig. 2). Recently the author came across a clever design for a bamboo joint (Fig. 3), based on plywood and glue. Nevertheless, wonderful traditional bamboo buildings can be seen, such as the exposition building built by a Chinese team for the Fenomena exposition (1984 and 1985; Fig. 4). Among the temporary structures, the scaffolding is well-known (Fig. 5). In summary, research is required on joints with an emphasis on strength, safety and simplicity. In the opinion of the author, scientific research can considerably enlarge the opportunities of traditional building methods.

Woven Bamboo

Due to the regular structure of the bamboo tissue (without knots or rays), it is easily possible to make split bamboo of say 1.5 mm thick and 20 mm wide using a sharp knife. With these strips woven bamboo can be made easily (Fig. 6). In this way, people make ceilings, walls and floors for their houses. In Thailand, woven bamboo is finished with glue, and used in this form for furniture. It is also a promising export item (price US $1.75/m^2$, thickness 2.5 mm).

Another possibility is to lay layers of bamboo strips criss-cross with glue in between, in order to make a kind of ply-bamboo (Fig. 7).

Bamboo in Bridge Construction

Referring to bamboo bridges, we should limit this subject to bridges for pedestrians only. (However, in 1937, the U.S. army in the Philippines built and tested a bridge with a free span of 1.5 m which was designed for a load of 16

Discussing bamboo bridges, we again meet the

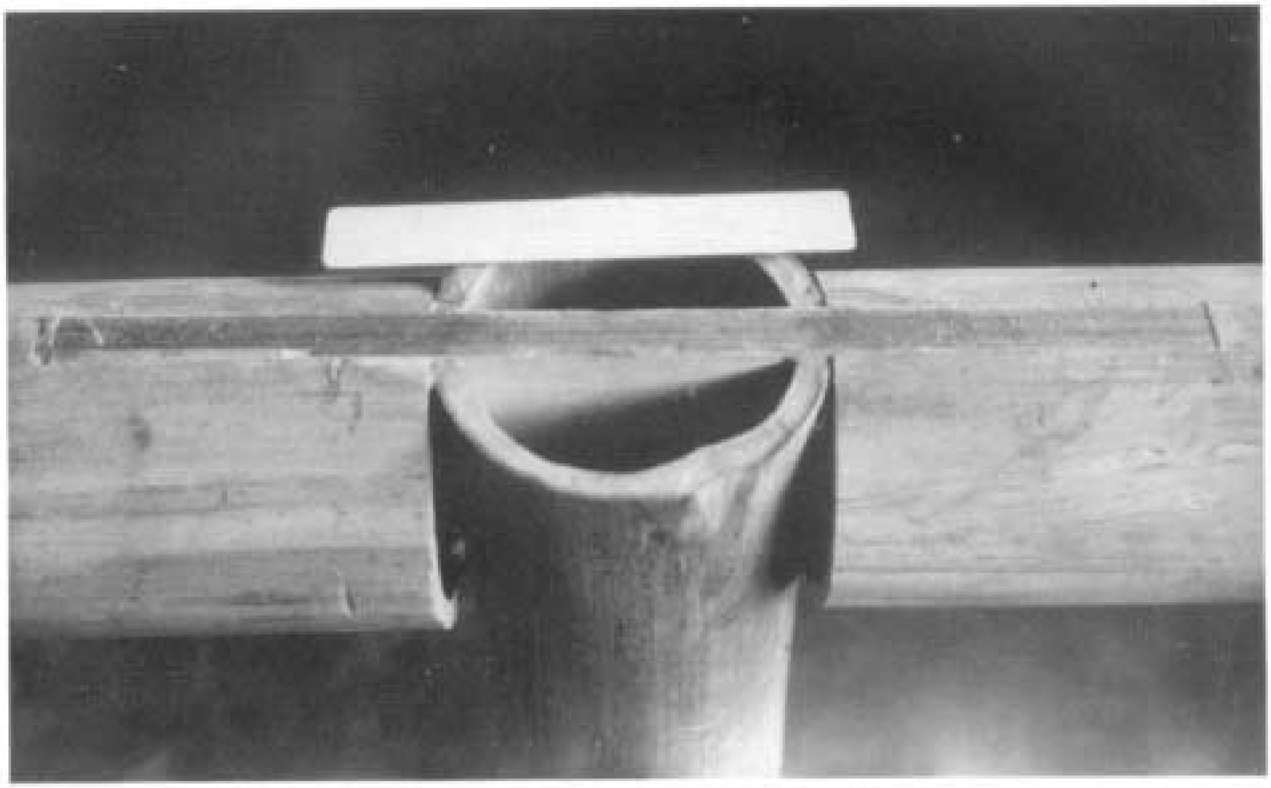

Fig. 3. Bamboo joint, designed at the Instituto Technologica Costa Rica (1987).

Fig. 4. Bamboo exposition building, built by the Chinese in Rotterdam, 1985.

Fig. 5. Bamboo-scaffolding (Shanghai, 1985).

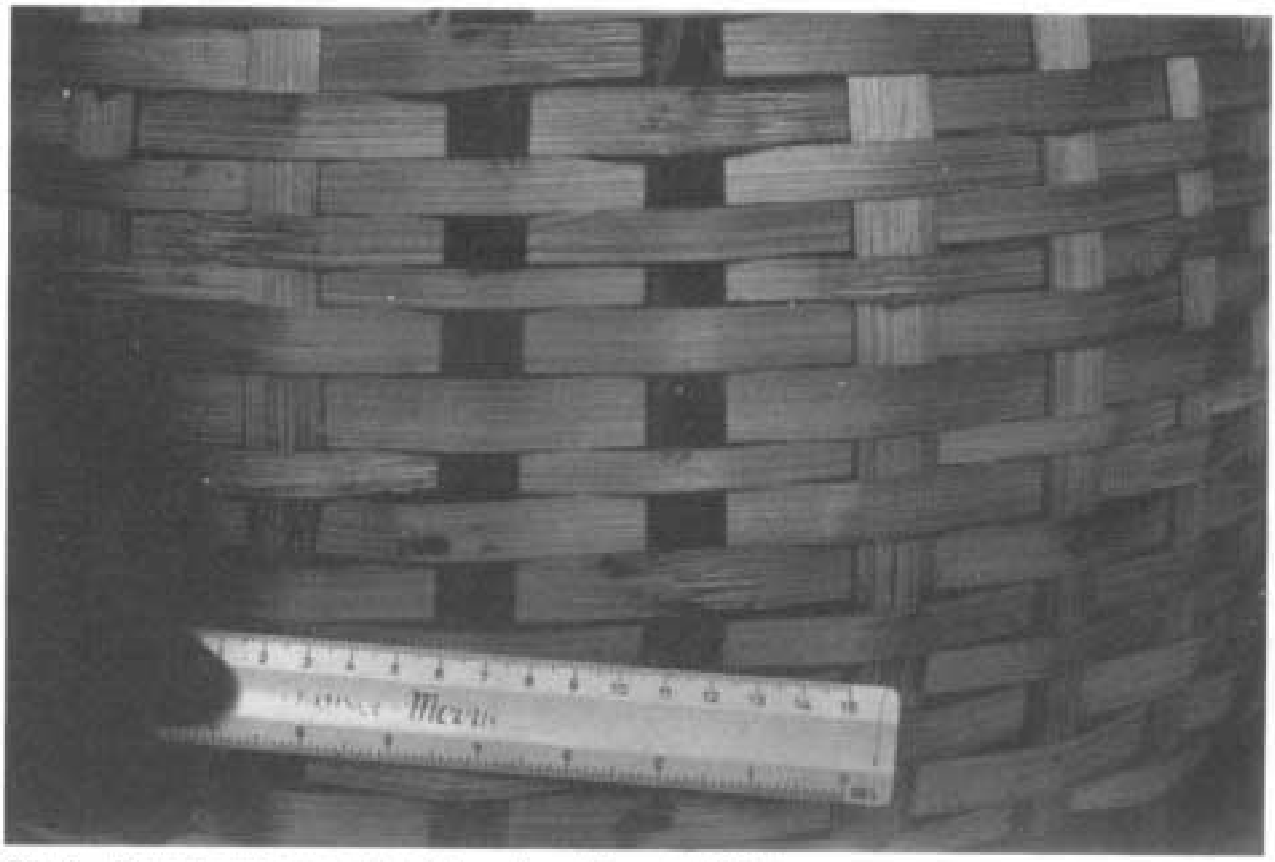

Fig. 6. Woven bamboo; scale is 150 mm long (Burundi, 1985).

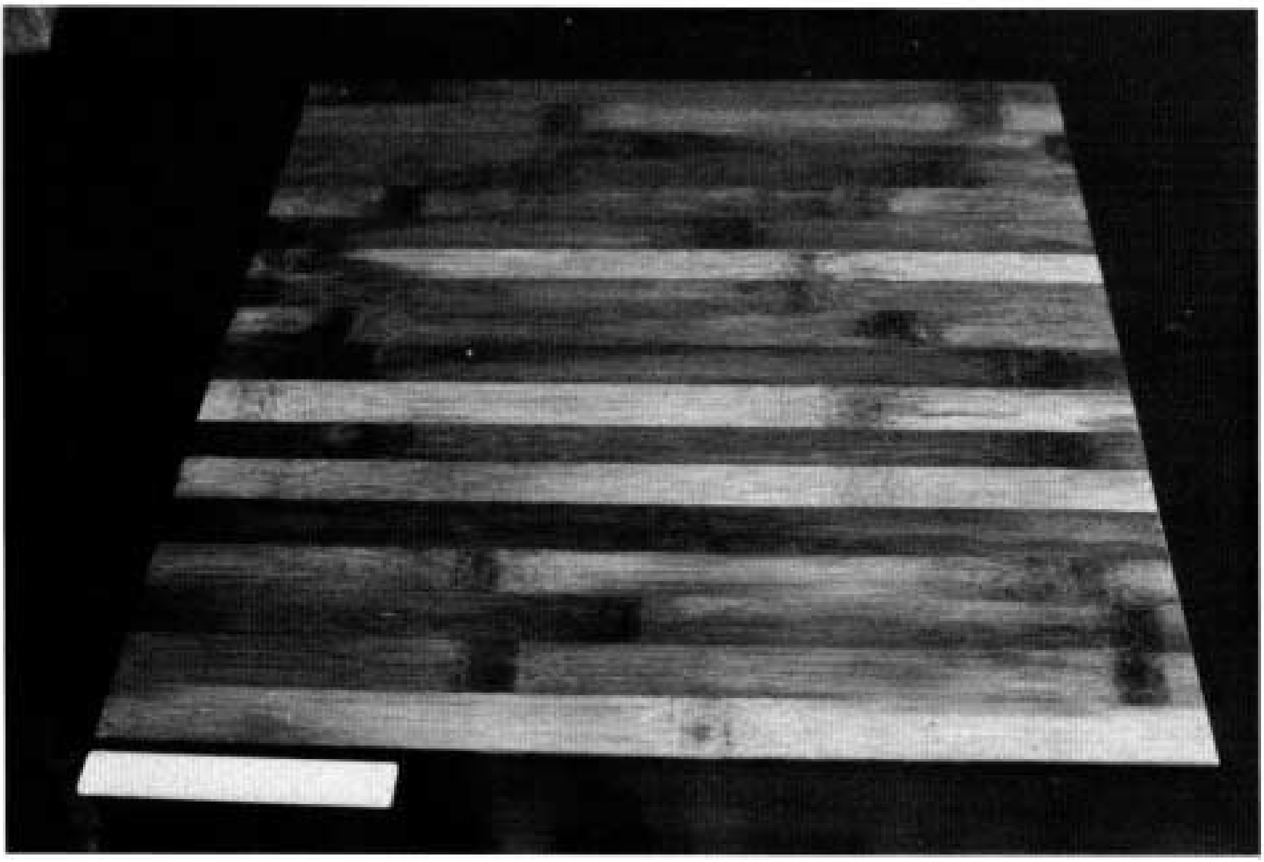

Fig. 7. Ply-bamboo, developed at the I.T.C.R. (1987).

problem concerning bamboo joints. In view of the fact that quite a number of bridges for pedestrian traffic are required in developing countries, research on joints is needed, as well as a method to transfer the technology from the laboratories to the users in the field.

Subgroup on "Building with Bamboo"

The author of this proposal is a member of both the IUFRO- P 5.04 group on bamboo and the CIB-W-18-B group on tropical hardwoods.

The main interest of the IUFRO-group is on forestry, botany, etc. and the CIB-group is mainly interested in hardwoods. Bamboo as a building material is a minor subject in both groups. A subgroup dealing with bamboo as a building material needs to be formed and linked to both groups. This idea was born during the W-18-B seminar in Singapore on 28 October 1987. The formation of the group will further encourage and coordinate research and development work on bamboo as a building material.

This subgroup shares with the IUFRO-group the interest on durability, preservation and the relationship between biological composition and strength. With the CIB-group it shares the interest in building codes and in building in earthquake and typhoon-prone areas. Meetings of the subgroup should, therefore, alternate with the meetings of the IUFRO and CIB-group in so far as practical problems could be solved.

Fields of Interest of this Group

This group should deal with the following subjects

a. Durabilitv
   - natural durability
   - traditional preservation methods
   - chemical preservation methods
   - viable treatment in a given situation (species, climate, end-use) to reach a given lifetime.

b. Mechanical properties
   - relationship with the biological composition of bamboo
   - compression, tension, bending, etc.
   - buckling
   - creep
   - relationship with age, M.C., position along the culm, node or internode, and mass per volume (Janssen, 1987).

c. Housing with bamboo
   Details of bamboo houses for different climates, cultures, etc. (Janssen, 1988).

d. Larger industrial and social buildings (like schools, clinics, factories); details, trusses.

e. Bridges (c, d and e include joints of bamboo).
f. Road-building (mats).
g. Reinforcement in concrete
   - the lifetime of bamboo in this alkaline environment
   - bond and shrinkage/swelling
   - strength and stiffness
   - creep.
h. Woven bamboo without glue for ceilings, walls, etc. and with glue as an export item.
i. Split bamboo with glue as plybamboo sheets for ceilings, walls, floors and export, and as plybamboo furniture.
j. Chipped bamboo mixed with cement and sand into board.
k. Bamboo piles and rafts.

Publications

Generally speaking, the following publications should be dealt with:

1. Books for researchers on a, b, d, e and g.
2. Books for designers and for education on topic b.
3. Building codes, for introducing bamboo technology into developing countries on topics b, d, e andg.
4. Standard construction books for housing on three levels:
   - "mother": "this joint can withstand 15 kN"
   - "child': this joint can bear . . . m^2 roof , depending on type of roof, typhoon, etc. is valid for one country only, or part of it; is meant for designers and engineers in a national language.
   - "grandchild": about the same as child, but in a vernacular language of local village people in the part of the country concerned. ("In a small house you need at least six of these members".) Such books will be needed on all topics except b.
5. Books on research and testing facilities in developing countries.
6. Mechanical testing standard for bamboo specimens.

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Know-how of Bamboo House Construction

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Abstract

Bamboos have great potential for making house-components such as trusses, purlins, roof grids, wallings etc. Intuitional use of bamboos has proved to be unsatisfactory with a service life not exceeding two to three years during which occasional repair or replacement is also warranted. In comparison a scientific use of bamboo can ensure a long trouble-free life. In this paper, the utilization aspects of structural bamboos are illustrated based on techniques developed in the Forest Research Institute and Colleges, Dehradun where an engineered house, suitable for a medium-sized family in a rural environment has been constructed by maximising the use of properly seasoned and chemically-treated bamboos. The methodology of reinforcing the mud-walls using treated bamboos, making of wire-pin and gusset-pin-joined trusses, wire-bound roof grids etc. have also been elaborated to make the appropriate techniques avuilable to the common people for constructing their own shelters according to their financial capability.

Introduction

The ever increasing population has created a global problem particularly in respect of food and shelter. In India, the housing problem is becoming severe day by day. As per estimates prepared by the National Buildings Organisation, the housing shortage in India is over 23.8 million units including 18.1 million in the rural sector. To prevent a slide-back in the housing situation, at least 17 million dwelling units would be required to be provided during the next four years thereafter. In the bleak backdrop of unmet housing needs, quick and economic construction of houses, preferably using indigenous materials is the prime need of the hour. Bamboo which possesses suitable structural properties, can play an important role as a low cost material for construction in India. It can be used for making house-components such as trusses, rafters, purlins, roof grids, walls and ceilings. As bamboo plants attain maturity in a few years, it can be produced in a very short rotation cycle (Shekhar & Bhandari, 1960). At present bamboo is extensively used as a construction material in Japan, Malaysia, Indonesia, Philippines, China, India and other countries. In this paper, the design of of house principally made of bamboo and suitable for a medium-sized family in a rural environment is described (Figs. 1-3).

Properties of Bamboo

1. As compared to some constructional timbers, bamboos possess better strength and can thus be suitably used for structural purposes. Due to its physical form with nodes and cross-partition walls, the bamboo-culm has a high strength to weight ratio. Hence it can make lighter but stronger structural components for

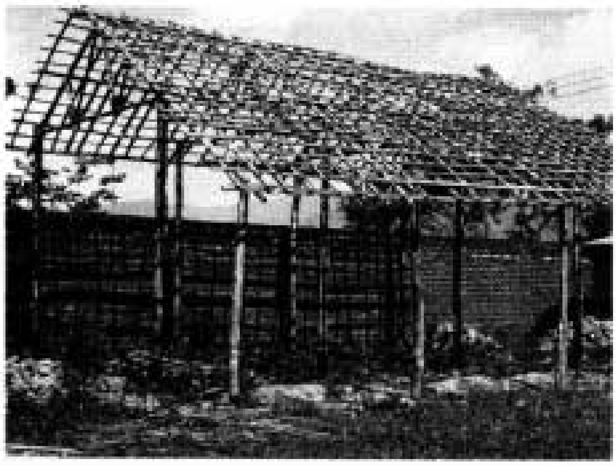


Fig.I. *Bamboo house (under construction) showing roof grid, eucalyptus poles and gussetted bamboo truss.*

Fig. 2. Bamboo house showing roof covering (by thatches), bamboo truss and bamboo-reinforced mud wall (construction in progress).

houses at comparatively low cost.

2. The bamboo-surface as obtained in nature is smooth, clean and hard, enabling its easy use for specific purposes without any wastage.
3. Bamboo can be easily seasoned especially in the split form and treated with preservatives to increase its useful life.
4. The length, thickness and weight of bamboo culms are conducive to easy and economic transportation, storing (with prophylactic treatment) and processing (splitting of the culms into strips with simple tools even by ordinary workers is a common feature in rural and hilly areas.
5. Treated bamboo strips of suitable sizes have been economically used for reinforcing mud walls, and also for cement concrete structures such as lintels, beams, slabs etc. commonly of smaller spans. Split culms plaited or arranged or woven in different forms and shapes can make good boards, mats and panels for light walling.
6. Because of their lightness, bamboo houses suffer very little damage due to earthquake. Temporary and quick construction is possible in case of urgent necessity in disaster-prone areas (Mathur, 1981).
7. The non-magnetic character of bamboo makes it suitable for use in anti-magnetic structures (Masani et al., 1977).

Strength Properties

The strength data for two species of bamboo as compared with teak and sal are given in Table 1

Table 1. Strength data for two species of bamboo as compared with teak and sal

Species	Strength at 12% MC in kg/cm'		
	Modulus of rupture	Modulus of elasticity	Max. crushing stress
Teak ***(Tectonagrandis)***	1054.60	132117	618.70
Sal (Shorea robusta)	1314.74	161706	639.80
(a) ***Dendrocalamus** strictus*	1307.70	179986	629.25
(b) ***Bambusa** balcoa*	1012.00	170143	450.00

Table 2. Common range of strength properties of bamboo

Specific gravity	0.575 to 0.656
Fibre stress at elastic limit	390 to 1000 kg/cm^2
Modulus of rupture	6 10 to 1600 kg/cm^4
Modulus of elasticity	$1.5X10^5$ to $2xl0^2$kg/cm
Average tensile stress at yield point	1400-2800 kg/cm^2
Ultimate compressive stress	794-864 kg/cm^2
Safe working stress in tension and bending taken for design	158 kg/cm^2
Safe working stress in compression taken for design	105 k&m^2
Safe shear stress for design	115-180 kg/cm^2

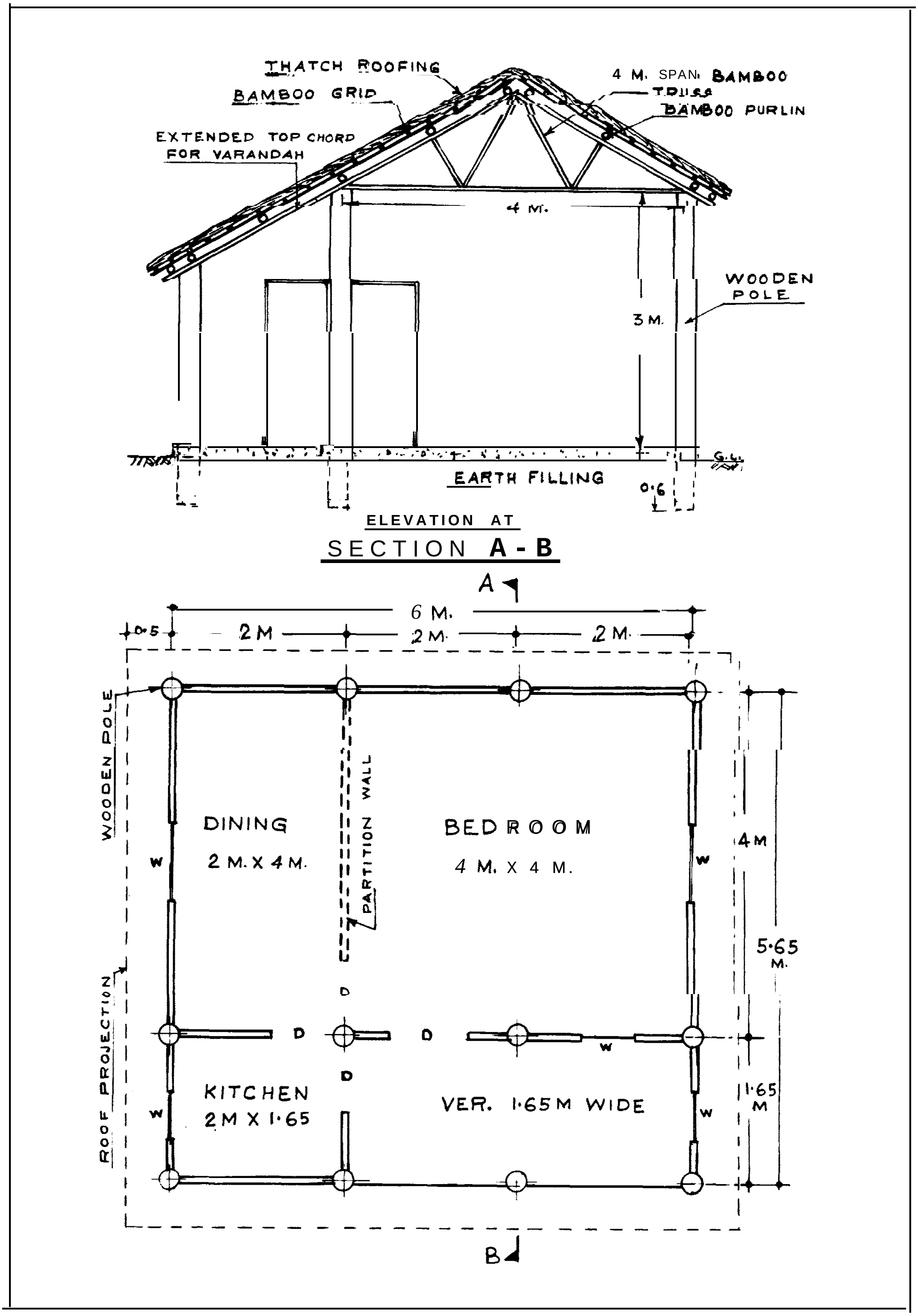


Fig. 3. Plan and elevation of a bamboo house.

(Limayee, 1952) and the range of strength properties in Table 2 (Masani *et* al, 1977).

Main Selection Criteria

Some common points that need to be borne in mind during the selection of bamboos for construction are:

1. Select bamboos of suitable species possessing the required structural properties.
2. Use only those bamboos for construction which are mature (at least three to four years old) and which have been or are likely to be felled when the starch content of the culm is at its lowest level: during October to February in India. This will minimise insect attack (Anonymous 1972a).
3. Bamboos whose wall thickness is 9 mm or more should be selected for beams, columns and truss construction (Mishra, 1988).
4. Choose straight culms having an almost uniform diameter of not below 8 cm to avoid fastening difficulties at the joints of the structures.
5. Bamboo culms selected for use should preferably have nodes or cross partition walls intact at both ends. They should be used after proper seasoning and preservative treatment.

Some Common Bamboos for Structural Use

Bamboos with a greater wall thickness having close nodes and which grow on ridges and warmer areas are often considered good for structural use, particularly for use in columns, beams, roof, rafters, purlins and trusses. Depending on the availability and cost, the following species may be selected for house construction:

1. *Derdrocalamus strictus* (Hindi- Bans Kaban, norbans) - Available in deciduous forests and cultivated through out Indian plains. Culms (5-15 m in length and 2.5-5cm in diameter) are generally solid and suited for structural use.
2. *Bambusa tulda* (Hindi - Peka) - Strong culm (6-20 m by 5-10 cm) suitable for construction of roofing and scaffolding.
3. *Bamhusa arundinacea* (Hindi - Bans) - Thorny bamboo. Culms (20-30 m by 10-20 cm) are thick-walled and often used for rafters, house-posts, tent poles, etc.
4. *Bambusa polymorpha* (Bengal and Assam - Betua) - Culms (15-24 m by 7-15 cm) available in eastern India. Considered one of the best bamboos for walls, floors and roofs of houses.
5. *Bamhusa vulgaris* (Bengal- Basini bans) - six 20 m in height and 5 to 10 cm in diameter. found is all over the tropical region, suitable for roofing and scaffolding.

Drying and Preservative Treatment

These operations are mandatory to make effective use of bamboos in construction for obtaining the desired strength and durability. Truss-joints etc. made with green bamboos will become loose due to shrinkage of the jointing members resulting in early weakening and collapse. Mature bamboo culms should be seasoned to about 12 percent moisture content.

Bamboo has drawbacks as a building material due to its susceptibility to damage by insects. fungi. termites etc. Techniques for application ofpreservatives include brushing, spraying, dipping, hot and cold bath treatment, Boucherie method and pressure treatment depending on the facilities available at or near the consruction sites. The use ofpreservatives and improved treatment techniques can extend the service life of the bamboo structure to a considerable extent. One simple and most common method to protect the freshly felled culms from beetle-attack and insect-infestation is to leach out the starch, sugars and other water soluble materials by submerging for three weeks in fresh or running water. Successful application of this technique has been reported from India, Burma, Fiji, Jamaica and other countries (Anonymous 1972b).

Construction and Erection Aspects

Barn boo Truss

Though rafter-purlin construction is still in vogue, trusses are being considered as improved roofing systems for supporting roof-loads and for transmitting them to the ground through columns and or walls. When the top and the bottom chords and strut members are properly jointed by suitable fastening devices. a truss can resist compressive and tensile forces conglomerately and as such act as a strong supporting component even against storms and earthquakes (Mishra, 1988).

On the basis of design criteria for a 4 m span nail-jointed timber truss (cross-section of members about 7 x 4 cm), bamboo trusses of 4 m span have been designed to withstand stresses of a similar nature though of lesser intensity) and fabricated using culms having an outer diameter of 9 cm and an inner dia of 6 and 7 cm (Fig 4). A full-scale layout of the designed truss is drawn and painted on the floor of the workshop. Selected culms are placed in position. Jointing ends/faces are cut in such a way that the gap between any two members is the minimum. Spikes are driven in the ground at the ridge and support points to maintain the designed shape and size of the truss. Primarily the joints are tightened by 18 SWG wire passed through previously made bores near the joints of the round bamboo pieces and the final jointing is completed using any one of the following methods.

Wire Bound Joints

Fourteen SWG wires are tightened around the joints (Fig. 4) by binding the respective pieces together. At least two holes are made in each piece and during winding the wires are passed through them to achieve good results.

Pin and Wire Bound Joints

Here, bigger holes are made on the culms to accommodate bamboo-pins of suitable diameter. Fourteen SWG wire is tightened around the pins on both sides along with some additional winding around the culms (Fig 4).

Fish-plated or Gussetted Joints

In this case, strong joints are made by placing 25 mm thick pieces of hard wooden planks or 12 mm thick structural plywood shaped according to the configuration of the joint, on both faces of the joint. These pieces are first assembled and kept in position by thin nails. Holes are then bored, two in each of the culms and 3.5 mm diameter nails are driven through them to unite and tighten the plates with the bamboo pieces in between. The diameter of the bores should be slightly less than the diameter of the nails. It is better and also cheaper to replace the nails by bamboo branch pins (solid) of about 8 to 10 mm diameter driven through suitable bores as shown in Figure 4.

Horned/Tongued Joint

In case of two members meeting at right angles, two horns or tongues are made at the end of the vertical member and accordingly two grooves are cut on the horizontal member to accommodate the horns. The members are then wire-bound or lashed, preferably by passing wires through small diameter holes drilled in the jointing members. Here due to cutting of grooves, the member becomes weaker and as such this type of joint is not generally favoured.

After fabrication, the trusses are transported to the place of work, erected over the previously fixed wooden (eucalyptus) poles or columns, the tops of which are made suitable by trimming or by adding two wooden plates to accommodate the truss. The truss is then fitted and fixed by at least two bolts in each column (Fig. 4). The slope, height, horizontality etc. of the roof are adjusted at this stage.

Purlins

Purlins are important components of a roofing system which act like beams, support the roof grid and transfer the roof load to the trusses below. Long, straight and comparatively small diameter culms having thick walls are selected as purlins. These are fixed over the nodal points of the trusses by wiring them with the top chord encompassing some prefixed bamboo pins there as shown in Figure 4.

Roof Grid

The roof grid is made by bamboo reeds or half or quarter-split bamboo culms. The individual pieces are first fixed over the purlins 25 cm apart like rafters running from eave to ridge. These are then properly wired or caned with the purlins. Similar members are wired over these perpendicularly with similar spacings to constitute a grid system to contain the roof covering materials (Fig. 1).

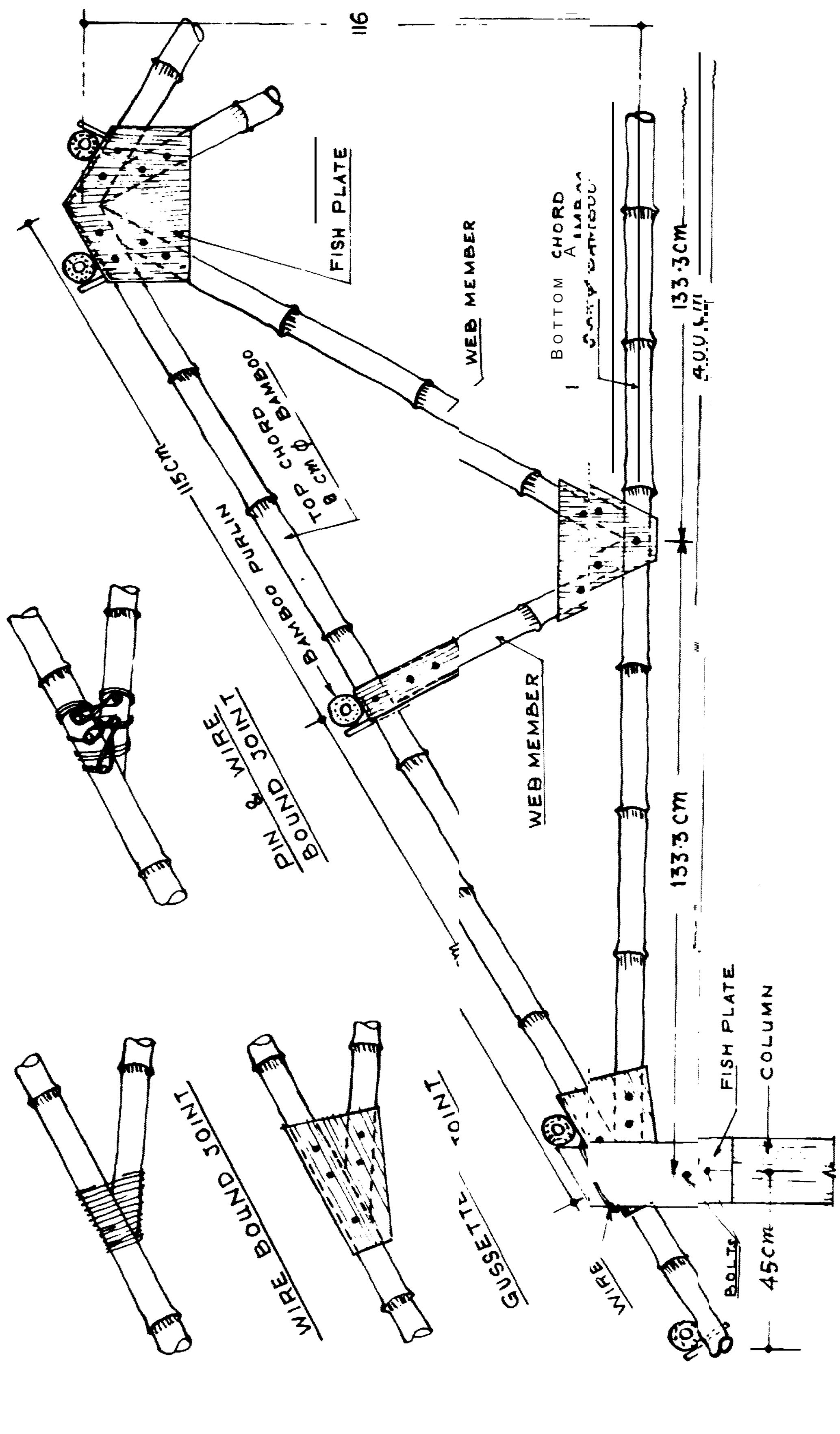
Roof Covering

Corrugated galvanised iron sheets or coconut or palm leaves, grass etc. can be used as roof cover, In the present example, a type of local thatch grass called foons (average length about 1 m) has been used to cover the roof. The grasses are first combed to remove loose and undesirable materials. These are taken to the top of the roof in the form of smaller bundles, opened and spread into a 10 cm thick layer at the eave-side. Bamboo strips are placed over the layer and tightened by galvanised iron wires or tough vines canes, or grass rope called "ban". Successive layers are placed and fixed from eave to ridge. The exposed lower portion of each layer should preferably not exceed 35 to 45 cm depending on the quality and length of the grasses. The ridge is covered by placing a layer of thatch on the top, bending and binding the same equally on both the adjacent sides. Due finishing is given by cutting the extra loose or overhanging material (Fig. 3).

Bamboo Walls

Bamboo-reinforced Mud Wall

Mud walls give protection against heat and cold. Older constructions have been observed to have walls thicker than 50 cm. Here, a 25 cm thick mud wall is reinforced with half/quarter-split bamboo-culms properly treated with hot bitumen. Vertical members 30 cm apart are inserted 25 cm into the ground and extended upto the lintel height. The


116
FISH PLATE
WEB MEMBER
BOTTOM CHORD
133·3cm
115cm
TOP CHORD 8 cm φ BAMBOO
BAMBOO PURLIN
WEB MEMBER
PIN & WIRE BOUND JOINT
133·3 cm
WIRE BOUND JOINT
FISH PLATE
COLUMN
WIRE
BOLTS
45cm

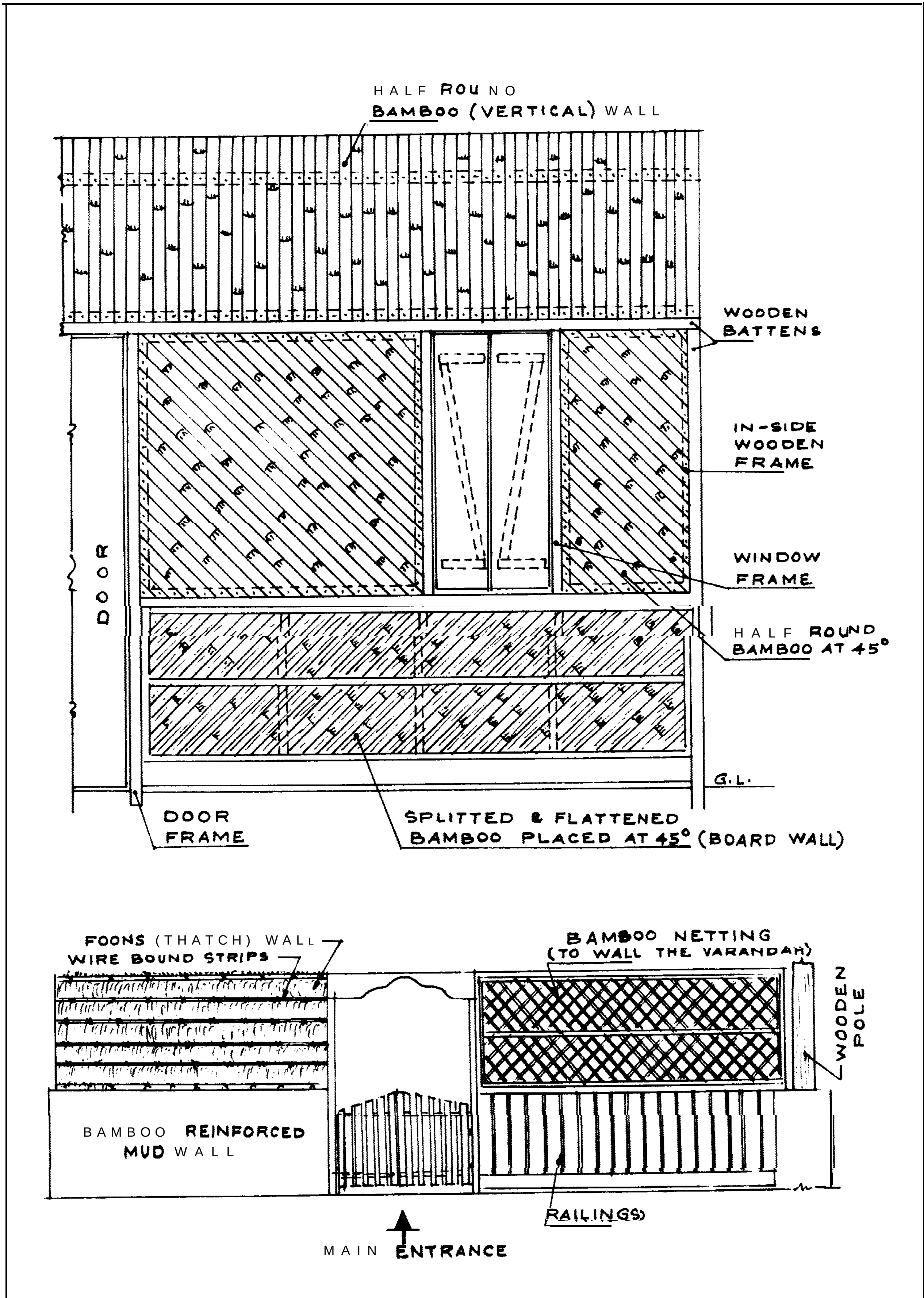


Fig. 5. Different types of bamboo walling

horizontal members are wired with similar spacing. Subsequently, properly moulded mud mixed with rice husk, cinder and a little lime and water are applied layer by layer in the upward direction keeping the bamboo grid in the centre. About 70 to 75 cm height of wall should be made in a day and allowed to dry to enable it to hold the next increment in height of the mud wall. Verticality as well as thickness of the wall is checked during the progress of work. When the mud wall dries well, the extra earth is trimmed off from the surfaces which are then plastered with a 2 cm thick mud-lime-cinder mortar. Finally, a 1 mm thick lime putty mixed with a little amount of gypsum is applied to give the surface a smooth finish. When white-washed, it gives a pleasing look.

Lighter Bamboo Walls

Lighter bamboo walls are common in rural housing. They are easy and cheap to make and can last long provided some preservative is applied and maintenance taken care of. Flattened bamboo-culms devoid of the nodal diaphragm or half-split culms are arranged vertically or at an 45" angle to make bamboo boards, which are duly battened and nailed to form the wall {Fig. 5). Coarse mats made of split bamboo-skins (by vertically splitting the bamboo thickness) woven in a variety of designs are also used to cover wall gaps and are supported by 6 x 2 cm wooden battens which are placed on both sides and nailed. Mats made with skins from the outside of the bamboo are generally used for the exterior wall after applying a coat of coal tar on the outer surface for affording protection against rain. The inner walls are given a paint coating of suitable colour. Bamboo-zafri and wattle-type walls are also used to hold mud plaster on both sides. Plaited bamboo splints of superior weave can be used as walling without plaster. Solid and straight culms as railings and culm strips woven diagonally in a net fashion can be used to cover and beautify the verandah (Fig. 5).

Bamboo strips 2 cm wide can be used in pairs to grip grass (foons) etc. to make lighter walls. The required length of strips are first laid on the ground (strips put concave side up) at a distance of 15 to 20 cm in a parallel series; combed foons or leaves are then spread over it and arranged in a thin but congested layer. A similar set of strips is placed (concave side down) over the layer and these are tightened by wire/cane, starting from one end. When complete, this makes a compact wall. This type of wall is used at the top of the gable end and also on the front side (Fig. 5) of the house. The walls are treated with CCA preservative before use to project them from possible attack of termites.

Conclusion

The construction of a low cost bamboo-house has been described here though some other building materials have also been used to achieve economy (plinth area rate, Rs. 250/m^2). The house with a total plinth area of about 36 m^2 has a earthen floor (bamboo flooring is also practised in hilly and coastal areas) with one bedroom, one dining-cum-store room, and kitchen and verandah as shown in the plan (Fig. 3). Doors, windows and wall frames are constructed using some fast-growing timbers of social forestry origin. Further research is suggested to test and select unexplored varieties of bamboo in order to determine their potential as building material to overcome the existing scarcity as well as minimise the cost of construction.

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Delft Wire-lacing Tool and a Unique Application-Making a Geodesic Dome of 18 m Diameter

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Abstract

The Wire-lacing Tool developed by the Delft Centre of International Co-operation and Appropriate Technology of the Netherlands can be used in lacing round hollow bamboos for structural and non-structural purposes, The system of lacing is simple and inexpensive and prevents any tendencies to split. A 'Geodesic Dome' of approximately 18 m in diameter and 9 m height using round CCA-preserved bamboos has been put together using this wire-lacing tool.

Introduction

One of the major problems in using bamboo in construction is in the utilization of its full tensile strength. To a large extent, a secured and reliable jointer is now available using the 'Delft Wire-lacing Tool'. It was developed by the Centre for International Co-operation and Appropriate Technology of the Netherlands. This tool is a manually operated unit and is used to bind galvanized wire of 2 to 5 mm diameter. It can be used to make various structures.

Description of the Delft Lacing Tool System

The Delft Tool has a hollow cylindrical bottom in which a smaller unit with holes rotates. On top of the unit, a specially shaped handle pulls the wire together and winds them. The wound wires are looped round the bamboo or wood in a manner suitable to get the desired strength and then twisted to form a permanent joint. The tool has a cutting action, which, after having stressed and twisted the wire, neatly cuts it off. This tool has been used very successfully in Africa and several other countries and now in India by us. It is simple to operate.

To arrive at the structural strength of such joints, the Centre at the Delft University had tested various structures, which are both general systems and geodesic-type structures and allowed these to be there under specific weights to arrive at the strength of the connection. They also worked out space structures using the same type of connections, which we believe, have been tested carefully. They seem to have excellent potential.

In India, a 'Geodesic Dome' made out of ASCU-treated bamboo of approximately 18 m diameter and 9 m height has been set up using the wire-lacing joint at the hubs. The dome was first covered with a plastic sheet and now with aluminium sheets.

Conclusion

With this simple but most effective jointing tool, many simple and complex structures can be made with complete design confidence.

Typhoon Damage to Bamboo Housing

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Abstract

This paper examines the performance of a number of low cost houses in recent cyclones in the Philippines and establishes the areas in which it could be improved. Many of the houses incorporated bamboo in the structure though few relied on it exclusively. In most cases the bamboo had adequate strength to carry the wind loads but the connections of the bamboo members could not sustain the loads for the duration of the ryphoon. The paper outlines some suggested remedies and a research programme is curretly underway that will quantify the resistance of bamboo connections to simulated typhoon winds.

Introduction

A United Nations funded regional network was established in Asia in 1983 to facilitate information exchange on the development of satisfactory low-cost housing. The UNDP/UNIDO Regional Network in Asia for Low-Cost Building Materials Technology and Construction Systems held two Seminars/Workshops on the problems associated with development of low-cost typhoon- resistant housing within the region.

The first, held in December 1986, established a dialogue among countries on the scale of the typhoon-related problems and made progress towards a solution. Within the Network countries alone, the damage figures are staggering - on an annual average - over 1000 people die and more than half a million are rendered homeless. These figures do not include the Bangladesh typhoon of 1979 in which over 300 000 people died. While some of the deaths and damage can be attributed to water effects, the poor structural response of buildings subjected to large wind loads is a major cause of community hardship during typhoons.

The second Seminar/Workshop held in July 1987 specifically addressed the need to supplement our knowledge of the engineering properties of materials used in low-cost housing by conducting structural damage assessments following the passage of typhoons. By examining the performance of buildings that sustained damage and those free of damage, failure envelopes could be drawn for many different building materials.

Within four weeks of the completion of the Seminar/Workshop on Typhoon Damage Assessment, a severe typhoon crossed over northern Samar, southern Luzon and northern Mindoro in the Philippines. In order to consolidate the theory established in the training sessions at the Seminar/Workshop, a structural damage investigation was mounted. This paper presents some preliminary observations from the damage assessment. The complete findings will be available when the full report is published.

Typhoon Herming

The Philippines has the dubious distinction of having the largest number of typhoons cross into its meteorological area in comparison to any other country in the world. On an average, over 19 typhoons per year are monitored by the meteorologists in Manila.

Typhoon Henning was the seventh typhoon to be monitored by the Philippines in 1987. It developed as an active disturbance south of the Marianas Islands, approximately 2500 km east of the Philippines on the 7th August 1987, and rapidly developed into a tropical depression. On the 8th. 9th and 10th, it moved slowly northwards and intensified, and on the 11 th, it changed direction to move westwards. At landfall over northern Samar, its central pressure was estimated at 935 hPa with a central wind speed of more than 200 kph.

Some reduction in wind speed and a slight increase in central pressure may have occurred as it crossed the Philippine archipelago. Typhoon Henning was the most intense to make landfall in

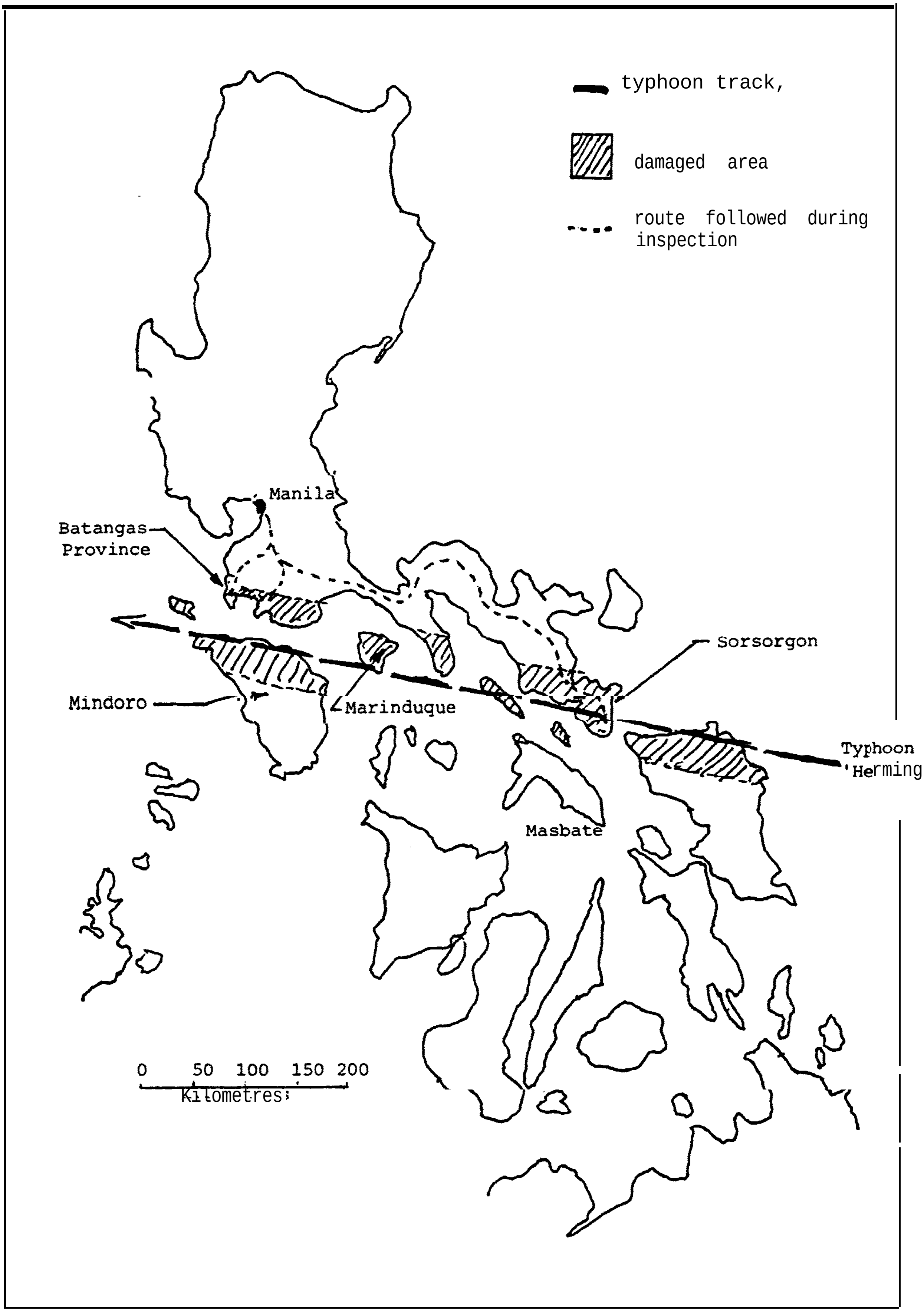

Fig. 1. Typhoon path and damaged areas.

Fig. 2. Photograph of an undamaged bamboo tied connection.

the Philippines in 1987 and the most severe in the affected areas since 1981 (Anonymous 1987).

Damage to Structures

Damage was widespread among the peninsulas and islands that were in the direct path of the typhoon. Due to logistical restraints, the assessment team was restricted to the mainland of Luzon, but still managed to inspect structures in three separate provinces. Figure 1 shows the estimated path of the typhoon, the severely damaged regions and the areas in which damage was assessed.

Over 100 structures were inspected. Some of these were simple structures such as road signs which were used to determine wind speeds. Each structure was documented with respect to its wind environment and the structural materials and system used. Damage was also carefully studied to determine the first elements that failed in each building. In order to facilitate the interpretation of damage, only buildings with simple damage were chosen.

The structures that were assessed could be categorised as follows:

houses	63
schools	18
signs	8
shelters	5
large buildings	6

Of the 8 1 smaller buildings examined, 60 percent had roofs clad with a thatch material and over 70 percent incorporated bamboo or a bamboo derivative somewhere into the structural system. The performance of these structures is examined in the remainder of this paper.

Bamboo Framing

Bamboo structural members were incorporated in a number of houses with mixed success. In many cases where failure occurred, it was often caused by inadequate connection of the bamboo members.

Some houses utilized only bamboo as the principal wall and roof-framing members and in these cases, few if any, nails were used in the construction of the houses. Where such houses had experienced failures of connections, it was due to inadequacy of the ties rather than failure of the bamboo itself. Siopongco (1986) depicts many of the common connection configurations used in the Philippines. A typical example is shown in Figure 2.

A variety of ties was seen but the most common was with rattan, which is a relatively stiff tie material. Where joints tied with rattan had separated, the failure was initiated by the unravelling rather than tensile failure of the rattan. The use of more flexible tie materials would permit the use of tighter knots and prevent untying under the action of repetitive typhoon loads.

Some buildings used frames that had a mixture of bamboo and bush timber as the main structural members. In such cases, the bamboo joints were not always tied and often nailed. Two buildings in which a mixture of timber and bamboo had been used failed due to the fact that the bamboo had split

Fig. 3. Nailing of split bamboo pieces.

at the nails. In both cases, even though bamboo had been substituted for round bush timber, no change was made in the fastening system. Nails had been driven through the bamboo into the timber as the only means of making the connection. In other cases where the joints had been both nailed and tied, they remained intact in the damaged building.

A number of cases of fractured bamboo were observed, but it was impossible to tell whether those failures were due to overload following failure of adjacent structural elements, or whether they were themselves primary failures. These details may be resolved in the complete analysis of such houses.

Use of Split Bamboo

In many cases, split bamboo was used as structural members in combination with thatched roofs. The most common thatch used in coastal areas was of nipa palm which was bound into tiles by wrapping the leaves over split bamboo or nipa palm stalks. The tiles were approximately one metre long and had a coverage of between 0.1 and 0.2 m^2 . The performance of the nipa tiles themselves was very dependent on the structural and aerodynamic form of the house. Where windows on the windward wall had been left or blown open, the nipa tiles suffered more damage than those on houses which had remained sealed. However, some patterns in the failure were quite obvious. The nipa tiles had been fastened to the roof structure in many different ways:

- The most common was nailing with one nail through the nipa tile into rafters at every crossing point.
- Some fastenings utilized ties with nylon fishing line at every crossing point in conjunction with nailing. One loop of fishing line was the most common form of this connection.
- In some cases, ties had been used on two crossing points on each tile, while the others were held by nails alone.
- In a few cases, alternative tie materials had been used. These included abaca twine, rattan and plastic strip.

In many cases, nailing was not used in conjunction with these materials. Figure 3 shows a detail of failure where a nipa tile had been secured only with nails. The cracks in the split bamboo are quite obvious. It is probable that the bamboo had split at the time of installation, but the damage was concealed by the nipa thatch. Upon uplift due to wind action the nipa tile would have lifted over the nail head with little resistance. In contrast with this type of failure, the performance of the roof was much better where the bamboo splits were tied to the roof structure at every crossing point. In one house, the owner had run out of nylon fishing line prior to tying the whole roof, and the untied area had been removed by uplift forces whereas the tied area had remained untouched.

Figure 4 shows a typical failure of a house in which only two points on each tile had been tied. In this case, the tiles had all remained fastened to the rafters at the tied joints, but had become

Fig. 4. Failure of a roof in which nipa tiles were tied at only two points (position of missing bamboo splits arrowed).

Fig. 5. Anahaw thatch.

separated from the roof structure at all of the nailed connections. The tied rafters had consequently become overloaded and broke, allowing their separation from the roof structure. Almost all of the houses in which partial tying of the nipa tiles had been done were similarly damaged.

Split bamboo had also been extensively used to anchor anahaw thatch as shown in Figure 5. The anahaw thatch had performed consistently better than the nipa thatch primarily due to the fact that it was virtually impossible to fix without tying. Conventional fixing techniques used split bamboo pieces on both the inside and outside of the thatch with nylon or rattan ties connecting the two. This attests to the success of ties in securing split bamboo members in a structure.

Fig. 6. External bamboo bracing (arrow).

Bamboo Walling

Bamboo walling was observed in three different forms:

- split bamboo lengths tied or nailed vertically to give a semi-permeable wall.
- woven bamboo sawali - frequently sandwiched between the frame on the inside and cover strips on the outside.
- crushed bamboo in which mats of bamboo formed by crushing single culms were placed in two layers and sandwiched between the frame and cover strips.

No bracing was observed in the walls of any of the houses that used these systems. As a result, racking had occurred with all of the systems. With the split bamboo lengths, the racking was so severe that the house was often a total loss. Houses with swali and crushed bamboo seemed to be stiffer, and the resulting racking deflection was often small, leaving the house quite serviceable.

Bamboo as Bracing

A number of houses with external bamboo braces were observed. These braces ran from the eaves level to the ground as shown in Figure 6. The purpose of this brace was to secure the house against lateral movement; however, the braces proved largely ineffective. The braces were rarely tied at the bottom which meant that they could carry no tension, and their slenderness prevented them from carrying much compression. Their value appears to be psychological.

Reconstruction of Damaged Housing

In all the areas inspected it was observed that the lightness of houses enabled their ready reconstruction. However, the reconstruction carried out frequently followed the same structural form as the damaged building. This clearly indicates the important place that education has in the establishment of sound building practices using bamboo. Several instances were seen where bamboo had remained intact to convince the assessment team that as a building material, bamboo is quite sound provided it is fixed satisfactorily. Publication of findings from this and other investigations in a manner that will be useful to owners and builders of low-cost houses still remains the greatest challenge facing research workers in this area.

Quantitative Study on Bamboo Connections

An Australian International Development Assistance Bureau project currently in progress at Curtin University of Technology aims at quantifying the effect of repeated loads on the performance of bamboo connections in various configurations. At present, preliminary testing has indicated the viability of the project.

Tests will be performed on bamboo connections using various lashing patterns and materials for round bamboo to round bamboo connections, and split bamboo thatch shingles to round bamboo or timber connections. These tests will provide quantitative information on:

modes of failure,
susceptibility to deterioration under repeated loading,

margin of safety in the connection, and
effect of the geometry of the connection and angle of the applied force.

The tests should establish whether there is a significant difference between the behaviour of the joints under repetitive loads applied in typhoons and under corresponding static loads. It is expected that the data will be of great use in establishing design procedures for cost-effective bamboo connections. There is a real need to pool data from other similar studies so that statistically significant results can be incorporated into standard engineering design methods.

Conclusions

Round bamboo major structural members and split bamboo minor structural members can be made to work effectively in low-cost houses provided sufficient attention is paid to methods of connecting (holding) them together.

- Nailed connections will not hold all species of bamboo during typhoon loads, as the bamboo has a tendency to split, allowing it to pull over nail heads.
- Rattan-tying of round bamboo can withstand typhoon loads provided the rattan is well tied and a sufficient number of turns is used.
- In securing split bamboo minor members in roof structures, a combination of nailing and tying with a single turn of nylon fishing line at every crossing point appears to be very successful.

Wall bracing must be used with bamboo wall cladding materials to prevent excessive racking.

Wall braces must be securely tied both at the top and bottom to function effectively. To that end, members built into walls are most efficient, because the lateral support offered by the wall allows them to carry loads under compression as well as tension.

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Building with Bamboo - A Solution for Housing the Rural Poor

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Abstract

Tests were carried out on bamboo-reinforced cement concrete building components by employing new techniques to solve the shrinkage-bond problem that is known to exit with this type of concrete. Three different techniques have been tried to improve the bond characteristics of bamboo. The technique in which bitumen-treated coir. rope is wound round bitumen-dipped bamboo to obtain a ribbed surface, proved to be the best. Strain measurements revealed that these beams behaved similar to conventional beams in bending and that the theory of reinforced concrete could be applied in the design of these members. Load deflection curves showed that the deflection is greater- than that found with conventional beams and is around 1/175 of the span. All the beams With three to four percent of bamboo reinforcement failed by developing flexural cr-asks. Some of the beams in which one to two percent of bamboo reinforcement was used failed in diagonal cracking and the bamboo strips broke at failure revealing the perfect bond that could be achieved through the new technique developed in this investigation. The designs of two basic bamboo-reinforced concrete elements which can be used to delvelop a system to mass-produce small housing units to suit the rural poor. are also included. Building with bamboo can be a plausible solution for housing the millions of homeless poor.

Introduction

Housing is a basic necessity of the human race. The daunting problem of housing in the developing countries is not entirely due to limited financial resources available for human settlements but also because of lack of application of appropriate technology which allows utilization of new, cheaper materials as substitutes for conventional expensive materials. Material saving through new innovations in design or which can save manpower by allowing pre-fabricated building and allows flexibility in planning and constructional techniques also need to be introduced.

An investigation was made to explore the possibilities of substituting bamboo for steel in reinforced concrete as tensile reinforcement and to develop precast bamboo-reinforced concrete standard elements like joists and planks required to build small dwellings suitable for the poor. Three different techniques were developed in the author's laboratory (in India) for using bamboo as tensile reinforcement in concrete to suit human settlement and development programmes.

Previous Investigations

Initially researchers faced problems concerning bond and volume change of bamboo when it was first used as embedded reinforcement. To solve this shrinkage-bond problem, techniques such as composite construction using bamboo as an external reinforcement were developed. The composite action between the concrete and bamboo was achieved through shear connectors. A renewed interest in embedded bamboo reinforcement arose on account of the military construction activities in South-east Asia. Geymeyer and Cox (1970) used the following techniques to improve the bond and prevent shrinkage.

1. Use of dried bamboo split into two halves. This technique, however, did not improve the bond. It also resulted in intolerable cracking of the concrete cover.
2. Coating of dried split bamboo with moisture barriers such as varnish, asphalt and paints.

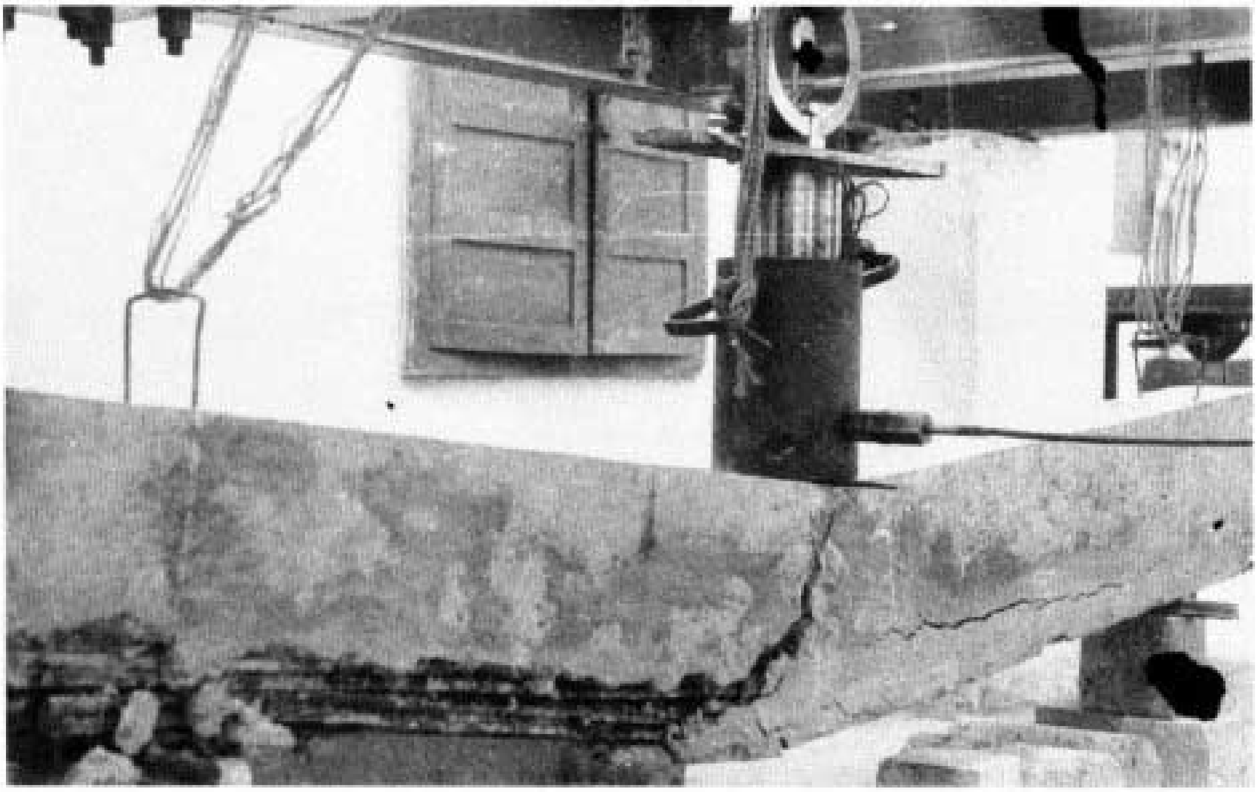

Fig. 1. Bond failure of untreated bamboo-reinforced concrete beam (probing test).

This technique only prevented problems associated with volume changes of bamboo.

3. Coating dried, split bamboo with epoxy or polyester resins and sprinkling sand to obtain a rough surface. However, epoxy resins are very expensive and the object of reducing the cost cannot be achieved by using these materials. This technique, however, successfully improved the bond between concrete and bamboo and also prevented cracking in the concrete cover.

Masani and Dhamani (1962) and Narayana and Rahman (1962) also adopted a composite construction technique in the use of bamboo in concrete. The former tried different treating procedures to avoid possible decay of bamboo. These investigators used a mixture of white lead and ten percent varnish and it has been said that such treatment increases the life of bamboo to nearly 60 years. Gupchup et *al.* (1974) also reported the results of their tests on the suitability of bamboo strips as tensile reinforcement in concrete.

Present Investigation

Tests were carried out on bamboo-reinforced cement concrete beams by employing three different techniques to solve the shrinkage-bond problem (Fig. 1). Locally available bamboo of 25 mm average diameter and 3 to 4 m length were used in the tests. Each bamboo was split length-wise into equal quadrants. Each strip was around 20 mm in width and 5 mm in thickness. Using small pieces of these strips, the longitudinal reinforcement was tied to form a ladder-like cage. Each cage consisting of two strips was about one percent of the cross-section of the beam.

Technique 1 - Bitumen-coated and Sand-surfaced Bamboo Strips

This technique consists of using bamboo strips with a uniform thin coat of hot bitumen applied with a brush and put under coarse sand fully covering the strips. These strips are removed after 24 h from the sand and cages are made for use as reinforcement. The bitumen coat is found to act as an effective barrier and prevents moisture from coming in contact with the untreated bamboo. The sand forms a very rough surface on the bamboo and thus considerably improves the bond between concrete and bamboo reinforcement.

Technique 2 - Bitumen-coated Strips with Nails as Spikes Along the Length of the Strips

In this technique, bitumen-treated bamboo strips were used to make the cages but the strips were not sand-surfaced. Along the length of the bitumen-treated bamboo strips, 2.5 mm long nails were driven at 7.5 mm pitch extending half-way on either side of the strips. These nails in the form of spikes prevented bond failure. This technique was found to be better than technique 1.

Technique 3 - Bitumen-coated Strips with Coir Rope Wound Around to Form a Ribbed Surface

In this technique, bitumen-treated bamboo strips were wound round with 2 to 3 mm diameter coir rope at a pitch of 100 mm along the strip from end to end. These strips so prepared were used to make the cages. The coir rope was also dipped in hot bitumen before being wound round the bamboo strip. This gave a surface similar to a ribbed steel surface. The ribbed surface was found to improve the bond considerably and thus improved the structural behaviour of the bamboo-reinforced concrete. The technique also made it possible to use bamboo-reinforced concrete for producing precast concrete elements for housing.

Experimental Work

Materials

Bamboos: Bamboos were obtained from the local market (in India). The average diameter was 25 mm. The length ranged from 3 to 4 m after cutting the end where the diameter was less than 25 mm. This was split longitudinally to obtain four strips from each bamboo. Two such strips gave an area approximately equal to one percent of the beam cross-section. Therefore, two strip-cages were made and one, two, three and four such cages were used to make up 1,2,3, and 4 percent, respectively, of bamboo reinforcement in the beams. The ultimate tensile strength (UTS) of the bamboo varied from 100 to 200 N/mm^2 and the modulus of elasticity was found to vary from 15 to 20 kN/mm2. In the computations, average values are used.

Cement: Ordinary Portland cement (ACC brand) was used in all the tests.

Aggregates: Sand from the Narmada river and locally available black stone coarse aggregate of maximum 20 mm size were used to make concrete.

Concrete: Concrete was proportioned by volume to give a strength of about 15 N/mm2 on the 28th day.

Test Specimens

For making probing tests on bamboo-reinforced concrete, a beam of size 150 x 500 mm and 5 m long was cast with 3 percent of bamboo reinforcement using half-split bamboos as obtained from the market without any treatment, with the objective of studying the failure in this type of beam. The beam was cast in a steel mould of adjustable type to vary the cross-sectional dimensions of the beam.

Standard test beams of 1.2 m long and 100 x 200 mm in cross-section were also cast with l-4 percent of bamboo reinforcement using all the three techniques described. Thus 12 beams in all were cast using Ml5 concrete. Along with the beam castings, six cubes and six cylinders were also cast to obtain compression and tensile strengths on day 7 and on the test day (normally on day 28). The beams were all cured in a water tank till one day before testing.

Testing Procedure

A test on a beam of 150 x 300 mm with untreated bamboo reinforcement was first carried out on a span of 3 m. This probing test was carried out under single central point load. The beam failed in bond and Figure 1 shows the test set up and the failure of this beam. The beam contained three percent of longitudinal bamboo reinforcement and there was no web reinforcement in it.

A series of beams of size 100 x 200 mm using the new techniques to improve bond were all tested on a 1 m span under a single concentrated central point load. These beams were reinforced with l-4 percent of bamboo reinforcement and there was no web reinforcement in the beams. Figure 2 shows the test set up.

Results

All the beams were tested in a reaction frame. Beams were loaded gradually with load increments of 1 kN. These were white-washed to easily locate the cracks at the initial stages of loading and the crack patterns traced at each increment of the load.

Strain Measurements

In some of the beams, strains were measured at mid-section. Demec pads were glued to the concrete surface a day before testing at 50 mm gauge length across the mid-section. Strains were measured till the first crack appeared in the beam using the Demec demountable mechanical strain gauge.

The strain profiles show that plane sections remain plane even when bending and the theory of reinforced concrete can be applied in the design of bamboo-reinforced concrete members. The average strain measured at the level of bamboo reinforcement was of the order of 0.003.

Deflection Measurements

In all the tests, the 50 mm Batty dial gauge was used and the deflections were measured at each

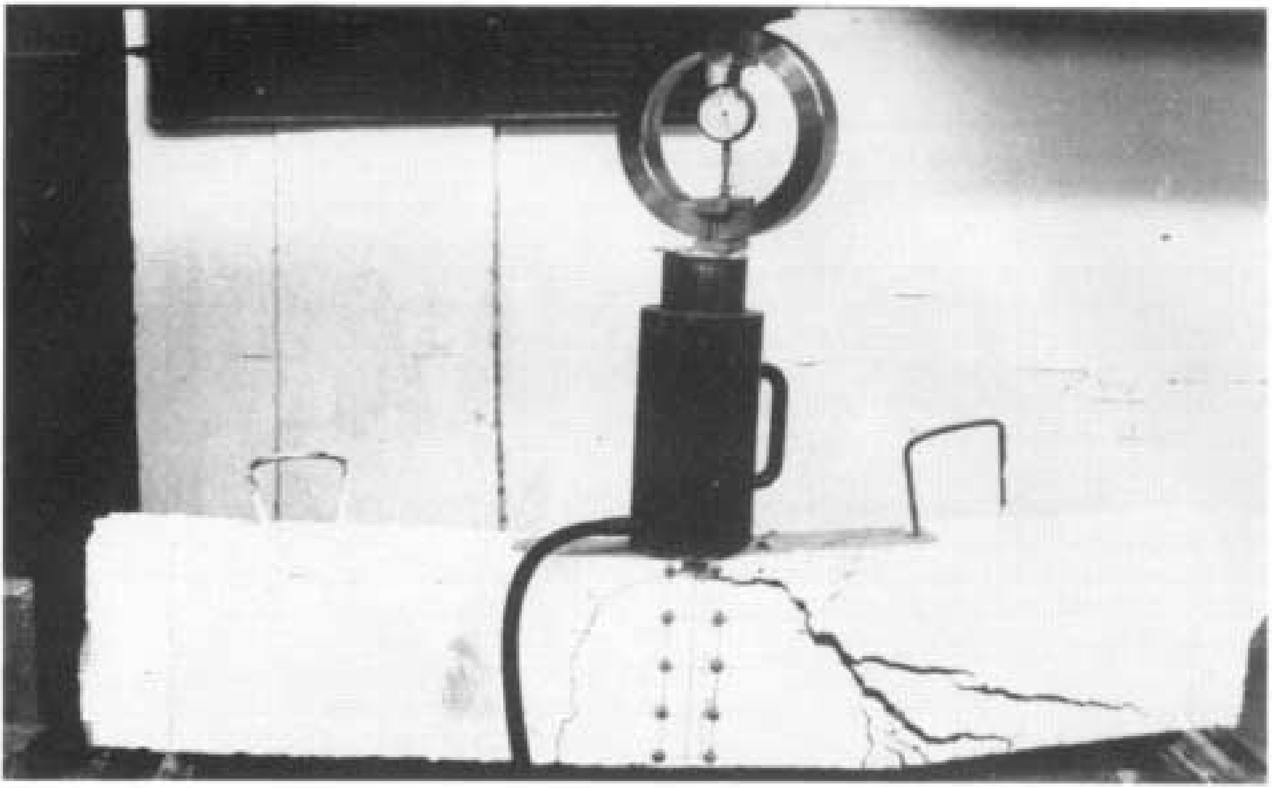

Fig. 2. Test set up for bamboo-reinforced concrete beams with different techniques.

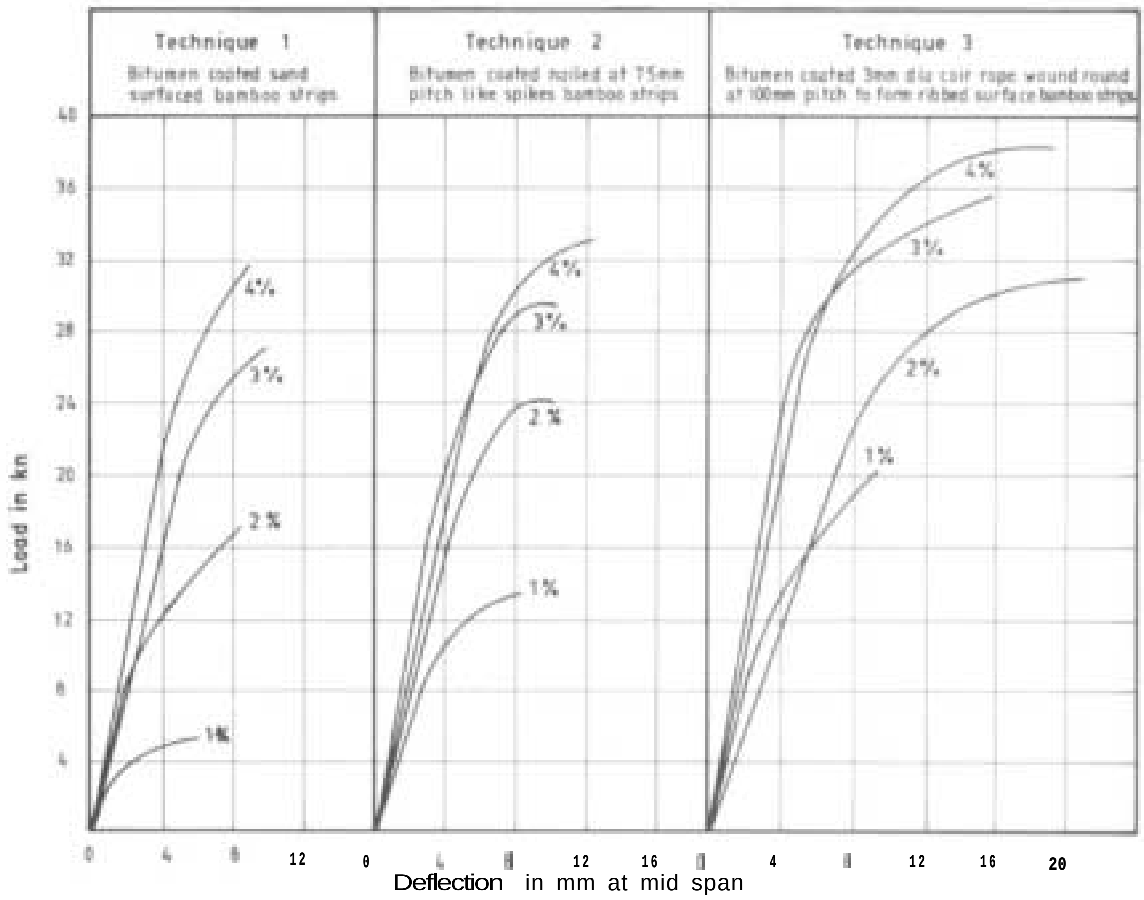

Fig. 3. Load deflection curves.