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THE INFLUENCE OF RAW MATERIAL GROWTH REGION, ANATOMICAL STRUCTURE AND CHEMICAL COMPOSITION OF WOOD ON THE QUALITY PROPERTIES OF PARTICLEBOARDS

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ABSTRACT

In the present study, the impact of raw material grown region on the physical, mechanical, surface properties and formaldehyde emission of the particleboard was investigated. *Ailanthus altissima* wood grown in Trabzon had longer fiber length and thicker fiber and trachea cell wall than those of the wood grown in Artvin. The highest amounts of lignin, ash, condensed tannin and solubility values were found in wood grown in Artvin. *Ailanthus altissima* wood grown in Trabzon had higher amounts of cellulose and hemicellulose than those of the wood grown in Artvin. Particleboards made from wood grown in Artvin had worse surface quality and mechanical strength properties than those of panels made from wood grown in Trabzon. On the other hand, the results showed that particleboards produced from wood grown in Artvin had lower thickness swelling and formaldehyde emision values than those of the panels produced from wood grown in Trabzon.

Keywords: Anatomical properties, chemical properties, formaldehyde emission, mechanical properties, surface roughness.

INTRODUCTION

Particleboard is a very popular engineered wood-based panel produced from wood particles, such as chips, sawmill, shavings, or sawdusts, and a synthetic resins. It is widely used in the production of furniture, interior decoration, cabinets, floor underlayment, home constructions, stair treads, table and counter tops and other industrial applications (Nemli and Demirel 2007). The most important quality indicators of particleboards can be specified as mechanical, physical and surface properties, and formaldehyde emission. The physico-mechanical properties of particleboards are very important in terms of their recommended use (Fernández *et al.* 2008). With regard to the surface roughness, it was mentioned that the surface roughness of the particleboard is highly crucial for coating applications, and any irregularities on the board surface may affect negatively the quality of the final product (Nemli *et al.* 2005). Another indication of quality and suitability of the particleboard is the formaldehyde emission, and in the study of Ayrilmis *et al.* (2016), it was reported that formaldehyde emitted from particleboards is one of the leading causes of indoor air pollution. Hence, formaldehyde emission from building materials such as particleboard is a vital issue required to be solved for building designers and researchers (Zhang *et al.* 2007).

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Many investigations have been carrried out on the influence of raw material and production factors on the quality characteristics of particleboards. These factors studied are cutting tool geometry, crushing conditions, particle compaction, fine screen usage, and press closing time (Hızıroglu and Graham 1998, Hızıroglu *et al.* 2004), the use of wood bark and pine cone (Balanchet *et al.* 2000, Ayrılmıs *et al.* 2009), formaldehyde/urea mole ratio, resin level, catalyst level and composition, post treatment and formaldehyde scavengers (Que *et al.* 2007), utilization of bagasse (Ghalehno *et al.* 2011), residue type and tannin content (Moubarik *et al.* 2013), pressing parameters such as times, temperatures, and pressures (Boon *et al.* 2013, Liu *et al.* 2015), the use of plasma treated wood particles (Altgen *et al.* 2015), log position (Muhcu *et al.* 2015), utilization of bamboo and rice husk (Melo *et al.* 2015), utilization of reed stem and canola (*Brassica napus*) straws (Kord *et al.* 2015, Kord *et al.* 2016), and the use of cotton (*Gossypium hirsutum*) stalks (Nazerian *et al.* 2016).

In this study, we aimed to reveal the relationship between the raw material growth region and particleboard quality characteristics such as flexural properties, internal bond strength (IB), thickness swelling (TS), surface roughness and formaldehyde emission of boards manufactured from woods grown in two different regions.

MATERIALS AND METHODS

Ten *Ailanthus altissima* (Mill.) Swingle trees were felled from private forests in Trabzon (41°04'27''/39°10'32''; 40°31'31''/40°28'32'') and Artvin (41°19'16''/41°14'45''; 41°22'15''/42°34'28'') cities of Turkey.

The age and diameter of the trees were 14-years-old and 18 cm, respectively. The bark of the logs was removed before chipping and all the trees were chipped using a ring type flaker after the foliage was trimmed. The chips were then reduced into smaller particles using a hammer mill. The chips were dried to 3% moisture content in a dryer. The dried chips were classified into two sizes using a 3,0-1,5-0,5 mm openings vibrating screen for the core and face layers. The particles remaining between 3 and 1,5 mm sieves were used in the core layer, while the particles between 1,5 and 0,5 mm sieves were used in surface layers. In the subsequent process, urea formaldehyde resin (solid content: 65%) was applied with a pneumatic spray gun. Based on the dry weight of the particles, 10% and 12% urea formaldehyde resin was separately applied for core and surface particles, respectively. It is important to say the adhesive type, the amount of adhesive and application conditions were kept equal for all boards. The ratio of the face thickness to the total thickness of a board, which is also known as the shelling ratio, was 0,40 for all samples. As a resin hardener, ammonium sulphate (concentration: 25%) was applied in s proportion of 1% based on the solid amount of ure formaldehyde adhesive. No wax or any other additives were used for the particleboard production. Mats formed manually in a frame with a size of 550 x 600 mm^2 were pressed by using a temperature of 150 °C and a pressure of 2,5 MPa for 6 min.A nominal thickness of 12 mm and an average target density of 0,75 g/cm^3 are used in the press of all panels. Two panel types of particleboard were produced and then the types were duplicated to have four experimental panels.

The produced experimental panels were conditioned at 20 °C and relative humidity of 65%. Physical properties- thickness swelling (TS), (EN 317, 1993) (after 2 and 24 h immersion), - and mechanical properties-modulus of rupture (MOR), modulus of elasticity (MOE) (EN 310, 1993), and internal bonding strength (IB) (EN 319, 1993) were then determined. Thirty experimental samples were prepared for each investigated property.

In determining the anatomical properties, 5 cm thick cross-cut disks sawn from the butt and at height of 1,30 m. The samples were taken from wood, boiled in water, stored in 50 % aqueous ethyl alcohol, and sectioned on a sliding microtome. The sections were stained with a combination of safranin and alcian blue combination to allow discernment of pit details. Macerations were prepared by means of Schultze method and stained in safranin (Ives 2001). The data were derived from 25 experimental measurements. This procedure is necessary for IAWA Committee on Nomenclature (IAWA 1964) and aggresses closely with the usage of Metcalfe and Chalk (1950). All other wood terms used conform the usage of the IAWA Committee on Nomenclature (IAWA 1964).

The preparation of test samples for detection of chemical properties was carried out following the prescription of TAPPI T 11 M-45 standard (TAPPI 1992). Alcohol–benzene, hot and cold water solubility, solubility in dilute alkali (1% NaOH), and lignin content were determined in accordance with TAPPI T 204 cm-9 (TAPPI 1997), TAPPI T 207 om-88 (TAPPI 1988), TAPPI T 212 om-98 (TAPPI 1998), and TAPPI T 222 om-02 (TAPPI 2002), respectively. Holocellulose, cellulose, and α-cellulose contents were prepared by the chlorite method (Wise and Karz 1962) and the Kürschner–Hoffner's nitric acid method (Browning 1967). Ash content was examined by TAPPI test method T 211 om-93 (TAPPI 1993). The acidity of wood was measured in an extract solution made by 3-g wood flour added to 100-ml water and boiled for 30 min (Prasetya 1989). Amount of condensed tannin (stiasny number) were decided in the light of Tisler *et al.* (1986). The chemical properties were determined uing three samples.

For the detection of surface roughness, ten experimental samples were used for each type of panels. The test samples were sanded with a sequence of 100- and 150-grit sandpapers. A total of 40 roughness measurements were performed, with 4 measurements for each of 10 samples. Two of the measurements were performed parallel to the sand marks while the other two were performed perpendicular to the sand marks. A Mitutoyo SJ-301surface roughness tester was used to perform roughness test. Three roughness parameters characterized by ISO 4287 (1997), which are average roughness (Ra), mean peak-to-valley height (Rz), and maximum peak-to-valley height (Ry), were considered to assess the surface properties of the samples.

Three samples (20 mm x 20 mm x 12 mm) were randomly taken from each type of particleboard for the determination of formaldehyde emission (FE) by the perforator method based on EN 120-1 (1994) standard.

One-way analysis of variance (ANOVA) was performed to assess the influence of the investigated properties on the quality characteristics of the samples. By using Newman-Keuls's test, significant diffirences between the mean values of the board types were analyzed.

RESULTS AND DISCUSSION

Anatomical properties

Table 1 presents the results of anatomical properties of the samples.

Table 1. Anatomical properties.

Raw material grown region/Wood properties	Fiber length (µm)	Thickness of fiber cell wall (µm)	Thickness of trachea cell wall (µm)
Trabzon	1230,5 (285,11) a	4,4 (1,27) a	6,6 (0,96) a
Artvin	1063,6 (195,93) b	3,9 (0,73) b	5,5 (0,70) b

Note: The values in parenthesis refer to the standard deviations in the samples: Different letters in the same column indicate that there is a statistical difference at 95% confidence level.

Ailanthus altissima (Mill.) Swingle wood grown in Trabzon had longer fiber length and thicker fiber and trachea cell walls than those of the wood grown in Artvin.

Chemical properties

Table 2 gives the mean values of chemical properties of raw materials.

Table 2. Chemical properties of raw materials.

Chemical properties	Raw material grown region	
	Trabzon	Artvin
pH	5,9 (0,04) a	5,8 (0,05) b
Solubility in dilute alkali (1% NaOH) (%)	19,7 (0,72) a	24,1 (0,71) b
Solubility in alcohol-benzene (%)	2,0 (0,04) a	2,4 (0,18) b
Solubility in cold water (%)	3,8 (0,05) a	6,3 (0,06) b
Solubility in hot water (%)	4,2 (0,03) a	6,6 (0,24) b
Cellulose (%)	49,8 (0,04) a	46,5 (0,10) b
Hemicelluloses (%)	29,1 (0,66) a	24,4 (0,51) b
Lignin (%)	21,3 (0,15) a	24,9 (0,11) b
Ash (%)	0,21 (0,02) a	0,35 (0,03) b
Amount of condensed tannin (Stiasny number) (%)	5,0 (0,37) a	6,1 (0,55) b

Note: The values in parenthesis refer to the standard deviations in the samples: Different letters in the same line indicate that there is a statistical difference at 95% confidence level.

Raw material growth region was determined to be effective on all of the chemical properties. The highest amounts of lignin, ash, condensed tannin and solubility values were found in wood grown in Artvin. *Ailanthus altissima* (Mill.) Swingle wood grown in Trabzon had higher amounts of cellulose and hemicelluloses than those of the wood grown in Artvin.

Surface properties

Table 3 presents the roughness values of the particleboards.

Table 3. Average roughness values of the particleboards.

Surface properties	Panel types	
	Trabzon	Artvin
Ra (µm)	6,2 (1,70) a	7,6 (1,48) b
Ry (µm)	45,0 (12,38) a	53,0 (6,99) b
Rz (µm)	27,9 (5,67) a	33,6 (4,54) b

Note: The values in parenthesis refer to the standard deviations in the samples: Different letters in the same line indicate that there is a statistical difference at 95% confidence level.

Raw material growth region statistically affected the surface quality of particleboard. Panels made from wood grown in Artvin had worse surface quality properties than those of panels made from wood grown in Trabzon. Extractives and ash negatively affect the bonding of wood. Poor bonding increases the surface roughness of particles (Lehman and Geimer 1974). Related to this, surface roughness values are increased. As can be seen in Table 2, wood grown in Artvin had higher solubility and amount of ash than wood grown in Trabzon.

Physical and mechanical properties and formaldehyde content

The physical and mechanical properties and formaldehyde emission values are presented in Table 4.

Table 4. Average mechanical and physical properties and formaldehyde content of particleboards.

Property	Panel types	
	Trabzon	Artvin
MOR (MPa)	14,3 (2,34) a	12,9 (2,87) b
MOE (MPa)	2025,1 (223,97) a	1905,2 (160,34) b
IB (MPa)	0,44 (0,080) a	0,35 (0,035) b
TS (%)[a]	15,2 (0,59) a	13,2 (0,71) b
TS (%)[b]	22,5 (0,29) a	20,6 (0,73) b
FE (mg CHOH)	6,2 (0,10) a	5,8 (0,12) b

Note: The values in parenthesis refer to the standard deviations in the samples: Different letters in the same line indicate that there is a statistical difference at 95% confidence level.

[a]: After 2 h immersion, [b]: After 24 h immersion.

Based on EN 312 (2005), the minimum requirements for MOR are 12,5 MPa and 13,0 MPa for general uses and interior application (including furniture), respectively, while the minimum MOE for interior application is 1800 MPa. The results revealed that the IB of the panels ranged from 0,35 to 0,44 MPa. The minimum requirements of IB for general purpose and furniture production are 0,28 MPa and 0,40 MPa according to EN 312 standard, respectively. Panel from wood grown in Trabzon had the required levels of MOR, MOE and IB for furniture production. The results showed that panels produced from wood grown in Artvin could be used for general purpose. On the other hand, it is possible to say that the produced boards did not meet the requirements of EN 312 for the TS because no wax or other water-repellent agents were used in the production process. The maximum allowable value of the formaldehyde content for E_1 quality is 8 mg CHOH/ 100 g dry sample (EN 120.-1, 1994). All panels met the required criteria of formaldehyde emission.

The test panels manufactured from wood grown in Trabzon had higher mechanical properties properties (MOR, MOE, and IB) than those of the panels manufactured from wood grown in Artvin. Fiber length, thicknesses of fiber and trachea cell walls of wood affect substantially the strength properties of particleboard. Longer fibers and, thicker fiber and trachea cell walls cause tighter and more compact wood structure and positively affect the strength properties (Baharoglu *et al.* 2013). It can be seen from Table 1 that wood grown in Trabzon had longer fiber length and thicker fiber and trachea cell walls than those of wood grown in Artvin. Cellulose is the skeleon of wood. High amount of cellulose improves the mechanical properties of wood (Ors and Keskin 2001). As can be seen in Table 2, wood grown in Trabzon had higher amount of cellulose than wood grown in Artvin. Wood grown in Artvin had higher solubility values than wood grown in Trabzon (as could be seen in Table 2). Higher amount of extractives in wood causes lower values of mechanical properties because the extractives adversely affect the strength of the adhesive bond. The reason for the high solubility is the high amount of extractives in wood. Extractives negatively affect adhesive bonding and adhesion. Extractives create air bubbles during hot pressing. Air bubbles cause weakened glue bonds (Ayrılmış and Winandy 2009). The ash content of wood grown in Artvin was substantially higher than that of wood grown in Artvin (as could be seen in Table 2). It is important to state that ash has no wettability. This leads to a reduction in the bond quality of the water based formaldehyde resins (Grigoriou 2003, Kim *et al*. 2006). This stuation can be a reason for the lower bending properties and IB strength of the parnels produced from wood grown in Artvin.

The results show that particleboards produced from wood grown in Artvin had lower TS values than those of the particleboards produced from wood grown in Trabzon. This situation can be clarified by the chemical and anatomical changes in the wood grown in different regions. Higher amounts of lignin and extractives, and lower amounts of cellulose and hemicelluloses were detected in wood grown in Artvin (Table 2). The polysaccharides components of wood cell walls, in particular hemicelluloses, are highly hydrophilic, whereas lignin and extractives re more hydrophobic. A reason for lower TS of the panels could be higher lignin and extractive amounts of the wood grown in Artvin (Borgin and Corbett 1974, Marshall *et al.* 1974, Bariska and Pizzi 1986, Vanleemput *et al.* 1987, Pasillias and Voulgaridis 1999). Wood grown in Trabzon had thicker fiber and trachea cell walls (Table 1). The water absorbs to OH groups in the cell wall. Thicker cell wall consists of higher amount of cellulose (Baharoglu *et al.* 2013).

The formaldehyde emission of the panels produced from wood grown in Artvin was substantially lower than that of the panels produced from wood grown in Trabzon. This is due to chemical differences in wood grown in different regions. A higher stiasny number (condensed tannin) is associated with a higher amount of polyphenolic extractive content in the furnish. Polyphenolic extractives reduce the formaldehyde emission (Wisherd and Wilson 1979, Yusuf 1996, Raffael *et al.* 2000).

CONCLUSIONS

In this work, the effect of raw material growth region on the quality features of particleboards was investigated. The results revealed that *Ailanthus altissima* swingle trees can be used to produce particleboards. The raw material growth region was a major parameter influencing all characteristics of the particleboards. The best strength and surface quality properties were obtained from the particleboards produced from wood grown in Trabzon. However, the TS and FE of particleboards produced from wood grown in Artvin were significantly lower than those of the particleboards produced from wood grown in Trabzon. From the results of the current study, it is possible to say that the chemical and anatomical differences of the wood grown in different regions influence all quality properties of particleboards.

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