Drewno 2015, Vol. 58, No. 195
DOI: 10.12841/wood.1644-3985.113.05

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THE SUSCEPTIBILITY OF NEOLITHIC WATERLOGGED BEECH WOOD (*FAGUS SYLVATICA* L.) TO DESTRUCTION BY *RETICULITERMES LUCIFUGUS* ROSSI

The article presents the results of a test on the resistance of Neolithic waterlogged beech wood (Fagus sylvatica L.) to destruction by subterranean Reticulitermes lucifugus Rossi. Methodology consistent with the ASTM D 3345-08 Standard was applied in the experiment. In the coercion test, the modern beech wood was destroyed at an intermediate stage between light attack and moderate attack with penetration, whereas the pine sapwood was heavily damaged. Under the same conditions, the waterlogged beech wood was seriously damaged or completely destroyed by the termites. However, unlike the modern pine and beech wood, all the termites died after feeding on the waterlogged beech wood. In spite of the complete destruction of the waterlogged beech wood in the coercion test, it seems that under natural conditions where there is a possible choice between different wood species, the infestation by termites of waterlogged wood uncovered in archaeological work does not necessarily happen. Wood containing few nutritional substances and substantial lignin, as well as having a high moisture content facilitating the development of parasitic microorganisms, will deter termites.

Keywords: beech, biodegradation, environmental changes, termites, waterlogged wood

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Introduction

The natural resistance of different wood species to destruction by termites has long been of interest. There are some species from Africa, Asia and South America, whose heartwood is relatively resistant to termite feeding [Unger 1978]. The impact of various chemical substances contained in the heartwood of those species on termites was examined a relatively long time ago [Becker et Petrowitz 1971, Becker et al. 1972]. In the last few years, the natural resistance of various wood species used economically in Africa [Ncube et al. 2012], India [Rashmi, Sundararaj 2013], South America [Gonçalves Peralt et al. 2004] and the USA (wood from Alaska) has been tested [Grace, Yamamoto 1994]. In addition, the natural resistance of different wood species and alternative forestry in Hawaii [Grace et al. 1996], as well as of some American wood species used in plate production [Kard et al. 2007], was the subject of research. The natural resistance to termite attack of different European species has also been of high interest [Schultze-Dewitz G. 1958]. It is assumed, however, that all European wood species of economic significance require chemical protection against termites [Unger 1978].

Among the factors influencing termite feeding in Europe, more attention has been paid to wood carbonization [Becker 1974, Peterson et al. 2008, Duarte et al. 2012] and fungal decomposition [Becker 1965, 1974, Schultze-Dewitz et Unger 1972, Unger 1973].

The objective of the present study was to determine the susceptibility of Neolithic waterlogged beech wood to destruction by termites. The first step of the experiment was an obligatory test. The damage to waterlogged wood by termites could be a problem in the near future. For many years, there have been reports concerning the occurrence of termites in cities outside the continuous range of those insects in southern and south-western Europe [Weidner 1954, Becker 1970, Becker, Kny 1977, Sellenschlo 1988]. In recent decades, world-wide trade has increased heavily, enhancing the possibility of the spread of various insect species, including termites. If it is true that the earth is to face global warming of 1.1-6.4 degrees Celsius during the 21st century, it raises the question whether insular populations of termites will spread to north-eastern parts of the continent. Wood uncovered at archaeological sites has not so far been exposed to significant destruction by native insects, even if it has remained at the site for a long time. Due to climate change and the expanding range of maritime borers, the Baltic Sea States Heritage programme was implemented. With the possibility of the wider dispersal of termites, will the wood uncovered at archaeological sites be at risk from those insects? The experiments performed in this research are an attempt to answer this question.

Materials and methods

The material used for the research was a very limited amount of Neolithic beech wood (dated around 3000 B.C.) taken from Zedmar culture during archaeological work conducted by the Institute of Archaeology at the University of Warsaw, at Szczepanki, Site 8, in the summer of 2007. The wood was located 65–67 metres below the surface, in black and brown peat of high humidity and with low access to oxygen. It was delivered to the laboratory several months after excavation and was kept under conditions preventing overdrying. Until the experiment took place in summer 2012, the wood was kept in the laboratory, frozen in a polybag.

Biological tests were executed according to the ASTM D 3345-08 Standard [2009]. The frozen wood was cut into samples measuring 25.4 × 25.4 × 6.4 mm. One group of samples was dried to a moisture content of approx. 8% (freeze drying was applied), while the other was left "wet", i.e. with a moisture content of approx. 500%.

5 samples of each group were used. Another group of 5 samples was taken from modern beech wood taken from 3 trees. The fourth group consisted of 5 samples of pine sapwood taken from 3 *Pinus sylvestris* L. trees.

Each sample, accordingly to ASTM D 3345–08 [2009], was placed separately on the bottom of a glass container with a volume of 450 ml and covered with 200 grams of white sand. The sand was screened, washed and heatsterilized. The saturation point of the sand, determined empirically, was reduced by 7%. The amount of distilled water, calculated in this way, was used to moisten the sand in the testing containers. The only deviation from the norm was the lack of benzalkonium chloride solution as an antiseptic.

In each of the above-described containers, 1 +/– 0.05 g of *Reticulitermes lucifugus* Rossi (Rhinotermitidae, Isoptera) termites were placed. *Reticuliteremes* is an ecologically and economically important genera of termites [Vargo, Hussender 2009]. According to Dominik and Starzyk [2004], the most widespread termite species in Europe is *R. lucifugus*. Pseudergates constituted approx. 90% of all the termites in each container. The containers with the termites and wood samples were kept for ca. 4 weeks in incubators, at a temperature of 27 degrees Celsius. The water was replenished weekly.

After four weeks, the approximate termite mortality was determined, according to ASTM D 3345-08 [2009], as follows: slight: 0–33%; moderate: 34–66%; heavy: 67–99%; complete: 100%.

The level of sample damage was classified based on a visual rating system and photos from ASTM D 3345-08 [2009], i.e.: 10 – sound, surface nibbles permitted, 9 – light attack, 7 – moderate attack, penetration, 4 – heavy, 0 – failure. In ambiguous cases, a medial grade was noted. The average wood damage level was calculated for each experiment variant.

The significance of the differences between the average results obtained in the experiment was verified statistically. The significance of the difference between the average levels of wood damage in each variant of the experiment was assessed using Chebyshev's inequality. Each time the absolute value of the difference between the arithmetic means of wood damage levels in two variants of the experiment was higher than or equal to the triple value of the standard error of the difference between the average wood damage levels, i.e.:

$$|\bar{x}_1 - \bar{x}_2| \geq 3 \cdot \varepsilon(\bar{x}_1 - \bar{x}_2)$$

where:

$\bar{x}_1$ – arithmetic average from one variant of the experiment (e.g. Neolithic waterlogged wood)

$\bar{x}_2$ – arithmetic average from other variant of the experiment (e.g. modern wood)

the difference between the arithmetic means was considered as significant. Otherwise, it was considered accidental.

The wood from each group of samples which had not been used for the termite experiment served to examine the chemical content. The cellulose content was designated using the Kürschner – Hoffer method. The holocellulose content was tested using the Tappi method, with apparatus typically used for cellulose content designation according to the Cross – Bevan method. The lignin content was examined using UV-Vis spectrophotometry. The wood was also tested for ash content using standard procedures.

Results and discussion

The procedure of the ASTM D 3345-08 [2009] standard used in the experiment made it possible to reduce the amount of wood 4.5 times and to shorten the period of the test 2 times in comparison to the PN-EN 117:2005 [2005] standard. The moisture content of the Neolithic beech wood which had been freeze-dried equalled 290% (+/– 40%) after the biological test, while the moisture content of the modern wood equalled on average ca. 90% (+/– 40%). The Neolithic beech wood which had not been subject to freeze-drying had an average moisture content of approx. 520% after the biological test. The sand on the bottom of the laboratory glass used in the experiment had a moisture content of ca. 10% after 4 weeks of the test.

The results of the biological test, as well as the chemical examination, are shown in table 1. The results of the statistical verification of the results obtained in the tests are shown in table 2.

Table 1. Level of wood damage, termite mortality and chemical content of wood in different variants of the experiment. (WNB – waterlogged Neolithic beech wood wet at the start of the study; FDNB – freeze-dried Neolithic beech wood)

Type of wood and sample number	Degree of damage of wood samples – visually rating	Average degree of damage	Approximate termite mortality	Content of cellulose, holocellulose, lignin, extractives and ash in wood
WNB 1	0/4 = 2	2	complete	cellulose 8.0 holocellulose 28.1 lignin 52.6 extractives 1.76 ash 3.4
2	0/4 = 2		complete	
3	0/4 = 2		complete	
4	0/4 = 2		complete	
5	0/4 = 2		complete	
FDNB 1	0	0	complete	
2	0		complete	
3	0		complete	
4	0		complete	
5	0		complete	
Beech – buk – 1	9/7 = 8	7,8	slight	cellulose 52.6 holocellulose 87.2 lignin 15.4 extractives 0.7 ash 0.81
2	7		slight	
3	9/7 = 8		slight	
4	9/7 = 8		slight	
5	9/7 = 8		slight	
Pine – sosna – 1	0/4 = 2	1,6	slight	cellulose 49.8 holocellulose 75.9 lignin 29.4 extractives 2.89 ash 0.41
2	0/4 = 2		slight	
3	0		slight	
4	4		slight	
5	0		slight	

WNB – waterlogged Neolithic beech wood wet at the start of the study
FDNB – freeze-dried Neolithic beech wood

Table 2. Statistical verification of the results obtained in the tests (WNB – waterlogged Neolithic beech wood wet at the start of the study; FDNB – freeze-dried Neolithic beech wood)

Type of wood	$\lvert\bar{x}_1 - \bar{x}_2\rvert$	Comparison	$3 \cdot \varepsilon(\bar{x}_1 - \bar{x}_2)$	Statistical verification of results
FDNB and WNB	0	=	0	significant difference
WNB and beech	5.8	>	0.6	significant difference
FDNB and beech	7.8	>	0.6	significant difference
beech and pine	6.2	>	2.3	significant difference
FDNB and pine	0.4	<	2.2	negligible difference
WNB and pine	1.6	<	2.2	negligible difference

WNB – waterlogged Neolithic beech wood wet at the start of the study
FDNB – freeze-dried Neolithic beech wood

As a result of the coercion test, the Neolithic beech wood was completely or almost completely destroyed, and all the termites died after 4 weeks of feeding. The modern beech wood was damaged by the termites to a much lower degree, as it provided more polysaccharides with no need for such intensive drilling. Termite mortality was insignificant in this case. The beech sapwood was very heavily damaged, to a similar degree to the Neolithic beech wood, yet termite mortality was comparably insignificant as in the case of the modern beech wood.

The feeding attractiveness of wood to termites is related to the wood species and part of the trunk [Schultze-Dewitz 1958, Becker et Petrowitz 1971, Becker et al. 1972, Grace, Yamamoto 1994, Grace et al. 1996], type and level of decomposition, as well as the species and the strain of fungi causing decomposition [Becker 1965, Schulze–Dewitz, Unger 1972, Unger 1975]. While the influence of fungal wood decomposition to termite feeding has already been the subject of research [Becker 1965, Schulze–Dewitz, Unger 1972, Unger 1973], no work have been found concerning waterlogged wood degradation by abiotic factors or bacteria. The high moisture content of waterlogged wood in situ also points to a high level of cellulose degradation [Hoffmann 1982] which is also the case in the present study. As a result of strong polysaccharide reduction in Neolithic wood, the termites were supplied with a low quantity of nutritional substances. The relative lignin content in the Neolithic beech wood was much higher than in the pine sapwood (by 80%) and in the modern beech (by as much as 140%). It is believed that the result of the decomposition of phenolic compounds in lignin may, in some technological processes, inhibit wood biodegradation factors [Kartal et al. 2004]. In the research carried out by Shanbhag and Sudararai [2013], significant correlation was found between the density, cellulose, lignin, and total phenolic contents of the wood and its degradation by termites. The higher the density of the wood, the lower the degradation. Similarly, a higher amount of lignin and total phenolic contents ensured a higher resistance, whereas cellulose drives termites towards the wood. Duarte et al. [2012] proved that thermally- modified wood is more absorptive and could enhance termite colonization. In the study of Thermally modified timber (TMT) according to the PN-EN 117:2005 [2005] standard with use of R. grassei termites, the mass loss of beech wood was 5.9% over 8 weeks.

During ca. 150 million years of evolution, termites have developed an optimal way of using symbionts in their intestines to decompose polysaccharides (which can be degraded in 1 day), however, lignin is very poorly decomposed [König et al. 2013]. Does the content of undecomposed lignin also limit the possibility of the trophic utilization of waterlogged beech wood by termites? The high ash content of the Neolithic beech wood (almost quadruple when compared to the modern beech wood, and more than eight times higher than in the pine sapwood) may be of some significance as well. In the case of the Neolithic waterlogged beech wood which was wet at the start of the study, one cannot exclude the antagonistic influence of bacteria contained in the wood on the termite symbionts.

The low degree of termite damage risk for waterlogged wood uncovered during archaeological work may be linked not only with the reduced content of nutritional substances and a relatively high content of lignin, but also with high moisture content. The better existence of the termites in the modern wood was influenced not only by the reduced content of lignin with an increased level of polysaccharides, but also by the lower moisture content of the wood. The moisture content of the modern wood was at an average level of approx. 90% (+/– 40%), while the moisture content of the freeze-dried Neolithic beech after four weeks of the experiment was at an average level of ca. 290% (+/– 40%). In the case of the Neolithic waterlogged beech wood wet at the start of the study, after four weeks of the experiment, the moisture content reached a level of ca. 520%. Meanwhile, the moisture content of the sand on the bottom of the laboratory glass was at an average level of 10%. There is a significant difference between the levels of damage of the waterlogged beech wood wet at the start of the study and the waterlogged beech wood after freeze-drying. Duarte et al. [2012] proved that thermally-modified wood is more hygroscopic and absorptive. They attribute this to the fact that the higher moisture content of TMT attracts the termites. On the other hand, an excessively high moisture content could discourage termites, as in the case of the waterlogged beech wood. It seems that, even if better conditions for the existence of termites occur as a result of possible global warming, the high moisture content of waterlogged wood uncovered in archaeological work, as well as the poor trophic conditions of the wood may prove lethal to termites.

Conclusions

The results obtained in the experiment, concerning the susceptibility of highly degraded waterlogged beech wood to termite feeding, allow the following conclusions:

1. In the case of coercion, the Neolithic waterlogged beech wood was heavily damaged or completely destroyed by the termites. The modern pine sapwood was heavily damaged, while the modern beech wood was damaged to a degree labelled as between light attack and moderate attack with penetration. However, unlike in the cases of the modern pine and beech wood, all the termites died after feeding on the waterlogged beech wood.
2. It cannot be unequivocally determined whether termite mortality was caused by the relatively high content of the lignin and the reduced content of nutritional substances, or by the much higher moisture content of the waterlogged beech wood as compared to the modern wood. The high moisture content undoubtedly contributed to the lower wood damage in the coercion test.
3. In spite of the considerable damage to the waterlogged beech wood in the coercion test, it seems that in the natural case of free choice of wood, the settlement of termites in waterlogged wood uncovered in archaeological work does not necessarily occur. Wood, containing few nutritional substances and substantial lignin, as well as a high moisture content enhancing the development of parasitic microorganisms, will deter termites.

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