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Cinnamon Bark Oil as an Effective Fungicide in Protecting the Surface of Wood-Based Softboards against the Development of Mold Fungi

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Abstract: Porous wood-based boards, like any lignocellulosic material, are susceptible to biocorrosion caused by mold fungi. Their durability can be extended by using biocides. Due to the fact that porous boards are considered an ecological material, it would be beneficial to also use natural agents to protect them. For this purpose, the surface of softboards was protected with a 30% solution of cinnamon bark oil in ethanol. Three application levels were used: 75 g/m^2, 120 g/m^2, and 200 g/m^2 of solution. It has been shown that the cinnamon bark oil solution used at an application rate of 200 g/m^2 is an effective fungicide, protecting softboards (SBs) against the development of mold fungi: *T. viride* and *C. globosum*. The dominant volatile component of cinnamon oil identified in the boards turned out to be cinnamaldehyde. Three months after treatment, this substance constituted 74% of the volatile components. The proposed treatment method allows for short-term preventive protection of boards against mold fungi.

Keywords: wood-based softboards; cinnamon bark oil; biocidal effectiveness; mold fungi; GCMS

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1. Introduction

The use of wood protection agents called biocides is intended to ensure the durability of material used in various environmental conditions in which it may be exposed to the destructive effects of biotic factors. The use of biocides is regulated by the provisions of Regulation No. 528/2012 of the European Union of the Parliament and of the Council on the supply and use of biocidal products. This means that only biocides containing active substances approved for use in European Union countries can be marketed in the European Union [1]. The regulation in question significantly limited the market of active substances approved for use in biocidal products in the EU, which was dictated by ensuring maximum safety when using biocides. Among the biocidal substances used to protect wood against biodegradation, only those substances remain on the market for which it has been shown in appropriate toxicological, ecotoxicological, risk, and exposure assessment tests that they

are safe for humans, animals, and the environment [2]. Taking into account the guidelines of European law related to environmental protection, research is increasingly undertaken to assess the biocidal effectiveness of substances or chemical compounds that come from the natural environment, which are safe and renewable. Both plant metabolites and substances of animal origin or microbial cultures are assessed [3–6]. The Biocidal Products Regulation guarantees the possibility of development and research on new biocidal substances and products. Taking into account legal regulations, it is worth looking for new, safe, and effective biocides that occur naturally in nature, which may constitute an alternative to a number of synthetic substances currently used in wood protection. Due to the increasing burden on the natural environment, decisive steps must be taken to design ecological wood protection products.

The fungicide potential of plants is enormous, as evidenced by numerous publications [7–10]. The effectiveness of extracts from *Nerium oleander* L. [11], *Gynadriris sisyrinchium* (L.) Parl [12], and mistletoe leaves (*Viscum album*) [13] in protecting wood against biocorrosion caused by fungi has been proven. Tascioglu et al. [14], using extracts from plants rich in tannins to impregnate pine, beech, and poplar wood, obtained satisfactory results in protecting the wood against brown-rot and white-rot wood decay fungi. Scientific literature indicates that essential oils [15], tannins [16], flavonoids [17], and alkaloids can be used to protect wood against biocorrosion [18]. Another interesting issue is the possibility of using natural extracts from various tree species to protect wood. The natural resistance of some tree species is associated with the presence of non-structural compounds located in the bark, heartwood, or leaves, whose role is to protect the tree against biotic decomposition factors [19,20]. These compounds are mainly terpenoids, terpenes, and tannins, especially numerous in Alaska cedar, Western juniper, and Port Orford cedar [21].

Cinnamomum osmophloeum Kaneh [22], *Cinnamomum camphora* Ness et Eberm [23], and *Cinnamomum cassia* (L.) J. Presl [24] are tree species whose extracts are characterized by fungicidal properties. Cinnamon leaf and bark extracts, although they differ in chemical composition, have strong antifungal properties. Wang et al. [25], in minimum inhibitory concentration (MIC) tests, confirmed the high effectiveness of low concentrations of cinnamon leaf oils against a number of fungi causing white and brown wood decay. Chittenden and Singh [26] indicated that the fungicide effectiveness of cinnamon oil is mainly attributed to the substances it contains—cinnamaldehyde and eugenol. The same authors also proved that wood-decomposing fungi react in different ways to the toxic effects of these substances. Cinnamon extracts and oils are also considered natural remedies against mold growth. Matan and Matan [27] proved that cinnamon oil in combination with clove oil protects rubber wood surfaces against the development of mold fungi. Hu et al. [28] showed that cinnamon oil can effectively inhibit the growth of *Aspergillus niger*, *Penicillium citrinum*, *Trichoderma viride*, *Botryodiplodia theobromae*, *Fusarium moniliforme*, and *Alternaria alternata.*

According to literature reports, the biocidal effect of cinnamon bark oil is related to the biochemical activity of substances that are the components of the oil. The main phytochemical components, such as cinnamaldehyde and eugenol, are responsible for the inhibition of ATPase, amylase and proteases, regulation of ion transport through the cell membrane, limitation of DNA replication, and spore lysis [29–31].

The development of mold on wood and wood-based materials is not a rare phenomenon, especially when they are used in variable temperature and humidity conditions [32]. A huge problem of mold concerns Euro pallets, which become less resistant to damage and pose a health hazard to users. Therefore, manufacturers of this type of product carry out multiple disinfection processes to extend their durability. Introducing synthetic biocides to wood or wood-based materials always involves a certain risk of harm to the environment, therefore the search for new formulations of protection products based on natural substances means greater care for sustainable development and human health. The possibility of using natural biocides to protect porous boards (SBs), considered to be ecological materials (produced practically without the addition of chemicals), seems to be particularly important.

In our research, we wanted to demonstrate that cinnamon bark oil, known for fungicidal properties [23], can be successfully used by producers of wood protection products to protect the surface of materials against the development of mold and may be an alternative to synthetic biocides used for preventive protection of wood. Cinnamon oil is a product of natural origin, a renewable product, and scientific research shows that its killing effect against mold fungi can be used to protect wood [33].

The aim of the work is also to propose a method for protecting the surface of a porous board, which is a material that is difficult to impregnate. The use of a patented jet treatment device allowed for easy dosing of a specific dose of the preparation onto the board surface without damage in the form of warping and delamination of the board.

2. Materials and Methods

2.1. Characteristics of the Research Material

Porous boards—softboards (SBs) (STEICO, Czarnków, Poland)—with a thickness of 5 ± 0.1 mm, humidity of 6 ± 0.5%, and a density of 229 ± 6 kg/m^3 were used for the tests, used as a base for panels and floating floors. The boards were characterized by the following properties: MOR—3.1 ± 0.3 N/mm^2, MOE—378 ± 76 N/mm^2, swelling after 2 h of soaking—18.0 ± 1.3%, water absorption after 2 h of soaking—382.6 ± 21.3%. Tests of board properties were carried out in accordance with the following standards: EN 310:1994 [34], EN 317:1999 [35], EN 323:1999 [36].

2.2. Wood Treatment

The modification of softboards (SBs) was conducted using the spray method with a 30% solution of cinnamon oil in ethyl alcohol (70%). The study encompassed three quantitative variants: 75 g/m^2, 120 g/m^2, and 200 g/m^2. To ensure uniform coverage of the sample material with the oil compound, the process was carried out using a proprietary laboratory spraying device [37] depicted in Figures 1–3. The device was based on computer-controlled movement of the spray head and the height of the working table using stepper motors, along with a set of solenoid valves regulating the flow of working material and compressed air. The device provides precise spraying of samples sized 15 cm × 40 cm.

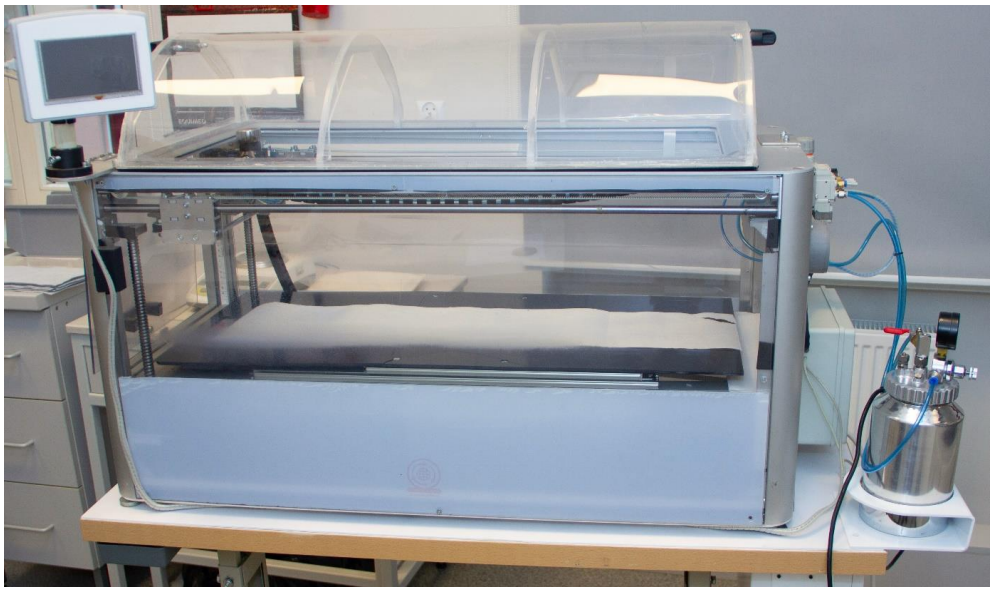


Figure 1. Laboratory spraying device (source: own research).

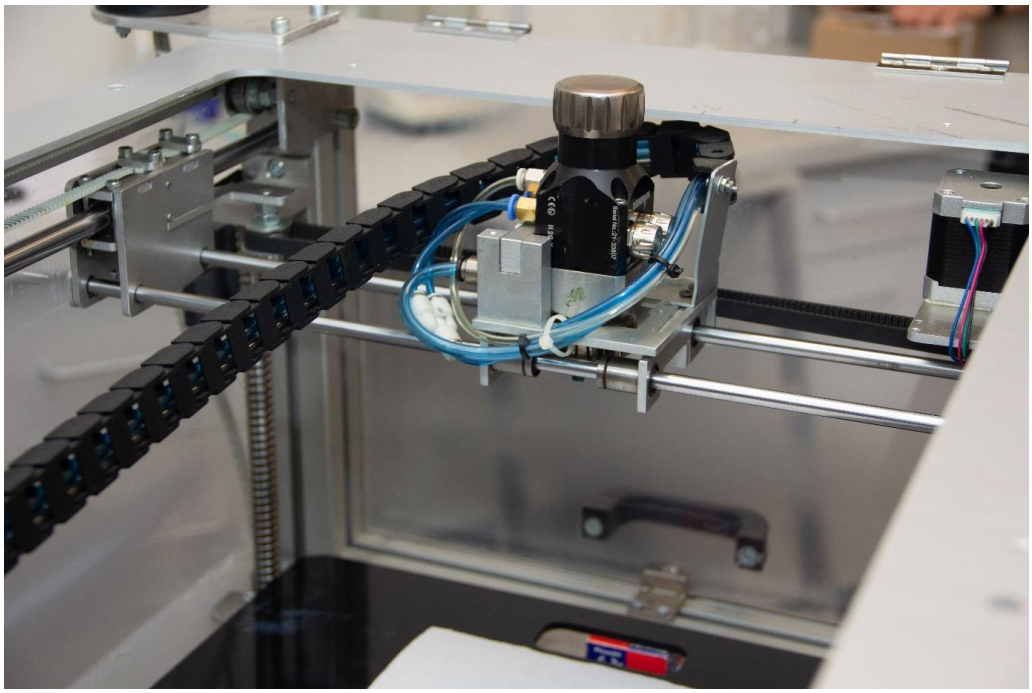


Figure 2. Spraying head with sliding system (source: own research).

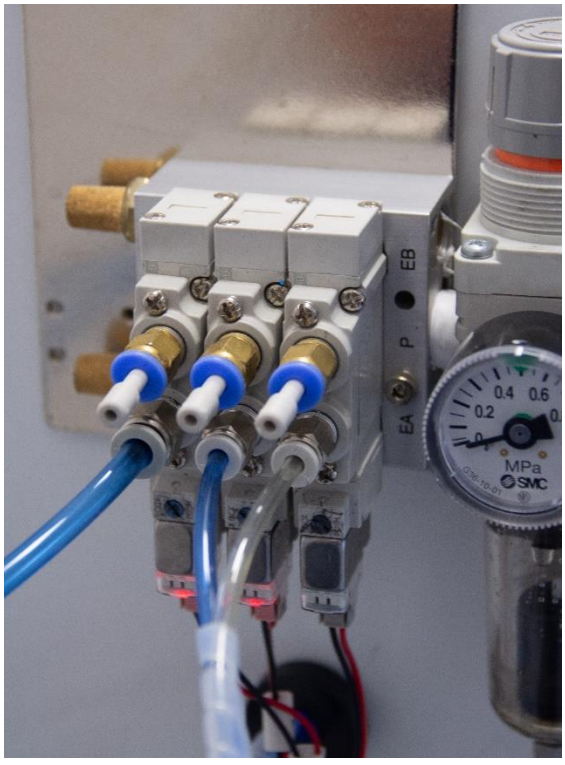


Figure 3. Panel of solenoid valves controlling media (source: own research).

During the application of compound, the following parameters of the device were used: forming and atomizing air pressure: 0.4 Mpa; substance pressure: 0.14 Mpa; distance between the sample and the spraying unit: 18 cm; movement of the spraying unit: bidirectional, single-axis, along the longitudinal axis of the spraying chamber over a length of 35 cm; the speed of the spray head movement ranged from 450 to 1250 mm/min (depending on the required quantity of sprayed solution per area unit of the sample). Samples

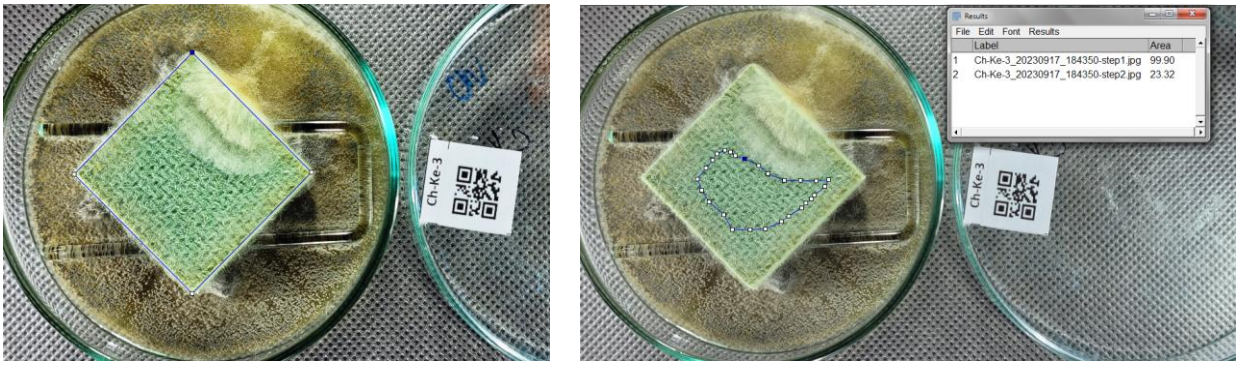
were sprayed unilaterally. After modification, each sample was dried horizontally at a temperature of 25 ± 1 °C and relative air humidity of 40 ± 5% for 48 h.

Samples intended to assess fungal growth were divided into three test groups: (1) samples whose effectiveness in protection against mold fungi was tested 24 h after treatment (24); (2) samples whose effectiveness in protection against mold fungi was tested 2 weeks after treatment and subjected to accelerated aging conditions (2T). These conditions consisted in keeping the samples in the dark, at a temperature of 38 °C and a relative air humidity of 80 ± 5%; (3) samples whose effectiveness of protection against mold fungi was tested after 3 months of storage at a room temperature of 20 ± 2 °C and a relative air humidity of 65 ± 5% (3M). Test samples from group 3 were also stored in a place protected from light.

Control samples were also divided into three groups and stored under the same conditions as the test samples. Control samples were saturated with ethyl alcohol, the same alcohol used to prepare the oil solution.

2.3. Assessment of the Effectiveness of Treatment against Molds

Samples of the treated softboard were placed on 2.5% MEA substrate (OXOID Ltd., Basingstoke, UK). The wood-based board samples were separated from the medium by glass spacers. This procedure was intended to prevent the components of the microbiological medium from having a direct impact on the material. The samples were placed in such a way that the treated surface was on the side of the Petri dish lid. Four inocula of the mold fungi *Trichodema viride* Pers., strain A-102 and *Chaetomium globosum* Kunze, strain A-141 (ATCC 6205) were placed at a specified distance opposite the center of each edge of the sample. The inoculum size was 2–3 mm. The cultivation of mold fungi was carried out in a Thermolyne Type 42000 thermal incubator (ThermoFisher Scientific, Waltham, MA, USA), under temperature and humidity conditions of 25 °C and 66 ± 2%. The degree of fungi growing over the surface of wood-based board samples was determined on the basis of high-resolution photographs taken daily for 14 days. The effectiveness of treatment was determined as the percentage of fungal growth on the sample surface in relation to the total surface of the test sample (Figure 4a,b). The percentage growth of fungi on the surface of samples was determined with an accuracy of 5% using the ImageJ2 image analysis program (Fiji v.1.52i) [38].



(**a**) (**b**)

Figure 4. Method for determining the growth of fungi on the surface of samples, using ImageJ 1.54f software: (**a**) Measurement of the total sample area; (**b**) Determination of the free field.

Step1—checking whether the measurement of the total sample area is P = 100. Permissible measurement error ±1%.

Step2—determining the area of the surface not covered by mycelium P1.

Step3—determination of the mycelium growth area on the sample surface P2 = 100 − P1.

2.4. GCMS Analysis

The wood-based softboard material samples (5 g) were divided into fragments with a surface area of 0.5 cm^2 each. The tested material was placed in a 100 mL conical flask secured with aluminum foil. Then, the sample was incubated for 2 h at room temperature to achieve maximum vapor pressure of volatile compounds. SPME solid-phase microextraction analysis was performed using 100 µm polydimethylsiloxane (PDMS) fiber (Supelco Ltd., Bellefonte, PA, USA). Fiber exposure was performed using the surface method for 30 min at 20 °C. After exposure, the fiber was transferred to the gas chromatograph injector, where the analytes were thermally desorbed. The process time and temperature were 5 min, 250 °C, respectively. Gas chromatography was used to analyze the chemical composition (GC-MS, Varian 450GC compressed 240 MS, Varian, Palo Alto, CA, USA). The carrier gas used was helium, the flow rate of which was 1 mL/min. The dispenser temperature was 250 °C. Separation of the analytes was carried out using a 30 m × 0.25 mm capillary column with a moderately polar HP-5 (polysiloxanmethylphenyl) stationary phase and a layer thickness of 0.25 µm. The column oven temperature program was as follows: start—50 °C for 5 min isotherm, then set to a temperature gradient of 10 °C/min to 300 °C (5 min isotherm). Based on NIST.08 and the Willey database, compounds found in the extracts were identified. GC-MS analysis was performed in duplicate.

2.5. Statistical Analysis

Statistical analysis of the results was carried out in Statistica version 13 (TIBCO Software Inc., Palo Alto, CA, USA). Analysis of variance (ANOVA) was used to test ($\alpha = 0.05$) for significant differences between factors. A comparison of the means was performed by a Tukey test, with $\alpha = 0.05$. In order to describe the relationships between the studied variables, the techniques of scaled heat maps made in R studio were used.

3. Results

3.1. Assessment of Biocidal Effectiveness against Mold Fungi

The assessment of biocidal effectiveness was expressed as the percentage of inhibition of the growth of mold fungi on the surface of wood-based softboard samples. The conducted research shows that the effective dose of biocide that completely inhibits the growth of *Trichoderma viride* cannot be less than 200 g/m^2 (Figure 5a). However, subsequent studies indicate that it is not sufficient for long-term protection (Figure 5 c,e). The assessment of biocidal effectiveness carried out on SB samples 3 months after application of the product showed a slight—less than 3%—increase in *T. viride* (Figure 5e). Lower doses of cinnamon oil solution, 75 and 120 g/m^2, did not protect the surfaces of wood-based board samples against growth by the *T. viride* (Figure 5 a,c,e). The application dose of 200 g/m^2 also effectively inhibited the growth of the *Chaetomium globosum*, both shortly after treatment (Figure 5b) and during 2 weeks of incubation (Figure 5d) of wood-based softboards at elevated temperature. During this short period of time, a greater sensitivity of the fungus to a lower share of biocide on the board surface was also observed. The biocide dose of 120 g/m^2 effectively inhibited the growth of *C. globosum* on the plate surface (Figure 5d). Three months after applying the oil to the plate surface, no fungicide effect was observed, although the growth of the fungus *C. globosum* on the sample with the highest dose of biocide was delayed in entrainment to the control plates (Figure 5f).

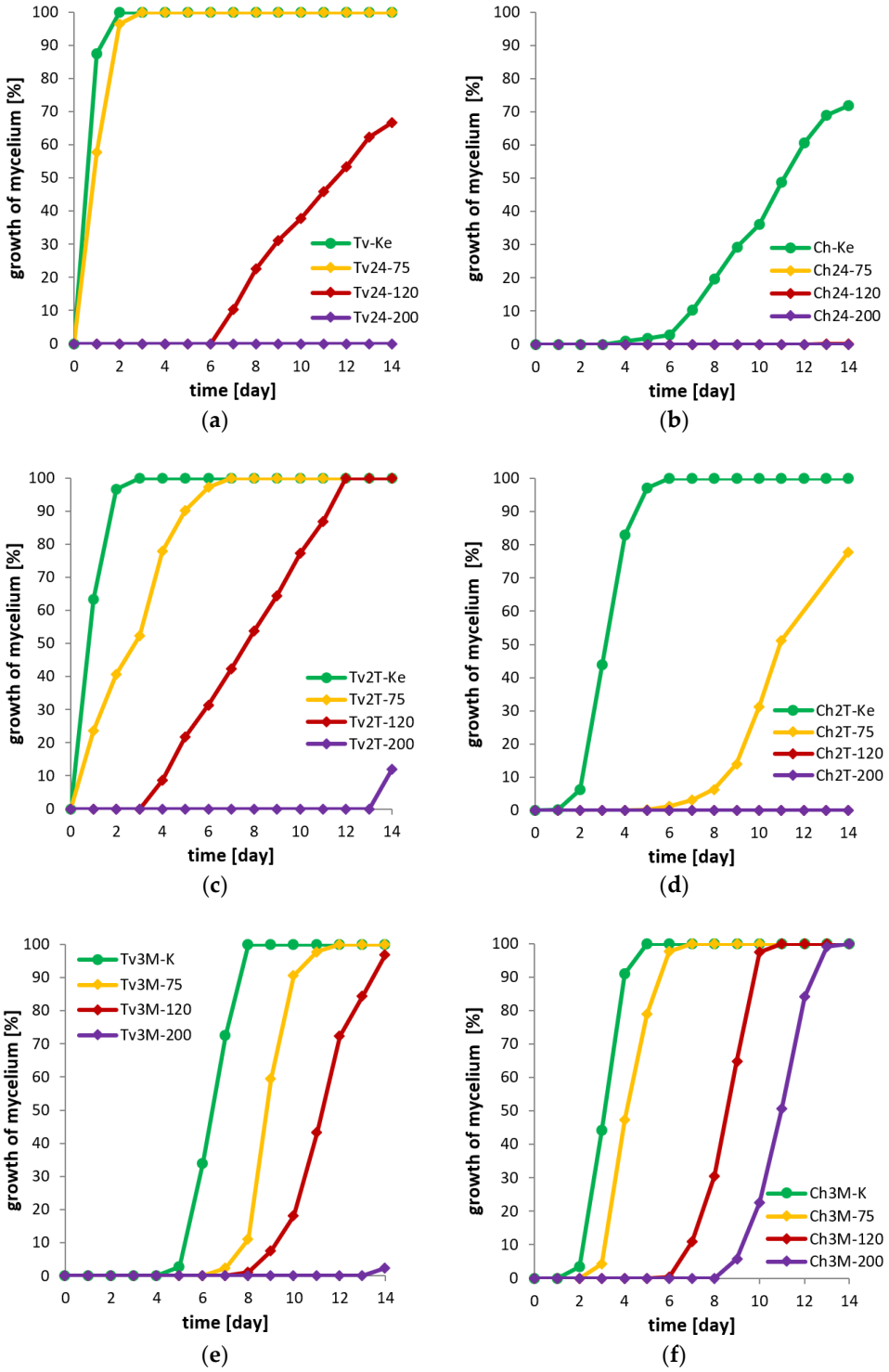


Figure 5. Percentage of fungi growing on the surface of wood-based boards (control and saturated with cinnamon bark oil): (**a**,**c**,**e**)—*T. viride*, (**b**,**d**,**f**)—*C. globosum*. Research shows: (**a**,**b**) effectiveness after 24 h (24); (**c**,**d**) effectiveness after 2 weeks (2T); (**e**,**f**) effectiveness after 3 months (3M). Legend: Ch, Tv—type of mold, K—control board, 75, 120, 200—not carrying the preparation at a dose of 75, 120, and 200 g/m^2.

Considering the influence of all the tested factors (fungus, concentration, time since treatment, test day) and the interaction between these factors on the growth of fungi on SBs (Table 1), it should be concluded that all of them had a statistically significant effect on the growth of the samples ($p < 0.05$). Among the factors tested, the concentration of

the biocide used had the greatest percentage impact (25.2%). The interaction between the type of fungus and the time since treatment was also characterized by a similar effect size (21.7%). However, it is worth noting here that individually both the fungus and the time since treatment had a small percentage impact (1.0% and 1.3%, respectively) on the growth of fungi on the surface of SBs. Similarly, most of the studied factors and interactions between these factors had a lower impact than the impact of factors not included in this study (error 6.4%).

Table 1. ANOVA for selected factors influencing the growth of mold fungi on the surface of samples.

Source of Variation	Sum of Squares SS	Mean Sum of Squares MS	Fisher's F-Test F	Significance Level *p*	Percentage of Contribution P [%]
Fungi	20,758	20,758	110.343	0.000000	1.0
Concentration	534,996	178,332	947.933	0.000000	25.2
Time since treatment	28,462	14,231	75.645	0.000000	1.3
Test day	257,004	18,357	97.580	0.000000	12.1
Fungi × Concentration	39,944	13,315	70.776	0.000000	1.9
Fungi × Time since treatment	460,021	230,011	1222.634	0.000000	21.7
Concentration*Time since treatment	66,936	11,156	59.300	0.000000	3.1
Fungi × Test day	20,980	1499	7.966	0.000000	1.0
Concentration × Test day	84,238	2006	10.661	0.000000	4.0
Time since treatment × Test day	30,111	1075	5.716	0.000000	1.4
Fungi × Concentration × Time since treatment	152,131	25,355	134.777	0.000000	7.2
Fungi × Concentration × Test day	39,125	932	4.952	0.000000	1.8
Fungi × Time since treatment × Test day	92,354	3298	17.533	0.000000	4.3
Concentration × Time since treatment × Test day	44,398	529	2.810	0.000000	2.1
Fungi × Concentration × Time since treatment × Test day	116,032	1381	7.343	0.000000	5.5
Error	135,075	188	-	-	6.4

Considering individually the influence of factors (concentration, time since treatment, day of the test) and the interaction between these factors on the growth of fungi on the surface of SBs by individual fungi: *Trichoderma viride* (Table 2) and *Chaetomium globosum* (Table 3), it should be stated that also in these cases, the greatest percentage impact was demonstrated by the concentration of the biocide used (31.8%—Table 2 and 21.9%—Table 3). The increase in concentration generally had a statistically significant impact on the percentage of samples covered by individual fungus (different homogeneous groups—Tables 2 and 3). Both in the case of *T. viride* and *C. globosum*, the time since treatment also had a significant percentage influence (25.2%—Table 2 and 20.8%—Table 3). Extending the time after treatment also generally had a statistically significant impact on the percentage of samples fouled by individual fungi (various homogeneous groups—Table 4).

Table 2. ANOVA for selected factors influencing the growth of *T. viride* on the surface of samples.

Source of Variation	Sum of Squares SS	Mean Sum of Squares MS	Fisher's F-Test F	Significance Level *p*	Percentage of Contribution P [%]
Concentration	368,996.9	122,999.0	430.839	0.000000	31.8
Time since treatment	291,613.5	145,806.8	510.729	0.000000	25.2
Test day	92,436.1	6602.6	23.127	0.000000	8.0
Concentration × Time since treatment	156,571.2	26,095.2	91.406	0.000000	13.5
Concentration × Test day	60,303.9	1435.8	5.029	0.000000	5.2
Time since treatment × Test day	37,236.4	1329.9	4.658	0.000000	3.2
Concentration × Time since treatment × Test day	49,956.1	594.7	2.083	0.000002	4.3
Error	102,204.5	285.5	-	-	8.8

Table 3. ANOVA for selected factors influencing the growth by *C. globosum* on the surface of samples.

Source of Variation	Sum of Squares SS	Mean Sum of Squares MS	Fisher's F-Test F	Significance Level *p*	Percentage of Contribution P [%]
Concentration	205,963.9	68,654.6	751.902	0.00	21.9
Time since treatment	196,416.1	98,208.1	1075.570	0.00	20.8
Test day	186,252.0	13,303.7	145.702	0.00	19.8
Concentration × Time since treatment	62,606.0	10,434.3	114.276	0.00	6.6
Concentration × Test day	62,723.6	1493.4	16.356	0.00	6.7
Time since treatment × Test day	85,219.1	3043.5	33.333	0.00	9.0
Concentration × Time since treatment × Test day	110,473.1	1315.2	14.404	0.00	11.7
Error	32,870.8	91.3	-	-	3.5

Table 4. Homogeneous groups regarding samples overgrown by fungi.

Factor	Value	Homogeneous Groups Regarding the Covered Area	
		Trichoderma viride	*Chaetomium globosum*
Concentration	Control	a, b	A
	75	b	B
	120	c	C
	200	d	C
Time since treatment	24	a	A
	2T	a	B
	3M	b	C

3.2. Identification of Biocide Volatile Components in SBs

Phytochemical tests were carried out on SB samples 3 months after application of the preparation. The study aimed to illustrate the percentage composition of volatile compounds in cinnamon extracts and which substances are dominant. The tests were carried out on samples that were not exposed to fungi.

Tests for the identification of volatile oil components contained in the boards three months after treatment indicated the presence of 26 substances (Table 5). The dominant oil component in the boards was cinnamaldehyde. The aldehyde content in the boards ranged from 67 to 74% (Table 5). The remaining volatile components occurred in amounts ranging from 0.2% to less than 6%.

Table 5. Chemical composition of the headspace fraction (HS) of softboard.

Systematic Substance Name	Common Name	No. CAS	RT [min]	Retention of the Preparation in the Sample [g/m^2]		
				200	120	75
				Peak Share in the Chromatogram [%]		
Benzaldehyde	-	100-52-7	8.28	0.26	0.20	0.31
Tert-butylobenzen	-	98-06-6	9.70	trace	0.56	0.40
Isopropenyl-1-methyl-1-cyclohexene	D-Limonen	5989-27-5	9.80	trace	0.31	-
1,3,3-Trimethyl-2-oxabicyclo[2.2.2]octane	Eucalyptol	470-82-6	9.85	0.22	0.97	0.57
p-mentha-1,4-diene	ɣ-Terpinen	99-85-4	10.39	trace	0.29	-
4-methylidene-1-propan-2-ylbicyclo[3.1.0]hexane	Sabinene	3387-41-5	10.94	trace	0.33	0.31
3,7-Dimethyl-1,6-octadien-3-yl acetate	Linalyl acetate	115-95-7	11.14	1.30	1.63	1.81
2-Phenylethanol	-	60-12-8	11.37	0.43	0.32	0.23
exo-1,7,7-Trimethylbicyclo[2.2.1]heptan-2-ol	Isoborneol	12-76-5	12.31	trace	0.24	0.22
4-Carvomenthenol	Terpinen 4-ol	562-74-3	12.49	0.42	0.50	0.57
3-Cyclohexene-1-methanol	alfa-Terpineol	98-55-5	12.71	3.16	4.05	3.90
Phenethyl acetate	-	103-45-7	13.68	2.35	2.69	2.99
trans-3-Phenyl-2-propenal	trans-Cinnamaldehyde	14371-10-9	14.05	74.45	68.38	67.84
1-methoxy-4-(1-propenyl)benzene	anethol	104-46-1	14.16	2.37	2.62	2.82
Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, 2-acetate	Isobornyl acetate	125-12-2	14.21	0.70	1.02	0.99
p-menth-1-en-8-yl acetate	Terpinyl Acetate	80-26-2	15.02	2.40	2.89	3.3
2-Methoxy-4-(2-propenyl)phenol	Eugenol	97-53-0	15.13	3.80	3.89	3.64
4-hexen-1-ol, 5-methyl-2-(1-methylethenyl)-, acetate	Lavandulyl acetate	20777-39-3	15.40	0.40	0.42	0.46
1,3-dimethyl-8-(1-methyl ethyl) tricyclo(4.4.0.0.02,7-)dec-3-ene	copaene	3856-25-5	15.45	0.42	0.98	0.98
4-Allyl-1,2-dimethoxybenzene,	Methyl eugenol	93-15-2	15.70	trace	trace	0.25
Bicyclo[7.2.0]undec-4-ene, 4,11,11-trimethyl-8-methylene-	β-Caryophyllene	87-44-5	16.06	0.67	1.61	1.75
3-phenyl-2-propen-1-yl acetate	cinnamyl acetate	103-54-8	16.26	4.72	5.37	5.73
3-phenyl-2-propenoic acid ethyl ester	ethyl (Z)-cinnamate	4610-69-9	16.53	0.33	trace	0.39
-Methylene-4,12,12-trimethyl-5-oxatricyclo[8.2.0.0^{4,6}]dodecane	-	1139-30-6	18.10	0.85	trace	0.48
Benzyl benzoate	-	120-51-4	20.04	0.26	trace	0.33
Octahydro-3,6,8,8-tetramethyl-1H-3a,7-methanoazulen-6-ol-6-acetate	Cedryl acetate	77-54-3	20.13	0.42	-	-

In the control boards, not treated with the oil solution, three volatile substances were identified, originating from raw materials intended for the production of SBs (Table 6).

Table 6. Chemical composition of the headspace fraction (HS) of control boards.

Systematic Substance Name	Ordinary Substance Name	No. CAS	RT [min]	Peak Share in the Chromatogram [%]
2-isopropyl-5-methylphenol	Tymol	89-83-8	14.30	9.29
hexyl hexanoate	-	6378-65-0	15.44	12.46
3,7,11-trimethyldodeca-1,3,6,10-tetraene	Farnesene	502-61-4	17.02	77.24

3.3. Graphical Identification of Research Results

The use of heat maps with a scaling function made it possible to capture hidden relationships between the analyzed variables in samples of wood-based boards treated with different doses of cinnamon bark oil solution (Figure 6). Figure 7 shows the relationships resulting from the growth of *T. viride* and *C. globosum* mycelium on softboards treated with cinnamon bark oil at a concentration of 200 g/m^2 after a 3-month storage period. The heat map in Figure 6 clearly shows that the predominant chemically active compound present on the SB was trans-3-Phenol-2-propenol, the highest concentration of which was recorded in samples treated in essential oil at a concentration of 200 g/m^2 (value A in the diagram). The content of this compound corresponded most closely with the content of 2-Methoxy-4-(2-propenyl)phenol, which was visible in the form of a cluster formed as a result of cluster analysis visible on the right. The analysis of the obtained data led to the distinction of the behavior of grafted mycelium on SBs after 3 months of storage and observation of their development for a period of 14 days (Figure 7). It is clearly visible that *T. viride* (Tv3M-200) did not develop on SBs protected with cinnamon oil, in relation to the control boards (Tv3-K), in which colonies of the studied fungus began to appear after 8 days, although much slower than in the case of *C. globosum*, where the beginnings of their colonies were visible after 3 days (Ch3M-K). Treatment of SBs with cinnamon oil at a dose of 200 g/m^2 (Ch3M-200) delayed the development of *C. globosum* colonies by 8 days compared to the control but did not provide longer protection of the plates against colonization with the tested mycelium.

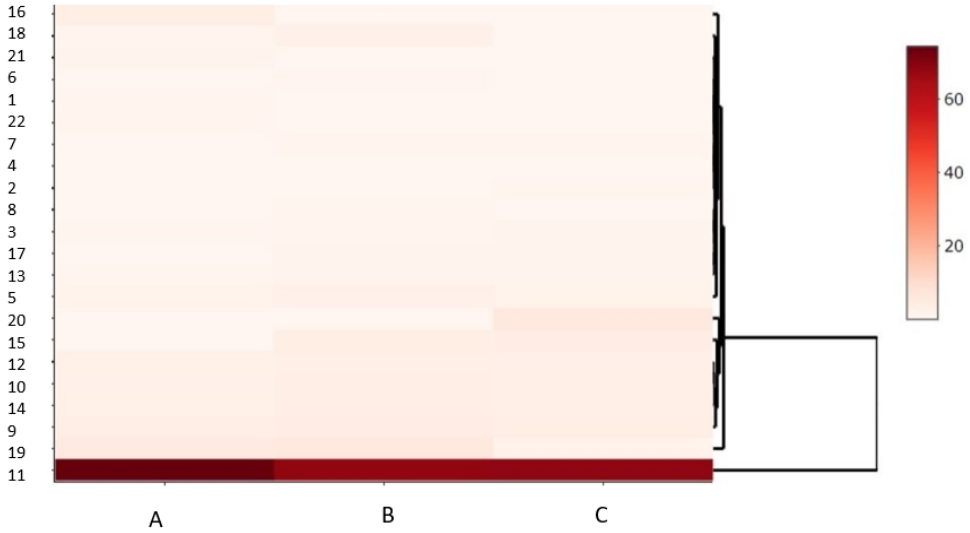


Figure 6. Imaging variations in the content of volatile components of cinnamon bark oil in wood-based boards: **1**—Benzaldehyde, **2**—Tert-butylobenzen, **3**—1,3,3-Trimethyl-2-oxabicyclo[2.2.2]octane, **4**—4-methylidene-1-propan-2-ylbicyclo[3.1.0]hexane, **5**—3,7-Dimethyl-1,6-octadien-3-yl acetate, **6**—2-Phenylethanol, **7**—exo-1,7,7-Trimethylbicyclo[2.2.1]heptan-2-ol, **8**—4-Carvomenthenol, **9**—3-Cyclohexene-1-methanol, **10**—Phenethyl acetate, **11**—trans-3-Phenyl-2-propenal, **12**—1-methoxy-4-(1-propenyl)benzene, **13**—Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, 2-acetate, **14**—p-menth-1-en-8-yl acetate, **15**—2-Methoxy-4-(2-propenyl)phenol, **16**—4-hexen-1-ol, 5-methyl-2-(1-methylethenyl)-, acetate, **17**—1,3-dimethyl-8-(1-methyl ethyl) tricyclo(4.4.0.0.02,7-)dec-3-ene, **18**—Bicyclo[7.2.0]undec-4-ene, 4,11,11-trimethyl-8-methylene-, **19**—3-phenyl-2-propen-1-yl acetate, **20**—3-phenyl-2-propenoic acid ethyl ester, **21**—-Methylene-4,12,12-trimethyl-5-oxatricyclo[8.2.0.04,6]dodecane, **22**—Benzyl benzoate. **A**—fraction (HS) of 200 g/m^2, **B**—fraction (HS) of 75 g/m^2, **C**—fraction (HS) of 120 g/m^2.

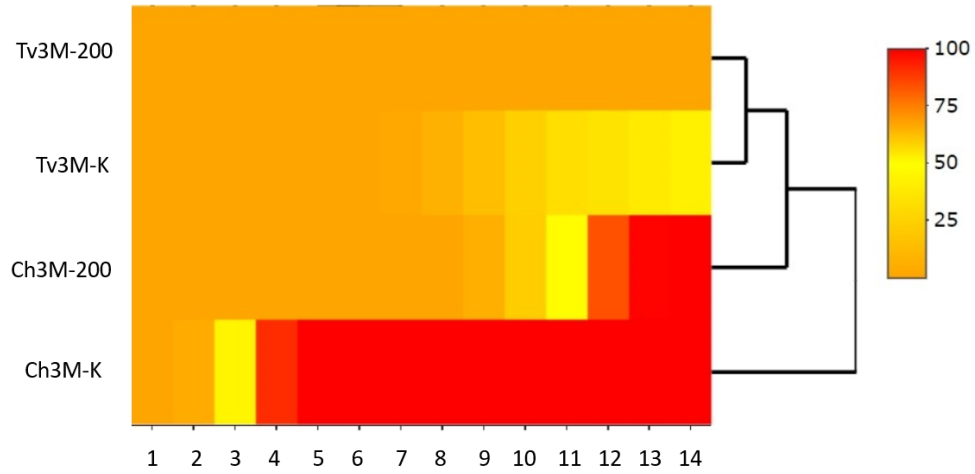


Figure 7. Heat map imaging of the growth of mold fungi during 14 days of cultivation: Tv3M-200 SBs treated with a dose of 200 g/m^2 of cinnamon oil solution, treated with *T. viride*; Ch3M-200 SBs treated with a dose of 200 g/m^2 of cinnamon oil solution, treated with *C. globosum*; Tv3-K, Ch3-M SBs without protection—control; 1–14—day of analysis.

4. Discussion

In recent years, the number of scientific reports on new biocidal preparations for wood protection applications based on substances of natural origin has increased [39,40]. The 30% solution of cinnamon bark oil used at a dose of 200 g/m^2 turned out to be a good fungicide, protecting wood-based boards against the development of mold fungi, but not effective enough to provide long-term protection. An ethanol solution of cinnamon bark oil can be used for preventive, short-term protection of surfaces against molds. The obtained test results confirm the reports of other authors about the biocidal effectiveness of cinnamon oil against mold fungi [41,42]. Substances with fungicide properties can be obtained from various parts of plants. Cinnamon oil can be obtained from both leaves and bark, but the composition of the active substances of such oils is different. Cinnamon leaf oil is rich in eugenol, which is also believed to have a fungicidal effect. However, eugenol has a more irritating and allergenic effect than cinnamic aldehyde, which dominates in cinnamon bark [43]. Cinnamon bark oil therefore appears to be a safer biocide for users [44]. However, the chemical composition of cinnamon oil depends not only on the part of the plant from which it is obtained but also on the species. According to Li et al. [23], the main phytochemical components of *Cinnamomum camphor* are camphor, eucalyptol, terpineol, linalool, and 4-terineol. In the SB saturated with cinnamon bark oil, 26 volatile substances were identified, with cinnamaldehyde being the dominant component. Three months after applying the oil to the surface of the board, this substance constituted 70% of the composition of volatile parts identified in the wood-based board sample. As research by other authors shows, cinnamon oil also effectively prevents the development of wood decay fungi [45], however, the biocidal effect is better in combination with other active substances [46]. Maoz et al. [47] assessed the fungicidal effectiveness of a combination of cinnamon oil with carvacrol, thymol, and extracts from the Inula viscose plant, while Antonelli et al. [48] used combinations of three essential oils: cinnamon, thyme, and wild-type thyme to impregnate wet archaeological wood. These latest studies show that essential oils can also be an important biocide in the protection of wood, which is a cultural asset and, additionally, material that is difficult to impregnate.

SBs are materials that are difficult to impregnate. Due to their structure and the lack of ingredients in the form of resins that bind and stabilize particles, the introduction of impregnations may cause delamination of the material. The structure of SBs also excludes the possibility of using many useful and simple treatment methods, such as dipping or pouring. However, simple treatment methods, such as the use of hand sprayers, may not ensure even distribution of the preparation on the surface. In our research, we proposed

a jet application method, which involves automatically applying the preparation to the surface of the tested material using a special nozzle. The proposed treatment method and the cinnamon oil used at a dose of 200 g/m^2 allow for temporary protection of the board surfaces against mold fungi, but it does not guarantee long-term protection and is no longer effective 3 months after application. Based on the statistical analyses, it is clear that the dose of the introduced preparation is the factor that determines the effectiveness of wood protection. However, when developing biocides, economic considerations should always be taken into account, which include the costs incurred for treatment but also the impact of higher doses on other properties of the boards, including the preservation of their structure.

Another factor that should be considered when using cinnamon oil as a biocide is its chemical composition. Essential oil is a complex mixture of substances that can completely inhibit the growth of fungi or only slow it down [49]. The cinnamon oil used in the experiment contained 26 volatile compounds, with cinnamaldehyde dominating. Nazzaro et al. [50] report that small amounts of this substance permanently disrupt transport through cell membranes, which leads to rapid death of the organism. Combination with eugenol, another substance found in the essential oil, further enhances this biological effect. The synergistic effect of cinnamaldehyde and eugenol against wood decay fungi is confirmed by the research of Hsu et al. [51]. The authors of the study showed that the combination of these two substances has a better fungicide effect than each tested separately.

To summarize the research results, it should be stated that cinnamon oil is a substance worth considering as a component of biocides in the protection of wood-based materials. This substance can also be used at the post-production stage and not as it is most often used for wood-based materials, i.e., during the production process.

5. Conclusions

Natural compounds such as cinnamon bark oil have great potential for use in the protection of wood and wood-based materials, although, unlike synthetic biocides, they also have certain limitations due to their chemical nature. The high content of volatile phytochemical ingredients makes them weather much easier. The high content of volatile ingredients in essential oils means that oils as biocides will not provide long-term protection of wood-based materials.

Based on the conducted research, it can be concluded that a 30% solution of cinnamon bark oil in ethanol at a dose of 200 g/m^2 protects SB samples against molds, but this protection is not long-lasting. It can therefore be concluded that cinnamon oil can be used for preventive, short-term protection of wood-based materials against mold fungi.

However, nothing stops us from conducting further research using this substance and trying to include it in the formulation of proven synthetic preparations intended for wood protection in subsequent research projects. Such actions could lead to a reduction in the amount of synthetic biocides in preparations, which is probably a good direction from the point of view of environmental protection.

It should be additionally added that an important contribution of the work is that it provides information on the effectiveness of cinnamon oil used to protect wood materials and, secondly, that the effect was documented in the process of surface protection at the post-production stage and not as it is most often used for plastics and wood, i.e., during the production process. All these findings open up the prospect of wider use of this product, not only for wood-based materials, but perhaps also for other products of natural origin, and this protection can be implemented in an environmentally safe manner, without the use of synthetic chemicals used today in the protection of technical materials.

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