Research Article
Araştırma Makalesi
DOI: 10.24011/barofd.588056

Bartın Orman Fakültesi Dergisi,
21(3): 758-770,
15 Aralık/December, 2019

Journal of Bartin Faculty of Forestry
p-ISSN : 1302-0943
e-ISSN : 1308-5875

Chemical, physical, and mechanical properties of particleboards manufactured from sodium hydroxide-treated sunflower (*Helianthus annuus* L.) stalks

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Abstract

In the present study, the effects of 1 to 5% sodium hydroxide treatments of sunflower stalk particles on the chemical composition and the physical and mechanical properties of particleboards were evaluated. Proximate analysis, gas chromatographic determination, and FTIR spectroscopic identification showed that the lignin, hemicellulose, and extractive contents of particles were reduced by alkali treatment, while cellulose contents were raised. Alkali treatments decreased the thermal stability of the particles according to TGA. Water absorption (WA) and thickness swelling (TS) analysis showed that alkali treatments also reduced the water resistance of the produced particleboards. Using modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB) strength analysis, the mechanical properties of produced particleboards were evaluated. Only the treatment with 1% sodium hydroxide resulted in excellent mechanical properties of the produced particleboards, meeting the requirements for general-purpose particleboards used in dry circumstances, according to the TS-EN 312 standard.

Keywords: Sunflower stalks, alkali treatment, physical and mechanic properties, thermal stability.

Alkali İşlem Görmüş Ayçiçeği (*Helianthus annuus* L.) Saplarından Üretilen Yongalevhaların Kimyasal, Fiziksel ve Mekanik Özellikleri

Öz

Bu çalışmada, ayçiçeği sapı yongalarının %1-5 sodyum hidroksit ile muamelenin kimyasal bileşim üzerindeki etkileri ve kimyasal bileşenlerdeki değişimlerin üretilen yongalevhaların fiziksel ve mekanik özellikleri üzerine etkileri değerlendirilmiştir. Gaz kromatografik analiz ve Fourier dönüşümlü kızılötesi (FTIR) spektroskopisi sonuçları uygulanan sodyum hydroksit derişimi arttıkça yongalardaki ekstraktif madde, hemiselüloz ve lignin miktarlarının azaldığını, selüloz miktarının ise arttığı göstermiştir. Termogravimetrik analiz (TGA), alkali uygulamaların yongaların termal stabilitesini azalttığını göstermiştir. Su alma (WA) ve kalınlığına şişme (TS) analizi, alkali işlemlerin üretilen yonga levhaların su geçirmezliğini azalttığını ortaya koymuştur. Elastikiyet modülü (MOE), eğilme direnci (MOR) ve yüzeye dik çekme direnci (IB) kullanılarak, üretilen yonga levhaların mekanik özellikleri değerlendirilmiş ve sadece %1 sodyum hidroksit ile muamele görmüş yongalardan üretilen levhaların, TS-EN 312 standardına göre kuru şartlarda genel amaçlı kullanılan levhalar için beklenilen değerleri karşıladığı görülmüştür.

Anahtar Kelimeler: Ayçiçeği sapı, alkali işlem, fiziksel ve mekanik özellikler, termal stabilite.

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Geliş (Received) : 06.07.2019
Kabul (Accepted) : 26.11.2019
Basım (Published) : 15.12.2019

1. Introduction

The social, technological, and economic development of humankind mainly depends on the efficient use of existing resources. Since ancient times, humans have been using wood-based products as important resources. However, an increased environmental consciousness, especially an increased importance attached to recycling, the unprecedented consumption of forest resources, and global warming have pushed people to use non-wood resources (Yasar et al., 2010a).

In various kinds of agricultural waste, non-wood resources are accessible, including stalks generated from sunflower (*Helianthus annuus* L.) production. In Turkey, the total sunflower cultivation area is 545,963 ha, producing 2,259,121 tons of stalks each year. Generally, the sunflower stalks are either left on the fields or utilized as fuel after harvest (Bascetincelik et al., 2005).

Some non-wood lignocellulosic resources, including pepper stalks (Oh and Yoo, 2011) eggplant stalks (Guntekin and Karakus, 2008), wheat stalks (Tabarsa et al, 2011), rice husks (Kwon et al., 2013), sugar cane (Ghalehno et al., 2011), cotton stalks (Yasar and Icel, 2016), sunflower stalks (Khristova et al., 1996), sorghum stalks (Khazaeian et al., 2015), and waste from vine pruning (Yasar et al., 2010b) have effectively been used to produce particleboards.

Various studies have reported treatments applied to particles and fibers to develop some properties of boards, including acetylation, sodium hydroxide treatment (Martins and Joekes, 2003, Nemli and Bardak, 2017), enzyme treatment (Raghavendra et al., 2004), heat treatment (Winandy and Krzysik 2007), treatment with boron compounds (Var et al., 2002; Zaidon et al., 2007), and other chemical treatments (Yasar et al., 2010b).

Alkali treatment is one of the most commonly applied methods to change the fiber and particle surface to increase the content of free hydroxyl groups in the material (Ndazi et al., 2007a, 2007b; Yasar and Icel, 2016). Some researchers have reported that alkali treatment provides a better bonding between fibers and particles to the enhanced roughness of the surface and raised hydroxyl groups (Lopattananon et al., 2008). Such treatment had noticeable effects on some properties of the manufactured boards (Yasar et al., 2010b).

In this study, particles from sunflower stalks were soaked in 1 to 5% sodium hydroxide solution. The changes in the chemical and thermal characteristics of the particles caused by these treatments were demonstrated and the effects of these treatments on the physical and mechanical properties of the produced boards were evaluated.

2. Material and method

2.1. Material

Sunflower stalks were gathered from Sandikli-Afyonkarahisar in Turkey. The stalks were milled by a hammer mill and sieved through 1-3 mm screens. The particles obtained were laid out and air-dried for 30 days.

2.1.1. Sodium hydroxide treatment of particles from sunflower stalks

The particles from sunflower stalks were separately soaked in sodium hydroxide solutions with concentrations of 1, 2, 3, 4, and 5% w/v at room condition for 24 hours. The treated particles were then sieved and rinsed with plenty of water after the addition of 10% CH_3COOH to neutralize surplus sodium hydroxide. The rinsed particles were air-dried for 30 days.

2.1.2. Main chemical component analysis

Control and sodium hydroxide-treated particles were milled and sieved through 40-100 mesh screens. After milling, the samples were first subjected to cyclohexane: ethanol at a ratio of 2:1 and then extracted with ethanol in a soxhlet apparatus.

The samples extracted with cyclohexane and ethanol were hydrolyzed using the acid hydrolysis method reported by Dill et al. (1984) was used with light alterations. The samples equivalent to 1 g oven-dried material were treated in 20 mL 72% H_2SO_4 at 30°C for 2 hours, diluted with distilled water to 360 mL, and kept in the JP-Selecta autoclave at 120°C for 30 minutes (Yasar et al., 2010a). Lignin was obtained as a residue and dried at 105 ± 2 ° C after filtering. Sugar units in the acid hydrolysate stored for GC determination to establish monosaccharide composition.

The holocellulose was prepared from the samples extracted with cyclohexane and ethanol, using the acid chlorite method developed by Browning (1967). Contents of α-cellulose and hemicellulose were determined from holocellulose samples using ASTM D1103. Hemicellulose weight was established via the difference in the weight of α-cellulose from holocellulose.

2.1.3. Monosaccharide composition analysis

A Perkin Elmer Autosystem XL device performed to analyze the monosaccharide composition, using the gas chromatographic method developed by Cao et al. (1997).

2.1.4. Fourier transform infrared (FTIR) spectroscopic and thermogravimetric analyses (TGA)

Homogenous powders were obtained from materials sieved through 40-100 mesh screens using a ball mill and used in FTIR spectroscopic determination and TGA.

Subsequently, 10 mg of homogenous powder mixed with 1000 mg KBr. Then self-supporting pellets were obtained after pressing of mixtures by compression of 8 tons. FTIR spectra of the samples were recorded between 4000 and 400 cm^{-1}, with a spectral resolution of 4 cm^{-1}, at room temperature.

TGA was carried out using 5 mg of powder. The temperature of heating was programed to 25 °C, followed to 900 °C by a rise of 10 °C per minute under nitrogen.

2.1.5. Particleboard production, physical and mechanical tests

Control particles and particles treated with 1, 2, 3, 4, and 5% sodium hydroxide were separately sifted through 3-1.5 mm screens to use in the middle layers and 1.5-1 mm screens to use in the outer layers of boards. Then particles were dried at a temperature of 102 ± 5ºC until the moisture content was 3%. The boards were prepared to comprise of 35% particles at the outer layer and 65% at the middle layer. The weights of the particles were measured according to their target board density of 0.65 g/cm^3. To the weighted particles were added the urea formaldehyde (UF) resin (11% of particle weight, w/w for outer layers and 9% of particle weight, w/w for middle layers) and the NH_4Cl hardener at a concentration of 35% (1% of particle weight, w/w for all layers) in a drum blender with a spray gun attachment. Properties of the employed adhesive are shown in Table 1. After blending, particles were manually dispersed on a steel plate in a 31 x 35 cm frame and then the hand-formed mat was placed into the hot press. Subsequently, the hand-formed mat was pressed for 5 min at 150 ± 5°C under 2.5-3 N/mm^2 to achieve a board thickness of 12 mm. All boards were placed in a climate room at a temperature of 20°C and 65% relative humidity for a month to stabilize board weight.

Table 1. Properties of the adhesive employed

Properties	Urea Formaldehyde (UF) Resin
Solid content (%)	65±1
Gel time (s, 100ºC)	25–30
Density (g/cm^3)	1.27–1.29
pH (25ºC)	7.5–8.5
Storage time (day, at 25ºC)	60
Viscosity (cps, 25ºC)	150–200
Free formaldehyde (max.) (%)	0.19
Flowing time (s, 25ºC)	20–30

The standards TS-EN 310, TS-EN 317, and TS-EN 319 were used to determine the modulus of elasticity (MOE), the modulus of rupture (MOR), internal bond strength (IB), thickness swelling (TS), and water absorption (WA) of the particleboards.

3. Results and Discussion

3.1. Extractive content

The results of extractive contents of the control and sodium hydroxide-treated particles and the findings of statistical analysis are shown in Figure 1. The extractive content of the control particles and the particles treated with sodium hydroxide at different concentrations ranged from 3.22 to 5.13%. The extractive content of the particles subjected to 1, 2, 3, 4, and 5% alkali treatment was reduced by 6, 23, 34, 36, and 37%, respectively, compared to the control particles. Troedec et al. (2008) and Carvalho et al. (2010) have already confirmed that some extractives, such as oils and waxes, were removed from the plant fibers through alkali treatment.

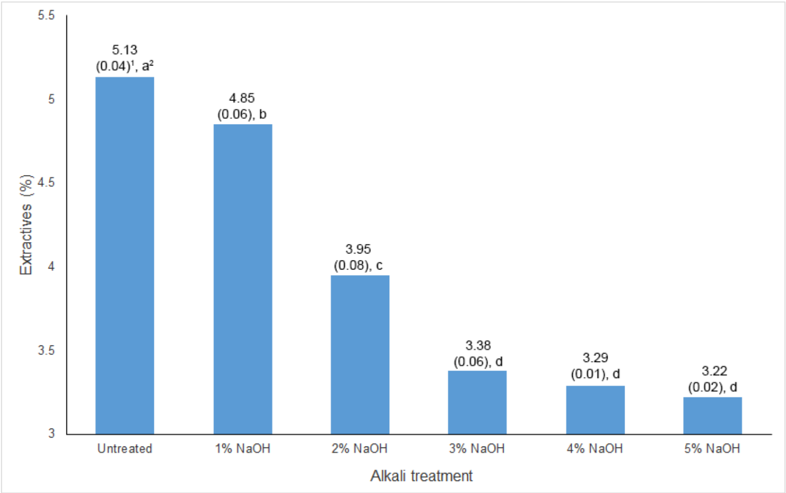

Figure 1. Extractive contents in control and sodium hydroxide-treated particles of sunflower stalks (1: Standard deviations, 2: Homogenous groups by Duncan test (p<0.001).)

3.2. Lignin content

The results of lignin contents of the control and sodium hydroxide-treated particles and the findings of statistical analysis are shown in Figure 2. The lignin content in the control and sodium hydroxide-treated particles from sunflower stalks ranged from 15.04 to 23.57%. The lignin content in the particles subjected to 1, 2, 3, 4, and 5% sodium hydroxide decreased by 4, 6, 26, 34, and 36%, respectively, compared with the control particles. Previous studies have emphasized that applying high concentrations of alkali to the lignocellulosic fibers at high temperatures over a long period results in the decomposition of lignin (Rajulu et al., 2002). In contrast, other studies have reported that lignin can be decomposed at high rates after the application of low concentrations of alkali at room temperature (Ndazi et al., 2007a, 2007b; Yasar and Icel, 2016). The findings here are supported by works indicating that lignin can be decomposed in noticeable amounts through the application of sodium hydroxide in low concentrations and at low temperatures.

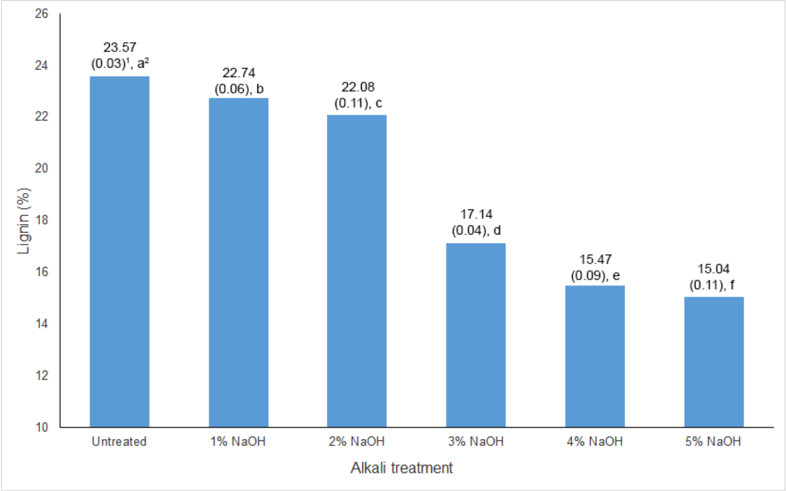

Figure 2. Lignin contents in control and sodium hydroxide-treated particles sunflower stalks (1: Standard deviations, 2: Homogenous groups by Duncan test (p<0.001).)

3.3. Hemicellulose and α-cellulose contents

The results of hemicellulose and α-cellulose contents of the control and sodium hydroxide-treated particles and the findings of statistical analysis are indicated in Figures 3 and 4. The hemicellulose content in the control and the sodium hydroxide-treated particles ranged between 13.75 and 23.65%, while the α-cellulose content ranged between 43.14 and 62.37%. Compared with the control particles, the hemicellulose content in the particles treated with 1, 2, 3, 4, and 5% sodium hydroxide decreased by 5, 8, 36, 41, and 42%, respectively, while the α-cellulose content increased by 6, 10, 36, 43, and 45%, respectively. The rise in α-cellulose can be confirmed by the relative reduction in the proportion of other main chemical components, which are instable against sodium hydroxide treatment. Based on previous studies, lignin, hemicelluloses, and extractives are more inclined to decomposition than cellulose when treated with sodium hydroxide (Ndazi et al., 2007b; Yasar and Icel, 2016).

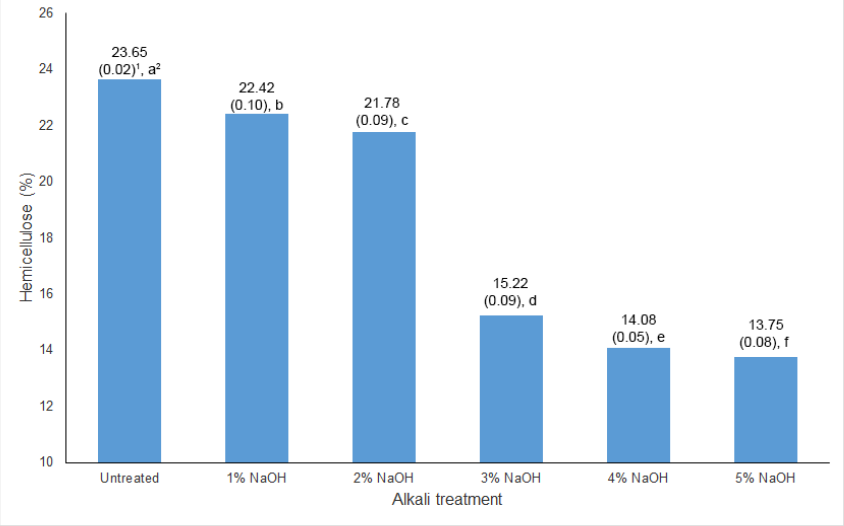

Figure 3. Hemicelluloses contents in control and sodium hydroxide-treated particles sunflowers (1: Standard deviations, 2: Homogenous groups by Duncan test (*p*<0.001).)

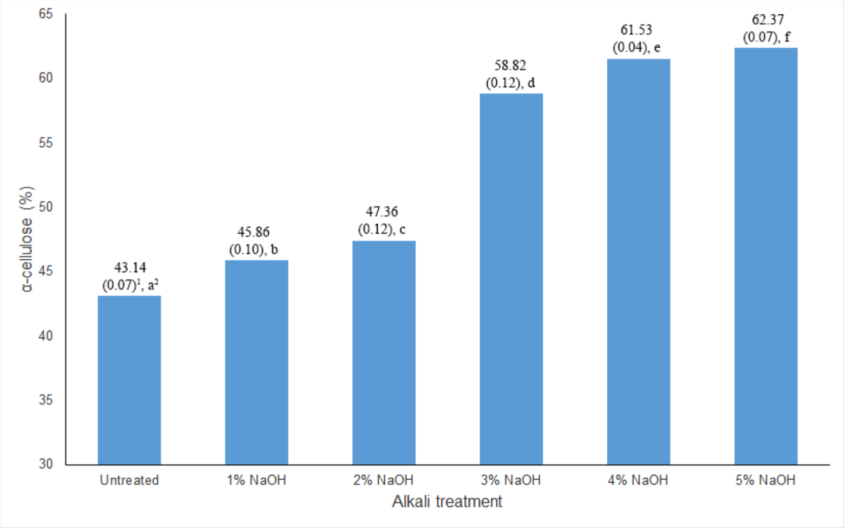

Figure 4. α-cellulose contents in control and sodium hydroxide-treated particles sunflower stalks (1: Standard deviations, 2: Homogenous groups by Duncan test (*p*<0.001).)

3.4. Monosaccharide composition

The monosaccharide units of sunflower stalks is presented in Figure 5. Glucose, galactose, mannose, xylose, arabinose, and rhamnose contents in control particles were 46.77, 1.78, 1.28, 20.55, 1.97, and 0.78%, respectively. Rhamnose, arabinose, mannose, or galactose were not found in sodium hydroxide-treated particles. The xylose (pentose of hemicelluloses) content decreased consistently from 19.75 to 11.3%, while the glucose content increased continuously from 56.02 to 73.15% due to alkali treatment. The increase in the glucose content with increasing sodium hydroxide concentrations revealed the relative rise in the cellulose content of the particles. The findings are in agreement with the findings of the hemicellulose and α-cellulose analyses of the study.

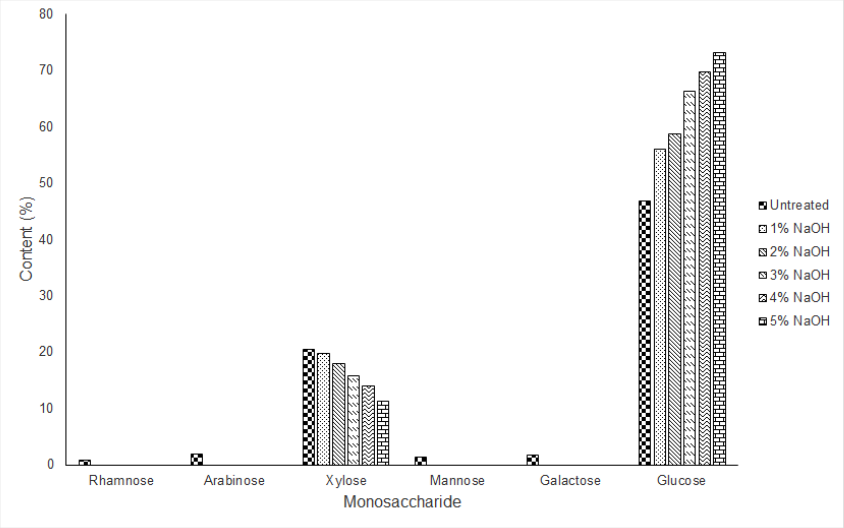

Figure 5. Monosaccharide composition of sunflower stalks

3.5. FTIR spectra

Lignin, hemicellulose, and cellulose contents of the control and the sodium hydroxide-treated were evaluated on the bands at 3460, 1750, 1470, 1390, 1270, 1060, and 845 cm^{-1} (Figure 6 and Table 2). The spectra were compared by dividing the intensity values of the concerned bands by the band at the 2950 cm^{-1} intensity value (Table 3). The values of the band at 3460 cm^{-1} were significantly higher in the sodium hydroxide-treated particles than in the control particles. The increase in this band value can be related to the increase in hydroxyl groups in the sodium hydroxide-treated particles. The band at 1750 cm^{-1} stood out in the control particles and disappeared in the sodium hydroxide-treated particles. Most likely, this was the result of the removal of acetyl groups in the hemicelluloses through alkali treatment. The absorbance values of the band at 1470 cm^{-1} decreased continuously in the sodium hydroxide-treated particles. The decrease in band values indicates that lignin degradation increased with increasing alkali concentrations. The band at 1390 cm^{-1} had a higher value in the control particles compared to the sodium hydroxide-treated particles. The absorbance value of the band at 1270 cm^{-1} was higher in the control particles than in the 1% sodium hydroxide-treated particles, while the band disappeared in the treatments with 2% to 5% sodium hydroxide owing to the removal of the hemicellulose's acetyl groups. The absorbance value of the band at 1060 cm^{-1} decreased continuously in the sodium hydroxide-treated particles. The band at 845 cm^{-1} disappeared in the sodium hydroxide-treated particles. The changes in the values of bands at 1060 and 845 cm^{-1} can be related to the reduction of lignin in the sodium hydroxide-treated particles.

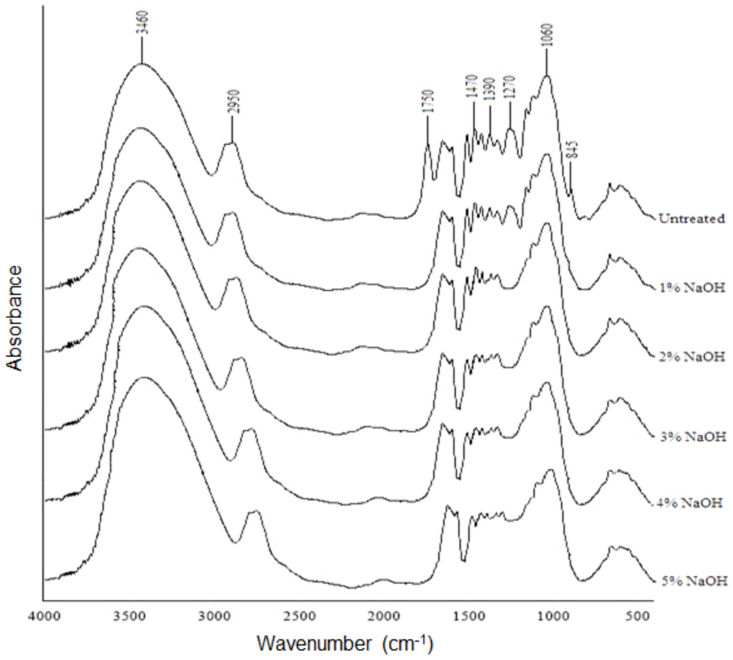

Figure 6. Infrared spectra of sunflower stalks

Table 2. The spectral interpretations of sunflower stalks

Band (cm^{-1})	**Assignment**	**Reference**
3460	H-bonded H-O stretching	Luna et al., 2012
2950	C-H stretching in aliphatic compounds	Luna et al., 2012
1750	C-O- stretching in hemicellulose	Luna et al., 2012
1470	CH_3 bending in lignin	Li et al., 2010
1390	C-H bending in lignin, cellulose, or xylan	Li et al., 2010; Mahato et al., 2014
1270	C-O stretching in the acetyl groups of xylan	Mahato et al., 2014
1060	Aromatic C-H in plane deformation and C-O deformation of primary alcohol in lignin	Luna et al., 2012
845	Aromatic C-H out of plane deformation in lignin	Mahato et al., 2014

Table 3. Absorbance intensity ratio of infrared spectra of sunflower stalks

(A_v/A_{2950})	**Control**	**1% Sodium hydroxide**	**2% Sodium hydroxide**	**3% Sodium hydroxide**	**4% Sodium hydroxide**	**5% Sodium hydroxide**
A_{3460}/A_{2950}	1.398	1.413	1.416	1. 419	1.420	1.421
A_{2950}/A_{2950}	1.000	1.000	1.000	1.000	1.000	1.000
A_{1750}/A_{2950}	0.97	-	-	-	-	-
A_{1470}/A_{2950}	1.052	1.017	1.015	1.007	0.998	0.978
A_{1390}/A_{2950}	1.021	1.013	1.011	1.009	1.001	0.991
A_{1270}/A_{2950}	1.047	1.030	-	-	-	-
A_{1060}/A_{2950}	1.314	1.304	1.297	1.291	1.287	1.285
A_{845}/A_{2950}	0.743	-	-	-	-	-

3.6. TGA and DTG thermograms

Water and extractives, to some extent, can be eliminated via thermal degradation of plant biomass until approximately 225°C, while the actual degradation starts once the different forms of secondary volatile products, especially hemicellulose, are decomposed at approximately 225°C and above, followed by the degradation of the other organic components (cellulose, lignin, and extractives) (Meszaros et al., 2007; Thurner and Mann, 1981).

The results of thermogravimetric analysis (TGA) of the control and the sodium hydroxide-treated sunflower stalk particles are shown in the TG (Figure 7) and the DTG (Figure 8) thermograms. Water and some volatile components in the particles were lost at a temperature from 60 to 130°C. The secondary degradation stage, where hemicellulose was first decomposed, started at 221°C. The actual decomposition in the sodium hydroxide-treated samples took place at a single phase from 221 to 357-365°C. A transition occurred in the control particles at about 331 °C, while the actual decomposition appeared between 221 and 390 °C at two phases.

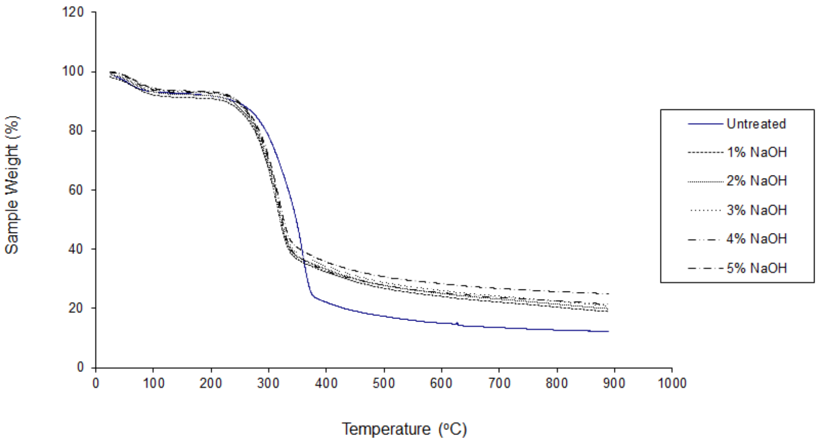

Figure 7. Thermal stability of sunflower stalks

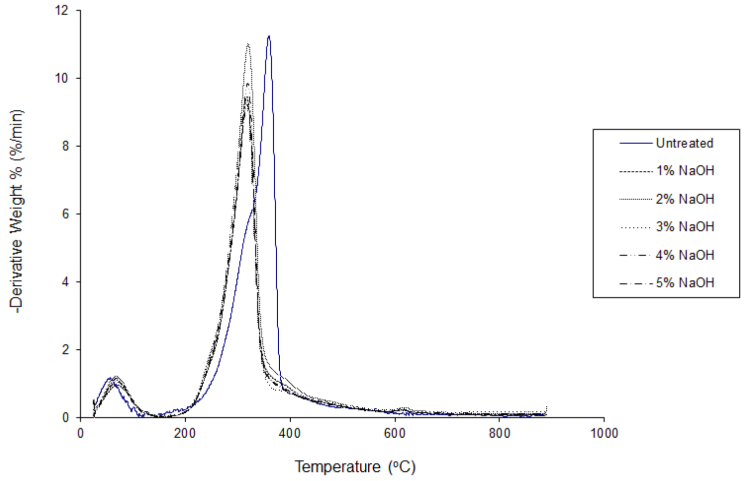

Figure 8. Decomposition rate of sunflower stalks

The two-phase decomposition curve of the control samples represents the two main reaction zones. The first decomposition phase ended at about 331°C in the control particles was assigned to the hemicellulose degradation, the elimination of some volatile components, and the degradation of part of lignin (Bodîrlău et al., 2007). The fact that the first decomposition zone did not appear in the sodium hydroxide-treated particles can be explained by the removal of noticeable amounts of extractives (waxes and oils), hemicelluloses, and lignin due to sodium hydroxide-treatment (Ndazi et al., 2007b).

The second decomposition phase in the control particles was observed in the range from 331 to 390°C and assigned to cellulose, lignin, and extractives degradation (Bodîrlău et al., 2007). The maximum decomposition between 221 and 365°C in the sodium hydroxide-treated particles was mainly related to the degradation of cellulose. The hemicellulose, lignin, and extractives were significantly removed due to sodium hydroxide-treatment (Ndazi et al., 2007b). Hence, the maximum decomposition temperature decreased by a minimum of 40°C in the sodium hydroxide-treated particles compared to the control particles.

The various thermal transitions in the control and the sodium hydroxide-treated particles from sunflower stalks are demonstrated in Table 4. The T_0 shows the temperature when the actual decomposing started, while T_1 indicates the temperature at the end of the first decomposing phase and T_f demonstrates the final decomposition temperature, which represents the temperature at which mass residue was produced. A part of mass residue consisted of the char part is related with the conversion of cellulose structure during the thermal decomposition (McGrath et al., 2003). The consistent reduction in the contents of other main chemical components in the particles treated with increased sodium hydroxide concentrations resulted in an increased cellulose content. Therefore, the consistent rise in the residue amounts in the sodium hydroxide-treated particles can be explained by the relatively consistent rise in the proportion of cellulose contents.

Table 4. Thermal analysis results of sunflower stalks

Particle	**T_0 (^{o}C)**	**T_1 (^{o}C)**	**T_f (^{o}C)**	**Residue at 900 ^{o}C (%)**
Control	221	331	390	12.13
1% Sodium hydroxide	221	-	365	18.92
2% Sodium hydroxide	221	-	363	19.92
3% Sodium hydroxide	221	-	361	20.92
4% Sodium hydroxide	221	-	359	21.47
5% Sodium hydroxide	221	-	357	24.99

3.7. Physical and mechanical properties of the particleboards

The results of physical and mechanical properties of the produced particleboards and the findings of statistical analysis are given in Table 5.

Table 5. Physical and mechanical properties of particleboards produced with sodium hydroxide-treated and with control particles of sunflower stalks

Board Type	WA (%)	TS (%)	MOE (N/mm^2)	MOR (N/mm^2)	IB (N/mm^2)
Control	88 (5.06)[1] a[2]	27 (0.41) a	1615 (6.53) a	10.21(0.20) a	0.43 (0.01) a
1% Sodium hydroxide	92 (2.53) a, b	29 (0.90) a, b	1904 (15.51) b	14.04 (0.55) b	0.39 (0.02) b
2% Sodium hydroxide	96 (3.27) a, b	32 (0.90) b	1722 (34.29) c	12.17 (0.29) c	0.32 (0.02) c
3% Sodium hydroxide	101 (3.51) b	36 (1.80) c	1596 (8.98) a	9.92 (0.15) a	0.28 (0.02) d
4% Sodium hydroxide	116 (4.33) c	39 (2.12) c	1349 (29.39) d	7.69 (0.34) d	0.25 (0.02) d, e
5% Sodium hydroxide	132 (5.31) d	44 (2.37) d	1154 (41.64) e	5.22 (0.54) e	0.23 (0.01) e

1: Standard deviations, 2: Homogenous groups by Duncan test ($p<0.001$).

Boards produced with sodium hydroxide-treated particles presented higher values of WA and TS than boards produced with control particles. The consistent rise in the concentration of the applied sodium hydroxide-treatment led to the increase in WA and TS values of particleboards. All particleboards failed to meet the requirement of the TS-EN 312 standard, which specifies TS values of maximum 16% for load-bearing and heavy-duty load-bearing applications. The decrease in the extractives, hemicelluloses, and lignin caused a consistent increase in the cellulose content of particles due to alkali treatment. Swelling of the crystalline structure in the cellulose during the alkali treatment may facilitate water ingress into the boards (Gwon et al., 2010). As a thin film, the wax and oil components in wood, which improve the water-repellent properties of the boards (Nemli et al., 2008; Nasser, 2012), were removed efficiently from the particles by sodium hydroxide treatment. The poor resistance to WA and TS found for boards produced with sodium hydroxide-treated particles may be partly ascribed to the lower concentrations of lignin, which presents a hydrophobic property. Although hemicelluloses were decreased during alkali treatment, the increase in cellulose resulted in an increased concentration of polysaccharides, which offer a hydrophilic property (Fengel and Wegener, 1984). The changes in the chemical composition due to alkali treatment may have contributed to the higher WA and TS values of boards made with treated particles.

Boards produced with 1 and 2% sodium hydroxide-treated particles presented higher MOE and MOR values than boards produced with control particles. MOE and MOR values were significantly poorer for particleboards produced with 3, 4 and 5% sodium hydroxide-treated particles. According to the TS-EN 312 standard, MOE and MOR values are required as minimum 1800 N/mm^2 and 10.5 N/mm^2 for interior fitment (including furniture) and for general-purpose applications in dry circumstances. In the study, only boards made from 1% sodium hydroxide-treated particles met the minimum requirement for MOE. Boards obtained from 1 and 2% sodium hydroxide-treated particles achieved the minimum requirement for MOR, whereas boards obtained with control and 3-5% sodium hydroxide-treated particles failed to achieve the minimum requirement for MOR. The boards produced with control, 1, 2, and 3% sodium hydroxide-treated particles satisfied the standard TS-EN 312 in term of IB strength, which is required as minimum 0.28 N/mm^2 for general-purpose end use. The reduction in MOE and MOR caused by treatment with 3-5% concentrations of sodium hydroxide were likely owing to the decrease in the crystalline region and the increase in the amorphous regions of cellulose during sodium hydroxide-treatment (Joseleau et al., 2004). The decrease in MOE and MOR due to chemical decomposition of the compounds of cell wall when sodium hydroxide was applied at a concentration higher than 1% can also be explained by the significant decrease in thermal stability. On the other side, lignin was removed effectively from the material surface during alkali treatment at higher sodium hydroxide concentrations. This resulted in a deficient adhesion on the surface of particles and in poor strength performance (Joseleau et al., 2004). Alkali treatment reduced the internal bond (IB) strength in comparison to the board produced with control particles. The reduction in the IB strength can be explained by the drop in the proportions of lignin during alkali treatment. Lignin acts as a natural adhesive and facilitates the bonding between the particles, resulting in improved adhesion and dimensional stability of the board (Joseleau et al., 2004). The continuous reduction in the lignin content of particles with increasing sodium hydroxide concentrations may have caused the weak adhesion between particles and, consequently, to the poor values of internal bonding. The results here are in agreement with previous studies (Mukherjee et al., 1993; Yasar and Icel, 2016) reporting that the application of more than 1% sodium hydroxide during treatment weakens the fibers and particles, resulting in weak strength performance.

4. Conclusions

Large quantities of sunflower stalks as a by-product of sunflower cultivation can be used in particleboard production. This study showed that the sunflower stalks must be modified to improve the mechanical properties of the particleboards. Alkali treatment of sunflower stalk particles affected the chemical composition and the thermal stability. Except for cellulose, the contents of other main chemical components (extractive, hemicellulose, and lignin) of particles decreased with increasing sodium hydroxide concentrations from 1 to 5%. The chemical degradation of particles also caused a reduction in thermal stability with increasing sodium hydroxide concentrations. The MOE and MOR values of the boards made with particles treated with 1 and 2% sodium hydroxide were improved compared to those of the boards produced from control particles. Other treatments were provided lower MOE and MOR values. All treatments reduced the IB strength of the produced boards compared to boards made with control particles. Using higher sodium hydroxide concentrations resulted in lower mechanical properties because of a stronger degradation of the chemical components of cell wall and deformation of the particle structure. Only boards produced with 1% sodium hydroxide-treated particles satisfied the standard TS-EN 312 in terms of MOE, MOR, and IB strength. The results lead to infer that sunflower stalk particles should ideally be treated with 1% sodium hydroxide prior to particleboard production to achieve acceptable mechanical properties, allowing general use in dry circumstances.

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