

Article

Effects of Prolonged Leaching on the Acute Ecotoxicity of Spruce-Pine Oriented Strand Board for Plants

Klára Kobetičová ^{1,*} , Hana Sedláčková ¹ , Martin Böhm ¹ , Jiří Brich ¹ , Jana Nábělková ² and Robert Černý ¹ 

¹ Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7/2077, 166 29 Prague, Czech Republic; hana.sedlackova@fsv.cvut.cz (H.S.); martin.bohm@fsv.cvut.cz (M.B.); jiri.brich@fsv.cvut.cz (J.B.); cernyr@fsv.cvut.cz (R.Č.)

² Department of Urban Water Management, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7/2077, 166 29 Prague, Czech Republic; jana.nabelkova@cvut.cz

* Correspondence: klara.kobeticova@fsv.cvut.cz

Abstract: In this study, the ecotoxicological effects of a selected OSB material on three model plants (green freshwater algae *Desmodesmus subspicatus*, duckweed *Lemna minor*, and seeds of lettuce *Lactuca sativa*) were tested. A 24 h and 168 h leachate of the same OSB material was prepared. Mg, Si, Ca, K, Fe, Zn, Mn, and Na were found in the samples. Their higher residues were measured in the 168 h leachate. Biogenic elements (N, P, C) were not detected. The acute effect was relatively slow (for algae up to 26%, for duckweed up to 20%, and for lettuce seeds with stimulation up to 37%). Prolongation of the leaching time did not show any effect on the results of the plant tests. Acute toxicity for the three plant species used was slow.

Keywords: OSB; oriented strand board; ecotoxicity; duckweed; algae; lettuce seeds; building materials



Citation: Kobetičová, K.; Sedláčková, H.; Böhm, M.; Brich, J.; Nábělková, J.; Černý, R. Effects of Prolonged Leaching on the Acute Ecotoxicity of Spruce-Pine Oriented Strand Board for Plants. *Buildings* **2024**, *14*, 1721. <https://doi.org/10.3390/buildings14061721>

Academic Editors: Takahisa Nakai and Tadashi Ohtani

Received: 23 April 2024

Revised: 29 May 2024

Accepted: 3 June 2024

Published: 8 June 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Oriented strand boards (OSBs) form an important part of materials commonly used in the construction industry. However, these materials tend to be composed of many parts and glued together with adhesives or protective mixtures of various origins. It is therefore necessary to know not only their properties for practical use but also their environmental effects. Generally, they are made of wood, created by pressing large wood strands in three or four layers, mixed with glue, and created under high pressure. The boards are produced with either a sanded or un-sanded surface. They are used in the construction of roofs, internal or external walls, floors, and as building elements (beams or supports). OSBs are also suitable for the construction of fences, stairs, underpasses, shelves, and worktops. The detailed chemical composition and detailed method of production are not usually indicated by the manufacturer due to production secrecy.

Wood shavings for their production usually come from spruce, but some new OSB materials with different cellulose strands, e.g., [1–3] or waste material have been developed, e.g., [4–6]. The properties of building materials, e.g., [7–10] and the ability to resist biodegradation effects were studied in the most recent articles [11–13]. Attention was also paid to the toxicity of the volatile substances that can be released from them (directly from wood or from glues) and have certain negative effects on human health [14–17].

Some studies also described the contribution of production, use, and disposal of these materials in Life Cycle Assessment studies, e.g., [18–22]. However, this is an indirect analysis of the effects of OSBs on both aquatic and terrestrial ecotoxicity and toxicity for humans.

There is very little information about their “direct ecological safety” for organisms. Some of these boards are produced for humid applications (OSB/3 and OSB/4 according to EN 300 [23]). Therefore, it can be assumed that they may be in contact with elevated humidity or that their waste from indoor applications can be used as secondary recycles.

Which components may be responsible for their potential ecotoxicity in these cases? The toxicity of leachates from wood pieces has been described in many studies, e.g., [24–29]; however, in all cases, pure untreated wood chips were tested, not strand materials mixed with certain adhesives. If toxicity was observed, it was caused mainly by volatile compounds such as phenols, resins, and essential oils [30–33]. Producers of OSB materials also artificially add variable organic substances (adhesives, biocidal substances), and it is possible that such chemicals can change the potential effects. Generally, we can assume that volatile compounds in adhesives such as formaldehyde can be released into the air, and we do not have much information about their ecotoxicity for organisms in soils or waters or in laboratory open test systems. Furthermore, all types of adhesives can definitely be cross-linked in OSB or, as a whole or in the partial form of individual substances, be slowly leached into the environment. The ecotoxicological effects of adhesives have not yet been described after their application in OSB materials in scientific databases such as Scopus or Web of Science, to our knowledge.

Another question also concerns the design of such biological experiments because we need to know not only the ecotoxic effects but also the reasons for them, as they can be affected by many experimental settings. The most important aspect is the leaching time of the tested material. Extending the duration of leaching can lead to an increased concentration of organic and inorganic substances in the leachate and thus affect toxicity [28,34]. Several studies have already been devoted to this issue. It is generally recommended to first carry out chemical analysis and, after stabilization of the detected residues in the sample, to choose a suitable length of sample leaching. However, this alludes to the possibility of bacterial contamination of the leachate, which can then negatively impact the results of ecotoxicity tests, especially with microorganisms but also with invertebrates. For these reasons, an ecotoxicological assay should not be longer than several days. One week should be the longest time period for bioassays when one wants to add new organisms to the leachates (own, unpublished personal experience).

In the present study, the ecotoxicity of a readily available oriented strand board was analyzed. The individual OSB material was selected as a representative of OSBs based on spruce wood, with artificial commercial adhesives being used for its production. The research significance of this study is derived from the finding that articles focused on the ecotoxicity of OSB boards are missing in the primary literature sources. The ecotoxicity of adhesives in general cannot be compared, as the same adhesive can behave differently when gluing different wooden elements, when added to mixtures such as OSB materials for gluing, e.g., plastic components, or when used in food, furniture, or cosmetic industries.

For verification of the effect of leaching time on ecotoxicity, two leachates were prepared, fresh (1 day) and aged (7 days), and then used in ecotoxicological bioassays with freshwater green algae, duckweeds, and terrestrial lettuce seeds. Supporting chemical analyses (inductively coupled plasma-optical emission spectrometry, ICP-OES) and determination of biogenic elements using cuvette spectrometric tests (Hach Lange) were performed to supplement and discuss the obtained ecotoxicological data. The research objectives of the study were as follows: 1. To study of the ecotoxicological potential of the selected OSB material on plants. 2. To compare the toxicity rate of 24 and 168 h leachates. 3. To compare the sensitivity of model plant species. 4. To have a discussion of the ecotoxicity based on our own chemical data.

2. Materials and Methods

2.1. Oriented Strand Board

A commonly available oriented strand board purchased on the Czech market was used in the present study. The board consists of spruce (80%) and pine (20%) wood strands bonded in the face layers with a melamine–urea–formaldehyde resin (MUF—8.5%). The dimethyl-diisocyanate (MDI—3.5%) was used to bond the wood strands in the core layer. In addition, a paraffin water emulsion (2.4%) was added to the adhesive mixture. The OSB board, with dimensions of 1250 mm × 2500 mm, was cut into individual test samples. For

the preparation of the leachate, a part of the plate weighing 100 g in the shape of a rectangle (25 × 100 mm) was used. Figure 1 shows an example of the tested OSB photographed with a CANON EOS 2000D camera (Canon Inc., Tokyo, Japan).

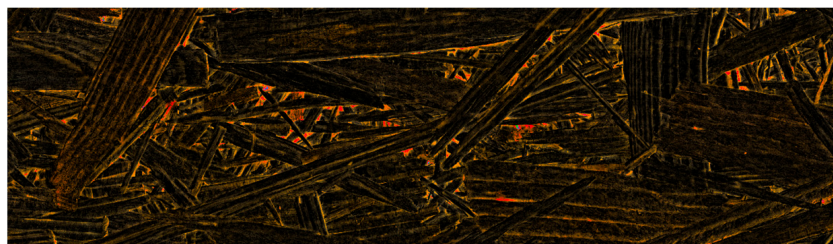


Figure 1. The photographed OSB board on which surface irregularities were visualized using the “Detect Valleys” function in the NIS Elements imaging software (Basic Research, ver. 5.10.01, Laboratory Imaging and Nikon Corporation, Prague, Czech Republic).

The dark color in the image represents the wood strands in the surface layer, and the red areas indicate voids. The illustrative photo shows that the OSB surface is not smooth but contains several voids. During the production of OSB boards, small wood strands are removed, resulting in gaps between the remaining strands. During the leaching process, water partially penetrates into the core of the board. The adhesive mixture is therefore exposed to water in addition to the wood strands themselves. Other compounds may also be released into the water from additives such as hydrophobic paraffin emulsion, various biocidal additives, or wood resins.

2.2. Preparation of Leachates

The leachate from solid samples was obtained according to the CSN-EN standard [35]. In the preparation of the leachate, the tested material in the form of a cut rectangle was mixed with distilled water at a ratio of 1:10 (100 g of solid material to 1000 mL of distilled water). The prepared mixture was stirred for 24 h or 168 h in overhead shaker Reax 20/4 (Heidolph Instruments, Schwabach, Germany). The leachate was filtered through filter paper (Whatman, grade 6) and analyzed. The leachates were used for the preparation of tested media in ecotoxicological bioassays or chemical analysis, and their pH was measured by a PC 70 + DHS multimeter.

2.3. Concentration of Inorganic Elements

The quantity of leached metals was determined according to [36].

2.4. Concentration of Biogenic Elements

Nitrogen, phosphorus, and carbon were analyzed spectrometrically as cuvette tests according to the appropriate guidelines of the tests’ producer (Hach, Germany, <https://cz.hach.com/lck>, accessed on 5 June 2024) by a Hach Lange DR/2400 device (Germany). The range of detection for individual elements was: total nitrogen 1–16 mg/L, total carbon 3–30 mg/L, total ortho-phosphate 3–30 mg/L.

2.5. Algal Toxicity Test

The test organism *Desmodesmus subspicatus* was bought from the Institute of Botany of the CAS, Třeboň, Culture Collection of Autotrophic Organisms CCALA, Czech Republic. The test was performed in accordance with [37]. After exposure, the algal biomass was expressed through absorbance values at a wavelength of 750 nm using spectrophotometer after 168 h of exposure. The organisms are shown in Figure 2.

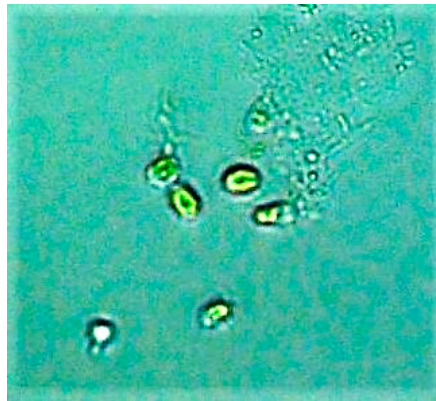


Figure 2. Photo of algal species *Desmodesmus subspicatus* under light microscope Olympus (magnification: 400×).

2.6. Duckweed Aquatic Toxicity Test

The duckweed aquatic plant toxicity test used *Lemna minor* (ZOO Braník, Prague, Czech Republic). The test was performed according to the [38].

Three replicates of 100 mL of controls or samples were prepared. A total of 12 fronds were used for each replicate, and the glass test chambers were covered with transparent film. All beakers were incubated for 168 h in $(24 \pm 2) ^\circ\text{C}$ and under a light cycle (16 h/8 h; light/dark; 5000–6000 lux). After the 7-day exposures, the number of fronds was ascertained via visual inspection. The photo of the organisms is shown in Figure 3.



Figure 3. Macro-photo image of fronds of duckweed species *Lemna minor*.

2.7. Plant Root Elongation Test

Lactuca sativa seeds were bought from Osiva-semena, Ltd. (Prague, Czech Republic). The test was conducted according to [39]. The photo of the organisms is shown in Figure 4.



Figure 4. Macro-photo of lettuce seeds *Lactuca sativa*.

2.8. Statistical Evaluation

A one-way ANOVA and Tukey–Kramer multiple comparisons test was performed to compare samples at the α level of 0.05. Based on the Tukey–Kramer test, the leachate, which was statistically similar to other samples and had no stimulation effect, was chosen as the time-dependent NOEC. The statistical analyses were performed using GraphPad Prism software (Version 5.1, GraphPad Software, San Diego, CA, USA).

3. Results

3.1. Chemical Analysis

Oxygenated distilled water was used for the preparation of leachates and control media. All control media fulfilled the criteria according to the relevant standards [36–38]. The measuring of the pH of the used media (two controls and two leachates) indicated similar values that were around neutral (see Table 1). Such pH values are suitable for performing ecotoxicity tests, and they should not constitute a reason for potential negative effects. The chemical analyses via the ICP method indicated the presence of microelements that are important for the life of the model organisms. However, they were detected mostly at very low levels. After 24 h, the leachates contained less nutrients than the leachates after 168 h. Toxic metals, such as Hg, Pb, Cd, Al, or Cr, were not detected (Table 2). Nitrogen, phosphorus, and carbon were not detected by cuvette tests.

Table 1. The pH values of the tested samples at the start of the experiments.

Sample	0 h	24 h	168 h
Distilled water	6.91	-	-
Tap water	6.66	-	-
24 h leachate	-	7.00	-
168 h leachate	-	-	6.96

Table 2. Chemical analysis of the OSB sample by ICP-OES—the leachates after 24 h and 168 h of leaching time (mg/L).

Sample	Ca	Fe	K	Mg	Mn	Na	Si	Zn
24 h leachate	0.00	0.00	18.2	0.40	0.20	0.50	0.40	0.00
168 h leachate	1.50	0.10	28.8	1.10	0.50	1.30	0.90	0.10

3.2. Ecotoxicity

The leachates were not toxic for lettuce seeds, a stimulation was observed. The toxicity for algae and duckweeds was relatively slow. The inhibition was calculated up to 26% (see Figure 5, Tables 3 and 4). There was no evident statistical difference between the toxicity of both leachates for all the model organisms (Table 4) according to the Tukey–Kramer test at an α level of 0.05. Generally speaking, the acute toxicity increased for organisms in the following rank: lettuce < duckweed $\leq$ algae. The NOEC time values were different for each of the test organisms (Table 4). The effective time was 24 h of leaching for algae and for duckweed. The leachates had stimulative effects on seeds, so the effective time for leaching was not determined.

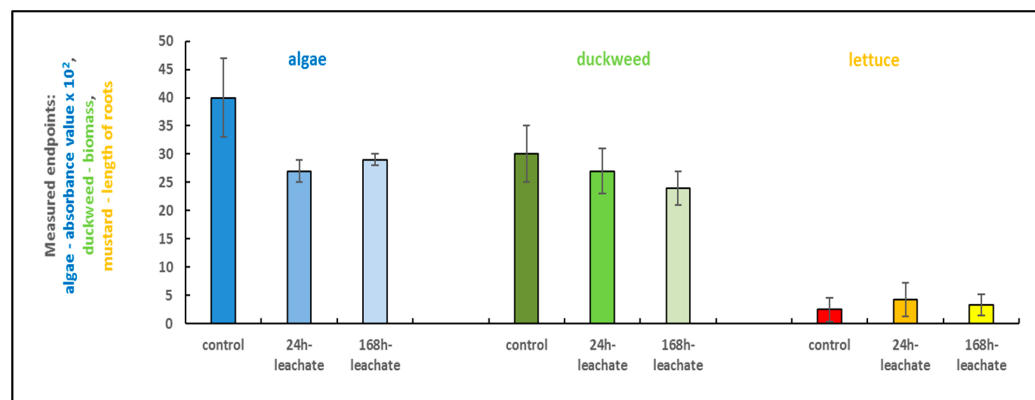


Figure 5. Measured endpoints in bioassays: algal test = biomass expressed as absorbance values, duckweed test = number of fronds, lettuce test = elongation of roots (in mm). All endpoints were observed after 168 h of exposure.

Table 3. Inhibition (“+”) / stimulation (“−”) of measured endpoints in comparison to the control: algal test = biomass, duckweed test = number of fronds, lettuce test = elongation of roots. All endpoints were observed after 24 or 168 h of exposure.

Species	24 h-Leachate	168 h-Leachate
Inhibition (%) ± SD		
<i>D. subspicatus</i>	26 ± 4.38	20 ± 2.10
<i>L. minor</i>	10 ± 2.36	20 ± 8.39
<i>L. sativa</i>	−37 ± 26.84	−34 ± 10.00

Table 4. Statistical evaluation: A one-way ANOVA and Tukey–Kramer test was performed to compare samples and controls at an α level of 0.05. The data not statistically different from the control are expressed as first time-dependent NOECs.

Species	24 h-Leachate	168 h-Leachate	Time-Dependent NOEC
Symbol for significance: “*” statistically significant difference, “ns” no statistically significant difference/ p -value			
<i>D. subspicatus</i>	*/ $p < 0.05$	*/ $p > 0.05$	<24 h-leachate
<i>L. minor</i>	ns/ $p > 0.05$	ns/ $p > 0.05$	24 h-leachate
<i>L. sativa</i>	ns/ $p > 0.05$	ns/ $p > 0.05$	Impossible to determine

4. Discussion

All the produced leachates had pH values around neutral (Table 1). Such water is suitable for the cultivation of model plant species according to the appropriate guidelines [37–39]. All the used bioassays belong to so-called acute tests with short durations (only several days of exposure) with the main simple endpoints. *D. subspicatus*, *L. minor*, and *L. sativa* are photosynthesizing organisms involved in the production of oxygen and sugars, e.g., [40]. Like other organisms, their cells contain basic nutrients (N, C, P, S, H). However, for their growth, reproduction, and metabolic processes, they still need other micronutrients (Ca, Mg, K, Fe, Mn, Cr, Na, Cu, Zn, etc.). The measured elements in the samples can therefore be beneficial or dangerous for organisms. It always depends on their dose and the combination of all elements in the mixture. Many years ago, the literature described how different elements in the solution can interact with each other and, thus, antagonism, synergism, or additive effects on variable organisms can occur, e.g., [41–44].

Heavy metals and other inorganic microelements were measured by an inductively coupled plasma optical emission spectrometer. This analytical method is currently recognized as being the most suitable for the analysis of elements in low concentrations of the order of nanograms to mg/L, e.g., [45–47]. However, it is not possible to determine

biogenic elements and halogens with this method. Therefore, biogenic elements were measured using cuvette assays using a spectrometer in this study. N, P, and C were selected because cuvette tests for hydrogen do not exist and sulfur occurs in the low amount in organisms—the average representation of these elements in organisms is as follows: carbon (29%), oxygen (50%), hydrogen (10%), nitrogen (2.7%), phosphorus (0.4%), sulfur (0.75%) [48].

The biological tests were performed according to the appropriate guidelines and the duration of the tests was extended to 168 h. All the selected control media and species are commonly used in ecotoxicological studies [37–39].

Slow acute toxicity was found for plants in the present study (Figure 4 and Table 4). The tested OSB produced in Central Europe contained mainly spruce, and this wood does not contain high amounts of resins and other volatile compounds. This corresponds to a study [49] where untreated spruce chips were less toxic than chips of pine in regard to bacteria and saline crustaceans. The other studies used model organisms—rainbow trout, daphnia, vibrio, and algae—and toxicities were observed in all cases, and it has been shown that leachates mainly from untreated wood and wood chips can be toxic to various organisms, e.g., [24,26,50–53]. It is evident that the leaching of organic and inorganic substances from the individual woods and materials on the base of woods is very different and cannot be generalized for woods of variable origin (species, locality, age of cut-down trees) and processing.

We can assume that the tested OSB material could contain a limited amount of certain phenolic compounds, and it is probable that, if some of them are leached from the tested OSB, they could be emitted into the air during the filtration process in the present study (as in all studies generally) or that their residues in the leachates were under the detection limits of the used cuvette tests.

OSBs generally also contain organic adhesives and other mixtures for their protection against molds. However, it is possible that the chemicals hardened in the board material during the manufacturing of the OSB are not leachable into water or, if so, in small concentrations. This hypothesis was indirectly confirmed for the tested OSB by the results of the cuvette tests where no carbon, phosphorus, or nitrogen was independently detected in the leachates within the range of detection limits for individual elements (each of the elements has its own methodology and test solutions for colorimetric reaction). Therefore, the tested board probably does not release potentially dangerous organic substances into leachates; however, if this is so, these chemicals released into the leachate are under the limits for their detection for individual elements or they can be released into the air in the same way as phenols.

Some inorganic elements (Ca, Fe, Mg, K, Mn, Na, Si, and Zn) were found in the samples but in relatively small quantities. It is probable that such levels can be used by plants as nutrients instead of being toxic. Potassium (K^+) was the most detected element in the present study. Some producers may add such chemicals into OSB materials for their protection against biodegradation. This element could perhaps cause slow toxicity for algae or duckweeds, or the toxicological potential was an effect of all elements in the mixture. In every case, in previously published studies (e.g., [54]), the toxicity for terrestrial plants in leachates from spruce or beech were not described, similarly to our study.

The sensitivity of plants to any sample depends on the selected species. *Lactuca sativa* is a lettuce species containing, on average, 220 mg K/100 g of leaf biomass, 19 mg Ca, 5 mg, 0.4 mg Fe, 0.3 mg Mn, 3 mg N, and 0.1 mg Zn/100 g of lettuce biomass [55]. All these elements can be absorbed by roots and led into the upper parts of plants (stem, leaves). For this reason, lettuce is probably relatively tolerant to the presence of the measured nutrients, and the elements could probably lead to its stimulation.

We can expect that some of the leached elements can be a source of nutrients for the other used species, as well as for lettuce. In their cells, green algae generally contain macroelements (Na, K, Mg, Ca, Cl) in milligrams to grams per kilogram and microelements and

trace elements (Fe, Zn, B, Co, Cr, Cu, F, I, Mn, Mo, Ni, Se, Sn, Al, As, Cd, Hg and Pb) in the order of micrograms to milligrams per kilogram [56].

The selected endpoints were prolongation of roots (*L. sativa*) and increasing of biomass—cells (*D. subspicatus*) or number of fronds (*L. minor*). They belong to the basic and simple parameters for measuring and that's why they were selected purposely in the present study. Their sensitivity is quickly evident, and it is sufficiently robust.

The results indicate that the 24 h-leaching time was adequate for organisms used with any toxic effect (algae and duckweed) because there was no clear difference between the 24 h and 168 h leaching periods. A period of leaching longer than 7 days is not suitable, as, with such leachates, bad microorganisms can occur that decrease the quality of the water. Such leachates can be contaminated by viruses, bacteria, or protozoa, and it can start to smell and rot and be unsuitable for organisms that need clean water and enough oxygen to live (daphnia, nematodes, fish, fish embryos, or annelids).

5. Conclusions

The effect of prolonged leaching time on the ecotoxicity of the selected OSB in three plant acute bioassays was investigated in the present study. The OSB sample was leached for 24 or 168 h. The results did not indicate increasing toxicity as a result of the prolongation of the test period. A slight inhibition of biomass growth was observed for algae and duckweed, which was probably caused by the complexity of leached elements. The inorganic elements in the leachates could likely be a source of nutrients for the growth of various plant species, mainly lettuce.

It can be concluded that leaching of various inorganic and organic substances requires scientific attention, depending on the used wood, adhesives, and the method of production of the boards. All these aspects, together with the selection of appropriate biological methods, are justified in the evaluation of the ecological safety of construction products, including OSB boards, which, after the end of their use, become part of construction waste and need to be dealt with. In any case, it is necessary to further study composite materials composed of natural and artificial components and include other organisms such as invertebrates and microorganisms into the ecotoxicological battery. The biotests focused on chronic effects, and multispecies toxicity could be another prospective direction for future experimental studies.

Author Contributions: Conceptualization, K.K.; methodology, K.K., J.N.; investigation, H.S., K.K., J.B., M.B.; writing—original draft preparation, K.K., J.N., R.Č., M.B.; writing—review and editing, K.K., R.Č.; supervision, K.K., M.B., R.Č.; project administration, M.B.; funding acquisition, M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Czech Science Foundation, project No. 21-20645S.

Data Availability Statement: The primary data are available upon request.

Acknowledgments: The authors would like to thank native speaker Marek Procházka for his revision of the English language.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Tian, F.; Xu, D.; Xu, X. Extruded Solid Biofuels of Rice Straw Plus Oriented Strand Board Residues at Various Proportions. *Energies* **2020**, *13*, 3468. [CrossRef]
2. Lopes, M.A.M.; de Souza Pádua, M.; de Carvalho, J.P.R.G.; Simonassi, N.T.; Lopez, F.P.D.; Colorado, H.A.; Vieira, C.M.F. Natural based polyurethane matrix composites reinforced with bamboo fiber waste for use as oriented strand board. *J. Mater. Res. Technol.* **2021**, *12*, 2317–2324. [CrossRef]
3. Nguyen, D.L.; Luedtke, J.; Nopens, M.; Krause, A. Production of wood-based panel from recycled wood resource: A literature review. *Eur. J. Wood Wood Prod.* **2023**, *81*, 557–570. [CrossRef]
4. Yorur, H. Utilization of Waste Polyethylene and its Effects on Physical and Mechanical Properties of Oriented Strand Board. *Bioresources* **2016**, *11*, 2483–2491. [CrossRef]

5. Barbirato, G.H.A.; Lopes Junior, W.E.; Hellmeister, V.; Pavesi, M.; Fiorelli, J. OSB Panels with Balsa Wood Waste and Castor Oil Polyurethane Resin. *Waste Biomass Valoris.* **2020**, *11*, 743–751. [\[CrossRef\]](#)
6. Hybská, H.; Mordáčová, M.; Samešová, D.; Čabalová, I. Ecotoxicological tests of the particleboards containing rubber waste. *Wood Res.* **2023**, *68*, 758–767. [\[CrossRef\]](#)
7. Joscák, T.; Teischinger, A.; Mueller, U.; Mauritz, R. Production and material performance of long-strand wood composites: Review. *Wood Res.* **2006**, *51*, 37–49.
8. Böhm, M. The influence of moisture content on thickness swelling and modulus of elasticity in oriented strand board bending. *Wood Res.* **2009**, *54*, 79–90.
9. Hodousek, M.; Böhm, M.; Lemaster, R.L.; Bures, M.; Berankova, J.; Cvach, J. Air Permeation Rate of Oriented Strand Boards (OSB/3 and OSB/4). *Bioresources* **2015**, *10*, 1137–1148. [\[CrossRef\]](#)
10. Jeong, G.Y. Forest Management on Mechanical Properties of Oriented Strand Board. *For. Prod. J.* **2016**, *66*, 371–377. [\[CrossRef\]](#)
11. Stombock, L.B.; Jeremic-Nicolic, D.; Baldwin, B.; Borazjani, H.; Diehl, S.V. Bioremediation of oriented strand board (OSB) Process Wastewater. *Bioresources* **2016**, *11*, 10002–10013. [\[CrossRef\]](#)
12. Widhalm, B.; Ters, T.; Srebotnik, E.; Rieder-Grading, C. Reduction of aldehydes and terpenes within pine wood by microbial activity. *Holzforschung* **2016**, *70*, 895–900. [\[CrossRef\]](#)
13. Crisostomo, M.C.; Soares Del Menezzi, C.H. Evaluation of the Effect of Thermo-mechanical Treatment on the Resistance of Commercial OSB to Decay Fungi. *Mater. Sci.-Medziag.* **2019**, *25*, 190–194. [\[CrossRef\]](#)
14. Brown, S.K. Chamber assessment of formaldehyde and VOC emissions from wood-based panels. *Indoor Air* **1999**, *9*, 209–215. [\[CrossRef\]](#)
15. Makowski, M.; Ohlmeyer, M. Influences on VOC emissions of wood-based panels. In Proceedings of the Ninth Panel Products Symposium, Llandudno, Wales, UK, 5–7 October 2005.
16. Gminski, R.; Tang, T.; Mersch-Sundermann, V. Cytotoxicity and genotoxicity in human lung epithelial A549 cells caused by airborne volatile organic compounds emitted from pine wood and oriented strand boards. *Toxicol. Lett.* **2010**, *196*, 33–41. [\[CrossRef\]](#) [\[PubMed\]](#)
17. Rybinski, P.; Syrek, B.; Szwed, M.; Bradło, D.; Zukowski, W.; Marzec, A.; Śliwka-Kaszynska, M. Influence of Thermal Decomposition of Wood and Wood-Based Materials on the State of the Atmospheric Air. Emissions of Toxic Compounds and Greenhouse Gases. *Energies* **2021**, *14*, 324. [\[CrossRef\]](#)
18. Richter, K.; Gugerli, H. Wood and wood products in comparative life cycle assessment. *Holz Als Roh- und Werkstoff* **1993**, *54*, 225–231. [\[CrossRef\]](#)
19. Rivela, B.; Hospido, A.; Moreira, M.T.; Feijoo, G. Life cycle inventory of particleboard: A case study in the wood sector. *Int. J. Life Cycle Assess.* **2006**, *11*, 106–113. [\[CrossRef\]](#)
20. Wilson, J.B. Life-cycle inventory of medium density fiberboard in terms of resources, emissions, energy and carbon. *Wood Fiber Sci.* **2010**, *42*, 107–124.
21. Ferro, F.S.; Silva, D.A.L.; Lahr, F.A.R.; Argenton, M.; Gonzalez-García, S. Environmental aspects of oriented strand boards production. A Brazilian case study. *J. Clean. Prod.* **2018**, *183*, 710–719. [\[CrossRef\]](#)
22. Piekarski, C.M.; Francisco, A.C.; Luz, L.M.; Silva, D.A.L. Life cycle assessment of medium-density fiberboard (MDF) manufacturing process in Brazil. *Sci. Total Environ.* **2017**, *575*, 103–111. [\[CrossRef\]](#) [\[PubMed\]](#)
23. CSN EN 300 (4926); Oriented Strand Boards (OSB)—Definitions, Classification and Specifications. CSNI: Prague, Czech Republic, 2006.
24. Taylor, B.R.; Goudey, S.; Carmichael, N.B. Toxicity of aspen wood leachate to aquatic life: Laboratory studies. *Environ. Toxicol. Chem.* **1996**, *15*, 150–159. [\[CrossRef\]](#)
25. Rex, F.J.; Dube, S.; Kruskopf, P.; Berch, S. Investigating potential toxicity of leachate from wood chip piles generated by roadside biomass operations. *Forests* **2016**, *7*, 40. [\[CrossRef\]](#)
26. Libralato, G.; Losso, C.; Volpi, G.A. Toxicity of untreated wood leachates towards two salt water organisms (*Crassostrea gigas* and *Artemia franciscana*). *J. Hazard. Mater.* **2007**, *144*, 590–593. [\[CrossRef\]](#) [\[PubMed\]](#)
27. Nascimento, M.S.; Santana, A.L.B.D.; Maranhao, L.S.; Bieber, L.S. Phenolic extractives and natural resistance of wood. In *Biodegradation—Life of Science*; IntechOpen: London, UK, 2013; pp. 349–370.
28. Heisterkamp, I.; Gartiser, S.; Schoknecht, U.; Happel, O.; Kalbe, U.; Kretzschmar, M.; Ilvonen, O. Investigating the ecotoxicity of construction product leachates as multicomponent mixtures. *Environ. Sci. Eur.* **2023**, *35*, 7. [\[CrossRef\]](#)
29. Machrafi, Y.; Prévost, D.; Beauchamp, C.J. Toxicity of phenolic compounds extracted from bark residues of different ages. *J. Chem. Ecol.* **2006**, *32*, 2595–2615. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Esteves, B.; Videira, R.; Pereira, H. Chemistry and ecotoxicity of heat treated pine wood extractives. *Wood Sci. Technol.* **2011**, *45*, 661–676. [\[CrossRef\]](#)
31. Barbero-Lopez, A.; Akkanen, J.; Lappalainen, R.; Peraniemi, S.; Haapala, A. Bio-based wood preservatives: Their efficiency, leaching and ecotoxicity compared to a commercial wood preservative. *Sci. Total Environ.* **2021**, *753*, 142013. [\[CrossRef\]](#) [\[PubMed\]](#)
32. Pino-Otin, M.R.; Navarro, J.; Val, J.; Roig, F.; Mainar, A.M.; Ballester, D. Spanish *Satureja montana* L. hydrolate: Ecotoxicological study in soil and water non-target organisms. *Ind. Crops Prod.* **2022**, *178*, 114553. [\[CrossRef\]](#)
33. Taskaeva, A.A. Collembola Communities (Hexapoda, Collembola) of Coniferous Forests in the Zone of Influence of Pulp and Paper Industry. *Contemp. Probl. Ecol.* **2022**, *14*, 651–664. [\[CrossRef\]](#)

34. Attoumani, R.B.; de Vaulfleury, A.; Crini, N.; Fatin-Rouge, N. Assessing natural clays of a contaminated site to stabilize and reduce the ecotoxicity of a coal tar. *Ecotoxicol. Environ. Saf.* **2020**, *190*, 110081. [CrossRef] [PubMed]
35. ČSN EN 12457-4 (838005); Charakterizace odpadů—Vyluhování—Ověřovací zkouška vyluhovatelnosti zrnitých odpadů a kalů—Část 4: Jednostupňová vsádková zkouška při poměru kapalně a pevné fáze 10 l/kg pro materiály se zrnitostí menší než 10 mm (bez zmenšení velikosti částic, nebo s ním). CSNI: Prague, Czech Republic, 2003.
36. Kobetičová, K.; Böhm, M.; Jerman, M.; Dušek, J.; Černý, R. Ecotoxicity and Biodegradation of Sustainable Environment-Friendly Bone-Glue-Based Adhesive Suitable for Insulation Materials. *Polymers* **2022**, *14*, 2209. [CrossRef] [PubMed]
37. OECD. *OECD Test No. 201; Alga, Growth Inhibition Test*; OECD Guidelines for the Testing of Chemicals, Section 2: Effects on Biotic Systems; OECD Publishing: Paris, France, 2006.
38. OECD. *OECD Test No. 221; Lemna sp. Growth Inhibition Test*; OECD Guidelines for the Testing of Chemicals, Section 2: Effects on Biotic Systems; OECD Publishing: Paris, France, 2006.
39. OECD. *OECD Test No. 208; Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test*; OECD Guidelines for the Testing of Chemicals, Section 2: Effects on Biotic Systems; OECD Publishing: Paris, France, 2006.
40. Scott, G.T. The mineral composition of phosphate deficient cells of *Chlorella pyreniodosa* during the restoration of phosphate. *J. Cell. Comp. Physiol.* **1945**, *26*, 35–42. [CrossRef]
41. Silva, A.R.R.; Cardoso, D.N.; Cruz, A.; Lourenço, J.; Mendo, S.; Soares, A.M.V.M.; Loureiro, S. Ecotoxicity and genotoxicity of a binary combination of triclosan and carbendazim to *Daphnia magna*. *Ecotoxicol. Environ. Saf.* **2015**, *115*, 279–290. [CrossRef] [PubMed]
42. De Laender, F.; Janssen, C.R.; De Schampelaere, K.A.C. Non-simultaneous ecotoxicity testing of single chemicals and their mixture results in erroneous conclusions about the joint action of the mixture. *Chemosphere* **2009**, *76*, 428–432. [CrossRef] [PubMed]
43. Angerville, R.; Boillot, C.; Perrodin, Y. Evaluation of the combined effects of binary mixtures of sodium hypochlorite and surfactants against *Daphnia magna* Straus. *Int. J. Environ. Technol. Manag.* **2009**, *10*, 353–370. [CrossRef]
44. Eom, H.; Kim, S.; Oh, S.E. Evaluation of joint toxicity of BTEX mixtures using sulfur-oxidizing bacteria. *J. Environ. Manag.* **2023**, *325*, 116435. [CrossRef] [PubMed]
45. Osmá, E.; Elveren, M.; Karakoyun, G. Heavy metal accumulation affects growth of Scots pine by causing oxidative damage. *Air Qual. Atmos. Health* **2017**, *10*, 85–92. [CrossRef]
46. Hosseini, S.V.; Aflaki, F.; Sobhanardakani, S.; Tayebi, L.; Lashkan, A.B.; Regenstien, J.M. Analysis of mercury, selenium, and tin concentrations in canned fish marketed in Iran. *Environ. Monit. Assess.* **2013**, *185*, 6407–6412. [CrossRef]
47. Nepal, A.; Antonious, G.F.; Bebe, F.N.; Webster, T.C.; Gyawali, B.R.; Neupane, B. Heavy Metal Accumulation in Three Varieties of Mustard Grown under Five Soil Management Practices. *Environments* **2024**, *11*, 77. [CrossRef]
48. Food Data Central. Available online: <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169249/nutrients> (accessed on 25 May 2024).
49. Svenson, H. Characterization, Toxicity and Treatment of Wood Leachate Generated Out-Doors by the Wood-Based Industry. Doctoral Thesis, Linnaeus University, Kalmar, Sweden, 2014.
50. Taylor, B.R.; Carmichael, N.B. Toxicity and chemistry of aspen wood leachate to aquatic life: Field study. *Environ. Toxicol. Chem.* **2003**, *22*, 2048–2056. [CrossRef] [PubMed]
51. Borga, P.; Elowson, T.; Liukko, K. Environmental loads from water-sprinkled softwood timber. 2. Influence of tree species and water characteristics on wastewater discharges. *Environ. Toxicol. Chem.* **1996**, *15*, 1445–1454.
52. Kaczala, F.; Salomon, P.S.; Marques, M.; Granelli, E.; Hogland, W. Effects from log-yard stormwater runoff on the microalgae *Scenedesmus subspicatus*: Intra-storm magnitude and variability. *J. Hazard. Mater.* **2011**, *185*, 732–739. [CrossRef] [PubMed]
53. Libralato, G.; Avezzu, F.; Ghirardini, V.A. Lignin and tannin toxicity to *Phaeodactylum tricornutum* (Bohlin). *J. Hazard. Mater.* **2011**, *194*, 435–439. [CrossRef] [PubMed]
54. Schrimpelova, K.; Mala, J.; Bilkova, Z.; Hrich, K. Organic substances in woodchip aqueous leachates and their ecotoxicity. In Proceedings of the 18th International Multidisciplinary Scientific GeoConference SGEM 2018, Sofia, Bulgaria, 2–8 July 2018; pp. 597–604. [CrossRef]
55. Locika Setá. Available online: https://cs.wikipedia.org/wiki/Locika_set%C3%A1 (accessed on 25 May 2024).
56. Mindell, E.; Mundis, H. *Nová vitamínová bible: Nejnovější informace o vitamínech, minerálních látkách, antioxidantech, léčivých rostlinách, o doplňcích stravy, léčebných účincích potravin i lécích používaných v homeopatii*; Ikarus: Prague, Czech Republic, 2006; p. 572.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.