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REVIEW ARTICLE

Review on bamboo treatment in India: A species-specific approach for enhanced durability

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Abstract: Bamboo is a versatile material that has been used for construction, furniture, handicrafts etc. since long and occupies an important place in the economy of rural areas. Being a fast-growing species, it provides an excellent alternate structural material. Natural service life of bamboo is only a concern, which is generally few months. However, after preservative treatment, a long service life is expected. Many preservatives and methods were adopted to treat bamboo in India. This paper provides a comprehensive review of the various treatment methods and strategies adopted in the bamboo treatment sector, with a focus on different bamboo species. It covers traditional methods, chemical treatment and other emerging innovative methods for bamboo in India. Additionally, the review explores the efficacy of various treatment, with a particular focus on understanding the treatability behaviour of commercially significant bamboo species.

Keywords: Bamboo, durability, preservation, treatability, treatment methods

Introduction

Bamboo consisting of cellulose fibers imbedded in a lignin matrix is a naturally occurring composite material which grows abundantly in most of the tropical countries. Some bamboo species have the extraordinary ability to grow up to four feet per day, making them among the fastest-growing plants on Earth. Asia's major bamboo producing countries are India and China, jointly accounting for approximately 70% of the bamboo resources in the region Mera and Xu (2014). In India, bamboo boasts rich genetic diversity, making it the second richest country in terms of bamboo species, with 136 species, including 125 indigenous and 11 exotic species. Three primary genera, namely *Bambusa*, *Dendrocalamus* and *Ochlandra*, make up around 45% of the total bamboo species found in India Tewari *et al*., (2019). Additionally, India has other important genera such as *Arundinaria*, *Dinochola*, *Gigantochloa*, *Chimnobambusa*, and *Teinostachyum* ISFR (2021). As per this ISFR (2021), India's total bamboo-bearing area is estimated 15.0 million hectares. In India, the National Bamboo Mission recognizes several important commercial bamboo species, including *Bambusa tulda, Bambusa bambos, Bambusa balcooa, Bambusa cacharensis, Bambusa polymorpha, Bambusa nutans, Bambusa bambos, Dendrocalamus hamiltonii, Dendrocalamus asper, Thyrsostachys oliveri, and Meloccanna baciferra*. Vishwanath and Arade (2016) has classified bamboo species according to their practical uses, including those well-suited for industrial and commercial purposes, giant bamboos, naturalized exotic bamboos with economic significance, reed bamboo, native monopodial species, ornamental bamboos, and endemic bamboo species.

Bamboo has a wide array of applications, making it indispensable in household products, cottage industries, construction materials, pulp production, fabric manufacturing, handicrafts, food production, agricultural applications, packing industries etc.

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Its unique combination of strength, straightness, lightness, hardness, varied culm sizes, abundant availability, ease of propagation, and short growth cycle renders it suitable for diverse purposes. Despite having more than 1500 documented uses, the commercial acceptance of bamboo remains limited in India. This limited acceptance could be attributed to several factors, including challenges related to suitable raw material, insufficient tools and machinery for primary and secondary processing, specific market demands, and concerns about its durability. The vulnerability of bamboo to insect and fungal attacks, both in its raw state and as finished products, hinders its widespread adoption Gnanaharan and Mohanan (2002). Due to which the treatment becomes important to improve its life span. The bamboo treatment includes both traditional as well as chemical treatment method. The chemical treatment suggested for structural and non-structural bamboo is given in IS: 9096 (2006) and IS: 1902 (2006), which comprises details about the recommended preservative, its retention and suitable treatment methods for specific purposes.

Since India has total 136 bamboos species and each species have distinct characteristics in terms of anatomy, physical properties, chemical composition and resistance to pest/disease. The general recommendation may not applicable to all bamboo species. Therefore, the primary aim of this paper is to explore diverse bamboo treatment approaches studied across various bamboo species in India, with the objective of evaluating the existing knowledge and practices in this domain specific to species level. Many authors have documented bamboo preservation treatments in a broad context, but this paper focuses on reviewing treatments specific to individual bamboo species.

Natural Durability

The ability of bamboo species to resist biological deterioration is called natural durability or natural resistance. Bamboo exhibits varying degrees of natural durability depending on its species, age, and environmental factors and usage. While some bamboo species possess natural resistance to decay and pests, others may be more susceptible to these factors. The longevity of bamboo structures largely depends on the rate of biological degradation. When left untreated and exposed to the outside conditions or in contact with soil, bamboo typically lasts less than a year. However, if kept under cover, its life may extend to 4 - 5 years, and even longer as high as 10-15 years under favourable conditions for example when used for rafters and internal framing (Liese and Kumar, 2003).

Currently, availability of systematic data on the natural durability of various bamboo species in India is limited specially when bamboo is exposed to ground contact and outdoor conditions. Table 1 showed natural life span of various bamboo species evaluated through grave yard test in India. Typically, the durability of both wood and bamboo is assessed using a grave yard test, following the procedure laid in IS: 4833 (1993). This test involves extended exposure in real-field conditions, which generally takes more than three years study. This long duration for study may be the reason for limited number of studies concentrated on subjecting bamboo to grave yard field testing. In India the major studies on bamboo durability were done by Purushotham (1963), Singh (1976), Singh and Tewari (1981), Liese (1980), Tewari (1981), Kumar and Dobriyal (1988), Choudhury (1993), Kumar *et al.*, (1994), Tripathi and Nautiyal (2008), where durability of *Dendrocalamus strictus, D. giganteus*, *D. membranaceus*, *Bambusa balcooa, B. nutans, B. bambos*, *B. polymorpha, Melocanna, Bambusa tulda* was studied through grave yard test. Kumar *et al*., (1998) reported natural life spans of 10 - 40 months for bamboo in ground contact. Review done by Dobriyal and Dev (2002) referred a study conducted in 1985 and 1988, where natural durability of three species i.e., *Dendrocalamus strictus*, *Bambusa polymorpha* and *Melocanna bambusoides* is reported. Natural durability of five bamboo species i.e. *Dendrocalamus strictus, Dendrocalamus giganteus, Bambusa balcooa, Bambusa nutans* and *Bambusa bambos* was evaluated through grave yard test by Tripathi and Nautiyal (2008). The results indicated that none of the species exhibited durability when in contact with the ground. Thirteen types of bamboo were studied to laboratory to determine their inherent resistance to *Microcerotermes beesoni* Snyder, a prevalent subterranean wood-destroying termite species by Mishra and Rana (1992). The results indicated that *Bambusa nutans* (weight loss 22.12%), *Dendrocalamus strictus* (weight loss 25.63%), *B. balcooa* (weight loss 27.42%), and *D. giganteus* (weight loss 29.92%) exhibited comparatively higher resistance than other species such as *D. calostachyus, B. vulgaris var.wamin, Oxytenanthera albociliata,*

Table 1. Natural durability of various bamboo species tested through Grave yard test in Indian conditions

Species	Natural Durability (life span)	Reference
Dendrocalamus strictus	18 to 30 months Average 19.3 Months	Kumar *et al*, (1994)
	15 months	Tripathi and Nautiyal (2008)
Dendrocalamus membranaceus	9 to 21 months Average 13 Months	Kumar *et al*, (1994)
Bambusa balcooa	Average 32 months	Purushotham *et al*, (1954)
	15 months	Tripathi and Nautiyal (2008)
Bambusa nutans	6-18 months Average 9.8 Months	Kumar *et al*, (1994)
	3 months	Tripathi and Nautiyal (2008)
Bambusa bambos	21 months	Tripathi and Nautiyal (2008)
Bambusa polymorpha	12-84 months Average 23.4 Months	Kumar *et al*, (1994)
Melocanna bambusoides	9-24 months Average 19.9 Months	Kumar *et al*, (1994)
Bambusa tulda	41 months	Purushotham *et al*, (1954)

D. membranaceus, B. vulgaris, Ochlandra travancorica, B. tulda, D. longispathus, and D. hamiltonii and showed similar resistance levels to certain durable timber varieties like *Shorea robusta, Anogeissus latifolia*, and *Garuga pinnata*.

Reason for poor durability: The performance of bamboo in the field is influenced by factors such as moisture content, treatment time, and retention of preservative. These factors played a role in the deterioration of the treated bamboo. Bamboo shares similarities with wood in terms of moisture sensitivity and the exchange of moisture with its surroundings. Studies have shown that bamboo can absorb a significant amount of moisture, up to 100% to 300% of its weight (Subrahmanyam, 1984; Mehra *et al*., 1951). During the initial stages, especially within approximately 20-24 hours, bamboo tends to undergo swelling due to this moisture absorption before reaching its fibers' saturation point (Junior *et al*., 2009, Bui *et al*., 2017). In a study conducted by Junior *et al.,* (2009), the absorption capacity of *Bambusa vulgaris* was investigated concerning different liquids over time. The research revealed that the bamboo's absorption rate is influenced by the density of the liquid. Specifically, the absorption behavior varied for water, ethylic alcohol, mineral oil, and two polyester resins, showing how the bamboo interacted differently with each substance throughout the duration of the study. In another study, Sharma and Mehra (1970) reported that green bamboo may have up to 150% moisture (oven-dry weight basis) and this variation could be 155% for the innermost layers to 70% for the peripheral layers.

Another factor is its chemical constituent. Bamboo culms consisting mainly 60-70% holocellulose, 20-25% pentosans, hemicellulose, lignin, silica (0.5 to 4%) and minor constituents like tannins, waxes and inorganic salts (Tomalang *et al*., 1980, Kurhekar 2012**).** Mathew and Nair (1990) and Gnanarahan *et al*., (1993) also reported the presence of high carbo-hydrates content, low tannins, resins and waxes in bamboo makes it more susceptible to insect and fungi.

The content varies between and within species and is dependent on the age of the culm, as well as the location along the height of the culm and within the culm wall (Li 2004). The lower portion of the culm is recognized for its increased durability, with the softer inner wall deteriorating more rapidly compared to the outer, harder section.

Bamboo Treatment

The durability of bamboo can be improved by imparting some treatment either traditional or chemical based. Some other techniques are also initiated in this direction, which are discussed below:

Traditional methods: Bamboo can be treated with traditional as well as chemical preservation techniques. Traditional methods are basically leaching, lime washing, smoking and baking, which is practiced by local people specially living in bamboo bearing areas (Kumar *et al.,* 1994, Anon 2006, Bebija *et al.,* 2017). Starch is generally removed by leaching, which improves bamboo permeability for further diffusion and pressure treatment. However, as mentioned by Anon (2006), the long water storage of bamboo for traditional leaching affects its mechanical properties. Another traditional method is lime washing. In this method, slaked lime ($Ca(OH)_2$) is applied to bamboo culms and mats, which further changed into calcium carbonate ($CaCO_3$) and reduce fungal attack by limiting the water absorption. Smoking is also acceptable traditional method, where bamboo is placed over fireplace in order to reduce the moisture content and biological degradation. Baking of culms on open fire is also practiced to remove the starch/sugars and produce tar, which helps to protect the bamboo from degradation (Anon 2006, Paduvil 2008). Bibija *et al*., (2017) studied conventional techniques used for preserving *Bambusa tulda*, including water soaking, curing, and smoking. The effectiveness of the water soaking method was evaluated under controlled laboratory conditions using the *Schizophyllum cummuni* and Graveyard tests. The study indicated that immersing bamboo in water for a month yielded optimal results in terms of enhancing its durability.

Chemical Treatment: Short term protection of bamboo can be achieved by these traditional methods, but for long term protection in service conditions, chemical treatment is preferred, which can be done with single chemical compound or mixture of many based on their compatibility and toxicity. These chemical preservatives are of three types based on the solvent carrier i.e., oil based, water borne based and organic type. Coal tar and creosote are most common oil-based preservatives being used for bamboo treatment. Oil treatment repel the water and give protection against fungal and borer. However, its unpleasant odour and color limits its use in commercial application. Water borne preservatives are dissolved in water and the salts are penetrated inside the bamboo and water evaporates after the treatment. The common examples are Boric acid: Borax and copper sulphate, Copper-Chrome-Arsenic (CCA), Copper-Chrome-Boron (CCB), Zinc chloride etc. Third one is organic based preservatives, which are commercially available in ready to use form for e.g., Trichlorophenol (TCP), Copper/Zinc naphthenates (metallic soaps) (Anon. 2006). As per IS: 9096 (2006), coal tar creosote, Copper-Chrome-Arsenic (CCA) Composition, Acid- Curpric-Chromate (ACC) Composition, Copper-Chrome-Boron (CCB) Composition, Boric-Acid-Borax, Copper-Zinc-Naphthenate/ Abietates are recommended for treatment of bamboos. Chemical treatment of bamboo as recommended in IS: 9096 (2006) and IS: 1902 (2006) are surface application (brushing, dipping), vacuum/ pressure process, hot and cold process, Fast fluctuating pressure (FFP) process and Boucherie process for structural use and diffusion process, modified Boucherie processes and Steeping or Butt end treatment method for non-structural purposes respectively. Damodaran *et al.,* (2020) suggested CCB at 6% (weight/volume) and 4% concentration for the pressure treatment of bamboos to get DSR of 8 kg/m^3 and 4- 5 kg/m^3 respectively. Simple Sap displacement technique for bamboo is also standardized at Institute of Wood Science and Technology, Bangalore (Rao 2001). Due to toxic effect of most of these preservatives, the plant based chemical products such as cashew shell oil and neem oil and fenugreek paper pulp slurry etc. were also tested for bamboo treatment by Paduvil Paduvil (2008). In addition, Paduvil (2008) also tried servo oil and caustic soda solution for bamboo treatment against *Dinoderus minutus* beetles. Table 2 shows the treatment methods explored for various Indian bamboo species with detail of major outcome in terms of retention and other noticeable facts.

The data indicates that *Dendrocalamus strictus* was predominantly studied by researchers, possibly due to its widespread availability across various regions in the country A variety of chemicals, including CCA

Table 2 Details of Preservative treatment and its outcome for various bamboo species

Species	Treatment method	Chemical/ Material	Outcome	Remark	Reference
Dendrocalamus strictus (green)	Butt treatment (with branches and leaves)	• Copper sulphate • Zinc chloride	Uniform distribution of preservative was achieved throughout the wall after one month from treatment and also, sufficient amount of preservative was noticed at the top end.	Butt treatment (with branches & leaves) was not found suitable for unwieldy branches or non-straight culms. This approach leads to preservative loss through absorption in the branches and leaves	Singh and Tewari (1980)
	Butt treatment (without branches and leaves)	• Copper sulphate • Arsenic pentoxide • Sodium dichromate • Zinc chloride • Boric acid Borax • ACC • CCA	The method was found suitable for treating bamboo with single salt preservatives like copper sulphate and Boron.	Only selective absorption of different elements in the preservatives was recorded.	Singh and Tewari (1980)
	Dip diffusion for 50 days	A. Copper Sulphate B. Acid-cupric-chromate (ACC) C. Zinc chloride D. Boric acid-borax E. Chromated zinc chloride F. Sodium dichromate (Each 6% concentration)	Absorption (Kg/m^3) / Round / Split A 17.28 29.46 B 10.71 14.46 C 31.92 40.37 D 32.18 42.62 E 14.31 18.23 F 12.56 22.90	After 50 days complete penetration of preservatives was noticed.	Singh and Tewari (1981a)
	Osmose treatment	• Copper sulphate paste • CCA paste • ACC paste	Bamboo was treated adequately with all studied chemicals.	Crystal of Copper sulphate was observed after some time of the bamboo treatment with Copper sulphate paste	Singh and Tewari (1981a)
	Double steeping	Steeping first in 20% Copper sulphate or 20% Zinc chloride for 48 or 96 hours and then in 20% Sodium dichromate for 48 or 96 hours respectively	Even distribution of the preservative was noticed in this method	The penetration of Copper sulphate-Sodium dichromate preservative was only about 40% in round bamboo.	Singh and Tewari (1981 b)
	Spraying and Brush coating	• 1% solution of Sodium PCP in water • 2% Boric acid: Borax (1:1) in water • 5% ACC in water • Untreated	Bamboo weight loss after in 8 to 10 months of storage 15% 14% 16% Untreated -22%	Sodium PCP was found most economical and effective.	Guha *et al*., (1980)

Steaming and quenching	First steaming the green bamboo at about 100^0C for 1 to 2 hours and then quenching in a water-borne preservative for about 2 days and then storing for a month.	Steaming for 2.5 hours and quenching for 48 hours resulted in a dry salt retention of 18 kg/m^3 of CCA	If septa could be punctured or small notches or holes could be made, this treatment would be applicable to any species to obtain better penetration and higher preservative loading.	Singh and Tewari (1981 b)
Soaking treatment	CCA at 4%	The total salts loaded in the basal section were 8.6 kg/m^3, whereas middle and top internodes absorbed 12.8 and 13.6 kg/m^3 respectively. The average retention of CCA was found 12.2 kg/m^3 in outer, 13.3 kg/m^3 in middle and 14.0 kg/m^3 in Inner section.	Preservative loading along wall thickness (outer, middle and inner) and in height varied.	Kumar and Dobriyal (1990)
Hot and cold method	Treated 0.9 m long samples in both round and split form with creosote-fuel oil mixture	Absorption was 54-57 kg/m^3, 69-72 kg/m^3 and 72-74 kg/m^3 after 3, 4 and 6 hours of heating time respectively.		Singh and Tewari (1979)
Diffusion methods	• ACC • Boric acid-Borax at 6%	Average absorption of ACC at 10 and 30 days dipping was 7.76- 15.53 kg/m^3 and 15.65 and 19.77 kg/m^3 respectively. Average absorption of Boric acid-borax at 10 and 30-days dipping was 7.73- 11.32 kg/m^3 and 10.86 and 20.16 kg/m^3 respectively	Both round and half split bamboo were treated.	Singh and Tewari (1979, 1981)
Sap displacement treatment by Boucherie process	Copper-chrome-borate (CCB)	Time taken for sap displacement was 24 hrs.		Rao (2001)
Water leaching method	Bamboo samples were kept into the water tank for one month and the water in the tank was replaced with fresh water every 7 days.	The samples leached with water showed only 9.6% decay compared to 55.6% in control specimens. The decay resistance efficiency was almost comparable to chemically treated culms.		Kaur *et al.*, (2013)

<table>
<tr><td>Dip treatment
Pressure treatment using vacuum 3 impregnation (60 mm MercuryVacuum for 30 minutes), Modified Boucherie equipment (Pressure: 2 Bars)</td><td>Extracts of jatropha leaves and lantana leaves, jatropha cake and neem oil</td><td>Copperised Neem Oil treated bamboo samples were found to be the most durable up to 3 years of exposure to field conditions.</td><td></td><td>Kaur et al., (2016)</td></tr>
<tr><td>A-Boucherie,
B-VAC-FRI,
C-Wick
D- Diffusion</td><td>Copper chrome arsenic (CCA) at 4% concentration</td><td><table><tr><th>Treatment</th><th>Average treatment time</th><th>Retention (kg/m^3)</th></tr><tr><td>A</td><td>5 hr</td><td>10.4</td></tr><tr><td>B</td><td>4 hr</td><td>14.2</td></tr><tr><td>C</td><td>14 days</td><td>7.2</td></tr><tr><td>D</td><td>7 days</td><td>9.6</td></tr></table></td><td>The samples treated with CCA through the Boucherie and VAC-FRI processes demonstrated outstanding performance, free from microbial attacks even after 24 months of installation. In contrast, all samples treated with the Wick process suffered complete damage within the same timeframe. Samples treated using the diffusion process yielded promising outcomes, with just 9% of them experiencing minor termite and fungus attacks.</td><td>Tripathi and Nautiyal (2008)</td></tr>
<tr><td>Pressure treatment of 3-5 kg/cm2 for one hour</td><td>CCA</td><td>Achieved retention of 8.6, 12.8 and 13.6 kg/m3 at base, middle and top portion of culm</td><td>Variation was noticed in CCA retention Along the wall thickness. Outer- 12.2 kg/m3, middle 13.3 kg/m3 and inner 14.0 kg/m3.</td><td>Kumar and Dobriyal (1992)</td></tr>
<tr><td>Pressure treatment</td><td>CCA, ACC, CCB at 5, 10 and 15 kg/m^3 and Creosote: fuel oil at 45, 60 and 100 kg/m^3 retention.</td><td><table><tr><th>Retention (kg/m3)</th><th>5</th><th>10</th><th>15</th></tr><tr><td>Preservative</td><td colspan="3">Average life (months)</td></tr><tr><td>CCA</td><td>32.5</td><td>83.2</td><td>144</td></tr><tr><td>ACC</td><td>49</td><td>77.5</td><td>120</td></tr><tr><td>CCB</td><td>34.5</td><td>87.5</td><td>102</td></tr></table>Average life (months) in creosote: fuel oil treated<table><tr><th>Retention (kg/m3)</th><th>45</th><th>60</th><th>100</th></tr><tr><td>Creosote: fuel oil</td><td>127</td><td>133</td><td>112</td></tr></table></td><td></td><td>Kumar et al., (1998)</td></tr>
</table>

Dendrocalamus strictus (dry)	Steeping process	CCA	Dry salt retention (DSR) of about 10 kg/m^3 was achieved in round samples in 6 days		Singh and Tewari (1979)
	Steeping process	5% CCA	Dry salt absorption of CCA was found 9.75 and 9.71 kg/m^3 in round and split bamboo after 6 days of dipping respectively and 13.15 and 14.43 kg/m^3 in round and split bamboo respectively after 12 days of immersion		Kumar *et al.*, (1994)
	Pressure and soaking method	ACA at 4% and CCA at 5 % (single node & double node bamboo)	Sufficient penetration and absorption of preservatives was achieved.	Culms which are difficult to treat at dry condition can easily be treated with ACA by soaking for 7 days	Dev *et al.,* (1993)
Dedrocalamus ritchy (Manga)	Diffusion method- Dipping for 14 days	• Boric acid borax • Copper chrome boron • Cashew nut shell liquid	Adequate data is not available.		Kurhekar (2012)
Dendrocalamus giganteus	A- Boucherie, B-VAC-FRI, C- Wick D- Diffusion	Copper chrome arsenic (CCA) at a 4% concentration	Treatment | Average treatment time | Retention (kg/m^3) A | 6 hr | 15.2 B | 7 hr | 6.2 C | 14 days | 9.0 D | 7 days | 10.6	This species performed well in field conditions.	Tripathi and Nautiyal (2008)
Dendrocalamus hamiltonii	Boucherie process	CCB (8, 10, 12%) at 1 and 1.5 kg/cm^2 Pressure	Portion | CCB loading (g/kg) at 1kg/ cm^2: 8% | 10% | 12 % Apical | 8.10 | 5.10 | 6.20 Middle | 4.30 | 6.40 | 5.53 Basel | 5.95 | 6.38 | 2.98	Portion | CCB loading (g/kg) at 1.5 kg/ cm^2: 8% | 10% | 12 % Apical | 1.10 | 8.30 | 2.34 Middle | 3.20 | 4.46 | 4.46 Basel | 2.98 | 3.83 | 4.68	Gurung *et al.* (2017)
Bambusa bambos	Butt treatment (with branches and leaves)	Copper chrome-arsenate (CCA)	Not applicable due to poor flow of preservative		Jayanetti (1975)

	Butt treatment (without branches and leaves)	• Copper sulphate • arsenic pentoxide • Sodium dichromate • Zinc chloride • Boric acid-borax • ACC • CCA	Suitable for treating bamboo with single salt preservatives like copper sulphate and boron	Treatment with multi salt preservatives like CCA was not found suitable. Only selective absorption of different elements in the preservatives took place.	Singh and Tewari (1980)
	Sap displacement treatment by Boucherie process	Copper-chrome-borate (CCB)	Time taken for sap displacement was 30 hrs.		Rao (2001)
	A- Boucherie, B-VAC-FRI, C- Wick D- Diffusion	Copper chrome arsenic (CCA) at a 4% concentration	Treatment / Average treatment time / Retention (kg/m^3) A / 5 hr / 5.5 B / 7 hr / 4.3 C / 14 days / 2.8 D / 7 days / 6.0	The performance of this species does not show significant improvement even when subjected to various methods of preservative treatment	Tripathi and Nautiyal (2008)
	Brush application	1. Sesame oil 2. Sesame oil and pure cashewnut shell oil 3. Cashewnut shell oil	Preservative 2 and 3 provided complete protection against Dinoderus borers. Cashew nut shell oil exhibited more potential than sesame oil alone as the medium.	Efficacy was tested on felled bamboo samples in the laboratory conditions using *D. minutus* beetles	Varma and Puduvil (2007)
Bambusa pallida	Boucherie process	CCB (8, 10, 12%) at $1 kg/cm^2$ and $1.5 kg/cm^2$ Pressure	Portion / CCB loading (g/kg) at 1 kg/cm^2 pressure: 8% / 10% / 12 % Apical / 6.80 / 3.19 / 6.16 Middle / 7.65 / 5.95 / 3.40 Basel / 5.31 / 1.70 / 5.53	Portion / CCB loading (g/kg) at 1.5 kg/cm2 pressure: 8% / 10% / 12 % Apical / 6.37 / 7.86 / 5.74 Middle / 6.16 / 4.67 / 4.88 Basel / 4.25 / 4.88 / 3.83	Gurung *et al.*, (2017)
Bambusa polymorpha	Butt treatment (with branches and leaves)	Treat 9.5 m long green culms			Purushotham *et al.*, 1953

Modified Boucherie method	• Zinc chloride • 'Boliden' salts • CCA, • CCB • Chromated zinc chloride • fireproof-cum-antiseptic composition		
Steeping process	5% CCA	Dry salt absorption of CCA was found 6.93 and 13.44 kg/m3 in round and split bamboo after 6 days of dipping respectively and 10.01 and 17.92 kg/m^3 in round and split bamboo respectively after 12 days of immersion.	Kumar *et al.*, (1994)
Pressure treatment	• CCA, • ACC, • CCB 5, 10 and 15 kg/m3 • Creosote: fuel oil at 45, 60 and 100 kg/m^3 retention.	Life in months Retention (kg/m3): 5, 10, 15 CCA: 36, 59, 113.5 ACC: 37, 40.5, 110 CCB: 30, 79.5, 130. Creosote: fuel oil — Life in months Retention (kg/m3): 45, 60, 100 98.5, 99, 89	Kumar *et al.*, (1998)
Steeping	CCA	Dry salt retention (DSR) of about 10 kg/m^3 was acheived in round samples in 6 days	Singh and Tewari (1979)
Hot and cold method	Treated 0.9 m long samples in both round and split form with creosote-fuel oil mixture	Absorption was 42-45 kg/m^3, 49-57 kg/m^3, and 67-72 kg/m^3 after 3, 4 and 6 hrs of heating time respectively.	Singh and Tewari (1979)

Bambusa nutans	Modified Boucherie method	• Zinc chloride, • 'Boliden' salts, • CCA, • (CCB), Chromated zinc chloride • fireproof-cum-antiseptic composition					Purushotham *et al*., (1953)
	A- Boucherie, B-VAC-FRI, C- Wick D- Diffusion	Copper chrome arsenic (CCA) at a 4% concentration	Treatment A B C D	Average treatment time 5 hr 7 hr 14 days 7 days	Retention (kg/m^3) 5.8 6.4 8.6 9.0	None of the treatment procedure was able toprovide substantial protection and a high number of samples got destroyed within 24 months of installation	Tripathi and Nautiyal (2008)
Bambusa balcooa	A- Boucherie, B-VAC-FRI, C- Wick D- Diffusion	Copper chrome arsenic (CCA) at a 4% concentration	Treatment A B C D	Average treatment time 22 hr 4 hr 14 days 7 days	Retention (kg/m^3) 10.8 5.9 5.3 10.8	Samples treated with Boucherie process performed best showing 100% of the samples running in field after 24 months of installation. Whereas, 65% and 52% of samples treated by V-F and D. methods respectively, are still running in field after 24 months	Tripathi and Nautiyal (2008)
	Soaking for 7 days	• Boric acid (BA, 5% w/v in water), • Copper acetate (CA, 5% w/v in water), • Phthalic anhydride (PA, 5% w/v in 1:1 DMF and MeOH), • Triethelene tetramine dithiocarbamate Na-salt (Triendtc, 5% w/v in water), • Kerosene	Bamboo samples treated with boric acid, copper acetate, maleic anhydride followed by dithiocarbamate and kerosene give good dimensional stability and it can resist termite and fungal attack better, where kerosene creates hydrophobic environment inside and surface of the samples.			Test was conducted for six months under termite colony colony under ambient environmental condition (average temperature of 28 °C and average relative humidity of 72%).	Borthakur *et al*., (2018)

		• Phthalic anhydride/Malic anhydride • Boric acid • Copper acetate • Plant extract (*Chromolaena odorata*)	Anti shrink efficiency was increased from 30.81% to 68.80% in sample treated with phthalic anhydride and 18.17% to 42.13% in sample treated with plant extract.		Borthakur and Gogoi (2009)
Bambusa tulda	Water soaking	Submerged in water for 1, 2 and 3 months and Durability test was done by inoculating pure culture of Schizophyllum commune - a white rot fungi using vermiculite	Biomass loss % after fungus inoculation for 16 week Un-treated: 19.26 1 month treat.: 10.81 2 month treat: 11.78 3 month treat: 14.36	Treatment of bamboo with water is significantly effective against white rot fungus.	Bebija *et al.,* (2015)
	Water soaking	Submerged in water for 1, 2 and 3 months	Average starch content was reduced upto 0.50 % in samples soaked for 3 months against the 3.64% starch in untreated samples.		Bebija *et al.,* (2017)
	Curing method	Matured culms of about 3-4 years old along with branches and leaves were leaned to a nearby tree for three different periods viz. 15, 30 and 45 days.	Average starch content was reduced upto 1.80 % in samples cured for 3 months against the 3.64% starch in untreated samples.		
	Smoking method	Different portion of culm seasoned over traditional fire place for 15, 30 & 45 days.	Average starch content was reduced upto 2.48 % in samples seasoned for 3 months against the 3.64% starch in untreated samples.		
	Dipping/ Soaking	Kaolinite clay suspensions followed by Kerosine oil and chemicals like boric acid, Copper acetate and sodium salt of diethyl diethyldithio-carbamate in sequence	Termite resistant capacity was found better in chemically treated sample then simple Kaolinite treated sample.		Sonowal and Gogogi (2010)

	Pressure method.	Thermosetting resin (Phenol formaldehyde, Urea formaldehyde and Melamine formaldehyde)	Treated samples possessed negligible reduction of MOR (1.30% for PF, 1.90% for MF and 2.20% for UF against 17.69% for untreated sample) and MOE (0.81% for PF, 1.11% for MF and 1.32% for UF against 21.15% for untreated sample)	Treated samples were exposed to soil infested with termite for a period of twelve months under natural environmental conditions (average temperature 26±C and RH 72%) followed by mechanical testing	Deka *et al.*, (2003)
	Sap displacement	CCB at 8% and 10% concentration for 48 hours	Treatment was found effective in the climatic conditions of Jorhat.	Lower concentrations of chemicals and traditional method of treatment were found ineffective in imparting protection against the damage.	Gurung and Negi, (2011)
		Diesel treatment followed by copper sulphate, CCB and Kerosene oil, Boric acid and borax	Diesel treatment followed by copper sulphate gave maximum protection and untreated and traditional treated sample were highly effected by termite and borer.	Study was done by graveyard test method for three years in climatic conditions of Jorhat.	Gurung *et al.*, (2009)
Melocanna bambusoides	Pressure treatment	CCA, ACC, CCB at 5, 10 and 15 kg/m^3 & Creosote: fuel oil at 45, 60 and 100 kg/m^3 retention.	Life in months Retention (kg/m^3): 5, 10, 15 CCA: 26.5, 33.5, 30 ACC: 26, 44, 63 CCB: 23.5, 32, 61 Life in months Creosote: fuel oil Retention (kg/m^3): 45, 60, 100 45.5, 56.5, 70		Kumar *et al., (*1998)
Pseudo-xytenanthera stocksii	Sap displacement treatment by Boucherie process	Copper-chrome-borate (CCB)	Time taken for sap displacement was 28 hrs.		Rao (2001)

CCB, Boron, Copper sulphate, Creosote, ACC, Zinc chloride and NaPCP, were examined for standardization through both pressure and non-pressure methods (Table 2). Other bamboo species, such as *Bambusa bamboo, B. balcoa, B. nutans, B. tulda, Bambusa polymorpha*, and *Melocanna bambusoides* were also subsequently investigated. Similar types of chemicals and treatment methods were applied to these species as well. It is important to notice that each bamboo species exhibited distinct responses to various chemicals and treatment methods. Even a minor alteration in treatment methods or chemicals yielded different outcomes, emphasizing the significance of studying treatment methods for other commercially important bamboo species as well. There are many other reports provide general information on preservative treatments for bamboo without specifying the particular species that was studied. INBAR-IPIRTI report suggested prophylactic treatment or soaking for 10 minutes in 1% solution of mixture of boric acid and borax in a 1:1 ratio for bamboo mat. Dhamodaran *et al*., (2020) reported most commonly practicable methods viz., the simple diffusion method for the treatment of round bamboo in small quantity as well as for the treatment of splits/slats and slivers and the industrial method for treating commercial volumes of bamboo. For increasing the service life of bamboo, Gnanaharan (2002) standardized the preservative treatment methods for bamboo used in construction sector but these treatments are general not specific to particular species.

Table 3: Degree of penetration of bamboo species after flow of preservative followed by application of stain

Species	Stain	Penetration index	Treatability
Dendrocalamus strictus	Creosote	0.83	a
	Wax dye	0.52	b
	Silver nitrate	0.63	b
Dendrocalamus hamiltonii	Creosote	1.00	a
	Wax dye	0.58	b
	Silver nitrate	0.54	b
Bambusa nutans	Creosote	0.87	a
	Wax dye	1.0	a
	Silver nitrate	1.0	a
Bambusa tulda	Creosote	0.92	a
	Wax dye	0.58	b
	Silver nitrate	0.46	b
Bambusa polymorpha	Creosote	0.79	a
	Wax dye	0.70	a
	Silver nitrate	0.70	a
Melocanna bambusoides	Creosote	1.00	a
	Wax dye	0.58	b
	Silver nitrate	0.46	b

Source: Dobriyal and Dev (2002)

Other treatment methods: Shockwave assisted preservative treatment of *Bambusa bombos* was also done by Damodaran and Gnanaharan (2008). In this method possibility of shockwave utilization for preservative impregnation of bamboos was explored to achieve the complete penetration of the preservative chemical. Bhat and Kallarackal (2007) aims to analyse factors promoting increased amylase activity in post -harvest culm tissues. Additionally, investigating the potential of artificial treatments to expedite starch degradation in culm tissues for quicker and desired outcomes.

Treatability

Penetration and distribution of active ions inside the cell structure of bamboo is very important to decide its durability. Treatment is based on mainly the retention and absorption of chemical achieved and durability is based on performance of treated samples in field condition. Study on distribution of chemical inside the cell structure is not attempted well, due to which the treatability class of different bamboo species is still in quest. Anatomical structure is very important to consider for treatability aspects. Kumar and Dobriyal (1990) studied the treatability of *Dendrocalamus strictus* as per the method mentioned by Kumar and Dobriyal (1983). In this study three internodes from top, middle and bottom was treated with CCA, Creosote, Silver nitrate and wax and penetration indices was calculated on the basis of degree of penetration of chemicals in different cell types like vessels, fibers, parenchyma. Results showed more uniform pattern of creosote: fuel oil compared to other water soluble and organic based preservatives. Penetration index was also studied for another bamboo species by Kumar and Dobriyal (1992), Kumar *et al*., (1988) and Dobriyal *et al*., (2001). The penetration index data of these bamboo species is shown in table 3.

Response of different parts of bamboo to preservative penetration affect the uniform distribution of preservatives, which subsequently affects its durability. The vascular bundles consisting xylem and phloem are generally higher in the periphery as compared to inner walls. In case of bamboo, parenchyma is responsible to store food, anatomical and chemical nature of the woody cells. The vascular bundles play important role in chemical treatment specially affecting the degree of chemical penetration. The chemical flow depends on size, shape and number of the vascular bundles occurring in the culm, which leads the treatment variation from outer to inner surface. As per Dobriyal and Dev (2002) the preservative penetration decreased with increasing distance of the tissue such as fibers and parenchyma from the vessels and the vascular bundles in the inner zone of the culm showed better treatment than the vascular bundles at the periphery. Liese (1959) also reported that the distance of conducting vessels plays important role in preservative penetration. The large size vessels get large amount of preservative compared to smaller vessels. Although, the vessels occupy a mere 10% of the bamboo culm volume, preservatives penetration also depends on other tissues surrounding the vessels.

Conclusions

Most of the research on bamboo treatment were focused on specific species like *Dendrocalamus* and *Bambusa* for preservation treatment. India boasts around 136 bamboo species, which could serve as alternative raw materials. The prevailing treatment methods primarily involve the application of copper, zinc, and boron-based chemicals to bamboo. Researchers had especially concentrated on treating bamboo in its green state rather than when it's dry. The findings are typically presented in terms of chemical retention and the performance of treated bamboo under specific conditions, including field tests. However, there's a lack of comprehensive explanations for the variations in preservative retention across different bamboo species, possibly related to their chemical composition and anatomical features. While the anatomical structure of some bamboo varieties has been well-studied, there is limited research on the flow channels and distribution of preservative chemicals within different structural parts of dry bamboo. Developing treatment methods specific to each bamboo species can result in a more efficient and effective approach, accounting for the wide diversity of bamboo types, their unique characteristics, and various applications. Such an approach has the potential to enhance durability, sustainability, and economic value. Therefore, it is recommended to conduct studies on different bamboo species to determine suitable treatments and improve their durability.

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