Final Technical Report

OPTIMISATION OF HARVESTING AND POST-HARVEST TECHNOLOGY TO ECONOMISE BAMBOO RESOURCE UTILISATION

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ABSTRACT

The present study was conducted to examine the possibility of improving the harvesting and post-harvest technology of two common bamboo species viz., *Bambusa bambos* and *Dendrocalamus strictus* which are widely distributed in the Western Ghats region in India. The specific objectives were to improve the harvesting techniques by developing some simple devices and to refine the methods of culm age determination for harvesting. The study also aimed at evaluating the efficacy of some traditional practices of post-harvest protection of bamboos from borers with a view to identifying promising eco-friendly treatment methods and ultimately to suggest an integrated pest management strategy against borer pests.

As an outcome of the study, a simple branch cutting tool was developed for removing the thorny branches prior to culm extraction. The manually operated cutter so designed, which could be mounted on a bamboo pole and operated from the ground, was useful to minimize the drudgery of harvesting operation. With a view to improve accuracy in judging the culm age/maturity in the field for harvesting, a traditional method based on culm tissue colour was explored. The colour of the culm tissue which was found to change from creamy white to yellowish or yellowish brown due to increased lignification with age was found to be a reliable indicator that could be used as a supplementary feature for culm age determination. The maturation was complete in three years in *B. bambos* and *D. strictus* and there was appreciable increase in basic density and decrease in the moisture content and shrinkage which are desirable from the angle of strength properties and stability.

Susceptibility of bamboo culms to borer beetles, mainly to *Dinoderus* spp., is a major problem in its utilization. It was found that borer attack was dependent on starch content of culms. The beetles and their larvae were found to prefer the inner, starch-rich portion of the culm wall for more productive feeding. The extent of starch content seemed to depend on locality and favourable growth conditions. Within a year, starch content was low from September to November. The natural borer population and the intensity of infestation were also low during this period. Culms in early stages of flowering had high starch and were highly susceptible to borers.

However, as the flowering and seed setting progressed, there was depletion of starch and consequently, susceptibility to borer attack was also reduced. An interesting observation noted during the study was the slow depletion of starch from culms during post-harvest storage due to the activity of amylase enzyme.

Among the traditional methods followed in rural areas for post-harvest protection of bamboo submersion of harvested culms in water for one to three months was found effective in preventing borer damage. Submersion caused degradation of storage starch in culm tissues due to the action of saprophytic microorganisms. A fungus of the genus *Acremonium* and bacterial species belonging to the genera *Pseudomonas* and *Klebsiella* were isolated. Other physical treatments such as heat curing/boiling in water were not effective. Similarly, harvesting trials conducted for one complete lunar month did not indicate any influence of the waning or waxing phases of the moon on the extent of borer damage. Among the traditional biological treatments, a preservative formulation of nine biological ingredients used by local carpenters for protection of wood was found to be effective against bamboo borers. Similarly application of neem oil was also equally effective. Brush application of these preservatives/repellants on the cut ends and branch scars of bamboo culms gave protection from beetles. However, application of fenugreek-paper pulp mixture and wall paint (black Japan) was not effective. Though a mite predator was found to attack the various life stages of the *Dinoderus* beetle, its scope as a useful biocontrol agent could not be evaluated. In the laboratory a fungal pathogen- *Beauveria bassiana* was found effective in causing mortality of the adult *Dinoderus* beetle.

Based on the results obtained, an integrated pest management strategy to protect bamboos from *Dinoderus* beetle damage to bamboos is suggested. This involves cutting the bamboo at low starch period, adopting traditional methods like water soaking, application of preservatives and following improved methods of stacking.

Keywords: Bamboo harvesting, post-harvest technology, culm maturation, culm age determination, traditional methods, moon phase, preservatives, *Dinoderus* beetle, starch and borer attack

1. INTRODUCTION

Our country is one of the major producers of bamboo in the world. With an annual production of over 3.2 million tonnes per year (Tewari, 1992) India holds the second position in bamboo resources next only to China. The total annual production of bamboo in the world is about 10 million tonnes. Out of the 110 genera and 1140 species of bamboos found in the world, 18 genera and 128 species occur in India distributed throughout the country. Bamboos are a common component of forests, degraded forest lands, homesteads and farmlands in the country.

Bamboo has been an important raw material for paper industry in India. About half of the country's bamboo production is consumed by the pulping industry. India uses about 3 million tonnes of bamboo for pulp manufacture as compared to 1 million tonnes used by China (Dhamodaran *et al*., 2002). Although due to shortage of forest-based materials in recent years, alternative fibre resources like agro-residues and wastepaper are being increasingly exploited by the paper industry, the former are still the preferred raw materials for some mills in the country even today. Due to its favourable fibre characteristics and chemical constitution, bamboo is found to be an ideal material for the manufacture of paper, paper products and rayon. However, the consumption of bamboo by the paper industry has remained almost steady from 1998 to 2001 except for a marginal increase (CSE, 2004).

Besides providing the much-needed raw material for pulp and paper industry, bamboo has played a significant role in the rural economy under Indian context due to its contribution to rural employment, agriculture, and housing. Use of bamboo in the traditional sector for basketry and mat-weaving and also in housing and agricultural sectors has a long history. For centuries, it has been an essential component of rural lifestyle contributing to diverse needs of the population. Bamboo has been a cheaper alternative to timber in construction of rural dwellings and making diverse utility items and has earned a reputation as 'poor man's timber'. Even today, bamboo is a source of livelihood to a significant proportion of rural population in the country. The traditional, basket and mat-weaving industry is one of the major consumers of bamboo resources. Thus during recent years there has been growing interest in the country to develop the rural bamboo-craft industry and improve the livelihood prospects of the bamboo-dependant population. Several programmes have been launched by both Central and State Governments, which are aimed at resource enhancement and total development of the rural bamboo sector.

In the present context of increasing shortage of timber in India, bamboo is being looked upon as a potential alternative to wood for many applications. Besides paper and rayon pulp, bamboo has also proven its suitability for other industrial products such as boards, paneling, furniture and handicrafts. The lignocellulosic material of bamboo resembles wood in many technical properties and hence can be utilised as a substitute to wood for many of these products. However, the alarming situation of depleting bamboo resources in the country due to clearing of forests and degradation of habitats pose a threat to the bamboo-based industries and the livelihood of the artisans dependent on the traditional bamboo-craft industry. Since mere replenishment of bamboo resources is not enough to meet the ever-increasing needs of future population, it is necessary to look for alternative measures that will promote more judicious utilisation of resources. This calls for all attempts to economise bamboo consumption through minimising harvest wastage and reducing losses resulting from biodegradation and other causes during post-harvest stage.

When bamboos are utilised for constructional or agricultural purposes, the culms harvested should be fully mature to provide optimum strength. The age of felling is thus critical for obtaining optimum quality. In the case of bamboo, mature culms are usually located in the inner part and are surrounded by more juvenile culms in a clump. Reaching the culms located in the inner part of the clump is rather difficult particularly when they lie amidst thick growth of spiny branches. Further, the techniques used by bamboo workers for judging the maturity of culms are arbitrary. Only experienced bamboo workers are able to use these techniques unfailingly. Thus there is a need to add accuracy to the methods of judging culm age/maturity for harvesting to avoid collection of immature culms.

The major problem with bamboo in contrast with durable woods is, perhaps, its high susceptibility to insect borers during post-harvest period. The borer beetle (*Dinoderus* spp.)

and their larvae, which feed on the starch stored in culm tissues, are capable of causing heavy damage to the harvested culms and articles made out of bamboo. Within a few weeks, the beetles are able to reduce a stack of bamboos into a powdery mass of frass. The beetles, which gain entry into the harvested culms by tunneling, lay their eggs, within the culm tissues. The larvae that hatch from the eggs feed actively on starch stored in culm tissues and grow, until they pupate. Both larvae and adult beetles are active feeders and cause heavy loss to stored bamboo.

It is obvious that the currently used technology is not adequate from the point of view of a wastage-free utilisation of bamboo resources. What is needed is to economise the use of the material and curtail the wastage by devising suitable harvest and post-harvest technology. Since the borer infestation in bamboos is related to the starch content in tissues, detailed investigations have to be carried out to confirm the relationship between storage starch and intensity of borer attack. Detailed studies on infestation pattern of the borers and the factors which promote borer attack will be required to suggest appropriate remedial measures. There was also a need to evolve simple, environment-friendly techniques for protection of bamboos from borer attack. Besides, the effectiveness of some of the traditional methods of 'curing' and preservative techniques practiced in rural areas need to be evaluated.

The Present Study

The present study envisages developing technologies to optimise the harvesting and post-harvest protection of bamboos with an ultimate aim of bringing down the wastage in bamboo utilisation. Thus improvements in harvesting technology are envisaged by introduction of appropriate tools useful to overcome the drudgery of harvesting operation. The scientific basis of the traditional methods used by the bamboo workers for judging the culm maturity for harvesting was evaluated. In addition, the effectiveness of the traditional practices of curing and preservation followed in rural areas was also tested for effectiveness. The main thrust of the study was to develop a simple, environmentally-safe technology that is feasible under local conditions to manage the post harvest bamboo from borer damage.

The objectives of the study were:

1. To design and develop portable powered tools suitable for bamboo harvesting
2. To develop reliable methods to assess culm maturity in the field, for harvesting
3. To examine the infestation pattern of borers and factors promoting borer damage during storage and service, with a view to develop preventive measures
4. To evaluate the effectiveness of various traditional curing/preservation practices and test their efficacy to suggest an integrated control strategy against the borer damage.

2. LITERATURE REVIEW

Harvesting is the first step in rationalisation of bamboo utilisation. Just as the technical quality of bamboo material obtained from different species of bamboos is variable, there is notable difference in the properties between culms of different age classes within a species and within the different portions of the same culm. Some of the parameters of this variation which have direct bearing on bamboo utilisation include culm/internodal length and diameter, density and strength properties, moisture content, shrinkage, permeability, anatomical structure and so on. Much of this variation is inherent to bamboo and cannot be artificially controlled. However, the only aspect that can be manipulated is the variation with respect to culm age and this can be achieved by harvesting bamboo at suitable age.

Obviously, harvesting bamboo culms at the right age and maturity is of great importance for getting the optimum quality suitable for several end use applications. However, the assessment of culm age in the field requires some experience and understanding of a few basic principles of clump and culm morphology. Generally in clump forming bamboos such as *B. bambos* and *D. strictus* the older culms lie at the center and the newly formed culms at the periphery of the clump. There can also be a difference in internodal length and diameter of the older and more recently formed culms. However, the most useful features that are widely employed for judging the culm maturity are the morphological features such as sheath characteristics, culm surface, texture and colour, branches and leaf scars. These features are also variable depending on the species and a few studies have been made to elucidate the changes in morphological features in relation to age in different species (Waheed Khan, 1962; Banik, 1993). However, the technique of using morphological features has not so far been perfected for all the bamboo species to facilitate the accurate age determination of culms.

It is generally observed that most of the physical and mechanical properties of bamboo material change with increasing culm age (Liese, 1992; 1995; 1998; Liese and Weiner, 1996; 1997; Hidalgo, 2003). Thus there are several publications highlighting the effect of age on technical properties and processing quality of bamboo (Abd. Latif, 1992; 1993; 1995; Abd. Latif and Mohd. Zin, 1992; Abd. Latif *et al*., 1990; 1993; Espiloy, 1994; Sattar *et al*., 1994). The properties that are affected with increase in culm age include the basic density, moisture content, strength properties, machining quality, etc., and therefore culm age is an important factor having direct bearing on bamboo utilisation.

The change of technical properties has been generally attributed to the developmental processes such as cell wall thickening and lignification occurring in the culm tissue during culm maturation/ageing. A number of studies have attempted to describe these anatomical changes occurring in the culm tissues (Alvin and Murphy, 1988; Majima *et al*., 1991; Liese and Weiner, 1996; 1997; Murphy and Alvin, 1997a; 1997b; Bhat, 2001, 2003). It is generally found that the maturation changes involving cell wall thickening and lignification of tissues are complete when the culm attains 3-4 years of age. Studies on ultrastructure of fibre walls have shown that the thickening of cell walls is due to deposition of additional cell wall lamellae (Liese, 1998; Gritsch *et al*., 2004). The process of fiber maturation with age is found to prolong for many growing seasons (Liese, 1998). However, in some species lignification of culm tissues is completed within one growing season (Itoh, 1990). The cell wall thickening of fibres and parenchyma that is found to continue even after maturation phase is believed to be due to ageing (Alvin and Murphy, 1988; Liese, 1998).

Research on bamboo harvesting has been mostly focused on the economics, yield, felling age, sustainable harvesting and methods of working bamboo clumps. There have been only limited studies on techniques and tools related to felling operation. Only a few studies (Wu and Tsao, 1976; Chandra, 1975) have compared the economics of mechanization of harvesting operation with that of manual felling. Much research has gone into developing tools and machines required for processing of bamboos (BIC, 1992; Gnanaharan and Mosteiro, 1997; IDC, 2001). However, a few attempts have been made to develop simple hand operated tools for harvesting and slicing (Bhat and Pandalai, 1999; Grewal *et al*., 1994)

There is one more aspect, which is equally important from the point of view of bamboo harvesting and utilisation. This is pertaining to the high susceptibility of harvested bamboo to insect borers. Beetles of *Dinoderus* genus, (Coleoptera: Bostrychidae) (*D. minutus* Fab. *D. brevis* Horn. and *D. ocellaris* Steph.) which are popularly known as *ghoon* borers in India

(Beeson, 1941; Sen Sarma, 1977) feed on the starch stored in culm tissues and cause extensive damage to harvested bamboo and articles made from it. Although there are various beliefs with regard to the susceptibility of bamboo to borer infestation, starch content is often regarded as a predisposing factor for the borer incidence and several studies have correlated the borer attack with the occurrence of starch in bamboo (Plank, 1950; Plank and Hageman, 1951; Joseph, 1958; Mathur, 1961; Liese, 1980; Nair *et al*., 1983; Dhamodaran *et al*., 1986; Mathew and Nair, 1994). The damage caused to bamboo is said to be proportional to starch stored in the culms and starch is detected by the beetles almost immediately after the culms are felled and assembled for drying and storage. (Hidalgo, 2003). According to Plank (1950), *Bambusa vulgaris* which has the highest amount of starch is highly susceptible of all bamboos, to borers. Flowered bamboo with starch completely depleted is found to be resistant to beetles (Liese, 1998). A few studies have thus suggested suitable 'low starch periods' for harvesting bamboos with a view to minimise the borer problem (Beeson, 1941; Sulthoni, 1987). It is found that bamboo harvested during summer is more rapidly destroyed than those felled after the rainy season as the latter has less starch (Liese, 1985; 1998). Observations by Sulthoni (1996) on traditional harvesting period (April- May) in East Java also support this finding. Similarly, some early observations from India have pointed out that the beetle damage in *B. bambos* and *D. strictus* is lower during the rainy season because their population dies down with the advent of rains. Thus it has been suggested that cutting the culms is advantageous in rainy season when the sap flow is low and the insects are probably not active.

However, storage starch is of considerable importance in determining the susceptibility of bamboo culms to borer attack. Starch is stored in the subterranean axes and in the culm tissues as energy resource for production of new shoots as well as for the mobilization of wound responses (Liese, 1998) and is stored as granules in the ground parenchyma and vascular parenchyma cells. It has been found that between species there is wide variation in the amount of storage starch. Starch content is also found to vary within the same culm. Generally the nodal portions of the culm and the septa contain higher amount of starch. Similarly, starch content is usually found higher in the upper parts of the culms than in the lower portions (Abd. Latif, 1995; Liese, 1998; Kumar and Mohinder Pal, 2003). Culm age is also found to influence a great deal on the abundance of starch in the tissues. Usually young, growing culms are virtually devoid of starch during the first year of their growth but as the age increases there is accumulation of starch in the tissues (Alam and Murphy, 1988; Weiner and Liese, 1996). On the contrary, there are some reports to show the absence of a definite relationship between culm age and accumulation of starch (Bhat, 2003).

Beetles causing damage to bamboo enter the culms through the cut ends, cracks on the surface or through branch scars left after trimming the branches. They lay eggs within the culm tissue, which pass through the different stages of life cycle. According to Plank (1948) once the insects penetrate the cut ends to the inner culm wall they extend their cylindrical galleries along the soft inner part of the culm wall. For the purpose of oviposition the adults extend their galleries at right angles to the grain and lay the eggs within the xylem vessels. The eggs hatch in 3-7 days. The larvae are found to feed actively for about 40 days and then pupate. Development from the time of deposition of egg to the emergence of adult averages 51 days (Hidalgo, 2003).

Besides the low starch periods which offer higher resistance to bamboo, there are also some popular beliefs in rural areas with regard to timing of the harvesting to minimise borer damage. It is believed in some parts of India that bamboo harvested during a certain phase of the lunar month evades borer attack. Deogun (1936) states that in Bihar, Orissa and in other parts of India it is commonly believed that if bamboo is felled in the bright phase of the moon, it is less susceptible to insect attack than when it is felled in the dark phase. According to Hidalgo (2003), in Columbia, the opposite was the belief held. Experiments conducted in India showed that there is a cycle of moisture percentage increasing from full to new moon and decreasing from new to full moon. The starch content, on the other hand, did not show any change with respect to lunar month. Thus it is clear that there are contradictory opinions about the lunar period and the borer susceptibility. However, experiments carried out at FRI, Dehra Dun have failed to find any connection between moon phases and insect attack. Experiments conducted by Plank (1950) at Puerto Rico and by Hidalgo (2003) in Colombia have also failed to show any scientific proof for this belief.

The lack of evidence in support of some such rural beliefs however, should not underrate all the traditional knowledge of post-harvest practices followed in rural areas. Some such traditional practices such as post-harvest ‘curing treatments’ to protect bamboo have been found to be effective for protection of bamboo. The traditional techniques followed in rural areas for protection of bamboo are summarised by Liese (1968), Sulthoni (1981, 1987) and Choudhury (1993). Some widely followed traditional treatments in India include immersion in water, heat curing, smoking, application of preservative/repellant coatings, etc. In Bangladesh a method of mud curing is practiced in which freshly cut culms are soaked in muddy pond for 1-8 weeks and then slowly dried in the shade (Choudhury, 1993). Yet another curing treatment known as clump curing (Mathur, 1961; Hidalgo, 2003) involves cutting the culms at the base and leaving them vertically leaning against other culms in the clump for 4 weeks to bring down the starch level. Other methods of traditional curing treatments include burying culms in beach sand, curing in seawater or application of slaked lime (Hidalgo, 2003).

Most of these treatments particularly the submersion treatments and the ‘curing in the clump’ are reported to decrease the starch content stored in culm tissues. Smoking is believed to deposit toxic substances and destroy the starch in the culm tissue and thus offering resistance to degradation (Hidalgo, 2003). On the other hand, traditional chemical methods of treatments are mostly intended to ward off the insects either due to repellent or toxic nature of the chemicals used. From China, Chang *et al*. (1979) reported that treating infested bamboos with *D. japonicus* under high pressure steam (5lb and 108^{o}C for 10 min) or soaking in hot water or solution of 0.033-0.001 per cent trichlorphon (Dipterex) for 8 hr, controlled the beetle. Varma *et al*. (1988) tested the effectiveness of several commercial formulations of insecticides against *D. minutus* and *D. ocellaris* under laboratory conditions and found HCH, cypermethrin and permethrein to be most effective. Although boric acid is a generally accepted preservative chemical for bamboo, unless sufficient quantity is ingested by the borer, the treatment cannot be effective. The efficacy of synthetic pyrethroides as a protectent against *Dinoderus* beetles, in comparison to a chlorinated hydrocarbon insecticide was also evaluated by Thapa *et al*. (1992).

3. MATERIALS AND METHODS

The species selected for the study were *Bambusa bambos* (L.) Voss and *Dendrocalamus strictus* Nees which are distributed throughout the Western Ghats and other parts of India. Both the bamboos are components of deciduous forests and are often cultivated in homesteads. *B. bambos* is commonly known as 'thorny bamboo' because of its spiny branches whereas *D. strictus* is called 'male bamboo'.

3. 1. Sample collection

Samples from healthy clumps were collected from both forest and homesteads. The localities of collection were Nilambur, Attappady and Palappilly in Kerala. When samples of known age were required, mostly homestead-grown bamboos were collected since the exact age of the culms could be ascertained from the farmers who owned the land. When sample collections were made from forest areas, age/maturity of the culms was ascertained from experienced bamboo workers engaged for felling the culms. The moisture content of the culms was measured in the field using a digital moisture meter (Protimeter, Mini). After felling the culms, the height and dbh were measured. On the basis of height measurement, the culms were subdivided into three equal parts *viz*., base, mid-height and top. From these representative portions, adequate number of culm segments of 1- 1.5m length were obtained for different laboratory experiments. Smaller samples for moisture content determination in the laboratory were wrapped in polythene bags and sealed to prevent moisture loss during transit. Similarly samples of 1 cm thickness from the representative portions were fixed in FAA (Berlyn and Miksche, 1976) for anatomical study. Apart from culm height and diameter, other details such as culm wall thickness, lacuna diameter, clump diameter, number of culms per clump etc., were recorded from the field.

3. 2. Laboratory studies

The culm segments were brought to laboratory and selected segments were further subdivided into 2cm thick cross sectional segments which were then used for determination of basic density, moisture content and shrinkage.

3. 2. 1. Basic Density

The green volume of the 2 cm thick samples was measured by water displacement metod. The samples were then dried for 48 hrs in an oven at 104º C. After cooling in a desiccator, the oven-dry weight of the samples was determined. Basic density was calculated by dividing the oven-dry weight by the green volume.

3. 2. 2. Moisture Content

The fresh weight of the samples was determined and the samples were dried for 48 hrs in the oven at 104º C. After cooling the samples in the desiccator, the oven-dry weight was determined. The difference between the fresh and dry weights obtained was divided by the dry-weight and multiplied by 100 to obtain the Moisture Content Percentage (M.C. %) of the samples.

3. 2. 3. Shrinkage

Portions of the culm wall of the 2 cm thick sections were split axially into outer, mid-part and inner parts and their radial and tangential dimensions were accurately measured using a screw gauge. After drying the samples in the oven, the dimensions were measured again. The difference in both radial and tangential dimensions in relation to respective green dimensions was multiplied by 100 to obtain the radial and tangential shrinkage percentages.

3. 3. Anatomical Studies

Culm samples fixed in FAA which were later transferred to 50 per cent alcohol were used for anatomical studies. After washing the samples in running water, 15 µm thick transverse and longitudinal sections were cut on a Reichert sliding microtome. Occasionally fresh material was also used for sectioning as required. The sections were double stained with Tannic acid–Ferric chloride and safranin. Toluidine blue (O'Brien *et al*., 1964) staining was also used whenever necessary. The stained sections were dehydrated and mounted in DPX mountant.

3. 3. 1. Histochemistry of lignin

Phloroglucinol method (Johansen, 1940) was used for the histochemical staining of lignin. The sections were placed on a slide and flooded with a saturated solution of phloroglucinol in 20 per cent hydrochloric acid. Lignified cell walls appeared red-violet.

3. 3. 2. Histochemistry of starch

Iodine-Potassium iodide reagent (I_2KI) was used for the localization of starch in the tissues. The sections were mounted in a solution containing 1g each of Potassium iodide and iodine in 100 ml of water. Starch grains stained dark blue.

3. 3. 3. Maceration

Maceration of the culm tissue was done following Franklin's Method (Franklin, 1946) using a 1:1 mixture of glacial acetic acid and hydrogen peroxide. The separated fibres were stained and mounted on a slide for measurement of cellular dimensions.

3. 4. Chemical Analysis

3. 4. 1. Starch

The amount of starch was also estimated colorimetrically using the method followed by Humphreys and Kelly (1961). The samples were powdered, treated with perchloric acid, made up to volume and centrifuged. The aliquot was made alkaline with 2N sodium hydroxide and decolourised with acetic acid. The colourless solution was allowed to react with potassium iodide and potassium iodate and finally brought up to volume. The absorbance was measured at 650nm in a photoelectric colorimeter. Potato starch was used as a standard.

3. 4. 2. Amylase

Amylase activity in the culm tissues was determined on successive days after harvesting using the method given by Sadasivam and Manickam (1992). For extraction of enzyme, the fresh tissue was homogenised in phosphate buffer (pH 7) and centrifuged. The aliquot (1 ml) was mixed with equal volume of 1 per cent starch solution and allowed to react at room temperature for 15 minutes. This was followed by addition of 2 ml dinitrosalicylic acid reagent and warmed on a boiling water bath for 5 minutes. The volume was made up to 10 ml by addition of distilled water. The absorbance was measured at 560nm. In the control, the reaction was terminated by addition of DNS reagent at zero time. A standard curve was prepared using maltose. A unit of amylase is expressed as mg of maltose produced (from 1g of oven-dry tissue) during 5 minute incubation with 1 per cent starch.

3. 5. Fabrication of Tool for Branch Cutting

Three models of a branch cutting tool were designed. One of the designs was fabricated at a fabrication workshop. The prototype was field-tested by conducting trials and further improvements made to reduce the weight of the tool add efficiency to the design.

3. 6. Survey on Borer Infestation

The borer damage in stored bamboo was assessed by conducting survey of depots in the following locations, *viz*., Angamaly, Alathur, Palakkad and Cherppulassery in Kerala. Monthly observations were made up to a period of one year. In addition to this, rural bamboo dwellings were also visited to assess the damage potential of borers.

3. 7. Laboratory culture of *Dinoderus minutus*

Adult beetles of *D. minutus* collected from the infested bamboos in the depots were brought to the laboratory and reared initially on bamboo in plastic containers. Part of the culture was also reared on dry cassava tuber (*Manihot esculenta*) as described by Nair *et al*. (1983). The culture was maintained at room temperature. Beetles already established in the laboratory culture were utilised for the various experiments.

3. 8. Evaluation of Traditional Practices

For systematic evaluation of borer damage and to test the efficacy of different traditional and non-traditional treatments methods, natural and artificial feeding experiments were conducted both under field and laboratory conditions. In most experiments the samples were subjected to borer feeding in triplicate conditions.

3. 9. Field experiments

Traditional methods like water soaking and harvesting bamboos during moon phases were tested in the laboratory and field conditions. Samples from three height levels of bamboo were cut into 50 cm long segments, placed in the field and subjected to natural borer infestation.

3. 10. Laboratory experiments

In the laboratory, feeding experiments were conducted in a specially designed glass tanks 60cm long, 25cm broad and 25cm high. The space inside the glass tank was partitioned into three compartments so as to make it convenient for placing three sets of samples of the same experiment. Two bamboo samples, 10cm long, were used for each replicate and 20 laboratory reared beetles were introduced into the compartments. The tank was then covered with nylon net and a metal frame over it in order to prevent the escape of borers. To confirm the effectiveness of the treatments 'choice tests' and 'no choice tests' were conducted simultaneously. The following traditional practices/treatments were evaluated employing the feeding experiments.

3. 10. 1. Water submersion

Freshly harvested culms were kept submerged in running water for 1 month and the susceptibility of the material to borers was tested at the end of this period. The data on borer damage was recorded for 3 subsequent months. In laboratory experiments on water submersion, different lengths of time ranging from 1 to 3 months were allowed. The resultant decrease in storage starch was analysed and the microorganisms associated with starch degradation were identified.

3. 10. 2. Heating

Culm segments were exposed to open fire for about an hour till the bright green colour faded. Care was taken to achieve uniform heating of the entire surface by rotating the culm segments. Material so treated was tested for borer susceptibility in the laboratory.

3. 10. 3. Boiling

In addition to heat treatment fresh culm segments were boiled in water for 1 hour and then tested for borer infestation. The changes in the morphology of starch grains of the culms due to boiling were examined microscopically.

3. 10. 4. Application of fenugreek-paper pulp slurry

Bamboo workers in some parts of Kerala (Nilambur) treat bamboo articles with a mixture of fenugreek (*Trigonella foenum-graecum*) and paper pulp. This mixture was prepared as follows. About 100 g fenugreek was mixed with 10 g of paper pulp and soaked in 2 liters of water for 24 hours. This slurry was applied on the cut ends of bamboo samples which were later subjected to feeding experiments in the laboratory.

3. 10. 5. Application of Neem oil

Neem (*Azadirachta indica*) seed oil which is usually used against stored insect pests was applied on to the cut ends of bamboo and the material so treated was tested for its susceptibility to borer damage.

3. 10. 6. Application of 'Carpenters' preservative

A recipe of preservative used against borer and termite damage by some carpenters as a traditional method in some parts of Kerala was obtained. This traditional method is mostly employed for preservative treatment of wood materials used in temples. The preservative was a concoction of 9 biological ingredients which included plant materials from the following families - Araceae, Zingiberaceae, Combretaceae, Plumbaginaceae, Burseraceae and Dipterocarpaceae . Each of this material at known quantity was powdered and boiled in a vessel containing 1 liter of sesame oil. The boiled preparation was cooled and the pasty product obtained was applied on to the cut ends of the bamboo. The treated material was later tested for borer susceptibility.

3. 10. 7. Harvesting bamboo during bright and dark phases of the lunar month

In rural areas it is commonly believed that bamboo harvested during the bright phase of the moon (between new moon and full moon) is more susceptible to borers than that harvested during dark phase (between full moon and new moon). In order to test the validity of the belief, harvesting experiments were conducted for one complete lunar month at 4-day intervals. The borer susceptibility of the material was tested.

3. 10. 8. Susceptibility of flowered bamboo culms

Culms from bamboo at two different stages of flowering, *i.e.*, at the inception of flowering and after the seed setting were obtained and their starch content was analysed. The material was subjected to feeding trials to verify its susceptibility to borers.

3. 10. 9. Entomopathogenic fungus

The potential of using a fungal pathogen, *Beauveria bassiana* was evaluated against *D. minutus* in the laboratory.

4. RESULTS AND DISCUSSION

Both *B. bambos* and *D. strictus* being sympodial in habit grow in clumps. As the clumps grow in size with increasing age, new culms arise from the underground rhizome usually surrounding the existing culms. The branches arising from the culms grow in all directions entwining with other culms and their branches and thus forming a meshwork of branches. In order to extract a culm, this tangling mesh needs to be cleared first to free the culm for removal. This is a tiresome and time-consuming operation particularly while dealing with thorny bamboos such as *B. bambos.* The worker has to climb through and spend considerable time to clear the branches up to a few meters from the ground level (Fig. 1).

Obviously, any device that can remove the drudgery of harvesting is the immediate need for bamboo workers engaged in extraction. For this reason a branch cutter that can be operated from the ground was identified as the foremost requirement for simplifying the harvesting operation. Simplicity of design and affordable cost were the main considerations for fabrication of the tool.

4.1. Design and Fabrication of the branch cutter

Long-reach branch pruners suitable for pruning branches of forest trees are commercially available. These are useful to reach high, out-of-reach branches and limbs. Most of such pruners operate with a rope that runs along the pole. Multiple pulleys and gear-driven levers are employed in such tools for generating high leverage for easy bypass or anvil cutting action. Alternatively, for limbs of larger diameter pole saws operated with rope are also available. Power driven pruners are also available which are rather expensive although some models are capable of a reach up to 6 meters or more when fully extended. Hydraulically powered or battery operated pruning shears are also not uncommon.

As a part of the present investigation three models of manually operated branch cutters were designed for fabrication. One of the main considerations while designing was to avoid complicated design involving pulleys and ropes. Out of the three designs developed (Fig. 2), a prototype of the design 'C' which appeared more compact and trouble-free, was got fabricated at a local workshop. The prototype was field tested several times and based on the problems faced under practical situations, improvements were incorporated into the device.

The cutter head consisted of a hook at the top with a beveled cutting edge on its inner side (Fig.3). A knife blade moved in a slide track towards the hook to grip the object first, and then continue sliding bypassing the hook till the cut was complete. The advancement of the knife blade was accomplished by turning the shaft which was provided with a screw thread of wider pitch. The free end of the shaft was connected to a short handle suitable for mounting the cutter head on a pole. The total length of the cutter head was 35cm and the width was 7cm and its weight was about 600 gm. The advancement of the knife blade was about 1 cm for a single rotation of the handle. The cutting components of the tool were made with tool grade steel. Operation of the cuter was fairly simple; hooking onto a branch and turning the pole was all that was required (Figs.4,5). An average branch of bamboo could be cut in less than a minute. Lack of projecting components in the design was advantageous for better maneuverability of the tool even through bushy growth of branches. The detachability of the components of the tool facilitated removal of the blade for sharpening /replacement.

4. 2. Maturation of Culms

The height growth of fresh culms that arise from the underground rhizomes is complete within a few weeks. The rapid elongation of the culm is the result of expansion of individual internodes (Liese, 1998). Although the tissue differentiation within individual internodes is completed in a few days (Hsiung, 1980) the tissues are tender during this stage. The maturation of the culm tissues that follows takes two to three years during which there is further reinforcement of tissues by the deposition of additional cell wall substances. These changes occurring at cellular level have been found to affect the physico-mechanical properties and processing characteristics. Maturation involves mainly thickening and lignification of cell walls.

4. 2. 1. Anatomical Changes of Culm Maturation

4. 2. 1. 1. Cell Wall Thickening

In general, the extent of cell wall thickening and lignification is not uniform but shows a gradation along and across the culm (Fig. 6). Fibres occurring in different locations of a fibro-vascular strand show a striking difference in their width and wall thickness (Alvin and Murphy, 1988; Murphy and Alvin, 1997a; 1997b; Bhat, 2001; 2003; Gritsch *et al*., 2004). Thus based on a study on *Phyllostachys viridioglaucescence* (Liese and Weiner, 1996; 1997) it has been found that the fibres can be characterized into three types; fibres with thick walls and polylamellate structure occurring contiguous to parenchyma, narrow fibres in the vicinity of vascular tissues and larger fibres occurring in the centre of the fibrous sheaths. It has also been found that in order to study the variation of cell wall thickening in fibres, these different types of fibres need to be characterized first (Liese and Weiner, 1996) In all the three types of fibres wall thickening does occur but to different extents (Fig. 7). In a study on *B. bambos* and *D. strictus* fibres were divided based on their width and appearance into three types namely, broad, moderately broad and narrow and their cell wall thickening was compared between <1-year-old and 5-year-old culms (Bhat, 2001, 2003). In the present study, the extent of wall thickening of broad (width 20-35µm), moderately broad (width10-20µm) and narrow fibres (width 5-10 µm) was compared in different age groups in *B.*

bambos and *D. strictus.* For this, 50 fibres each of each fibre type from outer, mid-part and inner portions of culm wall from culm base, mid-height and top levels of different age groups were measured and averaged to obtain the mean values for fibre wall thickness and lumen diameter. The data are presented in Table 1.

Table 1. Change in fibre lumen diameter and wall thickness (in µm) with increasing culm age

Species	Fibre Type	<1 Year	1 Year	3 Year	5 Year
B. bambos	Broad fibres	L 20.34 W 4.55	L 16.75 W 7.54	L 14.93 W 8.83	L 19.60 W 6.58
	Moderately broad fibres	L 8.05 W 7.76	L 8.75 W 7.05	L 7.33 W 7.24	L 8.32 W 9.30
	Narrow fibres	L 2.41 W 8.71	L 2.43 W 6.37	L 2.70 W 6.38	L 2.18 W 9.83
D. strictus	Broad fibres	L 20.46 W 3.83	L 17.20 W 6.00	L 12.10 W 9.70	L 14.76 W 9.70
	Moderately broad fibres	L 8.74 W 5.82	L 7.78 W 6.74	L 5.80 W 8.63	L 8.40 W 9.70
	Narrow fibres	L 2.93 W 6.21	L 3.39 W 6.28	L 2.52 W 6.87	L 2.97 W 9.40

L= Lumen diameter; W= Double wall thickness

It is seen from the table that there was some inconsistency in the data obtained particularly with regard to the values obtained for 5-year-old culms which is probably attributable to experimental error. Nevertheless, in both the species there was a conspicuous increase in the wall thickness and a decrease in the lumen diameter of broad fibres during the initial three years which is the period of culm maturation. Wall thickening of moderately broad fibres was prominent only in *D. strictus*, but not so marked in *B. bambos*. Similarly in narrow fibres the change was inconspicuous during the culm maturation period. These observations indicate that the different types of fibres undergo wall thickening to different extents during culm maturation. The present observations support the findings of Alvin and Murphy (1988) and Murphy and Alvin (1997) that there is continued wall thickening during culm maturation in the larger fibres up to three years. The fibres of the vascular caps which are smaller would have undergone wall thickening quite early and have little potential for further wall thickening during later years.

4. 2. 1. 2. Lignification

The extent of deposition of lignin in the cell walls of fibres and ground tissue is also found to be variable between different parts of a culm. Detailed studies on lignification in *Phyllostachys heterocycla* (Itoh, 1990) have shown that lignification proceeds from outer to inner part of the culm wall and from basal to top portion of a culm. However, within an internode lignification is found to progress downwards. Observations from the present study also conform to this general trend. In both *B. bambos* and *D. strictus*, the peripheral strands of the cross section of a young culm were the ones which were more lignified as compared to the inner ones as shown in Fig. 8. In the inner bundles of 1-year-old culms, lignification was limited the vessel walls and fibres at the outer periphery of metaxylem vessels, protoxylem and phloem. The outer fibrous sheaths were largely devoid of lignification (Fig. 9). However, with advancement of maturation these fibre strands also became lignified although to a lesser extent (Fig. 10). Thus a gradient in the extent of lignification persisted across the culm wall at all the stages of the culm even when the culm was fully mature. This observation is in accordance with our earlier observation in *B. bambos* and *D. strictus* (Bhat, 2001, 2003).

Similar difference in the extent of lignification was also evident along the length of the culm. Figs. 11 and 12 depict the difference as the two extremes between basal and top portions of a young culm in *D. strictus.* Even when appreciable lignification was evident in fibres of outer bundles at the culm base (Fig.11), fibres in the corresponding part at the top portion showed a feeble staining intensity showing low lignin (Fig. 12). This difference is again suggestive of progress of lignification from culm base to top as reported by Itoh and Shimaji (1981). Similar difference in the extent of lignification was also evident along the length of the culm. Figs. 11 and 12 depict the difference as the two extremes between basal and top portions of a young culm in *D. strictus.* Even when appreciable lignification was evident in fibres of outer bundles at the culm base (Fig.11), fibres in the corresponding part at the top portion showed a feeble staining intensity showing low lignin (Fig. 12). This difference is again suggestive of progress of lignification from culm base to top as found by Itoh and Shimaji (1981) and Itoh (1990). However, as the age advanced, these fibres also attained moderate lignification as evident from a 1-year-old culm (Fig.13), but at all age stages of the culm, a uniform lignification of tissues was not achieved. There existed a decreasing trend of lignification of tissues from outer to inner and from base to top of the culm.

4. 2. 2. Physical Properties in Relation to Culm Maturation

4. 2. 2. 1. Basic density

One of the noticeable changes taking place during maturation of culms with age is in basic density. This is directly attributable to the anatomical changes, mainly cell wall thickening and lignification, taking place in the culm. Density or specific gravity has a direct bearing on mechanical properties and thus the process of fibre maturation has important implications in utilisation of bamboo (Liese, 1998). Several studies have established that density of bamboo culms increases during maturation from 1 to 3 years (Liese, 1987; Liese and Weiner, 1996; Sattar, *et al*., 1991). Bhat (2001, 2003) reported a sharp increase in basic density during the initial two years of culm maturation in *B. bambos* and *D. strictus*; subsequent increase up to third year being more gradual. In the present study also more or less similar results were obtained. After the initial increase up to three years, the density more or less stabilized or increased only slightly up to 5 years (Fig. 14). The density values suggest that the maturation changes in the two species are complete when the culms attain 3 years of age.

4. 2. 2. 2. Moisture Content

Another noticeable change that occurs with increasing culm age is a conspicuous decrease in moisture content of the culm material. It is commonly observed that young culms possess high percentage of moisture content. Several studies have shown that the moisture content decreases distinctly with maturation of culms (Liese and Weiner, 1996; Abd. Latif and Mohd. Zin, 1992; Abd. Latif and Liese, 1998; Espiloy, 1994; Sattar *et al*., 1994). Earlier studies on *B. bambos* and *D. strictus* (Bhat, 2001, 2003) have also shown that M. C. percentage drops significantly during culm maturation. The results obtained in the present study are shown in Fig. 15. Young culms of less than 1 year of age possessed high moisture content of nearly 300 per cent or more in *B. bambos* and *D. strictus*. It is seen from Fig.15

that the M.C. percentage dropped significantly during the initial years, particularly during the first year of culm growth; the subsequent decrease was more gradual, as found in the earlier study.

The moisture content of bamboo has much significance in terms of its utilisation and thus much research attention is focused on this aspect. Detailed studies have been conducted to investigate the seasonal and between-site variation in M. C. per cent (Abd. Latif and Liese, 1998). Some studies have also shown that moisture content decreases even after culm maturation (Liese and Weiner, 1996).

4. 2. 2. 3. Shrinkage

The mean age-wise radial and tangential shrinkage values averaged for base, mid-height and top height levels of 5 culms each of *B. bambos* and *D. strictus* are presented in Fig. 16. It is seen that the shrinkage was very high (30-40% or more) in young culms less than 1-year-old. This explains the possible cause for excessive warping and deformation of young culms while drying as compared to mature culms. A high correlation between moisture content and shrinkage has been found in *B. bambos* and *D. strictus* (Gnanaharan, 1993) and the excessive shrinkage of young culms can be explained in terms of high moisture present in the tissues. Moreover, the identical trend of decrease in moisture content and shrinkage with increasing age further supports the existence of a correlation between the two. Among the two species *B. bambos* and *D. strictus*, it was the former which had higher shrinkage. As the culm age increased, there was a decrease in the shrinkage values to about 7-15% in *D. strictus* and around 15-20% in *B. bambos*. This observation is contrary to the results obtained for some Malaysian bamboos (Sattar *et al*., 1991) in which no definite trend in relation to age was found. Among the age groups compared, shrinkage was lowest in 5-year-old culms. In both *B. bambos* and *D. strictus* radial shrinkage was slightly higher than the tangential.

4. 2. 3. Judging Culm Maturity for Harvesting

It is obvious that for a number of uses, maturity of culms is an important requirement and the culms harvested should be fully mature to ensure optimum quality of the bamboo material. However, the methods of culm age/maturity determination for harvesting presently followed are not completely foolproof to enable the desired level of accuracy. Experienced workers engaged in bamboo harvesting rely on different indicators of culm maturity or combinations of these indicators. Chief among them are culm morphological features such as branching and colour and surface texture of culms, position of the culm within the clump, nature of sound produced when the culm is tapped with the knife, etc. A few studies have attempted to elucidate the age-wise changes in morphological features of bamboo culms with a view to refine the methods of age determination. Waheed Khan (1962) carried out such a study on 14 native and exotic species of bamboos growing in India. Banik (1993) elucidated the morphological features of five main commercial species of bamboos of Bangladesh.

In the present study it was observed that presence of culm sheath attached to the culm, even though in withered form, could indicate an age of around one year in both *B. bambos* (Fig.17) and *D. strictus* (Fig.19, at arrow). The culm colour was deep green and the surface appeared rather smooth or covered with whitish dusty bloom. The sheaths were absent in culms above two years of age by which time the culm colour appeared lighter green with a yellowish hue. The whitish bloom that was abundant in young culms was absent and the culm surface appeared rougher (Fig. 19). The surface became much more rough with brownish or brownish black spots when the culm age was over 3 years or more (Fig.18). Culms looked harder and less succulent at this stage.

As it is found that the moisture content of bamboo culms decreases remarkably during maturation of culms (Liese and Weiner, 1996; Abd. Latif and Liese, 1998; Bhat, 2003) and is consistently low in mature culms, an experiment was conducted to examine if the moisture content level of standing culms could be taken as an indicator for choosing mature culms for harvesting. Thus the moisture content of 3-year-old standing culms was measured in the field using a moisture meter. The recorded M. C. % was also cross-verified by values obtained by the usual method of oven-dying.

Table 2. Moisture content percentage of mature culms of *B. bambos* and *D. strictus*

	B. bambos	*D. strictus*

Range	52 - 122	58 - 145
Mean	79.16	101. 95
CV	23.23	20.77

However, the values obtained were not consistent and there was wide variation in culm moisture content (Table 2) between localities and season supporting the earlier observations of Abd. Latif and Liese (1998) that moisture content varies considerably with respect to locality and seasonal fluctuations in temperature and soil moisture. Hence it was concluded that moisture content cannot be used reliably for judging the culm maturity.

During the course of the study we came across a new technique of culm age determination used by some traditional bamboo workers while choosing the culms for felling. Before felling the culm, a flake of standing culm is sliced off so as to expose the fresh culm tissue. In young culms the colour of the exposed tissues was creamy white (Figs. 21, 23) but in 2-3 year old culms it was more yellowish or yellowish brown (Figs.22, 23). In over-mature culms there was further darkening of tissues. Thus it was possible to judge the culm maturity based on the colour of the culm tissue. All that was necessary was familiarity with tissue colours of different age groups of bamboo culms.

The darkening of tissue colour from off white to yellowish brown with increasing culm age was further investigated by histochemical staining for lignin. While in immature culms less than one-year-old, lignification of fibre walls was limited to the immediate vicinity of fibres (Fig. 24) with the free fibre strands remaining largely unlignfied, in mature culms, 2 to 3 years of age, a comparatively higher extent of lignification was noticed. A comparative view of the difference between one-year and three year-old culms of *D. strictus* is shown in Figs. 25 and 26. It is thus evident that the change in colour of the tissues with age is related to increasing level of lignification and that the practice of checking the culm tissue colour as an indicator of culm maturity is scientifically valid. This technique could be used at least as a supplementary indicator for age determination while harvesting bamboo culms.

4. 3. Starch Storage

4. 3. 1. Variation in Starch Distribution

Starch is stored in the subterranean portion and within culm tissues of bamboos as an energy resource. It is stored as granules mostly in the ground tissue, vascular parenchyma sheaths and also occasionally in fibres and protoxylem tracheids (Liese, 1998). It has been found in several bamboo species that the distribution of starch in the culm is generally uneven and there is greater accumulation of starch in some portions than the rest (Liese, 1998). Observations on *B. bambos* and *D. strictus* also support this. As reported for other bamboos, the nodal portions and the nodal diaphragms contained higher amount of starch (Fig. 27). Similarly the inner portions of the culm wall had higher starch than the outer portion. Average percentage of starch obtained for nodal and internodal portions in *B. bambos* were 3.18 and 1.65 respectively and that for *D. strictus* were 9.96 and 6.62.

Starch content is found to be variable between different species of bamboo. Mature culms of both *B. bambos* and *D. strictus* showed remarkable variation in the quantity of starch. In order to eliminate the variation due to seasonal influence and locality, culm samples from BH level of different age groups of both the species were collected in the same season (dry period, Dec- April) from the same locality. The average values of 5 culms per each age group for both the species are shown Table 3. It is seen from the mean values that the overall trend was a slight increase in starch content with the increasing culm age although not consistently. The high SD indicates vast variation in starch within the same age group. Analysis of variation showed no significant difference in starch content between age groups in both *B. bambos* and *D. strictus*

Table 3. Mean values of starch (%) in different age groups in *B. bambos* and *D. strictus*

Age groups	*B. bambos*	*D. strictus*
up to 1 yr	1.20 (0.8)	2.50 (0.75)
1-2 yrs	1.92 (0.11)	1.21 (1.29)
3 yrs	2.32 (2.03)	2.25 (1.35)
4-5yrs	1.33 (0.38)	1.64 (1.78)

Figures within parentheses are S. D. of the Mean

Hence the results obtained broadly conform to the general observation that starch content increases with the increasing culm age. However, the extent of difference observed in the present study between the age groups was not as pronounced as that reported in literature

(Alvin and Murphy, 1988; Weiner and Liese, 1996). Our earlier study (Bhat, 2001) also failed to record a consistent relationship between culm age and extent of starch in *B. bambos* and *D. strictus*. This indicates that besides season and age, there could be possibly other factors, such as clump health/growth conditions, influencing the extent of starch storage in culms.

4. 3. 1. 1. Variation in Starch along Culm Height

In order to assess the variation in starch content along the culm length, starch content was determined at base, mid-height and top height levels of 20 mature culms each of both the species. The results are presented in Table 4. From the mean values it is seen that starch

Table 4. Mean percentage of starch at different height levels of the culm

Position	*B. bambos*	*D. strictus*
Culm base	3.54 (1.77)	4.96 (3.34)
Mid-height	5.25 (3.21)	6.78 (4.72)
Top	4.98 (3.69)	6.93 (4.67)

Figures within parentheses are S. D. of the Mean

content was lowest in the basal portion of the culm although the trend was not the same in individual culms. Difference between mid-height and top levels was not much pronounced from the mean values. The high standard deviation values obtained indicate wide variation in starch percentage between and culms. Analysis of Variance showed no significant difference in starch content between different height levels of the culm. Similar non-significant difference between the height levels has been recorded in some earlier studies (Kumar and Mohinder Pal, 2003). However, some studies on distribution of carbohydrates in Malaysian bamboos have reported low starch at the culm base and higher amount of starch either in the mid-height level or in the top part of the culm (Abd. Latif 1995; Abd. Latif *et al*., 1991). On the other hand, instances have also been reported of higher starch content at the basal part of mature culms in *D. strictus*. In 1-year-old culms of the same species, the top portion contained higher starch content (Kumar and Mohinder Pal, 2003). Therefore, it is likely that there is no definite trend in variation of starch accumulation in different portions of a bamboo culm.

4.3. 1. 2.Variation in Starch in Relation to Site

In order to ascertain variation in starch content with respect to site, samples of 3 mature culms each of *B. bambos* and *D. strictus* were collected from Attappady, Nilambur, Palappilly and Peechi during the same period (4^{th} week of Jan. 2005). Average percentages

Table 5. Average percentage of starch recorded from different localities for *B. bambos* and *D. strictus*

Locality	*B. bambos*	*D. strictus*
Palappilly	2.59	0.93
Peechi	2.80	1.29
Nilambur	1.96	0.89
Attappady	9.28	13.33

of starch recorded for both the species are shown in Table 5. It is evident that in both *B. bambos* and *D. strictus* average starch content was low in culms obtained from Palappilly, Peechi and in Nilambur whereas a conspicuously high average value was recorded for Attappady. It is possible that the high starch in culms from Attappady has some relation with luxuriant growth of clumps observed in the site. Analysis of variance indicated a highly significant difference (1% level) in starch content between these sites in *D. strictus*. However, in *B. bambos* the difference was found non-significant.

4. 3. 2. Starch Distribution across the Culm Wall and Borer Susceptibility

Unevenness in the distribution of starch was also found between the outer and inner portions of the culm wall. The inner portion of the culm wall was found to contain more starch as compared to the outer portion. This is natural since the inner portion has relatively higher proportion of ground parenchyma tissue while the outer part is more fibrous.

When bamboo culms attacked by borers were examined, it was found that the intensity of boring was invariably higher in the inner portion suggesting a selective feeding behavior by borers. The typical pattern of borer damage to the culm wall is shown in Figs. 28a and 28b. It was evident that difference in starch content across the culm wall could be the possible cause for variation in the extent of borer damage. In order to ascertain the relationship, starch content and the proportion of ground parenchyma was examined for outer and inner portions of culm wall for *B. bambos*. The results obtained are presented in Table 6 which clearly show that the starch content is high in the inner portion of the culm wall. Analysis of variance showed that the difference in starch content between the culms and that between the height levels was not significant. However, there was a highly significant (1 % level) difference in starch content between the outer and inner parts of the culm wall as shown by the paired *t*-test of the data pooled together (t= – 4.232).

Table 6. Starch content and tissue proportions in outer and inner portions of culm wall at different height levels of *B. bambos* culms (mean value of 5 culms)

Portion of the culm	Starch Content (%)		Parenchyma (%)		Fibro-vascular Tissue (%)	
	Outer	Inner	Outer	Inner	Outer	Inner
Base	1.5 (1.0)	5.2 (2.1)	56.0 (4.0)	73.0 (8.4)	44.0 (4.0)	27.0 (8.4)
Mid-height	4.8 (3.0)	6.6 (2.7)	53.4 (7.3)	67.6 (6.3)	46.5 (7.3)	32.4 (6.3)
Top	4.8 (4.6)	8.2 (8.0)	46.9 (7.4)	65.6 (3.9)	53.0 (7.4)	34.4 (3.9)

*Values in parentheses show standard deviation

The proportion of the ground parenchyma tissue responsible for the starch storage was invariably greater in the inner portion of the culm wall which favored accumulation of starch. Maximum starch content was observed in the inner portion of the top height level of the culm. In contrast, it was lowest in the outer part of the basal portion. However, from the selective feeding behavior of borers and their larvae it appears that the beetles choose to feed on starch-rich tissues from the culms. Abundant availability of starch is a prerequisite for successful multiplication of borer population and this could be the possible reason for severe damage to inner part of the culm wall. The results support the observations of Plank and Hageman (1951) that the inner portion is more susceptible since it has higher proportion of starch.

The preference of starch-rich sites by the beetles is also helpful to explain the unequal extent of borer damage between culms in a single stack. It is often found that some culms in the stack escape the attack while others are severely damaged. The probable reason could be the level of starch in the tissues. Beeson (1941) specified a threshold level for starch in culms, below which the culms remain free from borer damage.

4. 3. 3. Starch Content in Flowered Clumps

It is generally accepted that during flowering of bamboo clumps the storage starch within the clumps is fully utilised for the development of flowers, fruits and seeds. Hence the flowered clumps are believed to be free of starch and hence resistant to borer damage. However, the observations noted in this regard have often been found to be contradictory. Although in majority of instances flowered clumps escaped borer damage, in some instances they were found to be highly susceptible. In order to verify the contrasting observations, culm starch content was determined at two different stages of flowering of the clumps of *D. strictus.* It was found that during the initial stage of flowering, the average starch content as high as 9.53 per cent was recorded from the culms whereas after seed setting it was only 1.74 per cent. Obviously much of the stored starch is consumed for seed development. Thus it is clear that the level of starch content or the borer susceptibility of flowered culms depends upon the stage of flowering (Figs. 29a, b). It is most likely that clumps in the late stage of flowering would have mostly exhausted their carbohydrate reserves which make the material unattractive to borers.

4. 3. 4. Starch Degradation in Harvested Culms

During the study it was found that the stainability of bamboo tissue with iodine reagent gradually declined as the days passed by after harvesting. Freshly harvested material showed intense staining (Fig.30a). But when the stainability was tested a few days later, there was a decrease in staining intensity (Fig.30b) indicating decrease in starch content. Further verification of the observation by staining of microtome sections of the material and chemical estimation of starch confirmed that there was reduction in starch content as days passed.

In order to investigate the cause of starch disappearance in harvested culms, activity of amylase was estimated in the tissues. The results obtained are shown in Fig.31. Activity of total amylase was detected two to three days after harvesting. Although the extent of enzyme activity was different in *B. bambos* and *D. strictus* in general, in both the species it increased after harvesting up to two to three days to reach peak activity. Subsequently, the enzyme activity declined before cessation, as the culms lost the moisture and became dry. No enzyme activity was evident after this stage.

Although metabolic activities in living tissues do not cease soon after harvesting, this aspect has not so far been studied in bamboos. As indicated from the present observation, the tissues of the cut bamboo probably continue to respire at the expense of stored starch for a few days until the tissues become dehydrated and natural desiccation sets in. The enhanced amylase activity in harvested culms is probably meant to maintain adequate level of sugar substrate in cells for the respiration process.

In the light of the above observation, the practice of clump curing followed in some parts of India may be considered. The method involves cutting the culm at its base above the first node and leaving it vertically leaning against other culms with intact leaves and branches, for 4 weeks (Hidalgo, 2003). The practice is believed to reduce starch content of the culm and offer resistance against borer attack. If the treatment is successful in bringing down the starch content in a culm, as believed, it is probably accomplished due to the natural amylolytic activity occurring in culm tissues as observed in the present study. Alternatively it is also possible that rapid drying up of culms in the open, after cutting may shorten the period of action of the enzyme system concerned with starch hydrolysis which may lead to failure of the treatment. However, experiments to test the effectiveness of the treatment have shown that the treatment is ineffective (Mathur, 1961).

4. 4. Borer Infestation

4. 4. 1. Borers infesting felled bamboo

Beetles belonging to the families Bostrychidae and Lyctidae are the major borer pests that cause severe damage to felled bamboo culms. Among them *Dinoderus* beetles (*Dinoderus minutus* Fab., *D. ocellaris* Steph. and *D. brevis* Horn.) of the family Bostrychidae are more common than others in all localities. *Dinoderus* beetles are known as ‘ghoon’, ‘shot borer’ or ‘shot hole borers’. They are also known as ‘powder post beetles’ because of their feeding habit of converting the woody material into powdery mass during feeding.

The bamboo powder post beetles are widely distributed in the tropical regions of the world. About 87 species of Bostrychids are reported to occur in India, Burma and Ceylon. Most of the Bostrychids are serious pests of household materials, furniture, plywood, tent poles and other articles.

4. 4. 2. Nature of Infestation

Dinoderus beetles are minute and cylindrical in shape with hard elytra. They have short, powerful mandibles which enable tunneling into woody tissues. The tiny borers fly towards bamboos soon after they are felled. According to Hidalgo (2003) flies swarming over the cut ends of felled green bamboo is a visible sign to indicate that it is going to be attacked. The high starch content of bamboo is known to be the major factor controlling susceptibility of felled culms to borers. The beetles enter through the cut ends, or other open portions such as trimmed branch bases at nodes or other mechanical wounds. The ecology and habits of the three species of beetles are more or less similar.

The pattern of infestation of *Dinoderus* beetles in stacked bamboo was examined at different bamboo depots. It was observed that the borers initially made a straight tunnel having 0.2 to

0.5 cm length in the axial direction. After burrowing for a length of 0.5cm in the inner part of the culm wall, the females changed the direction and made tunnels in transverse direction. The eggs were laid singly within the vessel lumens that were cut across while making the transverse tunnel. While laying eggs, the females inserted their ovipositor into the vessel lumens in the inner part of the culm wall. The eggs were usually deposited at about 1 mm distance from the transverse tunnel. Contradictory observations are reported on the number of eggs laid by a single female. According to Stebbing (1914) about 20 eggs were laid by a single female whereas Plank (1948) observed about 110 eggs laid by a female beetle. In the present study specific attempt to count the number of eggs laid by single female beetle was not made.

Observations recorded from different bamboo depots and other storage yards showed that infestation usually started from the bottom end of the culm rather than from the top end. It is possible that the bottom portion that has a thicker culm wall, abundant soft tissue, starch and moisture levels provides optimum conditions required for hatching of eggs and further development and survival of the larvae.

Intensity of borer attack in storage yards and other depots was not found to be uniform throughout the year. Beetle population was found to be fluctuating with season. During the months of September, October and November, the borer population was found to be very low and thus the intensity of attack by borers was also correspondingly very low. In *B.bambos* as observed in the two bamboo depots, Alathur and Cherpulassery, out of 1000 to 1500 bamboo culms examined at a time during this period, the attacked culms were as low as ten. In the laboratory culture also the population of beetles declined considerably during this period. This indicates a certain seasonal fluctuation in the population level of the beetles. Beeson (1941) stated that the third generation of beetles starting by the end of September overwinters as larvae and pupates in March, based on observations in northern India. The present observations also indicate that there could be a period similar to that, which is probably responsible for the drop in the observed population. However, based on the borer attack observed from December to March (Fig. 32). The low level of borer population does not appear to be so long under Kerala conditions.

4. 4. 3. Morphology and Life Cycle of *Dinoderus* Beetles

D. minutus is the most common species found throughout Kerala. It has dark brown body and anteriorly narrowing pronotum. The beetle is 2.5 to 3.5 mm in length with 10-segmented antennae. The last 3 segments of the antennae are broad with no hairs at the basal portion. Compared to *D. ocellaris*, *D. minutus* is less active.

D. ocellaris is slightly larger in size (3 to 4mm) than *D. minutus*. Body colour is reddish brown and the pronotum is hemispherical. Ten- segmented antennae having cluster of hairs at the base distinguishes it easily from *D. minutus*.

D. brevis is more or less similar to *D. minutus*, except that the antennae are 11-segmented and the elytra are shorter. This species was originally oriental but is becoming widespread now. The descriptions of the adult beetles and the larval morphological variations have been described by Gardner (1933).

4. 4. 3. 1. Life cycle

Population of *D. minutus* together with *D. ocellaris, Heterobosrychus aequalis, Lyctus africanus* and *Minthea rugicollis* was observed in a single culm in the storage yard. The biology and habits of these beetles have been studied in detail by Stebbing (1914), Beeson and Bhatia (1937) and Plank (1951).

To complete one generation, *D. minutus* took 80 to 90 days. Female beetles laid eggs in the inner part of the culm wall just below pith cavity membrane. The eggs were milky white in colour. They were elongated; one end of the egg was round and the other end was somewhat tapering (Fig.33). Eggs hatched after 5 to 7 days. The newly emerged larvae were almost crescent-shaped (Fig. 34). Being voracious feeders the larvae started feeding from the place of their emergence by making tunnels in the tissue. As the larvae advanced in their feeding activity through the tunnel, they left behind powdery excreta and frass which filled the cavity of the tunnel. The larvae were found to be very sensitive to heat and bright light as found from their behavior when observed under the bright light of the microscope. Larval period extended up to 40 to 42 days.

Pupation took place inside the tunnel and this stage lasted for a short duration of 3 to 5 days. The pupae were exarate with no cocoon covering formed on their outer side (Fig. 35). Thus based on the morphological changes the pupa could be easily separated out under the microscope. The newly emerged adults were off-white in colour and soft bodied (Fig. 36). They usually remained for 2-3 days inside the tunnel till the elytra got hardened. The adult beetles were cylindrical in shape with a hood like pronotum concealing the hypognathus head from above. Antennae were club loose consisting of ten segments. As reported by Plank (1951) when the beetles matured their body colour changed from deep amber brown to black (Fig. 37). After emergence, the adults either continued feeding inside the same culm or escaped to other fresh pieces of bamboos. The adult beetles lived for a period of about one month under laboratory rearing conditions.

As observed by Singh and Bhandari (1988), pairing took place inside the tunnel. However, pairing was also observed under laboratory conditions when beetles were taken out and kept in a petridish while conducting experiments. While recording observations in the depot also pairing of adults was observed outside the tunnel. According to Beeson (1941), a total of four generations occurred in a year. The population was found to be highly overlapped and all life stages of the borer could be seen at a time.

4. 4. 4. Rearing of *Dinoderus minutus*

In order to conduct several laboratory experiments, a culture of *D. minutus* was maintained in the laboratory with all life stages. For the initial rearing, borers were collected from different bamboo depots, brought to the laboratory and fed with bamboo strips. Dried cassava tubers (*Manihot esculenta*) are reported to be a good alternative food for *D. minutus* (Nair *et al*., 1983). Therefore, a culture was also maintained on this medium. The beetles were placed inside a glass tank of size 60cm x 25cm x 25cm which was covered with nylon net to prevent the escape of borers (Fig.38). A large population of borers could be obtained from both the media namely, dried cassava and bamboos. The population build up and survival of *D. minutus* beetles were excellent when the culture medium was bamboos with high starch content. Newly emerged beetles were separated out and utilised for various experiments. The beetles were picked up from the tunnels using a fine brush, so as to avoid any injury while transferring.

4. 4. 5. Traditional Practices of Protection of Bamboo from borer attack

The traditional practices for post-harvest protection of bamboos are classified into physical and chemical treatments (Hidalgo, 2003). These are generally simple, inexpensive techniques followed by bamboo workers in rural areas. The more widely used physical treatments include water submersion of harvested culms, exposing the culms to open fire, smoking, etc. Timing the harvesting operation to certain periods of lunar month to evade borer damage and the clump curing are some novel physical treatments, which have been practiced for centuries. The chemical treatments, on the other hand, involve application of some repellents and preservatives of biological origin.

4. 4. 6. Influence of Lunar Cycle on Borer Damage

An age-old belief widespread among rural population in India is the correlation between moon phases and borer damage. It is generally believed that if bamboo is harvested during the bright phase (waxing period) or during full moon it is liable to be attacked whereas bamboo harvested during the dark phase (waning period) escapes borer damage. Such a belief is also reported to exist in countries like Sri Lanka, Columbia and South America. In Columbia and South America, not only bamboos, but all trees are felled during the waning moon only, and not during the waxing period (Hidalgo, 2003). However, Deogun (1936) found that in Bihar, Orissa and a few other places in India, it is said that bamboos felled in the bright phase of the moon were less susceptible to insect attack than those felled in the dark phase. Nevertheless, this popular belief has elicited great research interest in India and elsewhere.

In order to evaluate the influence of moon phase on borer susceptibility of bamboo, collections were made from Attappady for a period of one full lunar month. Mature culms of both *B. bambos* and *D. strictus* were collected at four-day intervals and each culm was divided into three 50cm long segments in adequate replicates for culm base, middle and top portions. One set was placed in the field itself and another set was stacked in the storage shed (Fig. 39). Representative samples were subdivided into 10 cm long pieces and subjected to feeding experiments. Starch and moisture content of the bamboo culms were determined for all samples. Triplicate samples were maintained for feeding experiments and 10 lab-cultured beetles were introduced into each of the replicates. At 90 days, samples from the field and storage shed were taken to the laboratory to isolate newly emerged population. The results of Population Multiplication Index (PMI)), which is a ratio between the final and initial number of beetles within a specified period (Nair *et al*., 1983) of the borer population, are presented in Table 7.

Table 7. PMI in relation to waning and waxing of moon in *B. bambos* and *D. strictus*

Source	df	Sum of Squares	Mean Square	F	Sig.
Moon phase	1	3.063	3.063	0.070^{ns}	.796
Bamboo species	1	564.063	564.063	12.899**	.004
Moon phase x species	1	3.063	3.063	0.070^{ns}	.796
Error	12	524.750	43.729		
Corrected Total	15	1094.938			

** significant at 1% level; ns non-significant

Results of field trials show that there was no significant difference between the dark and the bright phases with respect to borer infestation (Table 7). However, with regard to the two species of bamboos *B. bambos* and *D. strictus*, there was variation in the extent of borer infestation which was significant. The interaction between moon phases and the species was not significant.

On the basis of experiments conducted on this aspect, different investigators have expressed diverse views although no positive relationship between borer damage and moon phases could be established. Smith (1908) attributes whatever differences noted in borer susceptibility to fluctuations in moisture content of the culms at the time of harvesting and not to moon phase *per se*. Beeson (1941) finds a fortnightly rhythm in moisture content of culms, moisture content being high during the waxing period and full moon. He suggests that sap of the culms flows down during wane, while the waxing moon draws the sap up. Another observation is that injurious insects are abundant during the waxing and the full moon. However, there is no relationship between the moisture content of a freshly cut bamboo and its subsequent liability of borer attack. Experiments conducted by Plank (1950) in Puerto Rico showed only a minor difference in the level of infestation between culms harvested during bright and dark phases. Similarly Hidalgo's experiments conducted in Colombia in 1987 by felling a large number of culms on all phases of moon also suggested no relationship between moon phases and borer attack (Hidalgo, 2003). Thus almost all studies made in this regard have not fond a relationship between borer susceptibility and lunar phase. The present investigation also supports the view that moon phase, in no way influences the borer damage in bamboo.

4. 4. 7. Physical Treatments

4. 4. 7. 1. Water Submersion

It has been generally believed that bamboos floated in rivers are less liable to be attacked by borers. Freshly harvested bamboo culms are kept submerged either in running or stagnant water for a certain length of time escape the borer damage. This method is used not only for bamboos but also for some perishable timber species for protection from borer attack. It is assumed that this treatment facilitates leaching out of the dissolved sugars and other materials, thus making it unattractive to the beetles. Water soaking followed by sun drying is also practiced in some parts of Kerala to increase the durability of bamboos.

In order to test the efficacy of the treatment experimentally, culms of both *B. bambos* and *D. strictus* were collected from Attappady. One-meter long segments from the basal portion were separated and taken to the laboratory as control set, whereas the remaining portion was tied into bundles and immersed in the nearby Siruvani River for one month. Heavy stones were kept over the bundle of bamboos in order to keep them fully submerged (Fig.40).

Starch and moisture content of the control and treated samples were tested in the laboratory. Control samples were subdivided into 10 cm long pieces and used for feeding experiments.

Feeding experiments were conducted in two ways -one in glass tanks in the laboratory and the other in a semi-open condition in a storage shed. In the feeding experiments conducted in glass tanks, two bamboo pieces of 10 cm length and 20 laboratory cultured *D. minutus* beetles were used. Population Multiplication Index (PMI was computed at 90 days.

Dried cassava tuber was used as control samples in choice tests. ‘No-choice tests’ were conducted with water soaked samples. PMI of both control and treated samples was recorded at 90 days. It is seen that both control and treated bamboos were severely attacked and a large population of beetles was isolated from both samples. In choice tests both soaked samples and cassava chips were severely attacked by borers.

Analysis of Variance of frass weight showed that there was no significant difference in the frass weight of bamboo samples subjected to water submersion and that of cassava tuber (Table 8). Similarly, the difference in PMI between treated material and the control was not significant.

Susceptibility of water soaked culms to borers was also tested in the field. Fifty cm long samples from base, middle and top regions of both *B. bambos* and *D. strictus* were placed in a storage shed. The storage shed had a good borer population since bamboos collected from different locations at different periods were stored there for periodic observation.

Table 8. Comparison of water submerged and control samples of *B. bambos* and *D. strictus* with respect to frass weight and PMI

	B. bambos					***D. strictus***		
Frass weight	Source	df	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
	Between Groups	1	0.792	0.792	0.527^{ns}	0.882	0.882	0.661^{ns}
	Within Groups	4	6.012	1.503		5.332	1.333	
	Total	5	6.804			6.214		
		B. bambos				***D. strictus***		
Population	Source	df	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
	Between Groups	1	130.667	130.667	1.798^{ns}	522.667	522.667	5.116^{ns}
	Within Groups	4	290.667	72.667		408.667	102.167	

	Total	5	421.333			931.333		

ns –non significant

However, the results obtained were contrary to the ones obtained in laboratory experiments. A marked difference in borer infestation was evident; while control samples were severely attacked, the treated samples were free from attack (Fig. 41a, b). Both samples were peeled out and the number of beetles was recorded. In treated samples of *B .bambos* there were only four beetles whereas 361 beetles were extracted from the control. In the case of *D. strictus* there were 63 beetles in the treated and 148 beetles in the control samples. A conspicuous difference was observed in the borer population between treated and control samples.

Because of the inconsistent results obtained in the two experiments it was not possible to arrive at a definite conclusion. However, it is indicative that the beetles showed less preference for bamboo soaked in water as in the experiment conducted under semi-open situation. The data on starch percentage estimated in the samples also suggests that water soaking was effective in lowering the storage starch level in the culms. The mean starch percentage (culm base, mid-height and top) in freshly harvested *B. bambos* was as high as 13.82 which reduced drastically to 6.32 after submerging in water for one month. Similarly, in the case of *D. strictus* starch content declined from a high initial 21.16 per cent to 12.71 per cent after submerging in water for one month. This explains the positive relationship between water soaking and starch depletion. Laboratory observations using samples collected from Attappady after soaking in water for a month showed that the stagnant water facilitated luxuriant growth of bacteria and saprophytic fungi on the bamboos. Bacteria belonging to genera *Pseudomonas* and *Klebsiella* and a saprophytic fungus belonging to the genus *Acremonium* which is known to thrive on storage carbohydrates were isolated. This observation indicates that the starch disappearance from culms stored under water is attributable to enzymatic hydrolysis caused by the microorganisms. Thus the traditional treatment of soaking of harvested culms under water is logically an effective method for protection of bamboo from borer damage.

Soaking felled bamboos in water is being widely employed in most bamboo growing countries (Sulthoni, 1985; 1988; Hidalgo, 2003). It has been observed that during the soaking period, the starch content of bamboo is reduced (Plank, 1950; Beeson, 1941; Chowdhury, 1993) which makes it less attractive to borers (Liese, 1980; Tamolang, 1980). However, the exact reason behind reduction in starch during the period when bamboos are soaked in water has remained unclear (Liese, 1980). Based on observations of the present study it is indicated that starch degradation is bamboo submerged under water is due to the activity of microbial population in the water.

4. 4. 7. 2. Heating

Heating the freshly harvested culms over open fire was yet another traditional method practiced by rural bamboo workers for protecting bamboos from borer attack. Here, the newly harvested bamboo culms are placed over fire or smoke for a few hours with repeated turning so that the entire surface of the culm receives uniform heating. In practice, this operation is performed in a ditch containing glowing coal. As a result of the treatment the green colour of the culm fades to olive or light brown, probably due to loss of moisture.

To test the efficacy of heating treatment, small culm segments of 10 cm length were heated directly over fire. An iron rod was inserted through the hollow (pith cavity) and the samples were placed above the fire by resting the rod on two supports at either ends (Fig. 42). The samples were rotated at intervals to facilitate uniform heating of all sides. Heating was conducted for a period of one hour. Samples so treated were subsequently subjected to feeding experiments. The PMI was computed based on data recorded after 90 days. Control and treated samples were severely attacked and a good population emerged from the samples. Out of two species tested, *D. strictus* was more severely attacked than *B. bambos*. Results of ANOVA of the PMI are presented in Table 9. It is found that there was no significant difference between treatment and control indicating ineffectiveness of the treatment. The difference between the two species of bamboos was found to be significant at 1 per cent level. However, it is difficult to assign any specific reason for the variation in PMI of the borers between the two bamboo species as there was not much difference on the starch content in both the species.

Table 9. PMI of beetles in *B. bambos* and *D. strictus* with respect to heat treatment

Source	df	Sum of Squares	Mean Square	F
Species	1	10837.500	10837.500	25.880**
Treatment	1	580.167	580.167	1.385 ^{ns}
Species x treatment	1	793.500	793.500	1.895 ^{ns}
Error	20	8375.333	418.767	
Corrected Total	23	20586.500		

** Significant at 1% level; ns non-significant

Although heating is rather widely practiced and described in the literature as a method of protection of bamboo against borers, its efficacy has not been experimentally evaluated. Bamboo stored in fireplaces or roof of conventional kitchen (where firewood is used) which generates heat and smoke remains unattacked by borers for years. This is said to be due to deposition of toxic substances from the smoke and also due to loss of starch while heating (Hidalgo, 2003). Rehman (1947) also reported that the method of baking the bamboo over gentle fire as a process of seasoning to bring down the moisture content, which is effective in overcoming fungal and insect problems. It is therefore possible that heat curing or exposure to smoke and heat probably brings down the moisture level of culms below the threshold level necessary for the survival and establishment of the borer population.

4. 4. 7. 3. Boiling

A modification of the heat treatment is followed by some handicraft industries, which involves boiling the culm segments in water for a certain period of time. For basket-weaving, the bamboo slivers are boiled in water before making the product. In practice, a teaspoonful of tamarind or common salt was also added during boiling by the basket-weavers. For testing out the efficacy of this method internodal samples of 10 cm length were boiled in an aluminum vessel for a period of one hour (Fig. 43). Treated samples were taken out, dried and subjected to feeding trials. Effect of boiling on storage starch in the tissues was examined by taking microtome sections. PMI was computed at 90 days and the data thus obtained was statistically analysed. It was found that boiling the bamboo culms brought about swelling and gelatinization of starch grains within the cells. While the control samples had accumulation of minute individual grains within cells (Fig. 44) samples subjected to boiling showed crowding and lump formation of starch within cells (Fig. 45). Thus it is possible that boiling can results in a physical change of swelling and gelatinization whereby the starch grains within the tissue are transformed into lumps.

The PMI of no-choice and choice tests showed the ineffectiveness of the treatment. Both the control and treated samples were found severely attacked and a large population could be isolated from each sample. Table 10 shows the results of ANOVA of the PMI.

Table 10. PMI of beetles in *B. bambos* and *D. strictus* with respect to boiling

Source	df	Sum of Squares	Mean Square	F
Species	1	9720.375	9720.375	8.153*
Treatment	1	11397.042	11397.042	9.559**
Species x treatment	1	513.375	513.375	0.431^{ns}
Error	20	23844.833	1192.242	
Corrected Total	23	45475.625		

** Significant at 1% level; * significant at 5% level; ns non-significant

The difference between treatment and the control was highly significant. A very large population of the beetles obtained from treated samples compared to the control (Table 11) is suggestive of the ineffectiveness of the treatment. The difference between the two species of bamboos was significant at 5 per cent level; but the interaction between the

Table 11. Population obtained from boiled and control samples of *B. bambos* and *D. strictus*

Species	Population Multiplication Index					
	Choice test		No choice test		Control test	
B. bambos	C1	37	T1	79	C1	10
	T1	119	T2	7	C2	0
	C2	112	T3	30	C3	6
	T2	65	T4	90	C4	4
	C3	29	T5	32	C5	3
	T3	58	T6	0	C6	9
D. strictus	C1	91	T1	159	C1	7
	T1	73	T2	88	C2	68
	C2	123	T3	63	C3	32
	T2	46	T4	18	C4	48
	C3	54	T5	147	C5	29
	T3	27	T6	60	C6	34

T= treated; C= control

species and the treatment was non significant. The results thus suggest that the physical change of gelatinization of starch brought about by boiling, and also probably by heating, does not prevent the borers from feeding and establishing their population within the culm tissue.

4. 4. 8. Treatment with Biological Preservatives

Traditional methods of treatment in rural areas involve application of mild preservatives or repellants to the cut ends or the entire surface of felled bamboo to prevent attack by borers. The materials used for this purpose are locally available products of biological origin with some proven insecticidal properties. Occasionally treatment with mineral chemicals such as common salt, caustic soda or similar ones having repellant effect is also being applied to protect stored bamboo from borer damage.

4. 4. 8.1. Neem oil

Neem oil is commonly used as a biological pesticide against insects. It is extracted from the seed kernels of *Azadirachta indica* (Meliaceae). Neem oil contains azadirachtin which is believed to be an effective repellent against many insect pests (Tewari, 1992). Effectiveness of neem oil against bamboo borers was tested in the laboratory. Small samples of bamboo were dipped in neem oil and taken out. The samples were then dried and subjected to feeding experiments (Fig. 46). PMI was computed at 90 days. It was found that the treated samples escaped borer infestation and control samples were severely attacked. Borer population obtained from control samples after 90 days was very large. Variation in population was recorded and analysed by two- way ANOVA to test the difference between species and treatments.

There was highly significant difference between the treatment and the control (Table 12). The two species of bamboos *B. bambos* and *D. strictus* differed significantly in their response to treatment. The species-treatment interaction was also found to be highly significant which implies that difference in size of population between treatments is different for two species. Based on the results obtained it is suggestive that neem oil application is an effective treatment for protection of bamboo from borers.

Table 12. PMI of beetles in *B. bambos* and *D. strictus* with respect to neem oil application

Source	df	Sum of Squares	Mean Square	F
Species	1	1414.502	1414.502	12.546**
Treatment	1	2536.025	2536.025	22.494**

Species x treatment	1	1414.502	1414.502	12.546**
Error	19	2142.133	112.744	
Corrected Total	22	7055.478		

** Significant at 1% level

However, further evaluation under field conditions would be required to confirm the practical utility of this treatment. It has been reported that neem oil is effective against various groups of insects like weevils, borers, beetles and locusts (Tewari, 1992). But under field conditions, these natural products can get denatured at a faster rate and very often will not yield useful results.

4. 4. 8. 2. Carpenters' Preservative

A traditional method practiced by some local carpenters of Kerala to protect the roof assemblies and joinery in temples, involves application of a formulation of several biological ingredients. The concoction is prepared from 9 ingredients. The final product obtained after boiling is a dark substance of somewhat thick consistency suitable for brush application. Wooden articles treated using this formulation is believed to last long without being attacked by borers. In order to test the efficacy of this preparation on bamboo, the preservative was prepared in the laboratory. The powdered ingredients were mixed with sesame oil in an aluminum vessel and heated up to boiling (Fig. 47). The extract thus prepared was transferred to a plastic container and each sample was dipped in the extract and taken out. Feeding trials were conducted in the laboratory after removing the excess preservative adhering to the samples (Fig. 48). PMI was recorded at 90 days and population variation was calculated by two- way ANOVA to test the difference between species and treatments. The results are shown in Table 12.

Table 12. PMI of beetles with respect to application of Carpenters' preservative

Source	df	Sum of Squares	Mean Square	F
Species	1	681.341	681.341	1.122 ^{ns}
Treatment	1	27901.786	27901.786	45.937**
Species x treatment	1	1.341	1.341	0.002 ^{ns}
Error	21	12755.214	607.391	
Corrected Total	24	41774.960		

** significant at 1% level; ns non-significant

The results obtained from different feeding trials such as choice test, no choice test and control showed that borers were selective in their feeding habit. Only the control samples were severely attacked and treated samples remained unattacked. ANOVA showed a significant difference (1 per cent level) between treatment and control. However, the between-species difference and the species - treatment interaction were non significant. The results clearly indicate that the treatment is very effective in preventing borer damage.

4. 4. 8. 3. Fenugreek and paper pulp

This method of preservative treatment is not widely used except by the local people of Nilambur in the Malappuram District of Kerala to protect their household articles made out of bamboo from borer attack. The treatment involves application of slurry prepared by mixing powdered fenugreek with water and paper pulp over the bamboo material.

In the laboratory, 500 g of dried fenugreek was powdered and sieved through a screen of 200 mesh size. About 100 g fine powder was taken and mixed with 10g of paper pulp. Two litres of water was added to the same and mixed well. Thus a 5 per cent slurry of fenugreek was obtained and the same was applied on bamboo material and feeding experiments conducted. The results are presented in Table 13.

PMI of the samples was computed at 90 days and it was found that only 6 treated samples out of 18 were attacked. Intensity of attack was low in *B. bambos* as compared to *D. strictus*. In choice tests, the borers preferred control samples and treated samples remained unattacked. From the ANOVA table it is clear that between species difference was highly significant but the difference between the control and the treatment was found non significant. Because of the intensity of borer attack in *D. strictus* and the larger population

Table 13. PMI of beetles with respect to application of Fenugreek/paper pulp

Source	df	Sum of Squares	Mean Square	F
Species	1	4704.000	4704.000	9.704**
Treatment	1	266.667	266.667	0.550^{ns}
Species x treatment	1	54.000	54.000	0.111^{ns}
Error	20	9695.333	484.767	
Corrected Total	23	14720.000		

** significant at 1% level; ns non-significant

of beetles recovered from the material compared to *B. bambos* there was significant difference between the two species. The difference between the treatment and the control and the species-treatment interaction was found to be non-significant. Obviously the treatment was not effective in preventing the borer attack.

4. 4. 9. Evaluation of other potential methods

4. 4. 9. 1. Locally made wall paint

A locally made wall paint known as Black Japan in trade, which is cheap and commercially available to ward off insects damaging in buildings was tested against borer damage. Since the cut ends of bamboo are generally the entry points for the borers, this emulsion was used as a means to block the borer entry into the culm. Efficacy of this paint was tested by applying it on the cut ends of bamboo with the help of a brush. Samples thus treated were subjected to feeding experiments. The results show that application of Black Japan gave some protection although not a total protection against borer attack. The differences between treatment and control and also between the two species of bamboos were highly significant. In the case of *D. strictus* the beetle population was quite high in the treated samples compared to the control samples. indicating the effectiveness of the treatment. In

Table 14. PMI of beetles with respect to application of black Japan

Source	df	Sum of Squares	Mean Square	F
Species	1	2440.167	2440.167	15.743**
Treatment	1	1568.167	1568.167	10.117**
Species x treatment	1	704.167	704.167	4.543**
Error	20	3100.000	155.000	
Corrected Total	23	7812.500		

** significant at 1% level

B. bambos, on the other hand, the level of infestation was low and some of the control samples remained free from borer infestation. The population formed at 90 days was found to be very low in both treated and control samples of *B. bambos*. Thus it is likely that application of a paint formulation such as Black Japan is helpful to minimise the damage from *Dinoderus* beetles to a certain extent. However, this method may prove effective in bamboo housing and bamboos used for construction.

4. 5. Mites as predators

During the course of rearing of *Dinoderus* beetles in the laboratory it was found that a few beetles were predated upon by mites (Fig. 50). The mites were later separated out and tested for their efficacy as predators. The mite belonged to the genus *Pyemotus* of the family Pyemotidae. The species level identification is pending with Zoological Survey of India, Calcutta. Based on further laboratory trials, it was found that this mite attacks and kills all life stages of *Dinoderus* beetles including larva, pupa and the newly emerged adults. The mite causes death by sucking the body fluid of the beetle, or larvae as the case may be. Various small-scale trials conducted to study the potential of this mite as a useful biocontrol agent did not yield encouraging results.

4. 6. Entomopathogenic fungus

Conidial suspensions were prepared from 14-day old sporulating cultures of *B. bassiana*. The spore-containing Potato Dextrose Agar medium was diluted with 8-10 ml of distilled water containing 0.05 per cent Tween 20. The resultant solution containing both spores and mycelia fragments was filtered through sterilized muslin cloth. The spores were recovered in the eluent and counted using a Haemocytometer. From this stock suspension, three dilutions viz.,-10^7,10^8 and 10^9 conidia/ml were prepared and directly applied on to the adult *D. minutus* beetles. There were three replicates per each dose with a control. The experimental beetles were placed in a petridish and the fungal suspension was sprayed using a hand atomizer. The treated beetles were transferred to surface sterilized 3x3 cm bamboo pieces as food. In the control set, the beetles were sprayed with sterile distilled water.

Table 15. The mean lethal time (LT_{50}) for the different doses

Dose (Conidia/ml)	LT_{50} (hr)	Confidence limits (95%)	Slope	Potency of Estimation 95% CL
$1X10^7$	314.5	275.462-388.741	3.35±.478	0.078

1X10^8	150.112	135.690-172.458	3.592±.597	0.106
1X10^9	103.266	96.38-109.739	6.728±.748	0.047

When *B. bassiana* was applied directly on to the beetle, infection was observed from the third day post inoculation. A dose of 1x10^9 conidia/ml was found to be the most effective, which resulted in 100 per cent mortality in 192 hours (Fig. 51) the mean lethal time (LT_{50}) taken for this mortality of the beetles under different doses are given in the Table 15.

Estimates of LC_{10}, $LC_{50,}$ and LC_{90} are given in Table 16; the LC_{50} for direct application was 4.1x10^7conidia/ml which indicated a high level of pathogenicity to *D. minutus.* Selvasundaram and Muraleedharan (2001) studied the pathogenicity of *B.bassiana* on the

Table 16. Lethal Concentration (LC) Values at 192 hrs.

Lethal concentra tion	Dossage (Conidia/ml)	Confidence limits (CL)	Slope limits (95%)	Potency of estimation
LC_{10}	4.3×10^6	1.4 × 106-8.4 ×10^6	1.314 ± .188	0.079
LC_{50}	4.1× 10^7	2.5 × 107-6.3 × 10^7		
LC_{90}	3.8× 10^8	2.1 ×108 -9.9 × 10^6		

shot hole borer of tea, *Enwallacea fernicatns*. They showed a difference in the susceptibility to the disease between different stages of the borer larvae. First instar larvae were found to be more susceptible with increase in spore concentration. In the present experiment, however, only adult beetles were used for the experiment.

4. 7. Integrated Strategy to Manage *Dinoderus* Beetles

The relevance of eco-friendly methods of crop protection is being increasingly felt in recent times. Though the concept of integrated pest management (IPM) has made its mark in agriculture and horticulture ecosystems, in forestry it is still in its infancy in India. The absence of reliable estimates on impact of insect attack on productivity has also been an impediment for developing an integrated pest management strategy in forestry. It is seen that in the case of bamboo pests, the information is available on individual pests and to some extent, on their control (Wang *et al*., 1998). But no attempt has been made to attempt a control strategy, especially against the post-harvest borer beetles. The reason could be that the pest infestation pattern changes over time and space and also quantitative data is not available on borer damage to substantiate the need for control. There is also a need to critically look into the lacunae in our knowledge in terms of pest ecology.

Dinoderus beetles generally infect the freshly harvested bamboo soon after it is felled. They thrive on the reserve carbohydrates stored in the culm tissue for their feeding and multiplication. Thus several studies including the present one have been helpful to prove the relationship between storage starch and borer infestation. As the level of starch in culms is seasonally variable and a high level of starch is conducive to borers, it would be a logical approach to schedule the harvesting operation to the season when starch is low. The advantage of this option is that it does not involve additional cost or effort. Thus a number of studies have focused on finding out the period of low starch content in order to identify an optimum period for harvesting and almost all such studies have recognized that the season following production of new culms as ideal in terms of starch content. As revealed from the present study also, the starch content is comparatively low during the period from September-December (Fig. 52). By this time the formation of new culms occurs in Kerala which coincides with the end of the first spell of monsoon (June- September).

One more observation recorded in the present study pertains to the natural population of beetles. A fall in natural borer population has been noted from September to early December which is attributed to overwintering (Beeson, 1941). During the same period, the level of borer attack was found to be low in bamboo depots surveyed in Kerala. Hence it is likely that the borer population during period will be low and can be considered as ‘safe period’ for harvesting of bamboos.

The study has also shown that some of the traditional methods of physical and biological treatments are very effective in preventing borer damage. Notable among the physical treatments is soaking in water which is found to be effective as indicated by the field experiments. The decrease in the percentage of starch as a result of water submersion and the occurrence of some starch degrading microorganisms in such material, further substantiate the scientific basis of this traditional technique. Hence water submersion is a promising treatment for adoption in areas with nearby water sources.

Among the traditional biological treatments tested, some of the biological repellants/ preservatives were found to be effective in preventing borer attack. Neem oil and carpenters' preservative were found to be very effective in preventing the attack by *Dinoderus* beetles. Probably, such a prophylactic treatment has great significance in preventing infestation of borers. However, further evaluation of biological preservations under field conditions would be required to draw final conclusions. The present study has also demonstrated a decline in starch content in culm tissue due to amylase activity during post-harvest storage. Prevention of entry of borers soon after harvest is a crucial aspect of protection of bamboo against borer attack. Subsequently, as the harvested culms lose their starch and moisture content, they may become unsuitable for borer infestation.

The above IPM strategy has to be further evaluated through short term and long term trials. The strength and weaknesses of the proposed scheme can be assessed only if someone practices the same. This will involve coordinated efforts on the part of the scientists, forest managers, industries and farmers and the overall objective should be to reduce the economic damage due to borer attack by integrating the locality-specific techniques available.

5. CONCLUSIONS AND RECOMMENDATIONS

5. 1. Conclusions

The possibility of improvements in harvesting and post-harvest technology of bamboos and identifying some eco-friendly techniques of protection of the harvested bamboos are explained in the present study. For many purposes for which bamboo is used, optimum quality of the material as governed by its properties is the main concern. As the newly produced culms undergo developmental changes of maturation with age for a certain period of time, their quality and properties keep on changing until they get more or less stabilized. Thus during maturation period of about three years in both *B. bambos* and *D. strictus* the basic density increases and the moisture content and the shrinkage decrease. Identification of mature culms in a clump for harvesting is often not easy. Certain morphological features are relied upon for judging the approximate age of culms. Some traditional bamboo workers in Kerala also rely on the tissue colour of bamboo for maturity determination. This is a reliable indicator of culm age/maturity since the creamy white tissue colour of young culms gradually darkens to yellow or yellowish brown due to increasing lignification as the culm matures.

Culm extraction from clumps is a difficult and time-consuming operation particularly in thorny bamboos like *B. bambos*. With the current level of technology being in use the worker has to climb up the culm and spend a few hours to clear the mess of thorny branches before the culm is cut and pulled out. A branch cutting tool has been designed and fabricated in the present study to make the harvesting operation quicker and easier.

Borer infestation on culms depended to a great extent on starch content in culm tissue. The borers and their larvae preferred the inner, starch-rich portion of the culm wall for more productive feeding. Culms in the early stage of flowering having abundant starch were heavily attacked while those in which seed setting was completed and starch was depleted, remained free from attack. These observations are suggestive of a direct relationship between starch content and borer damage and culms devoid of starch probably evade borer damage.

One of the interesting observations of the present study is the gradual depletion of starch from cut culms during post-harvest stage by hydrolysis of starch due to the activity of amylase enzyme. The enzyme activity was found to increase gradually after a few days, reach a peak and then decrease with the decrease of culm moisture content.

Among the physical treatments traditionally followed in rural areas for protection of bamboo, soaking in water was found to be one of the promising techniques to reduce borer incidence. Water submersion caused a reduction in starch content of the culms due to the activity of microorganisms such as *Acremonium* sp. (fungus), *Pseudomonas* sp. and *Klebsiella* sp. (bacteria). Other physical techniques like heating, boiling, etc. were not effective. The traditional belief that bamboo harvested during the waning phase of the moon is relatively less affected by borers is not supported by the present study.

Among the traditional biological treatments that were tested, application of neem oil and carpenters' preservative showed promising results. Both of them were applied to the cut ends of bamboo and were quite effective in preventing borer damage.

5. 2. Recommendations

Based on the study, the following recommendations are made with regard to the harvesting and post-harvest technology of two common bamboos *B. bambos* and *D. strictus.*

- Harvesting mature culms is important for optimum quality. For ascertaining culm maturity in the field while harvesting, besides morphological features, the colour of the culm tissue can also be taken as a reliable indicator for accuracy.
- In order to minimise the drudgery of extraction operation particularly of thorny bamboos like *B. bambos*, devices such as the branch cutter detailed in this report may be used.
- For effective post-harvest protection of bamboos the following Integrated Pest Management strategy is proposed.

  a. Cut the bamboo at a time/season during which the starch content will be less, which may not be consistent for all the localities and bamboo species
  b. Adopt traditional methods like soaking in water to remove excess starch in harvested bamboos, wherever facilities available
  c. Apply preservatives, either plant products as given in this report or chemicals at the cut ends and branch scars of bamboo to prevent borer attack

d. Follow improved stacking methods like raised platforms and provide shade to facilitate slow air drying of harvested culms and protect the treated bamboos from rain.

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