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CHARACTERIZATION OF AROMATIC FIBERBOARDS

Wei Wang[1,2], Hui Shen[1], Haiqiao Zhang[1], Yang Zhang[1,2],
Yanji Zhou[1], Danyang Zhao[1]
[1]Nanjing Forestry University
China
[2]University Of Tennessee
Usa

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ABSTRACT

For use as decoration panels, wood fiber was used to prepare a new type of aromatic fiberboard using hot-press technology that mixes spices and adhesives. Experiments showed that the use of different proportions of two kinds of spices, wormwood and lavender, mixed with waterborne acrylic adhesives, had a slight influence on the curing time and viscosity of the glue. The different mixtures equally affected the physical and mechanical properties of the fiberboard and the smells similarly affected brain wave frequencies. The experimental results showed that a 20% proportion of lavender and wormwood was optimal compared with 5%, 10%, and 15%, and this amount also provided the best health-care effect. This work provides the experimental data and a theoretical basis to achieve pharmacological and health-care effects for the development of aromatic and other special kinds of fiberboard for industrial applications.

KEYWORDS: Spices, aromatic fiberboard, waterborne acrylic acid, smell, brain wave.

INTRODUCTION

Increasing prosperity has led to increased consumer expectations of material goods. Natural products are especially desired for use in all aspects of life, with a strong desire for items related to nature and ecology (Gouveia et al. 2018). Compared to other products processed from raw materials, wood can be made into boards (Pan and Jiang 2019, Liu et al. 2019b,c) for use in the construction of homes and other buildings (Guan and Guo 2009, Liu et al. 2019d,e). Consumers value wood products that retain the features of the original wood, including texture, traits of specific varieties of wood, and the aroma of wood (Xie 2001). Processed, artificial boards lack some of the superior material qualities of the original wood, such as the ability to inhibit bacteria, repel mosquitoes, and purify air, and pleasing qualities such as delicate touch and wood texture (Yerlikaya and Karaman 2020, Kulman et al. 2019, Cinar 2018). Thus, specific processing and production technologies have been developed to make boards that more closely resemble the virgin wood.

Aromas can mask unpleasant smells in rooms and make people feel happy and relaxed (Liu et al. 2019a). Special aromas from spices, such as wormwood (Gu et al. 2018), lavender, citrus, and mint, also may have medicinal effects to promote mental and physical health (Wang 2008). Among the many available household products, aromatic fiber products (Huo 2004) were originally developed in the 1980s and are made using processing and production techniques including microcapsule and blend spinning methods. These products are becoming increasingly popular among consumers (Yuan and Ye 2007). Aromatic fiber textile technology can be used to produce artificial panels with specific effects. Although the preparation of specialized products can be expensive, aromatic fiberboard can be prepared more economically by the addition of spices into the wood fiberboard.

With increasing demands for wood, the expansion of the timber industry, and an increase in the per capita income, the domestic timber market import and export volume has gradually expanded with increased industrial production, house building, and manufacture of daily consumer goods. However, domestic timber resources are limited and there is growing consumer demand for high quality wood for use in houses with an emphasis on ecological design (Antov et al. 2020, Zeng et al. 2018). Continued efforts to improve ecological design and develop new wood materials will allow the continued development of China's timber industry with increased application of indoor wood materials with greater durability. In this work, spices were added during the production of wood fiber sheets than were then combined using glue via hot-press technology. The goal was to prepare materials with spices that could exhibit pharmacological effects such as improving the sensation of well-being (Zhu and Cui 2004). Therefore, a production and processing strategy was applied to prepare aromatic fiberboard for indoor use. The performance of the prepared aromatic fiberboard was tested and the effects of the smell of the prepared materials on brain wave activity were investigated.

MATERIAL AND METHODS

Materials

Wood fiber was obtained from the fiberboard workshop of the Junyi Mineral Products Processing Factory in Lingshou County (Shijiazhuang, China) (Fig. 1a). The water content of the wood fiber was ≤ 5%, the length was 0.5 mm to 1.0 mm, the ash content was ≤ 10%, and the bulk density was approximately 25-29 $g \cdot cm^{-1}$.

Fig. 1: (a) Wood fiber, (b) wormwood, and (c) lavender dry grain.

Wormwood was provided by Jinan Zhongsheng Wormwood Products Technology Co., Ltd. (Jinan, China) (Fig. 1b). Lavender was provided by the Sixty-Five Group of Fragrance Lavender Processing Plant in Huocheng County, Yili, Xinjiang, China (Fig. 1c). Chemical and physical properties of lavender and wormwood provided from producers are listed in Tab. 1.

Tab. 1: Basic properties of lavender and wormwood (data sheets).

	Wormwood	**Lavender**
Main ingredients	Camphor	Linalyl acetate, linalool
PH value	5.3	5.6
Viscosity (cp. 20°C)	11.3	11.8
Odour characteristics	Chinese herbal medicine, tastes strong	Floral, tastes strong
Spice effect	Medicinal, refreshing, plant dye, deworming	Medicine, sleep aid, soothe the nerves, plant dye

Non-toxic waterborne acrylic resin which contents methyl methacrylate (99%) (MMA), soybean protein (99%), ammonium persulfate (98%) (APS), polyvinyl alcohol (analytically pure, PVA), vinyl acetate (analytically pure, VAc) was used as an adhesive to prepare the aromatic fiberboard. Water and acrylic acid were mixed and stirred in a beaker at a mass ratio of 1:1 (water: acrylic acid = 1: 1). The proportion of each component contained in acrylic resin: 3.8% soybean protein, 15.4% PVA, 24.6% VAC, 55.4% MMA, 0.7% APS. The curing performance was tested after the waterborne acrylic acid was mixed with spices.

Aromatic fiberboard manufacturing process

Aromatic fiberboard manufacturing was performed using an electric blast drying oven (model OGH-101-2B, manufactured by Shaoxing Shangyu District Huyue Instrument Equipment Factory, Shaoxing, China); a 250 kN flat vulcanizing machine, manufactured by Huzhou Shunli Rubber Machinery Manufacturing Co., Ltd., Huzhou, China); a multi-functional mixer (model BH-25, manufactured by Daqing Tianyi Food Machinery Co., Ltd., Daqing, China); an electronic balance, model JN-B-5, manufactured by Guangzhou Yuhua Instrument Co., Ltd., Guangzhou, China; sheet mold, dimensions of 50 mm × 50 mm × 300 mm, manufactured by the Nanjing Forestry University artificial board laboratory, Nanjing, China; and a 20 kN control electronic universal testing machine (manufactured by Shenzhen Sansi Technology Co., Ltd., Shenzhen, China).

The dried fiber was sized and added spices at concentrations of 0%, 5%, 10%, 15%, and 20%, respectively, relative to the amount of wood fiber, regarding groups 0 through 4. Then the wood fiber and spices were mixed with acrylic resin (150 $kg \cdot m^{-3}$), and paved. The continuously formed mat was prepressed before being loaded into the hot press. The hot-pressing temperature was 125°C, the pressure was 2.5 MPa, and the hot-pressing time was 4 min. The sheet thickness was

10 mm and the density was 0.7 g·cm^{-3}. After hot-pressing, samples were cooled for 24 h before the physical and mechanical properties of the material were tested.

Extract analysis

The selected spices have special aromas caused by their ingredients. In order to investigate their effective constituents, the spices were subjected to distillation (Li et al. 2019). Impurities and hard branches were first removed from the dry spice granules, then 100 g spice samples were weighed and placed into a 1000 mL glass flask. The flask was connected to a water vapor generating device and the condensing pipe at both ends, and the condensing pipe was connected with a water oil separator for essential oil extraction. Distillation was performed for 7 h, and the extracts were collected. The extracts were mixed with Na2SO4, and the yield was calculated after the removal of water. The essential oils were stored via cryopreservation for further chemical detection and analysis.

The distillation equipment used in the study included an electronic balance (model JN-B-5, manufactured by Guangzhou Yuhua Instrument Co., Ltd., Guangzhou, China) and a digital thermostatic water bath (model HH series-1, manufactured by Qingdao Juchuang Environmental Protection Equipment Co., Ltd., Qingdao, China).

The extract components were detected by gas chromatography (GC) (6890N; Agilent Technologies Inc., Santa Clara, CA, USA) and gas chromatography-mass spectrometry (GC-MS) (S6890/5973N; Agilent Technologies Inc., Santa Clara, CA, USA) using a hue-mass spectrometer (Agilent Technologies, Beijing, China). The chromatographic conditions were as follows: vaporization chamber temperature of 250°C; Supelco 18275-06 A PTE-5 Capillary column (30 m × 0.25 mm × 0.25 μm); injection amount of 0.2 μL; nitrogen as carrier gas, the flow rate was 0.9 mL·min^{-1}, and the shunt ratio was 70:1. The temperature was set to 80 °C and maintained for 15 min, increased to 190°C at a rate of 2°C·min^{-1} and maintained for 15 min, and then increased to 300°C at a rate of 15°C·min^{-1}, and held at 300°C for 15 min.

Mass spectrometry conditions were as follows: Agilent Db-5MS (50 m × 0.25 mm × 0.25 μm) column with a flow rate of 1.1 mL·min^{-1}; multiplier tube voltage of 1623 V; scanning range of 45 AMU to 450 AMU; EI ionization mode; ion voltage of 70 eV; ion source temperature of 230°C; interface temperature of 290°C; and quadrupole rod temperature of 160°C.

Scent-smelling tests on brainwaves

A Model EK brainwave tester was used (Xuzhou Zhongma Diagnostic Apparatus Co., Ltd., Xuzhou, China). In this experiment, 70 adult subjects (equal numbers of men and women, and age range of 25 to 50 years old) participated in measurements of brainwaves after smelling different prepared materials. Before entering the test room, each volunteer was instructed on laboratory safety operation specifications and completed a personal health assessment.

This test was performed in the laboratory of artificial boards at Nanjing Forestry University. During the test, each subject maintained a free and comfortable sitting posture. Brain signals were detected using electrodes. Utilizing Fourier transform, the brain's electric wave, in the form of power and frequency, showed four kinds of curves (α, β, δ, and θ) (Wang et al. 2010). An 18-lead brainwave tester was used and volunteers were asked to keep a calm and relaxed state to enable accurate display and recording of brainwave data.

The goal of these spice-containing materials is that they will give off pleasing aromas (Wang et al. 2015). Medium-density fiberboard (MDF) without spices was used as the blank control group and samples prepared with 20% wormwood or 20% lavender, were tested. During the experiment, each samples of aromatic fiberboard (50 mm × 50 mm × 10 mm) was placed in a sealed bag of the same volume, and identifying label information was concealed. The experiment was conducted such that the subjects were encouraged to relax. New groups were brought in every 6 min, each cycle lasted 7 days, with a 3-day interval in the middle as a cycle, and the trial period for each subject of two months.

RESULTS AND DISCUSSION

Waterborne acrylic resin properties

The purpose of this experiment was to understand the effect of the addition of spices on the performance of the adhesive. Tests were conducted of four groups plus a blank control group, where the four groups included wood samples prepared with 5%, 10%, 15%, or 20% of spices. The results showed slight differences in the effects of wormwood and lavender, with only a small effect on the curing time of waterborne acrylic acid. Tang (2017) reported the experimental effect of adding water-based acrylic to wood, and using this method, the curing time is shorter. As shown in Tab. 2, a trend in the effect of spice addition ratio on the curing properties of the glue can be seen. After addition of 20% of wormwood and lavender, due to the weak acidity of waterborne acrylic acid (Li et al. 2015), decreased curing time was observed.

Tab. 2: Analysis of the effect of four different spices' addition ratios on the curing time of glue.

Experimental group→ Curing time (s) ↓	Blank control	Wormwood				Lavender		
		G.1	G.2	G.3	G.4	G.1	G.2	G.3
Test 1	70	73	74	75	69	79	64	63
Test 2	74	74	74	70	72	76	68	69
Test 3	75	71	68	72	68	73	69	70
Test 4	75	73	68	70	70	72	69	71
Mean values	73.5	72.8	71.0	71.8	69.8	75.0	67.5	68.3

GC-MS detection and analysis

As shown in Tab. 3, the extracts from wormwood consisted of 32 components, with 1,8-eucalyptol (15.36%), camphor (13.21%), 4-terpineol (5.26%), and chamomile (4.35%) present at the highest concentrations. The components present at concentration greater than 1.00% included terpenes (1.12%), β-myrcene (1.29%), γ-terpinene (1.61%), artemisia ketone (1.13%), artemisia alcohol (2.31%), 2-cyclohexan-1-ol (1.62%), borneol (2.89%), trans-caryophyllene (2.74%), big root geranyl-D (1.56%), trans-carvacrol (2.74%), eugenol (1.12%), and Spartan (3.25%). Components present at less than 1.00% included α-Pinene (0.95%), β-Pinene (0.45%), and Linalool (0.91%).

Tab. 3: Main ingredients of wormwood extract.

Keep time (min)	Compound	Relative content (%)
13.23	α-Pinene	0.95
16.25	β-Pinene	0.45
18.26	Camphene	1.12
21.33	β-Myrcene	1.29
24.12	γ-terpinene	1.61
25.33	1,8-Cineole	15.36
26.15	Artemisia ketone	1.13

29.38	Artemisia alcohol	2.31
34.26	Linalool	0.91
39.71	2-cyclohexen-1-ol	1.62
40.12	Borneol	2.89
43.12	Camphor	13.21
44.02	Terpineol-4	5.26
45.08	Trans-caryoophyllene	4.81
48.71	Germacrene-d	1.56
51.22	Trans-carveol	2.74
51.31	Eugenol	1.12
53.26	Spathulenol	3.25
54.13	Azulene	4.35

Tab. 4 shows that the extracts from lavender contained 42 components, with lavender acetate (15.51%), linalool (20.56%), and linalyl acetate (24.61%) present at the highest concentrations. Components present at more than 1.00% included 1,8-eucalyptol (1.35%), cis-ocimene (2.51%), neryl acetate (1.52%), octene acetate-1-ester (2.94%), α-santalene (1.85%), borneol (2.31%), lavender alcohol (4.35%), α-terpineol (1.92%), geranyl acetate (1.91%), oleoresin (5.89%), benzoic (2.13%), and geraniol (2.35%). Components present at less than 1.00% included α-pinene (0.23%), β-pinene (0.08%), camphene (0.35%), β-myrcene (0.41%), limonene (0.26%), α-terpinene (0.22%), butanoic acid, hexylester (0.41%), 1-octen-3-ol 9 (0.27%), nerol oxide (0.41%), camphor (0.44%), bomyl acetate (0.82%), β-bisabolene (0.15%), cuminaldehyde (0.81%), nerol (0.83%), and α-cadinol (0.94%).

Tab. 4: Main ingredients of lavender extract.

Keep time (min)	Compound	Relative content (%)
15.23	α-Pinene	0.23
18.66	β-Pinene	0.08
19.56	Camphene	0.35
22.39	β-Myrcene	0.41
25.36	Limonene	0.26
26.36	1,8-Cineole	1.35
27.58	cis-Ocinmene	2.51
31.22	α-Terpinene	0.22
36.56	Octen-1-ol acetate	2.94
38.45	Butanoic acid, hexylester	0.41
40.35	1-Octen-3-ol	0.27
42.12	Nerol oxide	0.41
43.22	Camphor	0.44
45.65	Linalool	20.56
46.12	Linalyl acetate	24.61
49.35	α-Santalene	1.85
53.22	Bomyl acetate	0.82
53.45	Lavandulyl acetate	15.51
51.55	Borneol	2.31
57.54	Lavandulol	4.35
57.72	α-Terpineol	1.92
58.65	Neryl acetate	1.52

58.92	β-Bisabolene	0.15
60.33	Geranyl acetate	1.91
61.52	Cuminaldehyde	0.81
62.11	Nerol	0.83
63.56	Geraniol	2.35
64.44	Caryophyllene oxide	5.89
70.23	Benzoic acid	2.13
71.39	α-Cadinol	0.94

Jiang et al. (2019) showed that wormwood extract has a significant physiological effect on the treatment of human diseases. Tang et al. (2014) reported that the extract of lavender has a good regulating effect on the balance of the human body. The extracts from wormwood and lavender mainly included monoterpene alcohol, with a low content of oxides. The linalool, linalyl acetate, lavender acetate, and other ingredients in lavender essential oil (Yang et al. 2010) can calm nerves (Re et al. 2000) and promote sleep (Hu et al. 2019). Lavender is relaxing (Lü et al. 2016), can reduce fatigue (Spesyvyi et al. 2019), and inhibit bacteria (Xu 2006). Monitoring brain wave frequencies can reveal if chemical components affect human physiology.

Analysis of physical and mechanical properties of aromatic fiberboard

Xu et al. (2011) found that adding plant flavors such as sandalwood or jasmine during wood hot pressing can improve the mechanical properties of fiberboard (Xu 2011). In this experiment, the mechanical properties of the aromatic fiberboard made by lavender and wormwood differed from those of common hot-pressed fiberboard. To assess if the prepared material could meet the requirements of GB/T 11718 (2009) specifying the mechanical properties of fiberboard given the effect on the curing performance of the acrylic resin, the aromatic fiberboard with 20% of added spices was selected for testing.

The spices were weighed precisely by an electronic balance and mixed with glue (waterborne acrylic acid) and wood fiber. The results (as shown in Tab. 5) showed that material prepared with 20% addition of spices improved the internal bond strength of the aromatic fiberboard compared to that with no spices, with 0.57 MPa for wormwood and more than 0.62 MPa for lavender. The addition of lavender somewhat increased the static bending strength of the aromatic fiberboard. Addition of wormwood improved the elastic modulus and the average water absorption thickness expansion rate of the aromatic fiberboard, and this trend was opposite when lavender was added. According to these results, there were relatively small negative impacts on the fiberboard from the addition of spices, so the overall effect was positive.

Tab. 5: Experimental variables of adding 20% wormwood and lavender.

Related variables	Component ratio (%)	Group1	Group2	Group3	Group4	Average
Internal bond strength (MPa)	0%	0.55	0.49	0.51	0.52	0.52
	20% Wormwood	0.59	0.51	0.59	0.57	0.57
	20% Lavender	0.61	0.63	0.62	0.63	0.62
Bending strength (MPa)	0%	19.23	19.11	20.01	19.12	19.37
	20% Wormwood	20.12	20.08	19.98	20.31	20.12
	20% Lavender	19.35	19.95	20.05	20.16	19.88
Elastic modulus (MPa)	0%	2128.25	2109.56	2125.33	2018.21	2117.84
	20% Wormwood	2209.11	2308.91	2318.36	2309.55	2286.48
	20% Lavender	2219.32	2255.99	2289.16	2291.36	2263.96

Water absorption thickness expansion rate (%)	0%	11.38	11.37	11.44	11.31	11.38
	20% Wormwood	12.38	12.83	12.92	12.81	12.74
	20% Lavender	12.21	12.39	12.56	12.53	12.42

Brain wave test comparison

To compare the stimulation and physiological effects on the human brain after smelling the odors emitted from aromatic and common fiberboard samples, brain response was monitored (Li 2010). Sowndhararajan Kandhasamy and Kim Songmun proposed that the influence of odor stimuli on human brain waves indirectly demonstrates the great influence of odor on the body's physiological response, emotions, and social behavior (Sowndhararajan et al. 2016). An odor induction experiment was used by Murali and Kulish (2007), who observed that inhaling a gas with a special odor can produce a corresponding stimulation response in the brain. Thus, electroencephalogram (EEG) analysis was performed for 70 volunteers who smelled wood samples with added wormwood and lavender, and the results are shown in Tab. 6. In the group that smelled the material with added wormwood, the proportion of α wave in the subjects was 45.64% ± 6.75% and the percentage of β wave was 26.44% ± 3.27%. Both were higher than the brainwave frequencies for the blank groups. In the group that smelled the material with added lavender, the α wave to β wave ratio was increased compared with the ratio in the blank group. The δ wave ratio in the two groups of added wormwood and lavender were 14.74% ± 2.75% and 14.54% ± 2.81%, respectively, indicating a downward trend. The θ wave ratios in these two groups were 17.51% ± 2.89% and 17.79% ± 2.85%, respectively, indicating an upward trend.

Tab. 6: Four types of brain wave frequency ratio/ x ± s.

Experimental classification	**Spice ratio (%)**	**α wave (%)**	**β wave (%)**	**δ wave (%)**	**θ wave (%)**
Blank control	0	45.51 ± 6.10	25.55 ± 3.33	15.52 ± 3.10	17.23 ± 2.60
Wormwood	20	45.64 ± 6.75	26.44 ± 3.27	14.74 ± 2.75	17.51 ± 2.89
Lavender	20	46.75 ± 6.56	26.56 ± 3.68	14.54 ± 2.81	17.79 ± 2.85

*X: average, S: standard deviation.

As shown in Tab. 7, experiments were conducted to evaluate preference for different addition ratios of spices using 70 recruited experimental volunteers. The results showed that a 20% spice addition was the most popular, with approximately 48% of participants preferred 20% wormwood addition and 46% preferred 20% lavender addition. This shows that the higher content of spices was preferred.

Tab. 7: Acceptance of spices' addition ratio.

Experimental classification	**Addition ratio (%)**	**Acceptance (%)**
Wormwood	5	30
	10	29
	15	45
	20	48
Lavender	5	40
	10	45
	15	35
	20	46

CONCLUSIONS

In this study, new aromatic fiberboard was prepared and tested. The test results showed that the addition of spices had few effects on board performance, but exhibited stimulating effects on human body function. Different proportions of wormwood and lavender spices were tested for effects on the curing time of waterborne acrylic acid. Higher ratios of added wormwood or lavender had greater effects on the adhesive curing time. Comparison of boards made with addition of the same amount of wormwood or lavender, the aromatic fiberboard prepared with lavender exhibited better mechanical properties. The average internal bond strength of the aromatic fiberboard containing wormwood was 0.57 MPa, and the average internal bond strength of the fiberboard containing lavender was greater than 0.62 MPa, with increased emission of fragrance. The results showed increased brain wave frequency with smell, with a faster increase for aromatic fiberboard prepared with lavender. Overall, the results show that the inclusion of spices in aromatic fiberboard had positive effects for stimulation of the human brain.

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Wei Wang[1,2*], Hui Shen[1], Haiqiao Zhang[1], Yang Zhang[1,2],
Yanji Zhou[1], Danyang Zhao[1]
[1]Co-Innovation Center Of Efficient Processing
And Utilization Of Forest Resources
College Of Furnishing And Industrial Design
Nanjing Forestry University
Academy Of Chinese Ecological Progress And Forestry Studies
Nanjing Forestry University
Longpan No.159, Nanjing
China
*Corresponding author: weiwang1912@163.com

[2]Center For Renewable Carbon
University Of Tennessee
2506 Jacob Drive, Knoxville, TN, 37996
USA