Proceedings IRG Annual Meeting (ISSN 2000-8953)

IRG/WP 18-50337

THE INTERNATIONAL RESEARCH GROUP ON WOOD PROTECTION

Section 5 **Sustainability and Environment**

Conversion by insects – alternative method for wood waste up-cycling

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Paper prepared for the IRG49 Scientific Conference on Wood Protection
Johannesburg, South Africa
29 April – 3 May 2018

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ABSTRACT

Building industry is a major consumer of materials and waste generator in Europe. The bio-based building materials are considered as interesting alternative in modern building sector due to their low environmental impact. However, in order to increase confidence for bio-based materials application, they should present satisfying performance during service life allowing at the same time their cascade use, material and/or energy recovery and recycling. New development in the wood modification offer well-performing solutions even in severe environments. However, the advantage of the high resistance against biological degradation can become a restraining factor at the end of their service life. Presented research is a part of the BIO4ever project, where beside of modelling of service life performance, alternative end-of-life solutions for novel facades biomaterials are investigated. The efficiency and ability of insects to convert different categories of materials was investigated during 24 weeks of laboratory tests with selected termite species. Considering discriminatory choice of termites, it can be stated that at least some of the materials category might be converted into valuable protein source at their end-of-life. The investigated termite species *Reticulitermes flavipes* was recently classified among edible insects. Proposed solution might therefore contribute to the global problem of nutrient deficiency by providing recommendation of the use of building biomaterial wastes as an alternative feedstock for further transformation into proteins.

Keywords: wood waste, insect conversion, termites, up-cycling, end-of-life strategy

1. INTRODUCTION

The human population is expected to grow to reach 9 billion in 2050. As a consequence, demand for food will increase exponentially which might be problematic considering observed climate change and high environmental impact of recent animal farming methods (Varelas and Langton 2017). Livestock and fish are important sources of protein in most countries. According to FAO report livestock production accounts for 70 percent of all agricultural land use (van Huis *at al*.

2013). With global demand for livestock products expected to increase to 465 million tons in 2050 new innovative solutions are required. Even if entomophagy is a part of prehistoric diet, nowadays it is not a commonly accepted nutrition approach, especially in Western cultures. However, utilization of insects for human food and livestock feed has some significant advantages, like high nutrient content, effective feed conversion rate, low greenhouse gas emissions and low water requirements. Insects are much more efficient in transforming phytomass to zoomass than conventional livestock. Their very good nutrient value, fast growth rate and the fact that they are the biggest animal group on the earth, make their potential as a food source interesting alternative (Premalatha *et al*. 2011).

The wood-destroying insects are considered as pests and the main efforts are currently directed to reduce their population. However, a new approach proposed by Schabel (2010) might change the perception of these insects. Their controlled production might be an alternative to support innovation and sustainability of the forest and wood based sectors. Beside primary forest residues, the bio-based building materials might be a potential source for bio-conversion. The building industry is a major consumer of various materials. The construction and demolition sectors generate one of the highest volumes of waste in Europe. There are three ways of preparation of wood wastes: direct use of raw materials, pre-treatment & bioconversion, and combination of above processes. Extensive research is conducted nowadays to promote cascade use of resources, their reuse and recycling. Bio-based building materials are considered as an interesting alternative in the modern building manufacturing. The new modification methods and surface treatments deliver better-performing solutions even in severe environments. However, the advantage of a good resistance against biological degradation can become a restraining factor in recycling, reuse or disposal/landfill. It must be therefore demonstrated that bio-based materials are significantly more favourable considering the whole life cycle, than the corresponding mineral and fossil based alternatives.

The presented research is a part of the BIO4ever project, where together with modelling service life performance, alternative end-of-life solutions for novel facades biomaterials are investigated. This work presents part of the short term scientific mission (STSM) conducted within the European COST action FP1407 “Understanding wood modification through an integrated scientific and environmental impact approach”. The objective was to investigate alternative pathways of wood waste transformation. Laboratory and field tests with selected fungi and insects were conducted with the aim of investigate their potential for bio-based building materials’ transformation. It was expected that certain organisms will speed-up the degradation process of the investigated building materials; however, their efficiency and ability to convert different materials was a question mark. The overall goal of the presented research is to contribute to solving the global problem of the nutrient deficiency, by providing recommendation on the use of building biomaterials wastes as an alternative feedstock for further transformation into proteins by relevant species of insects and/or decay fungi.

2. EXPERIMENTAL METHODS

2.1 Experimental set-up

Experimental samples (112 bio-based facades materials) classified into 7 categories according to the treatment type (Sandak et al. 2018) were cut into thin strips (150x20x5mm) and calibrated to 5mm thickness. Three replicates from each material were used for this test. The summary of biomaterials categories and number of independent representative samples tested within this trail are presented in Table 1.

Table 1: Categories of investigated materials and number of materials tested

Material category	Examples	Number of samples
natural	Wood (hardwood, softwood, exotic species), bamboo	17
chemical	acetylation, furfurylation	5
composites	panels, bio-ceramics, tricoya, wood plastic composites	7
coating & surface treatments	different coatings, carbonized wood, nanocoatings	16
impregnation	DMDHEU, Knittex, Madurit, Fixapret	23
thermal modification	vacuum, saturated steam, oil heat treatment	19
hybrid modification	thermal treatment + coating, thermal treatment + impregnation, acetylation + coating etc.	25

Laboratory tests with the European subterranean termites *Reticulitermes flavipes*, collected in the Oléron Island in France, were conducted at FCBA, Bordeaux, France. The logs containing termites were transported to the laboratory and termites were extracted from them (Fig 1 left). For each of four test-device boxes, 10g of termites were prepared (around 2500 insects). Four containers filled with moistened garden soil were used as test devices for this part of the experiment. The samples of test materials were installed randomly on each test box, and half buried up to half of their height in the soil (Fig. 1 right). In each container 1.2 l of demineralized water was added at the beginning of the experimentation. Containers were wet moistened once a month during the whole experiment. All four containers were kept close to each other in a climatic chamber at 28°C and 70% RH for 6 months.

Figure 1: Termites extracted from the logs (left) and experimental samples at the start of the test (right)

2.2 Samples' characterization

In all boxes the termites were active during the whole duration of the test. The first evaluation was conducted after 12 weeks, and the second after 24 weeks. One week before visual assessment and weight measurement, the samples were removed from the boxes, cleaned and conditioned to reach their equilibrium moisture content (EMC) corresponding to the air-dry state.

All samples were weighted and the mass loss was calculated according to Equation 1:

$$ML = \frac{m_0 - m_t}{m_0} 100\% \qquad \text{(Eq. 1)}$$

Where: *ML* mass loss [%], m_0 dry weight of the sample before the test [g], m_t dry weight of the sample after the test [g]

The samples were also graded by visual assessment according to EN 252. The rating scale 0-4 was adapted to the particular samples size tested within this experiment (Table 2).

Table 2: Adapted rating scale according to EN 252

rating	colour	classification	definition
0		No attack	No sign of attack
1		Slight attack	Superficial attack at some points or over small area
2		Moderate attack	Deeper and bigger area of attack (until 2cm²)
3		Severe attack	All samples under soil is attacked (over 2cm²)
4		Failure	Destruction of the sticks, transparency

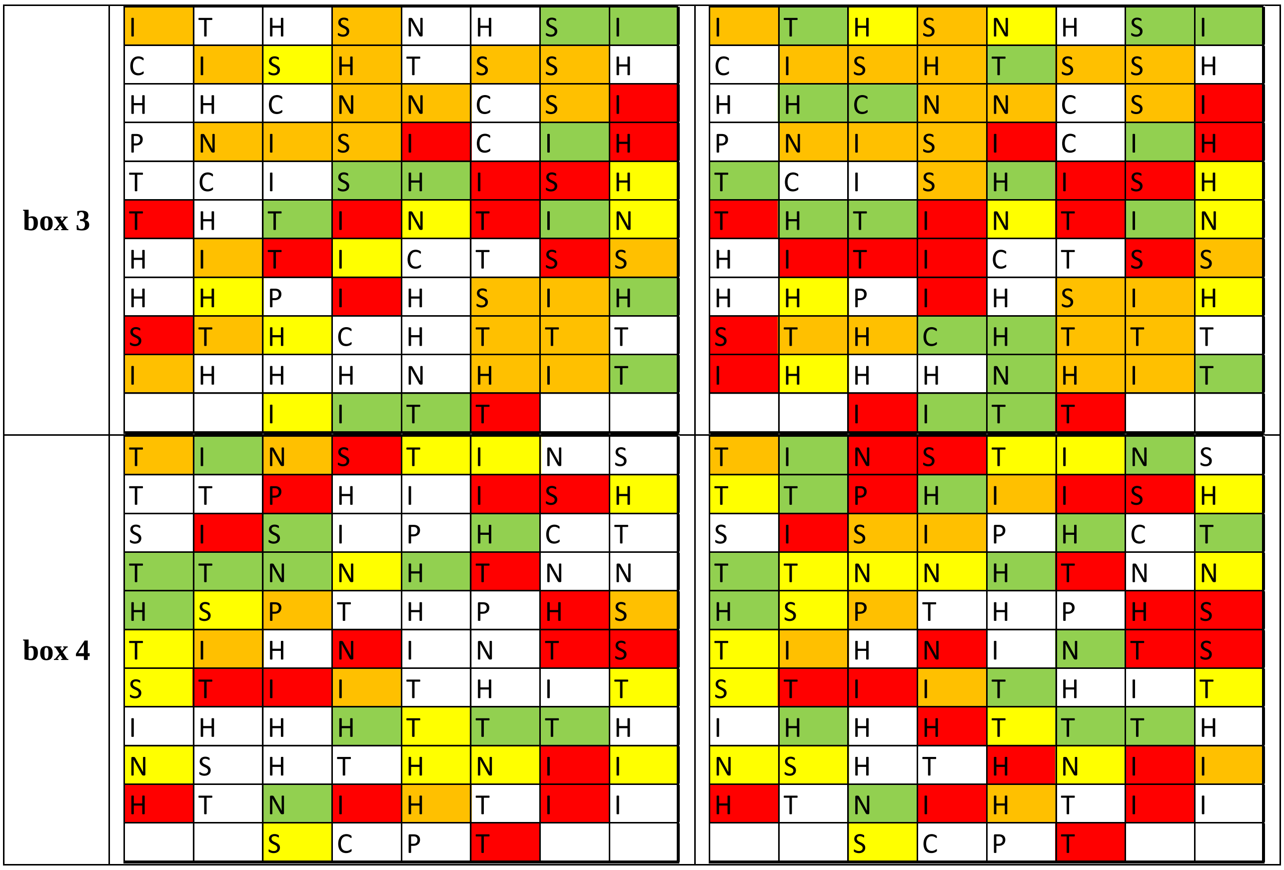
3. RESULTS AND DISCUSSION

3.1 Visual assessment

Seven categories of bio-based materials represented by 112 samples were evaluated after 3 and 6 months of degradation by termites. The results are presented in Table 3.

Table 3: Visual assessment of the experimental samples according to the rating scale adapted from EN 252

	3 months								6 months							
box 1	I	H	H	H	P	H	T	P	I	H	H	H	P	H	T	P
	S	N	T	N	H	I	C	N	S	N	T	N	H	I	C	N
	N	T	P	I	N	T	H	I	N	T	P	I	N	T	H	I
	T	N	I	T	H	P	T	S	T	N	I	T	H	P	T	S
	H	C	H	T	T	I	P	N	H	C	H	T	T	I	P	N
	H	S	I	N	T	S	H	I	H	S	I	N	T	S	H	I
	N	P	N	I	I	H	H	N	N	P	N	I	I	S	H	N
	I	C	H	S	I	S	S	N	I	C	H	S	I	S	S	N
	N	H	P	T	N	N	S	S	N	H	P	T	N	N	S	S
	N	T	C	S	H	H	H	N	N	T	C	S	H	H	H	N
			S	S	H	T					S	S	H	T		
box 2	T	I	H	I	H	I	S	N	T	I	H	I	H	I	S	N
	I	S	N	S	N	S	H	T	I	S	N	S	H	S	H	T
	I	I	T	I	H	N	H	N	I	I	T	I	H	N	H	N
	P	T	H	N	P	H	I	H	P	T	H	N	P	H	I	H
	S	S	I	P	S	T	S	H	S	S	I	P	S	T	S	H
	T	H	H	S	H	N	N	N	T	H	H	S	H	N	N	N
	H	T	I	I	I	P	I	S	H	T	I	I	I	P	I	S
	I	P	C	N	H	I	N	H	I	P	C	N	H	I	N	H
	I	T	C	S	N	H	I	I	I	T	C	S	N	H	I	I
	I	I	H	N	N	S	H	N	I	I	H	N	N	S	H	N
			S	N	I	P					S	N	I	P		



It is well visible that some of the materials were already very severely degraded after 3 months. However, materials representing some categories, such as chemical treatment, remained not attacked even after 6 month of exposure. Analogous results were obtained by analysis of the samples mass loss (data not shown). It is worth to be mentioned, that within same treatment category different results were obtained. Within category 1: natural, the teak wood was the most resistant and was not intact by termites even after 6 months exposure. Among composites (category 3), only fibreboard was degraded, while acetylated MDF, wood plastic composites and bio-resin panels remained not attacked. This demonstrates the influence of specific treatment conditions on selective choice of nutrients by termites.

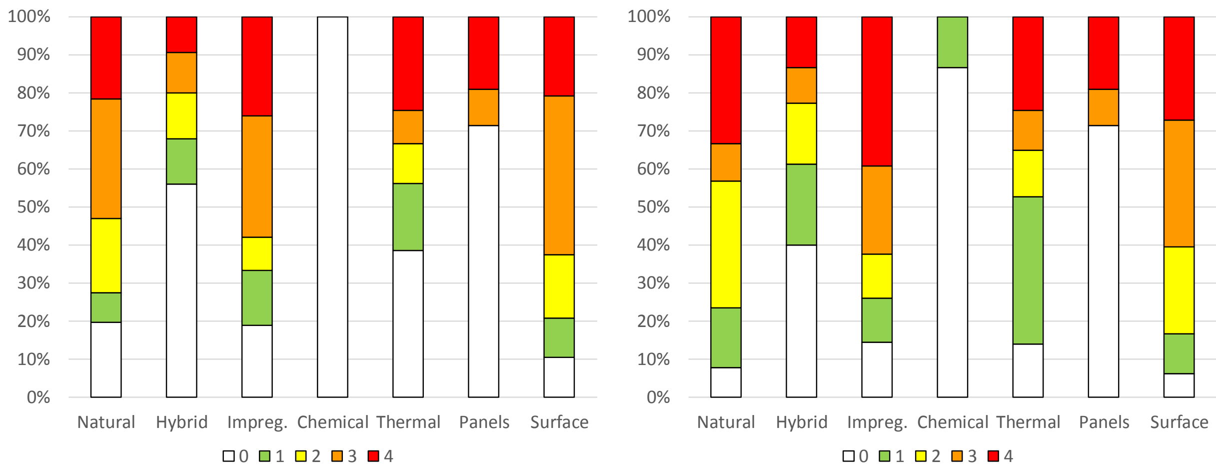


Figure 2: Results of visual assessment of samples degraded for 3 (left) and 6 months (right)

3.2 Digestion mechanism

There are several paths that insects are using to fully digest ligno-cellulosic materials such as wood. The key role play the gut microflora of termites, that supports biochemical pathways of digestion. Termites have developed cellulose digestion capabilities that allow them to obtain energy and nutrients from nutritionally poor food sources, such as lignocellulosic plant material and wood residues. Lower termites, which are equipped with both endogenous and symbiotic cellulases, feed primarily on wood and wood-related materials (Zhou et al. 2007). In the case of *Reticulitermes flavipes*, wood eaten by the termites is first broken up with the mandibles, then treated with host endoglucanases from the salivary glands, ground up into small particles in the gizzard, and then degraded by additional host cellulases in the midgut, freeing glucose for immediate absorption.

3.3 Nutrition potential of termites

Termites are rich in proteins, fatty acids and other micronutrients. The average protein content in adult insects is around 13-28 g/100g of fresh weight. The fat content is around 49% in the dry matter with palmitic acid, oleic acid and stearic acid being present. Termites are generally consumed fried, sun-dried or smoked. Sun-dried termites can be ground into powder and mixed with other food ingredients (van Huis *et al*. 2013).

Recently at least 1900 insect species have been documented as edible. The most common edible insects belong to Coleoptera, Lepidoptera, Hymenoptera, Orthoptera, Hemiptera and Isoptera species. Among Isoptera at least 43 edible termites' species are used for human and livestock food (van Huis *at al*. 2013). According to Ohkuma (2003) termites are one of the most important bioreactors, able to convert cellulose into glucose and energy. Several characteristic of termites make them potential candidates for solid waste transformation: limitless appetite, wide variety of potential food source, fast growth rate, variety of their habits that allow to find appropriate species for certain requirements, very high (up to 93%) assimilation rate of consumed food, good protein quality allowing their use as a poultry feed and alternative source of chemicals such as biofuel (Abbasi and Gajalakshmi 2015). Conversion efficiency of insects compared with other kinds of livestock holds the potential for decreasing the impacts associated with feed production (Halloran *et al*. 2016). The insects' farming should become therefore interesting alternative for the food production in the future.

4. CONCLUSIONS

There are three ways of preparation of wood wastes: direct use of raw materials, pre-treatment and bioconversion, combination of above processes. In this experiment raw materials were directly exposed to insects' activities. Considering the selective choice made by termites while exposed to the test materials, it can be stated that at least some of the material categories might be converted at their end-of-life.

The termites *Reticulitermes flavipes* tested within this experiment were recently classified as edible species by Yde Jongema, a taxonomist at the Department of Entomology of Wageningen University & Research, the Netherlands. Therefore, the results of this eco-degradation experiment might provide new knowledge in the emerging field of exploring insects as a food source.

Besides of being a valuable protein source, the production process has low environmental impact. The socio-economic benefits of insects' farming are also worth to be mentioned, since diversity of their habitat make their production available to given environment and local communities.

5. ACKNOWLEDGMENT

The BIO4ever (RBSI14Y7Y4) is ongoing project funded within a call SIR (Scientific Independence of young Researchers) by MIUR.

The authors gratefully acknowledge the European Commission for funding the InnoRenew CoE project (Grant Agreement #739574) under the Horizon2020 Widespread-Teaming program. Special acknowledgments to COST FP1407 for funding STSMs that contributed to the project. Authors acknowledge IRG Committee for Ron Cockcroft Award of Marta Petrillo.

BIO4ever project partners: ABODO (New Zealand), Accsys Technologies (Netherlands), Bern University of Applied Sciences (Swizerland), BioComposites Centre (UK), CAMBOND (UK), Centre for Sustainable Products (UK), Drywood Coatings (Netherlands), EDUARD VAN LEER (Netherlands), FirmoLin (Netherlands), GraphiTech (Italy), Houthandel van Dam (Netherlands), ICA Group (Italy), IMOLA LEGNO (Italy), Kebony (Norway), KEVL SWM WOOD (Netherlands), Kul Bamboo (Germany), Latvian State Institute of Wood Chemistry (Latvia), Lulea University of Technology (Sweden), NOVELTEAK (Costa Rica), Politecnico di Torino (Italy), RENNER ITALIA (Italy), Solas (Italy), SWM-Wood (Finland), Technological Institute FCBA (France), TIKKURILA (Poland), University of Applied Science in Ferizaj (Kosovo), University of Gottingen (Germany), University of Life Science in Poznan (Poland), University of Ljubljana (Slovenia), University of West Hungary (Hungary), VIAVI (USA), WDE-Maspel (Italy)

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