EFFECT OF PRODUCTION PARAMETERS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARDS MADE FROM PEANUT (*Arachis hypogaea* L.) HULL

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In this study, effects of panel density and adhesive ratio on some physical and mechanical properties of peanut (*Arachis hypogaea* L.) hull particleboards for general purposes were investigated. Panels were manufactured with various densities (0.5, 0.6, 0.7, and 0.8 g/cm^3) and adhesive ratios (core layer 8-9% and face layer 10-11%) using urea-formaldehyde (UF) as an adhesive. All panels were tested for some mechanical (internal bond, modulus of elasticity, and modulus of rupture) and physical (water absorption and thickness swelling) properties. Results indicated that increase in the panel density and adhesive ratio, resulted in an improvement in mechanical and physical properties. Only the panels with 0.8g/cm^3 density almost met the requirements for the TS-EN 312 Standard for general purposes. Also, the boards having the lower mechanical properties tested in this study can be used as insulating material in buildings because such materials would not be subjected to any mechanical stress.

Keywords: Peanut hull; Particleboard; Mechanical and physical properties; Panel density; Urea-formaldehyde ratio

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INTRODUCTION

The raw material demand of the global forest products industry increases annually. On the other hand, industrial wood production from the natural forests has been declining, and that forces the forest industry to find some other agro-residues and lingo-cellulosic biomass as an alternative raw material for industrial production. Therefore, substitute bio-based materials, recycling, more efficient conversion, and new products are expected to play important roles in the future of the forest industry. The use of renewable agro-fibers as a raw material in composites production is one approach and the use of renewable biomass may result in several benefits from environmental and socioeconomic perspectives (Rowell 1995).

Today, a number of renewable biomass resources are often accepted as waste materials and are mostly ploughed into the soil or burnt in the field. Almost 18.5 million tons of peanut have been harvested annually in the world. Therefore, around 7 million tons of peanut hull are left. Peanut is naturally grown in different regions of Turkey. It is planted on more than 30 000 ha in Turkey, and almost 80 thousand tons of peanut are produced annually (Celik and Gurdal 2005). In terms of chemical composition, peanut hull consists of 68.8% holocellulose, 42.5% α-cellulose, and 28% lignin, and its solubility in alcohol-benzene, 1% NaOH, hot water, and cold water were 7%, 33.5%, 11.75%, and 17%, respectively (Guler et al. 2008).

Many researchers have investigated agro-based particleboards made from a wide variety of agricultural residues, including kenaf (Grigoriou et al. 2000), wheat cereal straws (Han et al. 1998), bamboo (Rowell and Norimoto 1988), rice straw (Li et al. 2010), kiwi prunings (Nemli et al. 2003), date palm leaves (Nemli et al. 2001), cotton stalks (Guler and Ozen 2004), cotton carpel (Alma et al. 2005), hazelnut husk (Copur et al. 2007), needle litter (Nemli et al. 2008), grass clipping (Nemli et al. 2009), pine cone (Buyuksari et al. 2010), and sunflower stalks (Khristova et al. 1998; Guler et al. 2006). Previous studies investigated utilizing peanut hulls in particleboard and MDF production at different ratios with wood particles and fibers (Pablo et al. 1975; Guler et al. 2008; Akgul and Tozluoğlu 2008). Therefore, it seems that the number of plants using renewable biomass in production will increase in the future. Up to now there has been little information on the effect of production parameters of some physical and mechanical properties of agricultural wastes. Li et al. (2010) investigated the effect of particle geometry and resin type on some physical and mechanical properties of particleboards produced from rice straw. The objective of this study is to evaluate the effect of production parameters such as density and adhesive ratios on some physical and mechanical properties of waste peanut (*Arachis hypogaea* L.) hull particleboards using urea formaldehyde adhesive.

EXPERIMENTAL

Materials and Methods

For this study the peanut hull raw material was obtained from the field right after the peanut harvest from Osmaniye in the south of Turkey. Peanut hulls were first cleaned from dust and dirt, then coarsely chipped in a Conduct chipper. Then particles were classified using a horizontal screen shaker. The particles that remained between 3 and 1.5 mm sieves and between 1.5 and 0.8 mm sieves were utilized in the core and middle layers, respectively. Particles used in particleboard production were dried at 100 to 110°C in a technical oven to reach target moisture content (3%).

Panels were manufactured with various densities (0.5, 0.6, 0.7, and 0.8 g/cm^3) and adhesive ratios. The urea formaldehyde (UF) resin at 8 to 9% and 10 to 11% adhesive levels were used for the core and outer layers based on oven dry weight of particles, respectively. The properties of the UF resin are given in Table 1. One-percent ammonium chloride (33% NH_4Cl solution) was added to the resin as a hardener. The particles were placed in a drum blender and sprayed with a mixture of urea formaldehyde and ammonium chloride for 5 min to obtain a homogenized mixture.

The experimental design set up for the production of the panels is shown in Table 2. The dimensions of particleboards were 48 x 48 x 2 cm in pressing and after edge trimming the particleboards' final dimensions were to 45 x 45 x 2 cm, which the panel production parameters were given in Table 3.

Table 1. Properties of Urea-Formaldehyde (UF) Adhesive

Properties	Values
Solid content (%)	55±1
Density (25 °C) (g/cm^3)	1.20
pH	8.5
Viscosity (25 °C) (cps)	160
Ratio of water tolerance	10/27
Reactivity	35
Free formaldehyde (max, %)	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

Table 2. Experimental design of the three-layer particleboards

Board Type	Density (g/cm^3)	Adhesive (%)	
		Middle	Surface
A	0.50	8	10
B	0.60	8	10
C	0.70	8	10
D	0.80	8	10
E	0.50	9	11
F	0.60	9	11
G	0.70	9	11
H	0.80	9	11

Table 3. Production parameters of particleboards.

Parameter	Value
Press temperature (°C)	150
Pressing time (min)	6
Peak pressure (N/mm^2)	2.4-2.6
Thickness (mm)	20
Dimensions (mm)	480x480
Outer layer (Whole of board %)	35
Middle layer (Whole of board %)	65
Number of board for each type	2

Some physical properties – water absorption (WA) and thickness swelling (TS) (EN 317, 1996) – and mechanical properties – modulus of rupture (EN 310, 1996), modulus of elasticity (EN 310, 1996), and internal bond strength (EN 319, 1996) – were determined for the produced particleboards. The averages of 10 and 20 measurements were reported for mechanical and physical properties, respectively. The specimens were conditioned at a temperature of 20°C, and 65% relative humidity in a conditioning room until they reached equilibrium for at least 3 weeks.

Data analyses and statistical methods

For the physical and mechanical properties, all multiple comparisons were first subjected to an analysis of variance (ANOVA) at $p<0.01$, and significant differences between mean values of the particleboard groups were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

Table 4 shows the results of ANOVA and Duncan's mean separation tests for WA and TS of particleboards from peanut hulls for 2 and 24-h water immersion times. For 2-h immersion time, the effect of density on the TS value of the particleboards was statistically significant in the groups C-D and G-H, while the effect of adhesive ratio was significant in the groups D-H having 0.800 g/cm^3 density. For 24-h immersion time, the effect of density on the TS value of the particleboards was statistically significant in all groups. However, adhesive ratio did not show a statistically significantly effect on the TS value of the groups A-E. The board Type E had the lowest TS values with 8.4% and 11.83% after 2 and 24-h water immersion times, while the highest TS was found for Type D, having values of 15.74% and 25.71%, respectively. It was found that the board type E exhibited low water penetration and showed the highest water absorption values. This was assumed to be due to the highest amount of resin present in the board and the lowest density of the board compared with the other ones. The board Type D, on the other hand, was found to be less resistant to water penetration; hence, it showed the lowest water absorption at 24 h water soaking. Results showed that the increase in particleboard density resulted in a better thickness swelling performance and decreased water absorption, while the increment in adhesive ratio resulted in a lower thickness swelling and water absorption for the produced particleboards. This occurred because of the high density of the particleboards which were absorbing more water than the lower density ones. Also, if the dwell time inside the water increased, the adhesion strength of the particleboard decreased, resulting in a thickness increase. Furthermore, an increase in adhesive ratio enhances the resin bonding strength of the materials.

Table 4. Thickness Swelling (TS) and Water Absorption (WA) Test Results of ANOVA and Duncan's Mean Separation Tests of Peanut Hull Particleboards

Board Type	Density (g/cm^3)	2 h		24 h	
		WA (%)	TS (%)	WA (%)	TS (%)
A	0.505 (0.03)	81.62 (10.9)^w	8.96 (0.6)^p	94.88 (8.9)^t	12.34 (1.1)^{ps}
B	0.591 (0.03)	66.10 (3.1)^t	9.30 (0.8)^p	79.17 (2.8)^s	14.01 (0.8)^u
C	0.706 (0.04)	56.13 (4.3)^u	12.23 (0.6)^s	68.45 (4.2)^p	16.65 (0.9)^v
D	0.796 (0.03)	43.43 (2.5)^p	15.74 (0.4)^t	77.57 (6.3)^s	25.71 (0.3)^x
E	0.503 (0.02)	85.17 (4.4)^w	8.40 (1.3)^p	97.85 (6.0)^t	11.83 (1.1)^p
F	0.605 (0.04)	71.72 (7.4)^v	8.97 (0.5)^p	83.81 (6.4)^u	13.09 (1.9)^s
G	0.697 (0.03)	57.95 (3.6)^u	11.46 (2.7)^s	67.85 (2.7)^p	15.34 (1.8)^t
H	0.794 (0.03)	50.49 (8.7)^s	13.92 (1.9)^u	70.43 (6.8)^p	21.02 (1.5)^w

Mean values are the average of 20 specimens. Values in parentheses are standard deviations.
^{p,s,u,t,v,w,x} Values having the same letter are not significantly different (Duncan test).

TS values and panel density relationships of the panels are presented in Fig. 1.

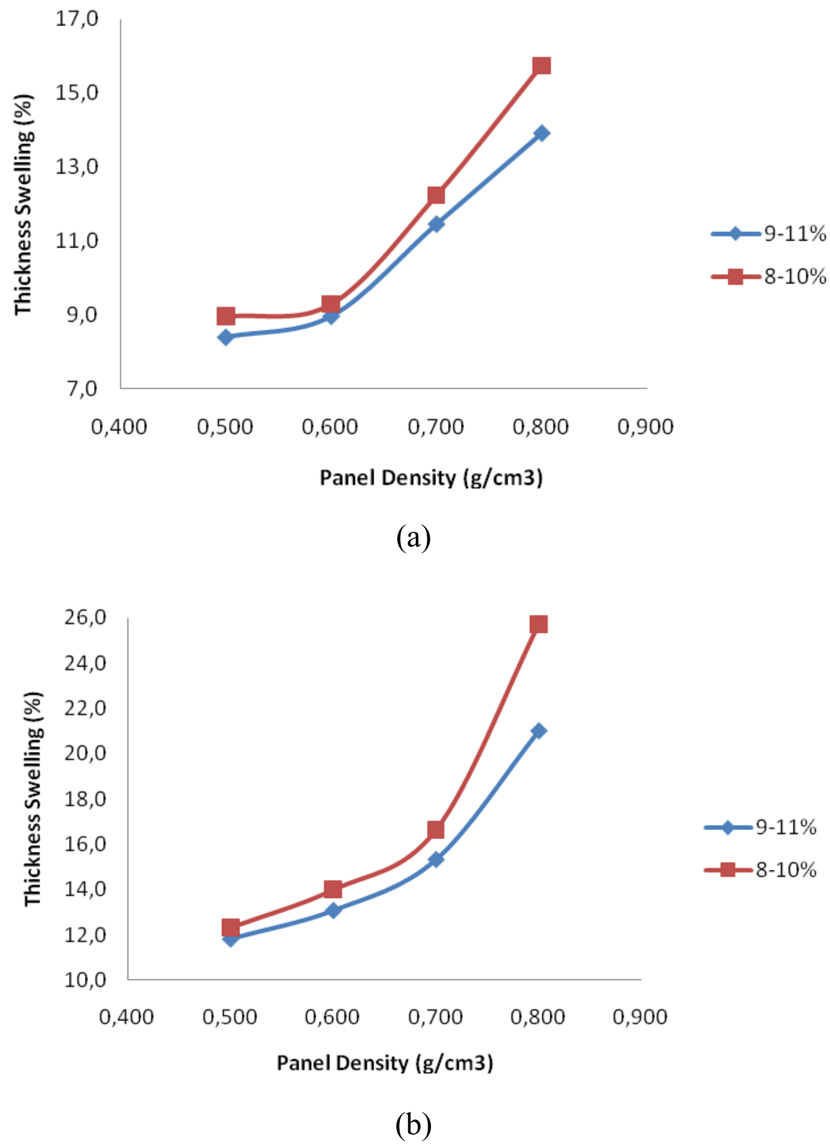

Fig. 1. Effect of panel density on thickness swelling value of the panels. (a) 2 h immersion time, (b) 24 h immersion time

Particleboards should have maximum thickness swelling values of 15% and 14% for 24 h immersions for load-bearing and heavy-duty load-bearing applications, respect-tively (TS EN 312, 2005). In general, the observed thickness swelling and water absorption values for particleboards were higher than 14%. Similar high TS values have been reported for the particleboards that are produced using agricultural residues such as 60.7% for tobacco and tea leaves (Kalaycioglu 1992), 35% for cotton stalks (Guler and Ozen 2004), and 19.6% for hazelnut hulls (Copur et al. 2007) after 24 h water soaking. These high values may be related to the fact that no wax or other hydrophobic substance was used during particleboard manufacture. Water-repellent chemicals such as paraffin could be utilized in the particleboard production to improve these properties. Heattreatment, use of phenolic resins, coating of the particleboard surfaces and acetylating of particles can also improve the water repellency of the panels (Nemli et al. 2005; Ayrilmis et al. 2009; Guntekin et al. 2008; Rowell and Norimoto 1988).

Table 5 shows results for the mechanical properties of the produced particleboard. Results showed that panel density and resin ratio significantly affected the modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) values of the produced panels. As the board density increased, compaction ratio was increased for the same density raw material. Higher compaction ratio provides a higher contact surface between the particles compared to lower compaction ratio. This causes higher flexural properties and internal bond (Dias et al. 2005). The highest MOR (12.14 N/mm^2) and MOE (1718.8 N/mm^2) values were measured for Type H panels having higher density and adhesive ratio. The lowest MOR (2.90 N/mm^2) and MOE (571.2 N/mm^2) values were obtained for Type A panels having lower density and adhesive ratio. MOR and MOE values increased with increasing panel density and adhesive ratio (Figs. 2 and 3). The required MOR and MOE values of 11.5 N/mm^2 and 1600 N/mm^2 are for general purpose and for interior fitments particleboards (including furniture) applications, respectively. The findings in this study showed that only Type H particleboards met the minimum requirements. In the case of IB, the measured values ranged from 0.16 to 0.41N/mm^2. The highest IB value was observed for Type H particleboard. Type F, G, H, C and D particleboards met the IB requirement of 0.24N/mm^2 for general purpose end-use.

Table 5. The Mechanical Properties of Particleboards Made from Peanut Hulls and the Test Results of ANOVA and Duncan's Mean Separation Tests

Board Type	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)
A	2.90 (0.5)^p	571.2 (35.0)^v	0.16 (0.03)^p
B	5.24 (0.5)^s	732.3 (56.9)^y	0.22 (0.01)st
C	8.54 (1.4)^t	1189.9 (55.6)^w	0.30 (0.02)^u
D	10.40 (1.1)^u	1485.2 (51.2)^z	0.40 (0.08)^v
E	3.12 (0.4)^p	653.9 (30.7)^p	0.17 (0.02)^{ps}
F	5.94 (0.7)^s	814.4 (20.6)^s	0.24 (0.03)^t
G	9.90 (1.0)^u	1273.9 (54.0)^t	0.32 (0.08)^u
H	12.14 (1.7)^v	1718.8 (40.5)^u	0.41 (0.07)^v

Mean values are the average of 10 specimens.
Values in parentheses are standard deviations.
^{p,s,u,v} Values having the same letter are not significantly different (Duncan test).

Similarly, lower strength properties have been reported for the particleboards that are produced using agricultural residues (Ayrilmis et al. 2009; Nemli et al. 2008; Guler et al. 2008; Nemli et al. 2009; Bektas et al. 2005). The boards having the lower mechanical properties tested in this study can be used as insulating material in buildings because such materials would not be subjected to any mechanical stress or mechanical properties. These particleboards could be improved by coating the particleboard surfaces or using phenolic resins in the panel production. Several research efforts showed that coating of the particleboard surfaces and use of phenolic resins can improve mechanical properties of the panels (Nemli 2003; Nemli et al. 2005; Chow et al. 1996; Lee and Kim 1985).

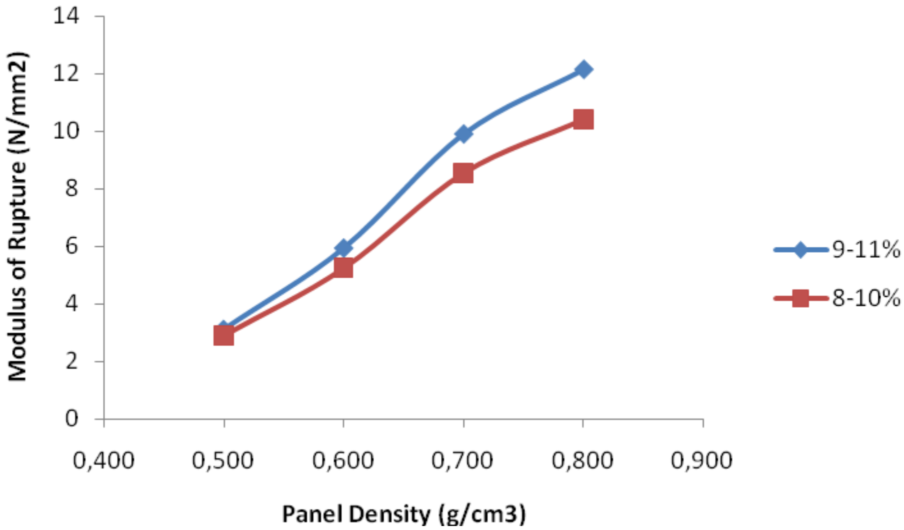

Fig. 2. Effect of panel density on modulus of rupture value of the panels

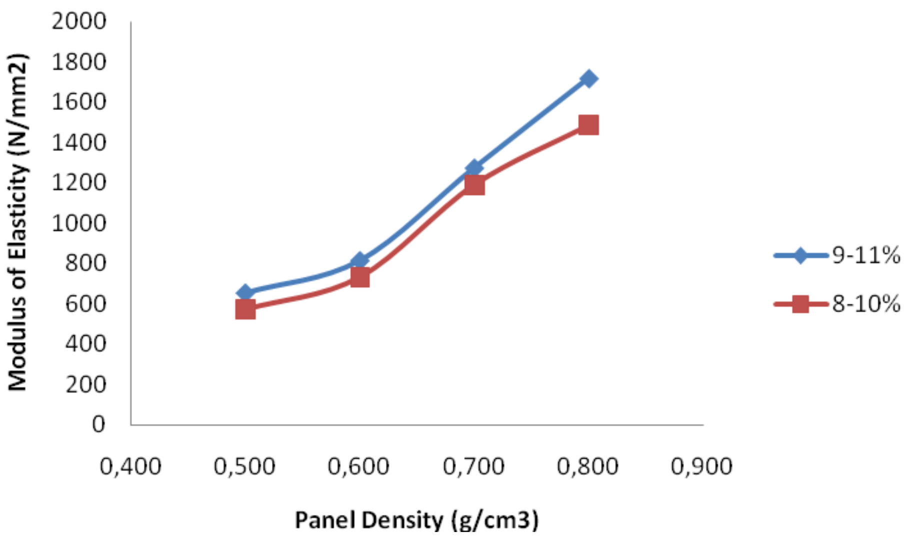

Fig. 3. Effect of panel density on modulus of elasticity value of the panels

Guler et al. (2008) stated that holocellulose, α-cellulose, and lignin content of the peanut hull are close to that wood. Its solubility in alcohol-benzene, 1 % NaOH, hot water, and cold water were higher compared to wood. Higher solubility of the peanut hull can provoke precuring of adhesive before the hot-pressing step. During the hot-pressing, the adhesive bond is broken down due to precuring, which adversely affects the internal bond strength of the panel (Lynam, 1969). The pH value of the peanut hull was found to be 6.07 and it is proper for good adhesion. When the pH of the material is between 5 and 6, good adhesion occurs in the manufacture of reconstituted panel (Nemli et al. 2008).

CONCLUSIONS

This study investigated the possibility of using peanut hull in the manufacture of three-layer particleboards using urea formaldehyde. Results indicated that only the panels having 0.8g/cm^3 density and 9 to 11% adhesive ratio met the requirements for the Turkish Enlarged Standard TS EN 312 (2005) and could be utilized for general purposes in dry-condition. The boards having lower mechanical properties tested in this study can be used as insulating material in buildings, because such materials would not be subjected to any mechanical stress. On the other hand, thickness swelling and water absorption properties, which can be improved by using of hydrophobic materials in the matrix, were found to be inferior. This study showed that peanut hulls as such can be used as a raw material in particleboard production by itself. Panel density and adhesive ratio were found to significantly affect physical and mechanical properties of the particleboard.

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