Effect of Seasoning of Different Woods on Resistance against *Odontotermes obesus* (Ramb.) under Laboratory and Field Choice and No-Choice Tests

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The effects of seasoning on resistance of sapwood and heartwood of *Dalbergia sissoo* Roxb., *Acacia nilotica* Wild., and *Pinus wallichiana* A. B. Jacks against consumption by *Odontotermes obesus* (Ramb.) was evaluated in no-choice and choice laboratory and field experiments. Seasoning was done in an oven at 60, 80, and 100 °C for 10 and 15 days. The amount of wood consumed generally decreased as the drying temperature increased, indicating that the drying process contributed to termites' resistance of the woods and made them unpalatable for the termites. The woods that were dried at 100 °C for 15 days showed a significant reduction in weight after the consumption by termites compared to the woods dried at 60 and 80 °C and control both in laboratory and field trials. Similarly, the wood that was dried at 100 °C for 15 days showed highest termite mortality rate in laboratory no choice and choice tests. Consequently, the termites showed maximum feeding propensity on unseasoned *P. wallichiana* and the minimum on seasoned *D. sissoo* measured with significant differences in weight loss and mortality. Based on the feeding indicated by wood weight loss, the descending order of preference was *Dalbergia sissoo* > *Acacia nilotica* > *Pinus wallichiana*. The importance of wood seasoning for termites' resistance is also discussed.

Keywords: Wood; Seasoning; Termites; Choice and no choice; O. obesus

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INTRODUCTION

Dalbergia sissoo (Roxb.), *Acacia nilotica* (Wild), *Eucalyptus globulus* (Labill), and *Pinus wallichiana* (A. B. Jacks) are major furniture woods; the latter is also important for paper and crate making in parts of Pakistan (Nouman *et al.* 2006). *D. sissoo* is internationally known as the most durable timber species. These woods, like several others, are subjected to various types of biodeterioration; termites and fungi are the leading causes of destruction at different stages of wood processing (Istek *et al*. 2005; Goncalves and Oliveira 2006). Termites, active in various ecological zones, destroy wood quantitatively and qualitatively, and thus a large amount of money is required for preservation of wood. *Odontotermes obesus* Ramb. (Termitidae: Isoptera) is one of the most damaging termite species in Pakistan (Sheikh *et al*. 2010). It has a broad range of preference toward many types of wood and for living trees as well (Roonwal 1978; Sheikh *et al*. 2010). *D. sissoo* is reported to be the most resistant to this species of termite in many studies (Akhtar and Ali 1979; Manzoor *et al*. 2010; Malik *et al*. 2012; Qureshi *et al*. 2012). Nevertheless, extent of resistance varies with the methods used to assess it.

In spite of the natural resistance of wood to termite infestation, protection is still needed to avoid monetary losses. Two important strategies to protect wood from termite infestation are heat treatment and application of toxic chemical preservatives. Because of disadvantages associated with the use of chemical preservatives, heat treatment can be regarded as the more suitable option. It has yet to be determined whether heat treatment is a long- or short-term strategy. The defining feature of heat treatment (*i.e.*, seasoning) is the drying of wood to reduce the moisture content to a level beyond which there is no further reduction in the weight of wood. The drying of wood depends on the temperature and the duration to which wood is subjected. In European thermal processes, the treatment of wood at high temperatures varies between 160 and 260 °C, and the main difference is due to the processing conditions, *i.e.*, steaming, use of oils, and exposure to oxygen or nitrogen. The most common treatment temperatures range from 160 to 190 °C for 4 to 5 h (PLATO-process) (Tjeerdsma *et al.* 1998), 180 to 220 °C for 18 h (oil-heat treatment) (Rapp and Sailer 2000), and 185 to 215 °C for 2 to 3 h (ThermoWood process) (Militz 2002; FTA 2003).

Air-dried Japanese cedar was exposed to saturated water vapor at 105 to 150 °C for 6 to 72 h, and the termite resistance capabilities were lost (Momohara *et al*. 2003). Kiln drying over 100 °C is known to shorten the period of wood seasoning. In this reported case, the seasoning time was reduced to 6 to 72 h (Hisada 2001; Momohara *et al*. 2003). Still, the thermal treatment of woods has revealed a significant correlation between termite resistance and weight loss after the heat treatment process (Mburu *et al*. 2007). In another study, thermally compressed pine wood panels were tested against *Reticulitermes flavipes*, at 120 to 150 °C for 1 h. The mass loss in the specimens progressively decreased at 120 °C as compared to control specimens (Unsal *et al*. 2009). Irrespective of the method of seasoning, sun- or oven-drying reduced the subterranean termites' attack on sapwood and heartwood of *Ficus religiosa* (L.) when they were sun-dried for 5 to 60 days, or oven-dried at 60, 80 and 100 °C for 10 or 15 days (Ahmed *et al*. 2013, 2014). Although thermal treatment has proven to be an effective method for deterring termites, recent studies have found contradicting results where drying has attracted termites and heightened weight loss was observed in heat-treated wood species (Rasib 2008; Sheikh *et al*. 2010; Aihetasham and Iqbal 2012). The differences in the methods of exposing the wood and termite species may account for the variation in results. However, wood seasoning may not only prevent termite infestation, it may also improve the wood's dimensional stability. Thus, the present study was conducted to investigate the effects of the reduction in moisture content of *D. sissoo*, *A. nilotica*, and *P. wallichiana* woods on termite feeding and mortality in laboratory and field choice and no-choice tests.

EXPERIMENTAL

Wood blocks of fresh sapwood and heartwood after splicing logs of *D. sissoo*, *A. nilotica*, and *P. wallichiana* were purchased from a local timber market, Jhang Road, Faisalabad, Pakistan, under the guidance of a wood expert in the Department of Forestry, Range Management and Wildlife at the University of Agriculture, Faisalabad.

Collection of Termites

The termite species, *O. obesus*, is naturally abundant in the Entomological Research Laboratories Building at the Postgraduate Agricultural Research Station (PARS), Jhang

Road, Faisalabad, Pakistan. The termites were collected using some corrugated cardboard traps (Ahmed *et al*. 2006). The termite-laden cardboards were brought to the Termite Management Laboratory, Department of Entomology, University of Agriculture, Faisalabad, Pakistan, for colony maintenance and subsequent use in the experiments.

Seasoning of Wood

The woods were seasoned by oven-drying to reduce the moisture content to below 20% of the initial moisture content. The sapwood and heartwood blocks, in three replicates, were oven-dried at 60, 80, and 100 °C for 10 and 15 d. The combination of 60 °C/10 d, 60 °C/10 d, 80 °C /10 d, 80 °C/10 d, 100 °C/10 d, and 100 °C/10 d were denoted as T1, T2, T3, T4, T5, and T6, respectively, while T0 was fresh/unseasoned wood.

Laboratory Tests

Completely Randomized Design (CRD) was followed in laboratory (no choice and choice) experiments to determine the effect of seasoning on weight loss of the different wood species and the termite mortality rate (%).

No choice laboratory test (wood weight loss)

ASTM D 3345-08 (2008) was followed for no choice laboratory test. Wood blocks (25 × 25 × 6 mm) were weighed before and after oven-drying. A control treatment of fresh sapwood and heartwood, without oven-drying, was also included. The wooden blocks were labelled and exposed to the termites for four weeks in a specially designed apparatus. The apparatus consisted of two plastic boxes: one box housed a main/central chamber for introducing termite workers and the second box had four food chambers for placing wood specimens. The main/central chamber was connected to the other four chambers with plastic piping. The four chambers were equally spaced among each other and from the central chamber. The boxes contained moistened soil at the bottom, and a lid was placed at the top of each box. For the no choice test, blocks of only one type of wood dried at the same temperature were tied in a bundle and placed in the food chambers as the only food source for the termites along with a control wood in a separate food chamber. One thousand termite workers and 50 termite soldiers were introduced into the central chamber. After four weeks, the wood blocks were removed from the food chambers and dried at a specified seasoning temperature for 24 h. Infested blocks were cleaned with a brush and electric blower to remove debris, dirt and fecal material and weighed on a digital balance to determine the percent weight loss using the following formula:

$$\text{Weight loss (\%)} = \frac{\text{(Weight before feeding - Weight after feeding)}}{\text{(Weight before feeding)}} \times 100 \quad (1)$$

No choice laboratory test (termites' mortality)

The mortality of the termite workers that were exposed to the seasoned wood pieces was calculated by placing seasoned blocks in 1-L glass jars filled with 500 g of sterilized soil. The test blocks were weighed before and after seasoning, and each treatment was replicated three times, along with a control treatment. Wooden blocks of the same type, dried at similar temperatures, were placed on the soil surface in a glass jar. Three replicates of unseasoned wood were exposed to termites in the separate jars. The jars were kept in the laboratory at 27 ± 2 °C and 85 ± 5% relative humidity and were exposed to the termites for four weeks. Two hundred workers and 20 soldiers were released into each jar. The termites' activity was checked after every 10 days, and the dead termites were counted and removed to calculate the percent mortality after four weeks by applying the formula:

$$\text{Mortality (\%)} = \frac{\text{Number of dead termites}}{\text{Total number of test termites}} \times 100 \qquad (2)$$

Choice laboratory test (wood weight loss and termites' mortality)

Wood blocks (25 × 25 × 6 mm) were weighed before and after seasoning. The dimensions of the specimens were made according to ASTM D 3345-08 (2008). A series of paired choice tests was conducted to determine the termites' preference for various wood species. Wood blocks of *A. nilotica* (sapwood and heartwood), *P. wallichiana* (sapwood and heartwood), *P. wallichiana* (sapwood and heartwood), and *D. sissoo* (sapwood and heartwood), were seasoned and individually tied in a bundle and kept in a food chamber. Using this method, three replicates of each wood species were prepared and placed in food chamber for four weeks, along with unseasoned wood in a separate food chamber. A similar arrangement of wood blocks was also used to determine the mortality rate of the termite workers. The methods used to determine weight loss and mortality rate were the same as those used for the no choice tests.

Field Tests

The arrangement, packing, and bundling of the woods for the choice and no choice tests under field conditions were identical to that of laboratory tests. Wood blocks were exposed to the termite workers in underground/subsoil concrete chambers of 60 × 60 × 75 cm, in which a narrow border was left for the termites to enter but prevented rats and other rodents from gaining access to the wood blocks (Ahmed *et al*. 2014). Each wood type was cut into 13 × 5 × 2 cm and weighed before and after oven-drying. The weight loss was calculated in the same way as the laboratory tests. When the consumed woods were brought back to the laboratory, the wood blocks were dried at a specified seasoning temperature for 24 h and the hygroscopicity (equilibrium moisture content) was evaluated using the AWPA E6-05 (2008) method.

Statistical Analysis

Field experiments were conducted using a randomized complete block design (RCBD) in three replications. The data were analyzed using a multivariate generalized linear model technique, following a factorial ANOVA test, using Statistix version 8.1 (Analytical Software, Tallahassee, FL). The means of significant parameters or interaction between parameters were compared using Tukey's Honestly Significant Difference (HSD) test for paired comparisons, and significance was accepted at $P < 0.05$.

RESULTS

The weight loss of seasoned and unseasoned woods after termite exposure as an effect of wood, wood type, and wood treatment showed significant differences for the no-choice laboratory test (Table 1). The drying of the wood resulted in less weight loss compared to fresh wood. The heartwoods showed less weight loss than sapwoods.

The weight loss in woods treated with high temperatures over a longer duration was significantly less than that at a low temperature and a shorter duration (F= 6.18; df= 4.75, 0.77; $P < 0.001$). Maximum weight loss was recorded in the control treatment (fresh wood) of *P. wallichiana* sapwood (53.85%) after four weeks of termite exposure, while the lowest weight loss was observed in *D. sissoo* heartwood (14.41%) dried at 100 °C for 15 d, which resulted in less weight loss (29.14%) in comparison to woods seasoned at 60 °C for 10 d. The weight loss in *A. nilotica* seasoned at 100 °C for 15 d (17.34%) was in between the above two extremes. The weight loss in the seasoned wood of *P. wallichiana* also showed a reduction (19.37%) in weight loss in comparison to the controls. The weight loss of *A. nilotica* sapwood (38.67%) and *P. wallichiana* sapwood (38.45%) was not significantly different between treatments T1 (60 °C for 10 d) and T2 (60 °C for 15 d), respectively. Similarly, the weight loss of *A. nilotica* heartwood and *P. wallichiana* sapwood (33.00% and 31.93%, respectively) were not significantly different from the *D. sissoo* sapwood (32.36%) for treatments T1, T2, and T4, respectively (Table 2).

The weight loss of the seasoned woods in the choice laboratory bioassay showed interactions among the treatments, woods, and wood types that were significantly different (F= 20.41; df= 5.42, 0.27; $P < 0.01$). The maximum amount of weight loss was recorded in the control treatment (T0) of *P. wallichiana* sapwood (51.51%) after four weeks of termite exposure, while the lowest amount of weight loss was recorded in the *D. sissoo* heartwood (16.27%) treated at 100 °C for 15 d (Table 3). The weight loss (30.67%) of *A. nilotica* sapwood in T3 (80 °C for 10 d) was not significantly different from the weight loss (30.41%) in the heartwood of *P. wallichiana* in T3. The weight loss (34.43%) in sapwood of *A. nilotica* in T2 (60 °C for 15 d) was not significantly different from the weight loss (34.29%) in *D. sissoo* sapwood in T1 (60 °C for 10 d). The seasoned *A. nilotica* wood showed a significant reduction in weight (20.33%) at 100 °C for 15 d as compared to the weight loss (47.01%) in T0. The *P. wallichiana* wood also showed a reduction in weight (21.60%) after seasoning (Table 3).

Table 1. ANOVA for Weight Loss (%) of Seasoned Woods Exposed to Termites in No-Choice Laboratory Tests

SOV	Df	F value	
		No choice	Choice
Replications	2		
Treatment	6	1987.26**	4488.57**
Wood	2	874.43**	2542.35**
Wood type	1	792.56**	1767.94**
Treatment*wood	12	34.92**	16.72**
Treatment*wood type	6	6.97**	3.79**
Wood*wood type	2	17.47**	44.18**
Treatment*Wood*wood type	12	6.18**	20.41**
Error	82		
Total	125		
NS = Non-significant ($P > 0.05$); * = Significant ($P < 0.05$); ** = Highly significant ($P < 0.01$)			

Table 2. Comparisons of Weight Loss (%) of Seasoned Woods Exposed to Termites in No-Choice Laboratory Tests

Treatments (°C/d)	Wood (Wood type)					
	A. nilotica (Sapwood)	*A. nilotica* (Heartwood)	*P. wallichiana* (Sapwood)	*P. wallichiana* (Heartwood)	*D. sissoo* (Sapwood)	*D. sissoo* (Heartwood)
	Weight loss (%)					
T0(Control)	48.43±0.10C	43.37±0.16E	53.85± 0.38A	51.61±0.20B	46.89±0.01D	41.68±0.17F
T1 (60/10)	38.67±0.43G	35.51±0.74HI	43.71± 0.23E	41.25± 0.34F	32.36±0.35J	29.14±0.32KL
T2 (60/15)	36.34±0.71H	33.00±1.00J	38.45± 0.25G	35.40± 0.70HI	30.39±0.11K	25.88±0.51OP
T3 (80/10)	34.50±1.19I	29.37±0.26KL	35.33±0.71HI	27.83± 0.75MN	28.60±0.08LM	22.03±0.55ST
T4 (80/15)	30.25±0.27K	27.03±0.77NO	31.93± 0.38J	27.80±0.47MN	26.60±0.18NO	20.89±0.38TU
T5 (100/10)	26.45± 0.67NO	24.62±0.15PQ	29.57±0.07KL	24.36±0.04QR	23.19±1.53RS	19.54±0.12U-W
T6 (100/15)	20.35±0.19UV	17.34±0.14X	22.65 ± 0.05S	19.37±0.12VW	18.29±0.15WX	14.41±0.09Y

ºC/d, ºcentigrade/days; The combination of 60 °C/10 d, 60 °C/10 d, 80 °C /10 d, 80 °C/10 d, 100 °C/10 d, and 100 °C/10 d were T1, T2, T3, T4, T5, and T6. T0 was fresh wood. Values are represented as Mean ± Standard Error (SE). Means sharing the same letter in a row or column are statistically non-significant (P > 0.05).

Table 3. Comparisons of Weight Loss (%) of Seasoned Woods Exposed to Termites in Choice Laboratory Tests

Treatment (°C/d)	Wood (Wood type)					
	A. nilitica		*P. wallichiana*		*D. sissoo*	
	Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
	Weight loss (%)					
T0 (Control)	47.01±0.11C	42.25±0.38E	51.51±0.70A	48.52±0.62B	44.66±0.23D	39.91±0.19F
T1 (60/10)	38.92±0.43G	36.38±0.30I	40.43±0.24F	37.55±0.25H	34.29±0.46K	30.14±0.88O-Q
T2 (60/15)	34.43±0.04K	32.37±0.15M	37.44±0.07H	33.36±0.19L	29.71±0.14P-R	26.09±0.26U
T3 (80/10)	30.67±0.30NO	29.68±0.15P-R	35.38±0.17J	30.41±0.27OP	27.79±0.14T	21.74±0.25X
T4 (80/15)	29.68±0.13P-R	26.28±0.09U	33.42±0.10L	28.81±0.57S	24.49±0.15V	20.67±0.18Y
T5 (100/10)	27.59±0.14T	24.41±0.16V	31.34±0.14N	23.48±0.14W	19.51±0.06Z	18.10±0.11a
T6 (100/15)	23.98±0.30VW	20.33±0.06YZ	29.14±0.05RS	21.60±0.19X	18.38±0.26a	16.27±0.19b

ºC/d, ºcentigrade/days; The combination of 60 °C/10 d, 60 °C/10 d, 80 °C /10 d, 80 °C/10 d, 100 °C/10 d, and 100 °C/10 d were T1, T2, T3, T4, T5, and T6. T0 was fresh wood. Values are Means ± Standard Error (SE). Means sharing the same letter in a row or column are statistically non-significant (P > 0.05).

Termites' Mortality in Seasoned Wood

The ANOVA of termites' mortality revealed that the interaction among seasoning, woods, and wood types was significantly different (df= 0.98, 0.25; P < 0.01; Table 4). These results exhibited a similar trend as can be observed in the percent weight loss data. The termites' mortality increased with rise in drying temperature. The minimum mortality was recorded in the control treatment (T0) of *P. wallichiana* sapwood (8.36%) after four weeks; the highest mortality rate (42.59%) was recorded in *D. sissoo* heartwood seasoned at 100 °C for 15 d, which increased from 17.28% in T1 (60 °C for 10 d) (Table 5).

Table 4. ANOVA for Termite Mortality (%) when Exposed to Seasoned Woods in No-Choice and Choice Laboratory Test

SOV	No choice		Choice	
	Df	F	df	F
Replications	2		2	
Treatment	6	3958.92**	6	5971.85**
Wood	2	1655.46**	2	3991.08**
Wood type	1	1508.64**		
Treatment*wood	12	94.49**	12	168.99**
Treatment*wood type	6	27.74**		
Wood*wood type	2	6.96**		
Treatment*wood*wood type	12	3.87**		
Error	82		40	
Total	125		62	
NS = Non-significant (P > 0.05); * = Significant (P < 0.05); ** = Highly significant (P < 0.001)				

Table 5. Comparisons of Termites' Mortality (%) of Seasoned Woods in No-Choice Laboratory Test

Treatments (°C/d)	Wood (wood type)					
	A. nilotica (Sapwood)	*A. nilotica* (Heartwood)	*P. wallichiana* (Sapwood)	*P. wallichiana* (Heartwood)	*D. sissoo* (Sapwood)	*D. sissoo* (Heartwood)
	Termites' Mortality (%)					
T0 (Control)	7.34±0.19X	9.56±0.18V	8.36±0.16W	10.93±0.06U	12.30±0.05T	13.46±0.16S
T1 (60/10)	12.41±0.14T	15.5±0.009P	8.44±0.57W	11.95±0.009T	13.65±0.18RS	17.28±0.21NO
T2 (60/15)	14.51±0.05Q	18.44±0.20LM	10.19±0.009UV	12.35±0.03T	15.45±0.28P	18.53±0.36L
T3 (80/10)	16.71±0.06O	20.47±0.34JK	12.43±0.23T	14.35±0.09QR	17.69±0.22MN	20.90±0.01J
T4 (80/15)	17.81±0.34L-N	23.11±0.69HI	16.67±0.24O	19.91±0.003K	20.80±0.34J	23.66±0.27GH
T5 (100/10)	21.12±0.65J	24.17±0.32G	19.95±0.009K	22.44±0.006I	26.42±0.04F	30.28±0.21D
T6 (100/15)	28.85±0.06E	34.54±0.04C	23.41±0.01GH	28.87±1.01E	35.68±0.05B	42.59±0.06A

ºC/d, ºcentigrade/days; The combination of 60 °C/10 d, 60 °C/10 d, 80 °C /10 d, 80 °C/10 d, 100 °C/10 d, and 100 °C/10 d were T1, T2, T3, T4, T5, and T6. T0 was fresh wood. Values are Means ± Standard Error (SE). Means sharing the same letter in a row or column are statistically non-significant (P > 0.05).

The *A. nilotica* heartwood showed a significantly (p>0.05) higher mortality rate (34.54%) than *P. wallichiana* heartwood (28.87%) seasoned at 100 °C for 15 d, which was not significantly different (p<0.05) from *A. nilotica* sapwood. The heartwood from each wood species exhibited a higher termite mortality rate than sapwood (Table 5). Results from the choice laboratory bioassay showed that the termite mortality rate for the interactions between seasoning, woods, and wood types was also significantly different (df= 6.566, 0.021; $P < 0.01$). The minimum mortality rate was recorded in the T0 (control) of *P. wallichiana* (5.21%) wood. However, the mortality rate significantly increased (27.84%) in T6. The highest mortality rate was recorded in the seasoned *D. sissoo* (39.14%) wood at 100 °C for 15 d (Table 6.).

Table 6. Comparisons of Termites' Mortality (%) of Seasoned Woods in Choice Laboratory Test

Treatments (°C/d)	Wood (wood type)		
	A. nilitica (Sapwood)/(Heartwood)	*P. wallichiana* (Sapwood)/(Heartwood)	*D. sissoo* (Sapwood)/(Heartwood)
	Termites' Mortality (%)		
T0(Control)	7.83±0.07Q	5.21±0.06R	10.58±0.09P
T1 (60/10)	13.48±0.02N	10.64±0.06P	15.75±0.009I
T2 (60/15)	16.39±0.03L	12.05±0.03O	19.31±0.009J
T3 (80/10)	20.81±0.35I	15.48±0.28M	23.94±0.09G
T4 (80/15)	26.47±0.03H	19.53±0.06J	28.46± 0.09F
T5 (100/10)	27.06±0.29E	24.58±0.08GH	33.75±0.04B
T6 (100/15)	31.70±0.03C	27.84±0.04D	39.14±0.23A

ºC/d, ºcentigrade/days; The combination of 60 °C/10 d, 60 °C/10 d, 80 °C /10 d, 80 °C/10 d, 100 °C/10 d, and 100 °C/10 d were T1, T2, T3, T4, T5, and T6. T0 was fresh wood. Values are Means ± Standard Error (SE). Means sharing the same letter in a row or column are statistically non-significant ($P > 0.05$).

Weight Loss in Seasoned Wood after Exposure to Termites in the Field Tests

The data obtained after the exposure of seasoned wood to a field no-choice test showed that interactions among seasoning, woods, and wood types were significant (df= 1.26, 0.20; $P < 0.001$; Table 7). The control treatment (T0) of *P. wallichiana* sapwood showed the highest amount of weight loss (53.50%) after four weeks of termite exposure, while the lowest amount of weight loss (20.61%) was recorded in *D. sissoo* heartwood in T6 (100 °C for 15 d), when compared to weight loss (35.58%) in wood treated at 60 °C for 10 d. The weights of *A. nilotica* and *P. wallichiana* woods in T6 were reduced as well (Table 8). The percent weight loss of woods in the choice field tests decreased as the drying temperature and drying time was increased. The maximum amount of weight loss was recorded in the control treatment (T0) of *P. wallichiana* sapwood (51.66%), after four weeks of termite exposure, while the lowest amount of weight loss was observed in *D. sissoo* heartwood (19.43%) at 100 °C for 15 d, which declined to 33.61% at 60 °C for 10 d. The *A. nilotica* wood showed an increase in resistance to termite attack after drying, and showed a reduction in weight (20.51%) after seasoning at 100 °C for 15 d. A significant reduction of weight in the *P. wallichiana* and *A. nilotica* woods was observed at the highest temperatures and over the longest durations of seasoning, when compared with the control treatment (Table 9).

Table 7. ANOVA for Weight Loss (%) of Seasoned Woods Exposed to Termites in No-Choice Field Tests

SOV	Df	F value	
		No choice	Choice
Replications	2		
Wood type	1	1986.20**	1247.31**
Treatment	6	5656.01**	1570.44**
Wood	2	1492.54**	4814.71**
Wood type* Treatment	6	23.42**	2.04**
Wood type*Wood	2	5.80**	10.19**
Treatment *Wood	12	15.08**	25.95**
Wood type* Treatment *Wood	12	6.21**	4.73**
Error	82		
Total	125		

NS = Non-significant ($P > 0.05$); * = Significant ($P < 0.05$); ** = Highly significant ($P < 0.01$)

Table 8. Comparisons of Weight Loss (%) of Seasoned Woods Exposed to Termites in the No-Choice Field Tests

Treatment (°C/d)	Wood (wood type)					
	A. nilotica (Sapwood)	*A. nilotica* (Heartwood)	*P. wallichiana* (Sapwood)	*P. wallichiana* (Heartwood)	*D. sissoo* (Sapwood)	*D. sissoo* (Heartwood)
	Weight Loss (%)					
T0 (Control)	50.62±0.30B	45.69±0.34D	53.50±0.13A	47.40±0.33C	46.71±0.04C	40.43±0.33FG
T1 (60/10)	39.70±0.01G	37.71±0.02I	44.37±0.12E	41.09±0.35F	39.70±0.17G	35.58±0.15J
T2 (60/15)	35.42±0.01J	33.26±0.11KL	38.72±0.13H	35.55±0.07J	33.78±0.87K	30.72±0.11MN
T3 (80/10)	32.84±0.34L	30.15±0.01NO	35.99±0.47J	32.72±0.61L	30.59±0.26N	27.51±0.27QR
T4 (80/15)	31.45±0.11M	28.16±0.02PQ	33.41±0.28KL	29.71±0.13O	28.54±0.08P	25.62±0.02TU
T5 (100/10)	29.84±0.03O	26.22±0.34ST	31.32±0.26M	26.59±0.32S	25.40±0.12U	22.07±0.01V
T6 (100/15)	26.90±0.13RS	22.24±0.12V	28.57±0.27P	25.13±0.13U	21.83±0.06V	20.61±0.18W

ºC/d, ºcentigrade/days; The combination of 60 °C/10 d, 60 °C/10 d, 80 °C /10 d, 80 °C/10 d, 100 °C/10 d, and 100 °C/10 d were T1, T2, T3, T4, T5, and T6. T0 was fresh wood. Values are Means ± Standard Error (SE). Means sharing the same letter in a row or column are statistically non-significant ($P > 0.05$).

Table 9. Comparisons of Weight Loss (%) of Seasoned Woods Exposed to Termites in Choice Field Tests

Treatment (°C/d)	Wood (wood type)					
	A. nilitica		*P. wallichiana*		*D. sissoo*	
	Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
	Weight Loss (%)					
T0 (Control)	49.47±0.27B	42.48±0.12E	51.66±0.15A	47.42±0.15C	44.77±0.29D	39.38±0.26F
T1 (60/10)	37.86±0.74G	35.22±0.10I	42.84±0.30E	39.48±0.15F	38.45±0.13G	33.61±0.21J
T2 (60/15)	33.45±0.06J	30.85±0.69LM	36.89±0.34H	33.95±0.78J	32.44±0.09K	28.38±0.21O
T3 (80/10)	31.42±0.27L	27.54±0.15P	35.30±0.13I	30.09±0.36MN	29.69±0.18N	25.45±0.14R
T4 (80/15)	29.49±0.15N	25.42±0.17R	31.59±0.10L	28.21±0.41OP	26.64±0.09Q	23.49±0.22S
T5 (100/10)	25.07±0.32R	23.39±0.23S	28.41±0.20O	26.58±0.25Q	23.31±0.06S	20.54±0.26V
T6 (100/15)	22.43±0.08T	20.51±0.25V	26.41±0.16Q	23.53±0.25S	21.45±0.06U	19.43±0.22W

ºC/d, ºcentigrade/days; The combination of 60 °C/10 d, 60 °C/10 d, 80 °C /10 d, 80 °C/10 d, 100 °C/10 d, and 100 °C/10 d were T1, T2, T3, T4, T5, and T6. T0 was fresh wood. Values are Means ± SE Means sharing the same letter in a row or column are statistically non-significant ($P > 0.05$).

DISCUSSION

Results of the present studies clearly showed that seasoning (heat treatment) of the woods improved the resistance in them against termite species. One effect of this practice is to reduce the moisture content of wood. *O. obesus* preferred the woods with higher moisture content (Ijaz and Aslam 2002; Varmaa and Swarana 2007). Agarwal (1980) linked the termite activity with moisture contents of woods and drying temperature. There was a positive relationship between the termites' feeding and moisture contents of wood. The preference for high moisture content woods by termites may be due to the more moist wood fiber being softer, making it easier to masticate (Delaplane and La Fage 1989). Termites preferred the highest initial moisture content wood blocks and continued to feed on them (Gautam 2011). A reduction in the moisture content makes it hard for the termites to feed upon, which was evident from less weight loss in the seasoned woods. Nakayama *et al*. (2005) reported that medium moisture content (79 to 103%) wood was preferred over high moisture content (133 to 191%) wood by *Coptotermes formosanus*.

The effectiveness of seasoning to reduce termite-induced weight loss as compared to control values and from other wood types was manifested in *P. wallichiana*, which recorded the lowest resistance towards termite's infestation in the present studies**.** Many reports agree with the present results with respect to prevention of weight loss in the seasoned woods (Matsumura *et al*. 1999; Boonstra and Tjeerdsma 2006; Esteves and Helena 2009; Upadhyay *et al*. 2010). However, more weight loss by *O. obesus* in the seasoned woods has also been recorded, and authors of these studies have concluded that *O. obesus* might have preferred dry woods (Sheikh *et al*. 2010). In this case the range of drying temperature and termites' exposure time were 50 to 100 °C and 24 to 48 h, respectively, on four different woods; *Fagus* sp., *Pinus wallichiana*, *Abies pindrow*, and *Cedrus deodara*. The dissimilarity with the present results results may be attributed to the time during which the woods were left for drying. Woods treated at high temperature (135 or 150 ºC) showed larger weight loss percentages than those treated at lower temperatures, which can be due to reduction in wood durability after drying at high temperature ranges (Momohara *et al*. 2003, Manzoor *et al*. 2009; Aihetasham and Iqbal 2012). Yet, the present study results are supported by Ahmed *et al*. (2013, 2014) who reported that lowest weight losses of sapwood and heartwoods of *Acacia nilotica* and *Ficus relogiosa* were observed in treatments with maximum period of seasoning (oven drying) at 100 ºC for 15 days.

Mortality was also reported when termites' workers were allowed to feed upon the seasoned woods. In no-choice laboratory tests, the lowest weight loss was observed in *D. sissoo* heartwood seasoned at 100 ºC for 15 days, and the termites' mortality was highest (42.59%) in the same treatment. Similar trends were seen in laboratory choice test. Findings of different researchers are in conformity with the present results for termites' mortality. For instance, *R. flavipes* workers and soldiers exposed to experimental drying at 34 to 35 °C had an average survival time of 3.0 to 6.2 h (Collins 1969); *R. flavipes* workers lived only 5.1 h when exposed to 30 °C (Sponsler and Appel 1990). These reports concluded that drying caused cuticular water loss to kill termites in a short period of time. Our results suggest that cuticular water loss may not be the only mechanism for water loss in subterranean termites. In the present experiments, termites under ideal temperature and RH conditions exposed to wood with low moisture content (MC) were not able to survive, which demonstrated that wood MC was a major factor in determining termite survival. It has been suggested that termites may continue to feed indefinitely on wood with 13 to 15% MC (Forschler 1999). Wood with MC ≤24% was not adequate to sustain a subterranean termite infestation with no soil contact, probably because water obtained from the wood by termite feeding did not compensate for water loss. At least 30% wood moisture was necessary for termites' survival for more than six months. Although ambient temperature is an important factor in survival of subterranean termites, long-term aerial infestations can only be maintained at ≥30% MC of the wood (McManamy *et al*. 2008). The other factors that can account for these mortalities are the chemical constituents and hardness of the seasoned woods. The termites' workers may find seasoned woods difficult to scrape, which is one of their feeding habits. The changed physical properties may provide another rationale for termites' mortality (Boonstra and Tjeerdsma 2006; Esteves and Helena 2009; Manzoor *et al*. 2010).

In addition to reduction in moisture content of wood, heat treatment causes its surface to become inactivated, which results in poor bond quality (Unsal *et al*. 2009). Chemical processes occur in layers near the surface that result in a modified surface with new characteristics. *O. obesus* usually scrapes surface layers profusely and consumes whole tissue or penetrates deep inside in case of severe infestation. A renewed wood surface after seasoning at various temperatures for different time periods may affect *O. obesus* feeding and survival.

Wood specimens, their types and drying regimes were significantly different among themselves. This interaction has shown that best treatment was found in heartwood at high temperature for the longest drying time. High temperature with extended drying time improved resistance of the most preferred wood, which indicates effectiveness of heat treatment to enhance service life of the woods. *P. wallichiana* is usually recorded as susceptible wood for the termite species (Manzoor *et al*. 2010). Weight loss (%) of seasoned (100 °C for 15 days) *P. wallichiana* sapwood in a no-choice field test was non-significantly different from that of *D. sissoo* sapwood heat treated at 80 °C for 15 days.

The method of exposure of woods to termites had no significant effect on weight loss in choice and no choice tests where in both cases low weight loss was observed when seasoned woods were used. The similar results were observed where wood specimens that had been oven dried for twenty four hours were evaluated in choice and no-choice tests against *Heterotermes indicola* (Wasmann) and *Coptotermes heimi* (Wasmann) (Malik *et al*. 2012). Thus, temperature and duration in particular set of conditions affect preference of woods towards termites' feeding and should be studied on the basis of standardized methods.

CONCLUSION

1. The impact of drying temperature showed that the amount of wood consumed in general decreased with an increase in the drying temperature, indicating that heat contributed to the improvement of resistance to termites.
2. Among all the treatment temperatures, wood dried at 100 °C for 15 days showed a minimal amount of weight loss and the maximal rate of termite mortality, when compared to the control (unseasoned) wood in both field and laboratory (no choice and choice) tests.
3. When *O. obesus* was given a choice of woods that were offered in combination, the termite species repeatedly preferred and maximally fed on *P. wallichiana*, and minimally consumed the *D. sissoo*.

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REFERENCES CITED

Agarwal, V. B. (1980). "Temperature and relative humidity inside the mound of *Odontotermes obesus* (Rambur) (Isoptera: Termitidae)," *Proc. Indian Acad. Sci.* 89(2), 91-99. DOI: 10.1007/BF03179148.

Ahmed, S., Mustafa, T., Riaz, M. A., and Hussain, A. (2006). "Efficacy of insecticides against subterranean termites in sugarcane," *Int. J. Agri. Biol*. 8, 508-510.

Ahmed, S., Nisar, M. S., Naseer, B., Hassan, B., and Shakir, M. M. (2013). "Determination of wood protection by seasoning and clove oil application against *Odontotermes obesus* Ramb. (Termitidae: Isoptera)," *Pak. Entomol.* 35(2), 83-87. DOI: 10.4172/scientificreports.696

Ahmed, S., Fatima, R., Nisar, M. S., and Hassan, B. (2014). "Evaluation of castor bean oil on *Acacia nilotica* as wood preservative against *Odontotermes obesus* (Ramb.)

(Termitidae: Isoptera),” *Int. Wood Prod. J.* 5(1), 5-10. DOI: 10.1179/2042645313Y.0000000053

Aihetasham, A., and Iqbal, S. (2012). “Feeding preferences of *Microcerotermes championi* (Snyder) for different wooden blocks dried at different temperatures under forced and choice feeding conditions in laboratory and field,” *Pak. J. Zool.* 44(4), 1137-1144.

Akhtar, M. S., and Ali, S. S., (1979). “Wood preferences and survival of *Coptotermes heimi* (Wasmann) and *Odontotermes obesus* (Rambur) (Isoptera),” *Pak. J. Zool.* 11(2), 303-314.

AWPA E6-05. (2008). “Standard method for determining the equilibrium moisture content of treated wood,” American Wood Protection Association, Birmingham, AL.

ASTM D 3345-08. (2008). “Standard test method for laboratory evaluation of wood and other cellulosic materials for resistance to termites,” ASTM International, West Conshohocken, PA.

Boonstra, M. J., and Tjeerdsma, B. K. (2006). “Chemical analysis of heat treated softwoods,” *Holz als Roh-und Werkstoff* 64(3), 204-211. DOI: 10.1007/s00107-005-0078-4

Collins, M. S. (1969). “Water relations in termites,” in: *Biology of Termites*, Krishna, K., and Weesner, F. M. (eds.), Academic Press, New York, NY, pp. 433-435.

Delaplane, K. S., and La Fage, J. P. (1989). “Preference for moist wood by the Formosan subterranean termite (Isoptera: Rhinotermitidae),” *J. Econ. Entomol.* 82(1), 95-100. DOI: 10.1093/jee/82.1.95 95-100.

Esteves, B. M., and Helena, M. P. (2009). “Heat treatment of wood: A review,” *BioResources* 4(1), 370-404. DOI: 10.15376/biores.4.1.370-404

Forschler, B. T. (1999). “Subterranean termite biology in relation to prevention and removal of structural infestations,” National Pest Control Association research report on subterranean termites, Dunn Loring, VA: National Pest Control Association Publications, pp. 31-50.

FTA. (2003). "Thermowood Handbook," Finnish Thermowood Association 1-1, http://www.thermowood.fi/english/index.html.

Gautam, B. K. (2011). “Role of substrate moisture, relative humidity and temperature on survival and foraging behavior of Formosan Subterranean termites,” PhD dissertation, Louisiana State University and Agricultural and Mechanical College, Baton Rouge, LA, USA.

Goncalves, F. G., and Oliveira, J. D. S. (2006). “Resistencia ao ataque de cupim-de-madeira seca (*Cryptotermes brevis*) em seis especies florestais,” *Revista Cerne. Lavras, MG.* 12(1), 80-83.

Hisada, T. (2001). “Present state of the wood drying in Japan and problems to be solved,” in: *Proceedings from the 7th International IUFRO Wood Drying Conference*, pp. 14-17.

Istek, A., Sivrikaya, H., Eroglu, H., and Gulsoy, S. K. (2005). “Biodegradation of *Abies bornmülleriana* (mattf.) and *Fagus orientalis* by the white rot fungus *Phanerochaete chrysosporium*,” *Int. Biodeter. Biodegr.* 55(1), 63-67. DOI: 10.1016/j.ibiod.2004.07.002

Ijaz, M., and Aslam, M. (2002). “Infestation trend of *Odontotermes obesus* (Rambur) on wheat crop (*Triticum aestivum* Linnaeus) in rain fed conditions,” *Asian J. Plant Sci.* 2(9), 699-701. DOI: 10.3923/ajps.2003.699.701

McManamy, K., Koehler, P. G., Branscome, D. D., and Pereira, R. M. (2008). "Wood moisture content affects the survival of eastern subterranean termites (Isoptera: Rhinotermitidae), under saturated relative humidity conditions," *Sociobiol*.52(1), 145-156.

Malik, S. A., Manzoor, F., and Shiday, B. M. A. (2012). "Laboratory and field evaluation on natural resistance and feeding preference of different wood species to subterranean termites (*Isoptera: Rhinotermitidae*, *Termitidae*) in Pakistan," in: IRG/WP 12-10769, *Proceedings from the International Research Group on Wood Protection (IRG, Stockholm) Annual Meeting* 2012, Kuala Lumpur, Malaysia.

Manzoor, F., Zameer, K., and Malik, S. A. (2009). "Comparative studies on two Pakistani subterranean termites (Isoptera: Rhinotermitidae, Termitidae) for natural resistance and feeding preferences in laboratory and field trials," *Sociobiol.* 53(1), 259-274.

Manzoor, F., Sheikh, N., and Zawar, A. (2010). "Laboratory and field evaluation for the resistance of commonly used woods against *Coptotermes heimi* (Wasmann)," *Nature Precedings* hdl:10101/npre.2010.4485.1 (pre-print).

Matsumura, J., Booker, R. E., Ridoutt, B. G., Donaldson, L. A., Mikajiri, N., Matsunaga, H., and Oda, K. (1999). "Impregnation of radiate pine wood by vacuum treatment II: Effect of pre-steaming on wood structure and resin content," *J. Wood Sci.* 45(6), 456-462. DOI: 10.1007/BF00538953

Mburu, F., Dumarcay, S., Huber, F., Petrissans, M., and Gerardin, P. (2007). "Evaluation of thermally modified *Grevillea robusta* heartwood as an alternative to shortage of wood resource in Kenya: Characterization of physicochemical properties and improvement of bio-resistance," *Bioresour. Technol*. 98(18), 3478-3486. DOI: 10.1016/j.biortech.2006.11.006

Militz, H. (2002). "Thermal treatment of wood: European processes and their background," in: IRG/WP 02-40241, *Proceedings from International research group on wood preservation (IRG, Stockholm) annual meeting 2002*, Cardiff-Wales, UK. 17pp.

Momohara, I., Ohmura, W., Kato, H., and Kubojima, Y. (2003). "Effect of high-temperature treatment on wood durability against the brown-rot fungus, *Fomitopsis palustris*, and the termite, *Coptotermes formosanus*," in: *Proceedings from the 8th International IUFRO Wood Drying Conference*, pp. 284-287.

Nakayama, T., Yoshimura, T., and Imamura, Y. (2005). "Feeding activities of *Coptotermes formosanus* Shiraki and *Reticulitermes speratus* (Kolbe) as affected by moisture content of wood," *J. Wood Sci.* 51(1), 60-65. DOI: 10.1007/s10086-003-0612-0

Nouman, W., Khan, G., Farooq, H., and Jamal, N. (2006). "An investigation to find out the reasons for adoption of agroforestry by farmers in district Faisalabad," *J. Anim. Plant Sci.* 16(3-4), 93-95.

Qureshi, N. A., Qureshi, M. Z., Ali, N., Athar, M., and Ullah, A. (2012). "Protozoidal activities of *Eucalyptus camaldulensis*, *Dalbergia sissoo* and *Acacia arabica* woods and their different parts on the entozoic flagellates of *Heterotermes indicola* and *Coptotermes* heimi," *Afr. J. Biotechnol.* 11(57), 12094-12102. DOI: 10.5897/ AJB 12.375

Rapp, A. O., and Sailer, M. (2000). "Heat treatment in Germany," in: *Proceedings of the Seminar, Production and Development of Heat Treated Wood in Europe*, Helsinki, Stockholm, Oslo.

Rasib, K. Z. (2008). "Feeding preferences of *Microcerotermes championi* (Snyder) on different timbers dried at different temperatures under choice and no choice trials," *Nature Precedings* hdl:10101/npre.2008.2048.1 (pre-print)
Roonwal, M. L. (1978). "Vegetational distribution of termites of Rajasthan (India) and their economic importance," *Proc. Indian Nat. Sci. Acad*. 44(5), 320-329.
Sheikh, N., Qureshi, A. M., Latif, M. U., and Manzoor, F. (2010). "Study of temperature treated woods for the preference and first food choice by *Odontotermes obesus* (Isoptera: Termitidae)," *Sociobiol*. 56(2), 363-373.
Sponsler, R. C., and Appel, A. G. (1990). "Aspects of the water relations of the Formosan and eastern subterranean termites (Isoptera: Rhinotermitidae)," *Environm. Entomol*, 19(1), 15-20. DOI: 10.1093/ee/19.1.15
Tjeerdsma, B., Boonstra, M., and Militz, H. (1998). "Thermal modification of non-durable wood species 2. Improved wood properties of thermally treated wood," in: IRG/WP 98-40124, *Proceeding from International research group on wood preservation (IRG, Stockholm) annual meeting 1998*, Maastricht, Netherlands.
Unsal, O., Kartal, S. N., Candan, Z., Arango, R. A., Clausen, C. A., and Iii, F. G. (2009). "Decay and termite resistance, water absorption and swelling of thermally compressed wood panels," *Int. Biodeter. Biodegrad*, 63(5), 548-552. DOI: 10.1016/j.ibiod.2009.02.001
Upadhyay, R. K., Jaiswal, G., and Ahmad, S. (2010). "Biochemical and enzymatic alterations after application of fipronil, thiamethoxam and malathion to *Odontotermes obesus* (Isoptera: Termitidae)," *Acta Univ. Sapientiae Agri. Environ*. 2(1), 58-79.
Varmaa, R. V., and Swarana, P. R. (2007). "Diversity of termites in a young eucalyptus plantation in the tropical forests of Kerala, India," *Int. J. Trop. Insect Sci.* 27(2), 95-101. DOI: 10.1017/S1742758407788458.

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