Turkish Journal of Agriculture and Forestry

Volume 34 | Number 3 Article 3

1-1-2010

Certain physical and mechanical properties of medium density fiberboards manufactured from blends of corn (Zea mays indurata Sturt.) stalks and pine (Pinus nigra) wood

MEHMET AKGÜL

CENGİZ GÜLER

YALÇIN ÇÖPÜR

Recommended Citation
AKGÜL, MEHMET; GÜLER, CENGİZ; and ÇÖPÜR, YALÇIN (2010) "Certain physical and mechanical properties of medium density fiberboards manufactured from blends of corn (Zea mays indurata Sturt.) stalks and pine (Pinus nigra) wood," *Turkish Journal of Agriculture and Forestry*: Vol. 34: No. 3, Article 3. https://doi.org/10.3906/tar-0902-26
Available at: https://journals.tubitak.gov.tr/agriculture/vol34/iss3/3

Research Article

Turk J Agric For
34 (2010) 197-206
© TÜBİTAK
doi:10.3906/tar-0902-26

Certain physical and mechanical properties of medium density fiberboards manufactured from blends of corn (*Zea mays indurata* Sturt.) stalks and pine (*Pinus nigra*) wood

Mehmet AKGÜL, Cengiz GÜLER, Yalçın ÇÖPÜR

Department of Forest Products Engineering, Faculty of Forestry Düzce University, Konuralp Yerleşkesi,
81620, Düzce - TURKEY

Received: 16.02.2009

Abstract: Corn stalk is a renewable natural resource that currently has limited industrial utilization. The objective of this study was to examine some chemical properties of corn stalk (holocellulose, α-cellulose, lignin and ash content, alcohol-benzene, hot and cold water solubility, and solubility in dilute alkali [1% NaOH]) and to evaluate its suitability for medium-density fiberboard (MDF) production. Panels were produced using mixtures of corn stalk (*Zea mays indurata* Sturt.) and pine (Turkish *Pinus nigra*) fibers in various proportions (from 0% to 100%). The panels produced had density levels of 0.6, 0.7, and 0.8 g cm^{-3}. The physical and mechanical properties of the manufactured panels were tested. Chemical analysis shows that the holocellulose, α-cellulose, and lignin content of corn stalk was similar to that of wood and some other crop residues. The ash content of corn stalk was higher than that of soft- and hardwoods. Mechanical test results indicate that the panels produced utilizing solely corn stalk met the required standards, except the panels with a density of 0.6 g cm^{-3}. Increasing the pine fiber ratio in the panel mixture improved panel properties.

Key words: Corn stalk, Turkish black pine, medium density fiberboard, chemical composition, fiber properties, physical and mechanical properties

Mısır (*Zea mays indurata* Sturt.) sapları ve karaçam (*Pinus nigra*) odunlarından üretilen orta yoğunlukta lif levhaların bazı fiziksel ve mekanik özellikleri

Özet: Mısır sapları yenilenebilir doğal kaynaklardan olup hâlihazırda endüstriyel kullanımı oldukça sınırlıdır. Bu çalışmanın amacı mısır saplarının bir kısım kimyasal özelliklerini (holoselüloz, α-selüloz, lignin ve kül miktarları, alkol-benzen, sıcak ve soğuk su ve seyreltik alkali (% 1 NaOH) çözünürlükleri) belirlemek ve orta yoğunlukta lif levha (MDF) üretimi için uygunluğunu değerlendirmektir. Bu çalışmada, farklı oranlarda (% 0'dan % 100 kadar) mısır sapları (*Zea mays indurata* Sturt.) ve karaçam (*Pinus nigra*) lifleri kullanılarak MDF'ler üretilmiştir. Üretilen levhaların yoğunlukları 0.6, 0.7 ve 0.8 g cm^{-3} tür. Üretilen levhaların fiziksel ve mekanik özellikleri belirlenmiştir. Yapılan kimyasal analizler mısır saplarının holoselüloz, α-selüloz ve lignin miktarlarının diğer tarımsal artıklar ve odun ile kıyaslanabilir olduğunu göstermiştir. Mısır sapları yapraklı/iğne yapraklı ağaçlara nazaran daha fazla kül miktarına sahiptir. Mekanik test sonuçları ise 0.6 g cm^{-3} yoğunlukta üretilen levhalar hariç, diğer levhaların standartlarda belirtilen minimum değerlerin altına düşmeden, sadece mısır sapları kullanılarak MDF üretilebileceği görülmüştür. Diğer taraftan karışımdaki mısır sapları miktarının azalması ile daha iyi özelliklere sahip levhalar üretilebileceği belirlenmiştir.

Anahtar sözcükler: Mısır sapı, karaçam, orta yoğunlukta lif levha, kimyasal içerik, lif özellikleri, fiziksel ve mekanik özellikler

---

* E-mail: mehmetakgul@duzce.edu.tr

Introduction

The annual wood raw material supply of Turkey is about 11 million m^3. Even though the wood supply in Turkey has increased by 35% during the last 5 years, it is insufficient to meet industrial demand and Turkey imports almost 2 million m^3 of wood raw material annually. The wood industry in Turkey is undergoing rapid growth. Particleboard production was 1.6 million m^3 in 1993 and rose to 4.2 million m^3 in 2008. Fiberboard production also increased rapidly, from 80,000 m^3 in 1993 to 3.2 million m^3 in 2008 (OGM 2009).

Medium-density fiberboard (MDF) is a fibrous-felted and homogeneous panel produced using wood or other lignocellulosic fibers combined with synthetic or other suitable adhesives under heat and pressure (ANSI A208.2 1994).

The production of fiberboard has been increasing consistently due to its numerous advantages over solid wood and other composite materials. Fiberboards with uniform fiber distribution in their structure meet most end-use requirements. With fiberboards, smooth and solid edges can easily be machined and finished for various purposes, especially furniture production. Smooth and uniform surfaces also provide an excellent substrate for paint and decorative overlays. The surface smoothness of MDF makes it the best material for cabinet manufacturing (Copur et al. 2008).

High wood usage results in deforestation and dependency on foreign sources. Use of agricultural residues, such as wheat, rice, barley, cereal straw, and corn stalk, instead of wood may help to overcome this problem. The potential of the biomass waste of Turkey is almost 54.5 million t year^{-1} and corn stalk accounts for 4.2 million t year^{-1} (Akgül et al. 2005; Fidan et al. 2008). The utilization of agricultural residues in wood processing offers numerous economic, environmental, and technological advantages. The most practical advantage appears to be its contribution to the economy by supplementing wood raw material. Agricultural residues are renewable materials and their industrial use is an environmentally friendly practice. Additionally, agricultural residues are plentiful, widespread, and easily accessible; however, unlike wood residues, which are available throughout the year, agricultural residues are harvested and collected once or twice a year, resulting in additional storage costs, and the threat of fire, spoilage, and rodent infestations.

In order to meet future demand and to overcome the shortage of wood, several studies have examined the suitability of agricultural residues in the forest industry as raw material components. Chow (1974), Youngquist et al. (1993), and Youngquist et al. (1994) provide accounts of worldwide research dealing with the utilization of non-wood plants in the forest industry. Several researchers examined the practicality of using wheat straw (Eroğlu and İstek 2000), cotton stalk (Gençer et al. 2001; Güler and Özen 2004), cotton carpel (Alma et al. 2005), sunflower stalk (Bektas et al. 2005), kiwi prunings (Nemli et al. 2003), hazelnut husk (Copur et al. 2007), and hazelnut shell and husk (Copur et al. 2008) in composite panel production; however, the literature contains only limited data concerning the use of corn stalk in MDF production. Therefore, the aim of the present study was to investigate the potential utilization of corn stalk as a supplement to wood in MDF production.

Materials and method

Corn stalk and pine (*Pinus nigra*) wood fibers were the raw materials utilized in MDF production in this study. Corn stalk was collected from the field immediately after harvest and the obtained materials were cleaned of dirt and dust.

Chemical analysis

The chemical properties of both corn stalk and pinewood were examined. Test specimens were sampled and prepared according to Tappi T 257 om-85. Holocellulose and α-cellulose contents were determined according to the chloride (Wise and Karl 1962) and Tappi T 203 om-93 methods, respectively. Tests were performed to determine the lignin (Tappi T 222 om-88) and ash (Tappi T 211 om-93) content. Solubility properties were determined based on alcohol-benzene (Tappi T 204 om-88), cold and hot-water (Tappi T 207 om-93), and 1% NaOH (Tappi T 212 om-93) methods.

Morphological analysis

The Schultze method, as described by Jane (1956), was used for maceration. Microslides were prepared with glycerine-gelatine gel. A light microscope with a screen was used for measurements.

Experimental design and materials

Experimental panel groups were designed with 3 different panel densities (0.60, 0.70, and 0.80 g cm^{-3}) and 5 wood and corn fiber compositions (100%, 75%, 50%, 25%, and 0%), with 2 replicates of each (Table 1). In total, there were 30 treatments: total treatments = 3 density level × 5 fiber compositions × 2 duplicates.

Fiber production

Fibers from both pine chips and corn stalks were generated using a pressurized disc refiner with a feed pressure of 10 and 40 N m^{-2}; the fibers were air dried and bagged for panel manufacturing at Divapan, Inc (Turkey).

Panel production

Production parameters are shown in Table 2. To produce the panels, 11% (based on oven-dry wood weight) urea formaldehyde (Table 3) was used as an adhesive, 1% (based on oven-dry wood weight) wax as a water repellent, and 1% (based on oven-dry wood weight) ammonium chloride (solid content 33%) as hardener. The materials were mixed for 3 min to obtain homogenized resin distribution. Fibers were dried to 11% water content in 3-4 s. Fiber mats were pressed for 6 min at 150 °C, and then the produced panels were conditioned at 65 ± 5% RH and 20 ± 1 °C, in accordance with TS-642-ISO 554 (1997).

Test specimens were cut from the panels according to TS-EN 326-1 (1999) and the samples were kept in a conditioning room. The physical and mechanical properties of the produced panels were evaluated. Water absorption and thickness swelling of the materials were determined according to EN 317 (1999). The specimens were tested for bending and modulus of elasticity (EN 310 1999), internal bond strength (EN 319 1999), and hardness (ASTM D 1037-78 1994). The data obtained were statistically analyzed using analysis of variance (ANOVA) and Duncan's mean separation test for thickness swelling, water absorption, and all mechanical properties.

Table 1. The experimental design.

Board Type	Corn Stalk fiber (C)	Pine Fiber (P)	Number of board for each type
A	100	0	2
B	75	25	2
C	50	50	2
D	25	75	2
E	0	100	2

Table 2. Production parameters of fiberboards.

Parameter	Value
Press temperature (°C)	150
Pressing time (min)	6
Press pressure (N mm^{-2})	2.4-2.6
Thickness (mm)	18
Dimensions (mm)	480 × 480

Table 3. The properties of urea-formaldehyde (UF) adhesive.

Properties	Unit	Value
Solid content	%	55 ± 1
Density (20 °C)	g cm^{-3}	1.227
Viscosity (20 °C)	Cps	185
Flowing time (20 °C)	S	25-40
Free formaldehyde (max.)	%	0.7
Gel time (100 °C) (10% NH_3SO_4)	s	40-60
Shelf time (20 °C)	day	45
pH	-	7.5-8.5

Results

Table 4a shows some of the chemical properties of the corn stalk and pinewood examined in the present study, and a comparison with the values for some other crop residues and wood species obtained from the literature. The results indicate that the holocellulose content of corn stalk was lower than that of hardwoods, and was in the range of softwoods and cereal straw. The observed α-cellulose content in corn stalk was comparable to that in softwoods, hardwoods, and cereal straw. In terms of lignin, the content in corn stalk was lower (20.2%) than that in softwoods, hardwoods, and hazelnut husk, but was higher than that in cereal straw. Corn stalk cold and

Table 4. a) Chemical composition of corn stalks (current) and pine wood (current), cotton carpel (Alma et al. 2005) cereal straw (Eroglu 1988), hazelnut husk (Copur et al. 2007), and soft/hardwoods (Fengel and Wegener 1989).

Raw material	Holo-cellulose %	α-cellulose %	Lignin %	Ash %	Solubility, %			
					Alcohol - benzene (2/1)	1% NaOH	Hot water	Cold water
Corn stalks	67.5	44.5	20.2	8.10	13.0	44.7	18.1	17.4
(Std. deviation)	(0.10)	(0.28)	(0.23)	(0.21)	(0.18)	(0.27)	(0.15)	(0.11)
Pine (*Pinus nigra*)	64.7	35.5	33	0.9	2.50	19.0	2.25	3.88
(Std. deviation)	(0.16)	(0.22)	(0.18)	(0.11)	(0.24)	(0.24)	(0.09)	(0.15)
Cereal straw	64-71	36-46	12-17	3-12	2-4	38-40	12-7	4-7
Cotton carpel	71.6	31.2	20.5	5.54	6.63	48.6	12.2	8.39
Hazelnut husk	55.1	34.5	35.1	8.22	1.63	50.4	20.9	18.2
Hardwoods	70-78	38-50	30-35	0.35	2-6	14-20	2-7	4-6
Softwoods	63-70	29-47	25-35	0.35	2-8	9-16	3-6	2-3

b) Morphological analyses of corn stalks (current) and pinus nigra (current) wheat straw (Tutuş and Eroğlu 2003) and *Fagus orientalis* (Akgül and Tozluoğlu 2009).

Material Type	Cell wall thickness (μm)	Fiber length (μm)	Lumen width (μm)	Fiber width (mm)
Corn stalk	4.7	1.12	7.3	20.6
(Std. deviation)	(0.18)	(0.21)	(0.18)	(0.16)
Pinus nigra	4.95	1.21	26.23	36.12
(Std. deviation)	(0.12)	(0.25)	(0.22)	(0.09)
Wheat straw	5-5.5	0.86	5.46	11-19
Fagus orientalis	4.46	0.67	8.66	17.94

hot water solubility were much higher than those of the other materials, but was similar to those of hazelnut husk. Alcohol-benzene solubility of corn stalk was the highest and 1% NaOH solubility of corn stalk was higher than that of the other materials, except hazelnut husk and cotton carpel. The morphological properties of corn stalk are shown in Table 4b and the results indicate that the fiber properties of corn stalk were similar to those of conventional industrial wood (juvenille and branch wood).

The thickness swelling and water absorption of the produced fiberboards after 2 and 24 h of water immersion are shown in Figures 1 and 2, and Figures 3 and 4, respectively. In addition, the results of ANOVA and Duncan's mean separation test are given in Table 5 and Table 6. Mean thickness swelling percentage of fiberboards produced using a mixture of corn stalk and pinewood fibers differed significantly based on water immersion time ($P < 0.001$), and thickness swelling increased with soaking time, from 2 to 24 h, in all board types. Mean bending strength of the fiberboards varied from 31.3 to 10.3 N mm^{-2}, and modulus of elasticity varied from 1334.7 to 3413.4 N mm^{-2} (Figures 5 and 6). All the boards produced in the present study, except for board type A (0.6 g cm^{-3} density), had higher bending strength (minimum: 20 N mm^{-2}) than required by TS-EN-64-5 (1999) for general-purpose fiberboards. The internal bond (IB) strength of the produced fiberboards varied from 0.15 to 0.53 N mm^{-2} (Figure 7). The minimum required value in the standards is 0.55 N mm^{-2} for general-purpose TS-EN-64-5 (1999). The present results indicate that all the produced fiberboards met the minimum standard required for all purposes, except IB strength. Increased board density led to an increase

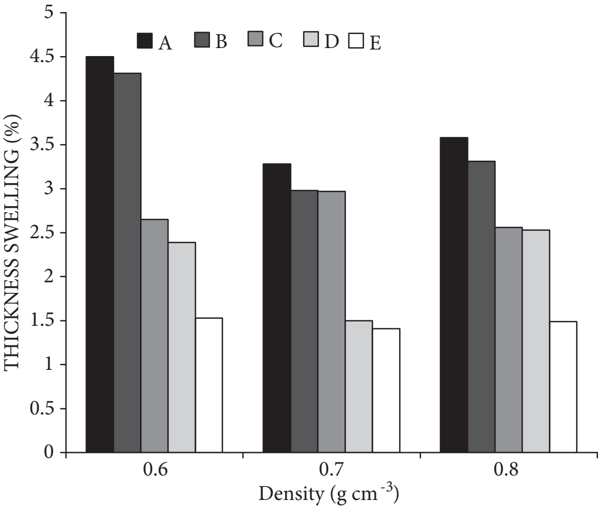

Figure 1. The 2-h thickness swelling of the panels.

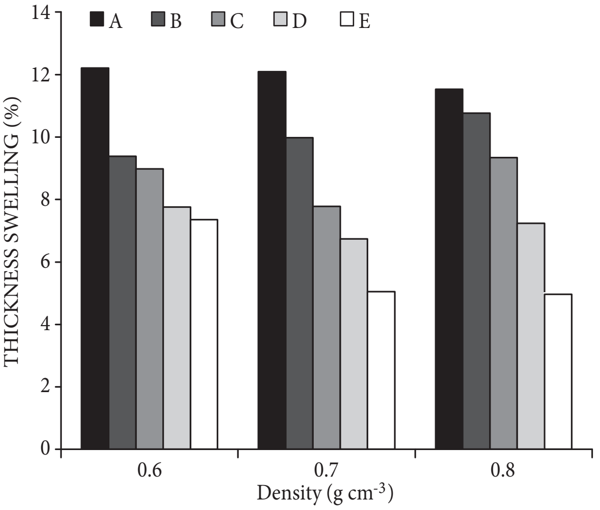

Figure 2. The 24-h thickness swelling of the panels.

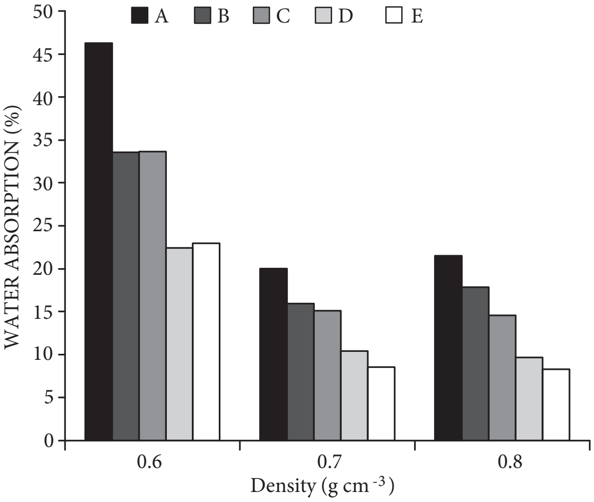

Figure 3. The 2-h water absorption of the panels.

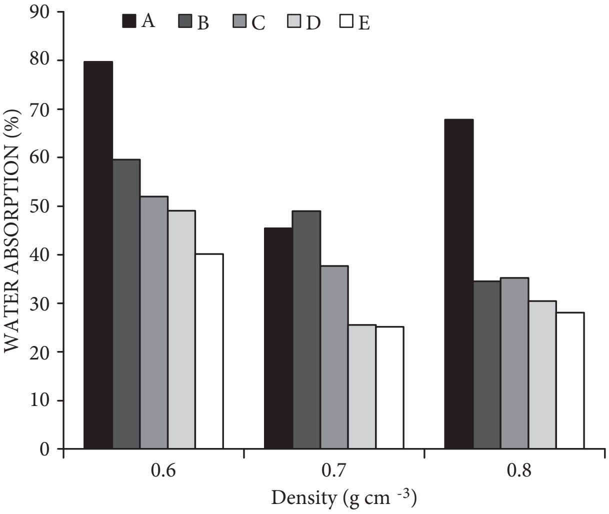

Figure 4. The 24-h water absorption of the panels.

in IB strength. Increasing the quantity of corn stalk in the mixture decreased the IB strength of the produced panels. Similar results have also been observed in other crop boards, such as hazelnut husk (Copur et al. 2007).

The surface hardness of the produced panels shows that the density of the boards significantly affected their hardness; denser panels resulted in harder surfaces (Figure 8). For panels with a density of 0.6 g cm^{-3}, the hardest panel surface was obtained when panels were produced using a mixture of 50% corn stalk and 50% pine fibers. For panels with a density of 0.7 and 0.8 g cm^{-3}, the surface hardness of the panels generally decreased as the proportion of corn stalk in the mixture increased (Figure 8).

Discussion

The findings of the present study indicate that the density of the panels affected the mean thickness swelling percentage of most of the produced panels; however, panel type C and E for 2 h, and panel type A

Table 5. Thickness swelling test results of ANOVA and Duncan's mean separation tests of fiberboards produced using corn stalks and pine fibers.

Dependent Variable

Source	Type III Sum of Squares	df	Mean Square	Sig.
2h thickness swelling				
Corrected Model	135.383[a]	14	9.670	0.000
Intercept	1120.776	1	1120.776	0.000
Sample	110.464	4	27.616	0.000
Density	10.588	2	5.294	0.000
Sample * Density	14.331	8	1.791	0.000
Error	42.658	135	0.316	
Total	1298.816	150		
Corrected Total	178.040	149		

a. R Squared = 0.760 (Adjusted R Squared = 0.736)

Source	Type III Sum of Squares	df	Mean Square	Sig.
24-h thickness swelling				
Corrected Model	758.423[a]	14	54.173	0.000
Intercept	11188.111	1	11188.111	0.000
Sample	670.625	4	167.656	0.000
Density	7.113	2	3.557	0.004
Sample * Density	80.684	8	10.086	0.000
Error	83.226	135	0.616	
Total	12029.759	150		
Corrected Total	841.648	149		

a. R Squared = 0.901 (Adjusted R Squared = 0.891)

for 24 h resulted in insignificant differences in thickness swelling, even when the density of the panels varied. Mean thickness swelling differed according to panel type and panel density. Thickness swelling of panels depends on several factors, including insufficient resin content and distribution, furnish moisture, poor compatibility of the furnish and adhesive, chemical composition of the furnish, etc. The higher mean thickness swelling observed in the present study for panel type A, B, and D for 2 h, and type B, C, and D for 24 h could be explained by the higher number of water-attractive OH groups in the denser panels. On the other hand, the highest mean thickness swelling in less dense panels (type A and B for 2 h, and type D and E for 24 h) could be explained by the compatibility of the furnish and adhesive.

The present study's results show that dimensional stability of the panels was not dependent only on a specific variable, but on several of the factors mentioned above. In general, the dimensional stability of the panels decreased as the ratio of corn stalk increased, based on both 2- and 24-h testing (Table 5) (Figures 1 and 2). This result is not surprising, considering the chemical composition of pinewood and corn stalk fibers. As corn stalk contains less water-resistant lignin and more water-attractive carbohydrates, including more available OH groups, the results show higher thickness swelling and higher water absorption values for board type E than for the other boards (A, B, C, and D).

The thickness swelling values obtained in the present study for 24 h were lower than the required TS-EN 312 value of 14% for all boards. This was

Table 6. Water absorption test results of ANOVA and Duncan's mean separation tests of fiberboards produced using corn stalks and pine fibers.

Dependent Variable				
Source	Type III Sum of Squares	df	Mean Square	Sig.
		2h water absorption		
Corrected Model	16175.484[a]	14	1155.392	0.000
Intercept	60283.133	1	60283.133	0.000
Sample	5164.122	4	1291.030	0.000
Density	10305.278	2	5152.639	0.000
Sample * Density	706.084	8	88.261	0.000
Error	637.041	135	4.719	
Total	77095.659	150		
Corrected Total	16812.525	149		

a. R Squared = 0.962 (Adjusted R Squared = 0.958)

		24-h water absorption		
Corrected Model	29104.104[a]	14	2078.865	0.000
Intercept	230828.536	1	230828.536	0.000
Sample	18653.107	4	4663.277	0.000
Density	693.011	2	346.505	0.164
Sample * Density	9757.987	8	1219.748	0.000
Error	25529.921	135	189.111	
Total	285462.561	150		
Corrected Total	54634.025	149		

a. R Squared = 0.533 (Adjusted R Squared = 0.484)

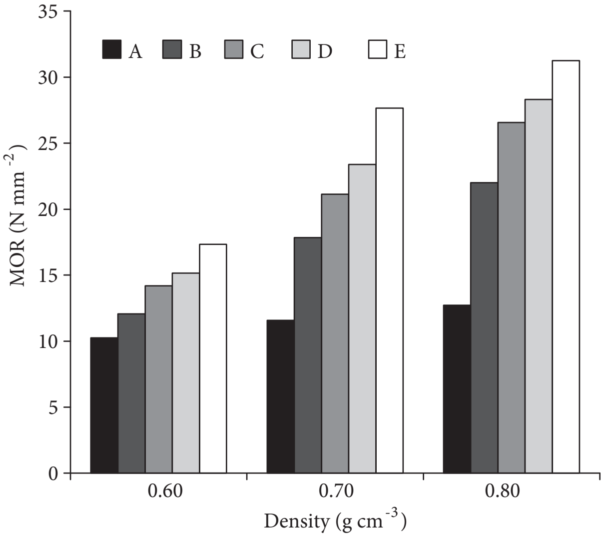

Figure 5. Bending strength of panels.

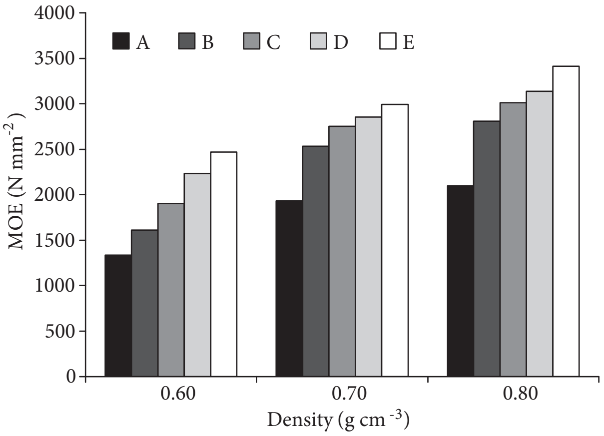

Figure 6. Modulus of elasticity of panels.

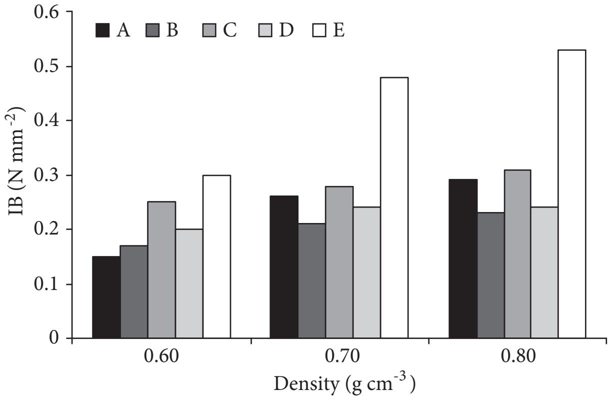

Figure 7. Internal bond strength of panels.

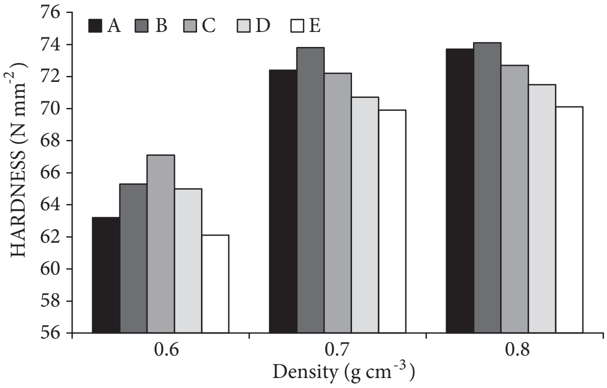

Figure 8. Janka hardness of panels.

possibly due to the water-repellent chemicals used to produce the boards. In similar studies of crop panels higher thickness swelling values were observed: 20%, 22%, 24%, 25%, 25%, 26%, and 27% for flax (Kozlowski et al. 1987), tobacco straw (Kalaycıoğlu 1992), cotton stalk (Güler and Özen 2004), hemp (Kozlowski et al. 1987), sunflower stalk (Bektas et al. 2005), cotton carpel (Alma et al. 2005), and tea plant waste (Kalaycıoğlu 1992), respectively.

The water absorption values of the fiberboards produced using corn stalk differed according to density ($P < 0.001$) and water immersion time ($P < 0.001$). Increasing the soaking time from 2 to 24 h, as expected, resulted in higher water absorption values (Table 6) (Figures 3 and 4). Significantly less water was held by the panels when panel density increased from 0.6 to 0.8 g cm^{-3}. Denser fiberboards with less void spaces in their structure were expected to absorb less water. This observation is compatible with previous findings (Güler and Özen 2004). However, when the panels with a density of 0.7-0.8 g cm^{-3} were compared, it was observed that available OH groups played a primary role due to the compaction of the panels and, as a result, less dense boards resulted in higher water absorption. More open spaces in lower density fiberboards can account for this finding.

The bending test involves both tear and shear forces (Ye et al. 2007), and because corn stalk has short fibers they have more surface area, resulting in lower adhesion in a unit surface area, which led to lower bending strength of the panels that included corn stalk fibers. The minimum modulus of elasticity required by the standard (1800 N mm^{-2}) for general-purpose fiberboard was met by all the panels, except panel types A and B, which had densities of 0.6 g cm^{-3}. The results show that increasing board density had a positive effect on the bending strength and elastic modulus of the fiberboard ($P < 0.001$), and the highest bending strength and elastic modulus were observed for panels with a density of 0.8 g cm^{-3}. Higher ratios of corn stalk in the mixture had a negative effect on bending strength. The highest bending strength and modulus of elasticity were observed in panels that consisted solely of pine fibers. Similar results were also reported by other researchers for wheat straw (Eroğlu and İstek 2000), cotton stalk (Gençer et al. 2001), hazelnut shell and husk (Copur et al. 2008), cotton carpel (Alma et al. 2005), hazelnut husk (Copur et al. 2007), and kiwi prunings (Nemli et al. 2003). Higher surface hardness of the panels with a density of 0.7 and 0.8 g cm^{-3} may have been due to the compactibility of the corn stalk fibers, which are soft and flexible.

Conclusions

The present study examined the suitability of corn stalk for fiberboard production. Corn stalk is a bio-resource with limited use in the industry. In terms of chemical composition, corn stalk had less water resistant lignin, resulting in higher thickness swelling and water absorbency in the panels that had corn stalk in the mixture. Corn has higher ash content and higher solubility values than soft- and hardwoods. In addition, the fiber properties of corn stalk were observed to be similar to those of conventional industrial hard- and softwood.

The present results show that general-purpose fiberboards could be produced using only corn stalk fibers (except for panel type A with a density of 0.6 g cm^{-3}). In general, corn stalk in the mixture resulted in a decrease in panel properties; however, it is possible to produce fiberboards from a mixture of corn stalk and pine fibers without falling below the property values required by the standards.

Acknowledgements

The financial support (2004 K 120 200) of the Turkish State Planning Organization is gratefully acknowledged. We thank Divapan Integrated Wood Company for their help with fiber production. This research was carried out at the Fiberboard Laboratory of the Department of Forest Industrial Engineering, Düzce University, Turkey.

References

Akgül M, Şen S, Güler C (2005) Utilization of biomass as en energy source in Turkey. 14th European Biomass Conference and Exhibition Biomass for Energy, Industry and Climate Protection, 17-21 October, Palais des Congrès, Paris, France, pp. 345-348.

Akgül M, Tozluoğlu A (2009) Some chemical and morphological properties of juvenille woods from beech (*Fagus orientalis* L.) and pine (*Pinus nigra* A.) plantations. Trends in Applied Sciences Research 4: 116-125.

Alma M H, Kalaycıoğlu H, Bektaş İ, Tutuş A (2005) Properties of cotton carpel-based particleboards. Industrial Crops and Products 22: 141-149.

ANSI A208.2 (1994) Medium Density Fiberboard (MDF). National Particleboard Association, Gaithersburg, MD.

ASTM D-1037-78 (1994) Standard Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials, The American Society for Testing and Materials, USA.

Bektaş İ, Güler C, Kalaycıoğlu H (2005) The manufacture of particleboards using sunflower stalks (*Helianhus annuus* I.) and poplar wood (*Populus alba* L.). J of Composite Materials 39: 467-473.

Chow P (1974) Dry formed composite board from selected agricultural residues world consultation on wood based panels. Food and Agriculture Organization of the United Nations. New Delhi, India.

Copur Y, Güler C, Taşçıoğlu C, Tozluoğlu A (2008) Incorporation of hazelnut shell and husk in MDF production, Bioresource Technology 99: 7402-7406.

Copur Y, Guler C, Akgul M, Tascioglu C (2007) Some chemical properties of hazelnut husk and its suitability for particleboard production, Building and Environment 42: 2568-2572.

EN 310 (1999) Wood based panels, determination of modulus of elasticity in bending and bending strength. European Standardization Committee, Brussels.

EN 317 (1999) Particleboards and fiberboards, determination of swelling in thickness after immersion. European Standardization Committee, Brussels.

EN 319 (1999) Particleboards and fiberboards, determination of tensile strength perpendicular to plane of the board. European Standardization Committee, Brussels.

Eroglu H (1988) Lif Levha Endüstrisi Ders Notları. Karadeniz Teknik Üniversitesi Yayın No: 304, Trabzon.

Eroğlu H, İstek A (2000) Medium density fiberboard (MDF) manufacturing from wheat straw (Triticum aestivum L.). Inpaper International 4: 11-14.

Fengel D, Wegener G (1989) Ultrastructure, Reactions. In: Wood Chemistry, Walter de Gruyter & Co., Berlin.

Fidan, MS, Bozali N, Ertaş M, Alma MH, Bölek Y (2008) Alternatif enerji kaynakları: katı atıklardan yakıt briket üretimi. VII. Ulusal Temiz Enerji Sempozyumu UTES'2008, 17-19 Aralık, İstanbul, pp. 221-230.

Gençer A, Eroğlu H, Özen R (2001) Medium density fiberboard manufacturing from cotton stalks (Gossipium hirsutum L.). Inpaper International 5: 26-28.

Güler C, Özen R. (2004) Some properties of particleboards made from cotton stalks (*Gossypium hirsitum* L.). Holz als Roh-und Werkstoff 62: 40-43.

Jane FW (1956) The Structure of Wood. Adam and Charles Black, London.

Kalaycıoğlu H (1992) Utilization of annual plant residues in production of particleboard. ORENKO-92, 1st National Forest Product Congress, Trabzon, Turkey, pp. 288-292.

Kozlowski R, Piotrowski R (1987) Produkcja plyt pazdzıezowo-trocinowych (Flax Sshives saw dust production), Prace Instytutu Krajowych Wlokien Naturalnych (Works of the Institute of Natural Fibers) Vol. XXXI, pp. 132-142.

Nemli G, Kırcı H, Serdar B, Ay N (2003) Suitability of kiwi (*Actinidia sinensis* P.) prunings for particleboard production. Industrial Crops and Products 1: 39-46.

OGM (2009) Orman ürünlerinin ihracat potansiyeli ve ormancılıkta 2023 stratejileri. http://www2.ogm.gov.tr/dokumanlar/trapor150609.doc.,Ankara.

TS-EN-64-5 (1999) Fiberboards–Specifications – Part 5: Requirements for dry process boards (MDF). TSE, Ankara.

TS EN 326-1 (1999) Wood-Based panels-sampling, cutting and inspection-part 1: Sampling test pieces and expression of test results. TSE, Ankara.

TS-642-ISO 554 (1997) Conditioning and/or standard atmospheres for trial and Standard reference atmosphere. TSE, Ankara.

Tutuş A, Eroğlu H (2003) A practical solution to silica problem in straw pulping. APPITA Journal 56: 111-115.

Wise EL, Karl HL (1962) Cellulose and Hemicellulose in Pulp and Paper Science and Technology. Vol: I, Pulp, Edited by C. Earl Libby. McGraw-Hill Book Co., New York.

Ye XP, James J, Monlin K, Al W, Deland M (2007) Properties of medium density fiberboards made from renewable biomass. Bioresource Technology 98: 1077-1084.

Youngquist J, English BE, Spelter H, Chow S (1993) Agricultural Fibers In Composition Panels. In: Maloney, Thomas M, ed. Proceedings of the 27th International Particleboard /Composite Materials Symposium; March 30-31; April 1; Pullman, WA: Washington State University.

Youngquist J, English B, Scharmer S, Chow P, Shook S (1994) Literature review on use of non-wood plant fibers for building materials and panels. Gen Tech Rep FPL-GTR-80. USDA Forest Serv., Forest Products Lab., Madison, Wis.