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THE POTENTIAL FOR USING CORN STALKS AS A RAW MATERIAL FOR PRODUCTION PARTICLEBOARD WITH INDUSTRIAL WOOD CHIPS

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ABSTRACT

In this study particleboards were manufactured from mixtures of corn stalks (*Zea mays indurate* Sturt.) and industrial woodchips at several ratios. The corn stalks and industrial wood particles were mixed at ratios 0, 25, 50, 75 and 100 % respectively. The suitability of corn stalks chips for particleboard production was examined. Urea formaldehyde resin was used as a binder in 3-layers particleboards. Produced panels were tested for certain mechanical and physical properties. The manufactured boards were tested according to EN standards. In addition, the chemical properties of corn stalks were evaluated. Experimental results indicated that increase in corn stalk chips in the mixture generally diminished the mechanical and physical properties.

KEYWORDS: Particleboard, corn stalks (*Zea mays indurate* Sturt.), wood chips, physical properties, chemical properties, mechanical properties.

INTRODUCTION

In recent years the utilization of agricultural waste and annual fibers for particleboard or other composite board production is going popularity. Particleboard is known one of the most important products of forest products industry. Throughout the years, the production coast of particleboard has increased while the quality of product was reduced.

Agricultural waste materials and annual plants have become alternative raw materials for the production of particleboard or fiber composite materials. The most frequently referred alternative non-wood materials are flax, bagasse, hemp, reed and cereal straws such as rice and wheat straw (Youngquist et al. 1994). Today, chemical pulp and panel products using wheat straw and other crop residues are being commercially manufactured in a number of countries including Turkey (Cőpűr et al. 2007). There is still an outgoing research interest to find alternative sources of raw materials for composite manufacturing.

In recent studies; cotton stalks (Gűler and Özen 2004), cotton carpel (Alma et al. 2005), hazelnut husk (Gűler et al. 2009), oil palm (Ratnasingam et al. 2008), bamboo chips (Papadopoulos et al. 2004), kenaf core and kenaf stalks (Xu et al. 2004; Kalaycioğlu and Nemli 2006), date palm branches (Nemli et al. 2001), corn and cotton stalks (Kargarfard and Jahan Latibari 2011) eggplant stalks (Guntekin and Karakus 2008), wheat straw and corn pich (Wang and Sun 2002), vineprunings (Ntalos and Grigoriou 2002), peanut hull (Gűler and Bűyűksari 2011), sunflower stalks (Khristova et al. 1998; Bektas et al. 2005; Gűler et al. 2006) and pepper stalks (Guntekin et al. 2008) have been investigated.

The problems of the industrial usage of agricultural residues in particleboard industry refer to the high cost of collecting, transporting, and storing of the residue materials. Some of these problems could be overcome by building local, small scale mills, close to the rural areas.

In Turkey, corn, sunflower, rice, wheat, straw, sugar cane and cotton are produced for vegetable oil fiber or food industries. The waste products of these agricultural plants are consumed for animal feed fertilizer or heat production.

In Turkey the total wastes biomass resources potential reaches 56.240.000 ton/year (Tab. 1), of whileare 36 million ton wheat straw, 2.5 million ton cornstalk, and 3 million ton cottonstalk, and 2.5 million ton sunflowerstalk 1 and 1.3 million ton graperesidues and the others 940.000 ton. Due to the expected applications of the efficient new modern technologies on the available biomass resources this contribution effet will be increased in the future (Akgűl et al. 2010).

Tab. 1: Turkey's annual plant stalks production (ton/year).

Annual plant	Production (estimate)
Wheat straw	36.000.000
Barley stalk	8.000.000
Corn stalk	2.500.000
Cotton stalk	3.000.000
Grape residues	1.300.000
Rice straw	200.000
Rye	240.000
Tobacco	300.000
Hemp	2.000.000
Reed	200.000

One of the agricultural residues, corn stalks (*Zea mays indurate* Sturt.), is produced by former Argentina, Brasil, ABD, Ukraine, India, Paraguay and Turkey. Mediterranean, Black Sea, Marmara, Aegean and Southeast Anatolia Regions in Turkey is covered with corn stalks plant about 6.5 million decares. The possible utilization of corn stalks in particleboard industry might produce economic benefits and contribute to environmental sustainability. Therefore, this study focuses on the potential use of corn stalks as a source of board making raw material.

MATERIAL AND METHODS

Corn stalks obtained from the Duzce region of Turkey were cleaned from dust and dirt. Corn stalks (*Zea mays indurate* Sturt.) were coarsely chipped. Industrial wood chips were obtained particleboard factory. The particles were screened by utilizing a horizontal vibration sieve.

3-1.5 mm average size particles were used in the core section of particleboard while 1.5-0.8 mm average size particles were utilized in the shell layers.

All particles used in this study were dried at 100-110°C in a technical oven until 3 % moisture content to be reached. The resin was applied 9 % for the core layer and 11 % for the shell layers based on oven dry weight. The properties of the UF resin are given in Tab. 2. As a hardener, 33 % of ammonium chloride solution was used for all of the UF resin boards. Panels with a target density of 0.70 $g.cm^{-3}$ were manufactured using 0, 25, 50, 75 and 100 % corn stalk chips in the mixture. Experimental design was given in Tab. 3. The dimensions of the produced particleboards were 50x50x2 cm in pressing and after edge trimming the final dimensions of the particleboards were to 47x47x2 cm. The pressing conditions were as follows; press temperature: 150°C, press time: 7 min, press pressure: 2.4-2.6 $N.mm^{-2}$ and production parameters of boards used in this study.

Tab. 2: Properties of the UF adhesive.

Properties	UFa
Solid (%)	55±1
Density ($g.cm^{-3}$)	1.20
pH	8.5
Viscosity (cps)	160
Ratio of water tolerance	10/27
Reactivity	35
Free formaldehyde (%)	0.15
33 % NH_4Cl content (max, %)	1
Gel point (100°C, sec.)	25-30
Storage time (25°C, max day)	90
Flowing point (25°C, sec.)	20-40

Tab. 3: Experimental design raw material.

Board type[a]	Raw material	
	Corn stalks	Industrial wood chips
A	-	100
B	25	75
C	50	50
D	75	25
E	100	-

[a]The density of the boards made from corn stalks and wood chips was 0.70 $g.cm^{-3}$.

Prior to testing, the boards produced were conditioned at 65 ± 5 % relative humidity (RH) and 20 ± 1°C in according to TS 642-ISO 554 (1997) hardboard method. The samples were cut from the experimental boards to determine some physical and mechanical properties in accordance with TS-EN 310 (1999), TS-EN 317 (1999), TS-EN 319 (1999), and TS-EN 312 (2012) standards.

The chemical properties of the corn stalk were also determined and specimens were sampled and prepared according to Tappi T 257 (1985) standard. Holocellulose was determined according to the chloride method (Wise and Karl 1962). Alpha cellulose was separated from the other components by soaking the specimen in a 17.5 % solution of sodium hydroxide

(Tappi T 203 cm-09). The lignin T 222 (1998) and ash T 211 (1993) contents were also studied. Alcohol-benzene T 204 (1997), cold and hot-water T 207 (1999) and 1 % NaOH T 212 (1998) solubility were determined.

An analysis of variance (ANOVA) test was applied to evaluate the effects of board typesusing SPSS software (SPSS 19 2010). Significant differences between variableswere determined by Duncan test at $p<0.05$ level.

RESULTS AND DISCUSSIONS

Tab. 4 indicated results for the mechanical properties of the produced particleboard. Results indicated that corn stalks ratios used in particleboard production significantly affect modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) of the product. As expected, the MOR, MOE and IB values decreased as corn stalk percentage increased from 0 to 100 % (Fig. 1). The highest MOR and MOE values of 14.08 and 2937 $N.mm^{-2}$ were observed when only industrial woodchips was utilized in the manufacture of the particleboard (E), respectively. On the other hand, the lowest MOR and MOE values of 9.13 and 1419 $N.mm^{-2}$ were obtained produced panels with corn stalks ratio of 100 %. It can be easily seen that mechanical properties of particleboards were reduced with the increase of corn stalks ratio in the panels (Fig. 1). The standard method (TS EN 312 2012) recommends a minimum MOR and MOE values of 11.5 and 1600 $N.mm^{-2}$ for the particleboards manufactured for general propose-use, respectively. The findings in this study showed that three panel types in particleboards met the minimum requirement for MOR (C, D and E type) and MOE (B, C, D and E type).

Tab. 4: The mechanical properties of particleboards made from corn stalks and industrial wood particles and the test results of ANOVA and Duncan's mean separation tests.

Mechanical Properties	Board Type	Mean [a]	Std. Deviation	Std. Error	X_{Min} [b]	X_{Max} [c]	p [d]
MOR ($N.mm^{-2}$)	A	14.08[p]	2.33	0.67	11.92	18.23	*
	B	13.28[s]	1.38	0.35	11.61	15.75	*
	C	11.86[u]	1.65	0.48	10.28	15.08	*
	D	10.97[t]	1.39	0.40	8.06	13.62	*
	E	9.13[v]	1.28	0.10	7.61	11.29	*
MOE ($N.mm^{-2}$)	A	2937[p]	276	91.28	2650	3690	*
	B	2573[s]	130	32.70	2370	2880	*
	C	2482[s]	188	54.28	2033	2810	*
	D	1689[u]	157	32.84	1436	1974	*
	E	1419[t]	114	27.05	1125	1708	*
IB ($N.mm^{-2}$)	A	0.447[p]	0.123	0.033	0.336	0.666	*
	B	0.379[s]	0.046	0.014	0.315	0.465	*
	C	0.334[s]	0.046	0.012	0.270	0.413	*
	D	0.202[u]	0.036	0.010	0.170	0.291	*
	E	0.193[u]	0.030	0.008	0.139	0.255	*

[a]Mean values are the average of 12 specimens; [b]Minimum value; [c]Maximum value; [d]Significance level; *significant at 0.001 for ANOVA; [p,s,u,t,v]Values having the same letter are not significantly different (Duncan test).

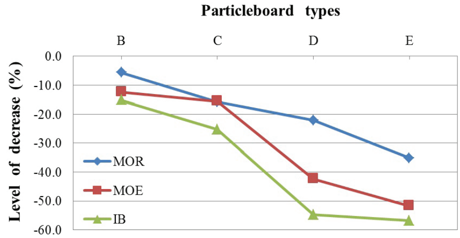

Fig. 1: Percent decrease in average values of mechanical properties of the panel types.

In the case of IB, similar to the other mechanical properties, the highest IB value of 0.447 $N.mm^{-2}$ was observed with the particleboard produced using 100 % industrial wood chips. The lowest IB value of 0.193 $N.mm^{-2}$ was obtained produced panels with corn stalks of 100 %. Only C, D, E type particleboards met the IB requirement of 0.24 $N.mm^{-2}$ for general purpose end-use.

Tab. 5 shows the results of ANOVA and Duncan's mean separation tests for water absorption (WA) and thickness swelling (TS) for 2 and 24 h water immersion times. The highest WA (58.3 and 63.39 %) and TS (24.61 and 25.55 %) were observed with the particleboard (A) having 100 % corn stalks in the mixture for 2 and 24 h water immersion times, respectively. Increase in corn stalks percentage in the mixture resulted in a higher TS and WA for particleboards produced using corn stalks and wood chip mixtures (Fig. 2). The observed results indicated that the particleboards (A, B, C, D and E) including corn stalks in the mixture resulted in higher TS (more than 14 %) required by TS EN 312 (2012) standard. Utilizing water repellent chemicals, such as paraffin in the production may improve these properties.

Tab. 5: Thickness swelling (TS) and water absorption (WA) test results of ANOVA and Duncan's mean separation tests of particleboards produced from corn stalks.

Physical properties	Board type	Soaking time (min)	Mean (%)[a]	Std, Deviation	Std. Error	X_{Min}[b]	X_{Max}[c]	p[d]
Thickness swelling (TS)	A	2	17.94 [u]	0.28	0.063	17.43	18.55	*
	B	2	19.14 [s]	0.46	0.103	17.82	19.61	*
	C	2	19.56 [s]	0.71	0.16	18.13	20.62	*
	D	2	23.50 [p]	2.65	0.592	20.62	29.68	*
	E	2	24.61 [p]	3.03	0.677	21.05	29.74	*
	A	24	18.54[t]	0.31	0.069	17.98	19.08	*
	B	24	20.27[u]	0.65	0.146	18.78	21.88	*
	C	24	20.78[u]	0.8	0.178	19.14	21.96	*
	D	24	24.23[s]	2.76	0.617	21.3	32.02	*
	E	24	25.55[p]	3.08	0.689	21.69	30.25	*
Water absorption (WA)	A	2	43.27 [t]	0.78	0.174	41.29	44.24	*
	B	2	46.84 [u]	1.08	0.242	44.1	48.36	*
	C	2	48.62 [u]	1.21	0.27	45.05	50.53	*
	D	2	55.90[s]	4.33	0.969	49.72	66.32	*
	E	2	58.30 [p]	6.52	1.459	51.02	68.03	*
	A	24	46.67 [t]	0.75	0.167	45.27	47.87	*
	B	24	50.66 [u]	1.29	0.288	47.15	52.31	*
	C	24	52.29 [u]	1.39	0.311	48.46	54.6	*
	D	24	59.44[s]	4.57	1.022	52.7	70.38	*
	E	24	63.39 [p]	7.02	1.57	55.64	74.02	*

[a]Mean values are the average of 20 specimens; [b]Minimum value; [c]Maximum value; [d]Significance level of 0.001 (for ANOVA); [p,s,u,t]Values having the same letter are not significantly different (Duncan test).

Tab. 6: Chemical composition of corn stalks, some plant wastes and soft/hardwoods (%).

Raw Material	Holocellulose	α-cellulose	Lignin	Ash	Solubility			
					Alcohol-benzene (2/1)	1% NaOH	Hot water	Cold water
Corn stalk	69.12	50.43	13.01	8.99	4.07	52.8	17.27	19.66
Peanut husk	68.8	-	28	-	7	33.5	11.75	17
Hazelnut husk	55.1	-	41.4	-	2.0	50.4	20.9	18.2
Cereal straw	64-71	35-39	12-17	3-12	2-4	38-40	12-17	4-7
Cotton carpel	71.6	42.5	20.5	5.54	6.63	48.6	12.2	8.39
Hardwoods	70.78	45-50	30-35	0.35	2-6	14-20	2-7	4-6
Softwoods	63-70	45-50	25-35	0.35	2-8	9-16	3-6	2-3

Certain chemical properties of the corn stalks and some other crop residues and soft/hardwoods were listed in Tab. 6. A comparison between corn stalks and other crops; cereal straw (Eroglu 1988), cotton carpel (Alma et al. 2005), peanut hull (Gűler and Bűyűksari 2011) and softwoods and hardwoods Sjostrom (1993) indicated that the holocellulose content corn stalks was close to the other crop residues and wood species except for hazelnut hull (Cőpűr et al. 2007). Exception observed when comparison made with hazelnut hull including lower amount of holocellulose. The lignin content corn stalks was higher than cereal straw, but it was much lower when compared with peanut hull, hazelnut hull, cotton carpel, softwoods and hardwoods. Alcohol-benzene solubility was determined close to cereal straw and lower than peanut husk and cotton carpel. 1 % NaOH solubility was obtained much higher than all of wood species and crop residues. Hot water solubility was similar to cereal straw and cold water solubility of corn stalks was determined higher than others.

CONCLUSIONS

This study investigated the possibility of using corn stalks and industrial wood mixture to manufacture three-layer particleboards. The results indicated that it is possible to produce particleboards from the mixture of corn stalks and industrial wood chips by using urea-formaldehyde adhesives.

The produced panels (C, D and E types) tested for mechanical properties complied with the minimum requirements in the standards for the general grade particleboards.

Even though increase in the concentration of corn stalks particles in composite matrix reduces both the physical and mechanical properties of the particleboard, almost all the studied properties (that is, modulus of rupture, modulus of elasticity, internal bond strength) of the produced panels comply with the minimum requirements in standards for general grade particleboards with the exception of TS and WA. As there are no hydrophobic additives used in these panels, these properties can be improved by the utilization of hydrophobic materials in the matrix.

The produced boards can be utilized for general purposes as well as furniture for interior environments and the results obtained showing that corn stalks could be an alternative raw material for particleboard industry.

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