Use of Infused Black Tea Leaf Wastes in Particleboard Production

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This study investigated the effect of using infused black tea leaf wastes (TLW) on the three-layer particleboard's mechanical, physical, and formaldehyde emission properties. Particleboards were composed of 70% core layer and 30% surface layers. The TLW was used in the core layer, surface layers, or as whole material. Mechanical and physical properties, including internal bond strength, modulus of rupter, modulus of elasticity, water absorption, thickness swelling, and density of the samples, were determined according to EN 319 (1993), EN 310 (1993), EN 317 (1993), and EN 323 (1993) standards, respectively. The perforator method determined the formaldehyde content EN 120, (1999). Results showed that 100% TLW utilization in surface layers (Board Type: T/W/T), core layer (Board Type: W/T/W), or whole particleboard (Board Type: T) did not provide the standard internal bond (IB) requirement of 0.35 N/mm^2. W, 15%T+85%W, and 30%T+70% board groups fulfilled the IB strength TS EN 319, (1993). 15%T+85%W board group provided the best modulus of rupter values. The amount of formaldehyde emission in the groups with 15%T+85%W, 30%T +70%W met the E1 standard. Results showed that TLW could be an alternative raw material by mixing with wood particles in particleboard production.

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Keywords: Infused black tea leaf waste; Particleboard; Mechanical and physical properties; Formaldehyde emission

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INTRODUCTION

Particleboards are produced by pressing the mixture of lignocellulosic material and suitable binder under certain temperature and pressure (Gonçalves *et al*. 2018). The extensive use of particleboards can be associated with the economic advantage of low-cost wood raw material, cheaper binding agents, and easy processing. Particleboards are among the most popular materials used in interior and exterior applications in floors, walls, doors, and furniture's (Wang and Sun 2002).

Wood is used as a raw material in particleboard production. It has a wide area of use, especially as raw material for paper and wood-based panels (Karakuş 2007). The demand for wood raw material resources is increasing, causing the search for new materials in the board sector. The high demand for wood materials and decrease of forest resources because of fires has elevated the significance of waste agricultural materials as a wood substitute of the usage. As a lignocellulosic material, besides soft wood and hard wood (Kamdem *et al*. 2004), sugar cane, cotton stalks, flax (Papadopoulos and Hague 2003), bamboo (Rowel and Norimoto 1998), wheat stalk (Mengeloğlu and Alma 2002), rice husk (Yang *et al*. 2003), sunflower stalk (Bektaş *et al.* 2002), and tea mill waste (Örs and Kalaycıoğlu 1991), are also utilized in particleboard manufacturing.

Particleboards are being manufactured extensively with addition of urea formaldehyde (UF), phenol formaldehyde (PF), melamine formaldehyde (MF), melamine-urea formaldehyde (MUF), and methylene diphenyl (MDI) as adhesives. The UF adhesives are commonly preferred for low-cost, faster reaction time in the hot press, water solubility, low cure temperatures, resistance to microorganisms, and versatility (Boran *et al.* 2011). However, the important drawback of particleboard bonded with UF resins is its formaldehyde emission (Zhang *et al.* 2013).

Formaldehyde is a dangerous gas even in small amounts, as it can cause serious health problems. Formaldehyde emission can cause diseases ranging from serious allergic reactions to cancer in the skin, eyes, and respiratory tract, depending on the concentration of exposure. The formaldehyde emission from wood-based panels depends on a lot of factors such as wood species, type of adhesive, additives, moisture content, board composition, and pressing conditions (Salem *et al*. 2011). Thus, the reduction of formaldehyde emission from wood-based panels has been studied by researchers in the adhesive and wood-based materials industries for many years (Uchiyama *et al*. 2007; Kordkheili *et al*. 2015).

Tea is one of the most popular drinks around the world and can be consumed hot as well as cold. It is prepared from the infusion of the tea leaf and buds of *Camellia sinensis* (Graham 1992). China, the number one tea producer in the world with 2,270 million tons, has an annual tea consumption of 0.75 kg/person. Turkey is fifth with 259 thousand tons of annual tea production while it is at first place *per capita* in annual tea consumption with 3.5 kg/person.

Tea leaf contains polyphenols and policosanol as well as minerals and vitamins, high levels of tannins, and crude fiber-components (Angga *et al.* 2018). Black tea contains 7% to 14% tannins in its composition (Tekeli 1976). A significant amount of tea waste is generated during factory production, pruning, and consumption of tea plants (Kalaycıoğlu *et al.* 1992).

In general, tea, which is infused every day in homes and workplaces, creates waste after consumption. İnfused black tea leaf waste (TLW) is classed as organic waste. These wastes, which contain high amounts of organic matter, cause environmental pollution (Erdoğan *et al.* 2004). Yüksek *et al.* (2019) reported that approximately 200,000 tons of infused black tea wastes were generated annually in Turkey. In previous studies, the use of waste tea leaf fibers in thermoplastic composite and particleboard production and their physical, mechanical, biological, and thermal properties were examined (Yalınkılıç *et al.* 1998; Çavdar *et al.* 2011). However, it was observed that the infused black TLW were not used in the panel industry. In this study, the suitability of the infused black tea leaf waste to be used as an alternative raw material source in the particleboard sector was investigated.

EXPERIMENTAL

Materials

In this study, wood particles (red pine and poplar wood) and urea formaldehyde (UF) adhesive were donated by Kastamonu Integrated Adana MDF Facility, Turkey. Waste infused black tea was collected from the school cafeteria.

Chemical Analysis of Infused Black TLW

Samples for chemical analysis were prepared according to TAPPI Standard TAPPI 257-os-76 (2012). Alcohol/benzene extracted samples were used for the determination of holocellulose, alpha cellulose, total cellulose, and lignin contents. The chemical composition of infused black TLW was determined following TAPPI standard procedures: holocellulose Wise's chloride method, cellulose TAPPI T203 cm-99 (2009), Alpha cellulose TAPPI T203 cm-71 (2009), Lignin TAPPI T222 cm-O2 (2006), Hot and cold-water solubility TAPPI T207 cm-99 (2008).

Methods

Particleboards manufacturing

In this study, particleboards were produced using wood particles and infused black TLW (Fig. 1). Wood particles and infused black tea leaf waste were dried in an oven at 103±2 °C. Particleboards with three layers (surface layers and one core layer) were manufactured. Six different particleboard groups were manufactured. Five samples were tested from each group to determine their properties. The experimental design of the study is presented in Table 1. The surface and core layers accounted for 30% and 70% of the total board weight, respectively. Based on oven-dry weight of the particles, 9% and 11% UF adhesives (65 ± 1 % solid) were used for core and surface layers, respectively. Based on the solid content of adhesives, 1% and 1.5% ammonium chloride hardener were added to the adhesives for face and core layers, respectively.

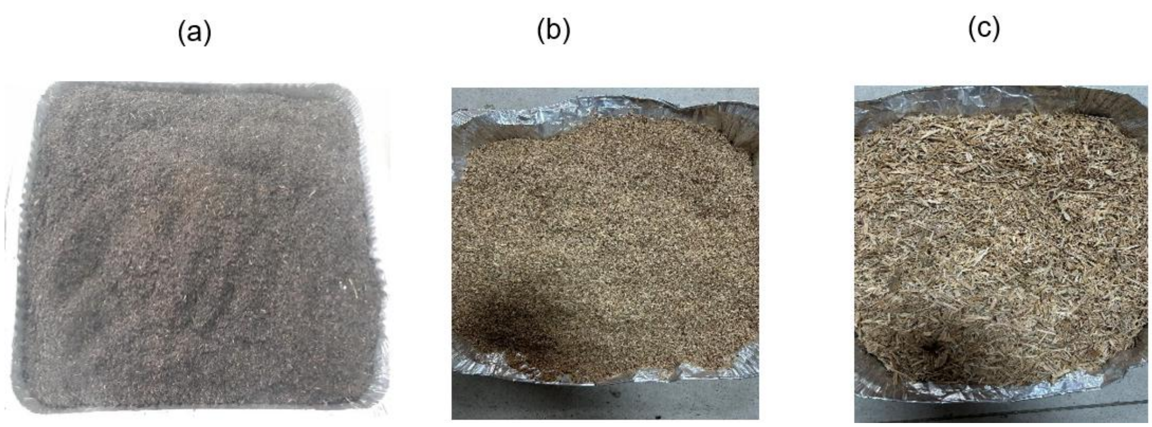

Fig. 1. Raw materials**:** (a) infused black tea leaf waste; (b and c) wood particles

Fig. 2. Particle board test sample

Table 1. Experimental Design of the Study

	Wood Flour (%)		Tea Waste (%)	
	Surface layer	Core layer	Surface layer	Core layer
W	100	100	--	--
T	--	--	100	100
T/W/T	--	100	100	--
W/T/W	100	--	--	100
15%T+85%W	85	85	15	15
30%T/+70%W	70	70	30	30

Depending on the formulations, UF adhesives, wood particles (outher layer and middle layer chips obtained from the factory) or/and infused black TLW were dry-mixed in a high-intensity mixer to produce a homogeneous blend. The blends were laid into a frame of 500 mm × 500 mm. A hot press was used to form the particleboards (90 to 120 bar). Security bars (18 mm) were used for two sides of the mat. Pressing temperature and time were set at 200 °C and 240 s, respectively. While producing group T, the press temperature was calibrated as 6 min at 150 °C. After pressing, particleboards were conditioned at a temperature of 20 °C and 65% relative humidity.

Particleboard Testing

Testing of the samples was conducted in a climate-controlled testing laboratory. Densities were measured by air-dried density method according to the TS EN 323 (1993) standard. Modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), thickness swelling (TS), water absorption (WA), and formaldehyde emission (FE) performances of the samples were determined according to TS EN 310 (1993), TS EN 319 (1993), TS EN 317 (1993), and TS 4894 EN 120 (1992) standards, respectively. For mechanical properties, five test samples Fig. 2. were selected for each of the six groups and tested using Zwick Z010 (10 kN) universal testing machines (Ulm, Germany).

Data Analysis

Design-Expert® Version 7.0.3 statistical software program (Minneapolis, MN, USA) was used for statistical analysis. An analysis of variance (ANOVA) test was used to determine the effects of the factors.

RESULTS AND DISCUSSION

Particleboards were produced in the medium density. In this study, bending strength, modulus of elasticity, internal bond strength, thickness swelling, water absorption, formaldehyde emission performances of all samples were determined. The arithmetic mean and standard deviation of tested groups are given in Table 2.

Table 2. Summary of Mechanical and Physical Properties, and Formaldehyde Emission of Particleboards

ID	IB (N/mm²)	MOR (N/mm²)	MOE (N/mm²)	TS (%)	WA (%)	FE (mg/100g)	Density (g/cm³)
W	0.67 (0.03)*	12.0 (1.9)	1915 (329)	32.2 (3.1)	90.1 (2.3)	9.47	0.71 (0.07)
T	0.04 (0.00)	3.1 (1.0)	493 (156)	-	-	4.78	0.73 (0.05)
T/W/T	0.30 (0.03)	9.8 (1.4)	1518 (289)	39.8 (0.8)	106.7 (3.3)	4.28	0.69 (0.01)
W/T/W	0.09 (0.01)	7.1 (2.0)	1301 (344)	59.0 (2.6)	123.9 (7.7)	4.98	0.75 (0.03)
%15T+ %85W	0.48 (0.02)	12.9 (1.7)	2075 (303)	34.6 (1.8)	96.5 (6.7)	5.99	0.7 (0.04)
%30T+ %70W	0.46 (0.07)	9.9 (1.8)	1620 (277)	33.5 (6.3)	109.9 (11.0)	4.91	0.66 (0.07)
Stand.	0.35	13	1600	Max.15	Min.80	E1≤8.00**	

*Values in parenthesis are standard deviations.
**According to the EN 120 (1992) perforator method, which stays in EN 13986 (2005) standard for European Countries, E1 limit for wood based boards such as particleboard and MDF

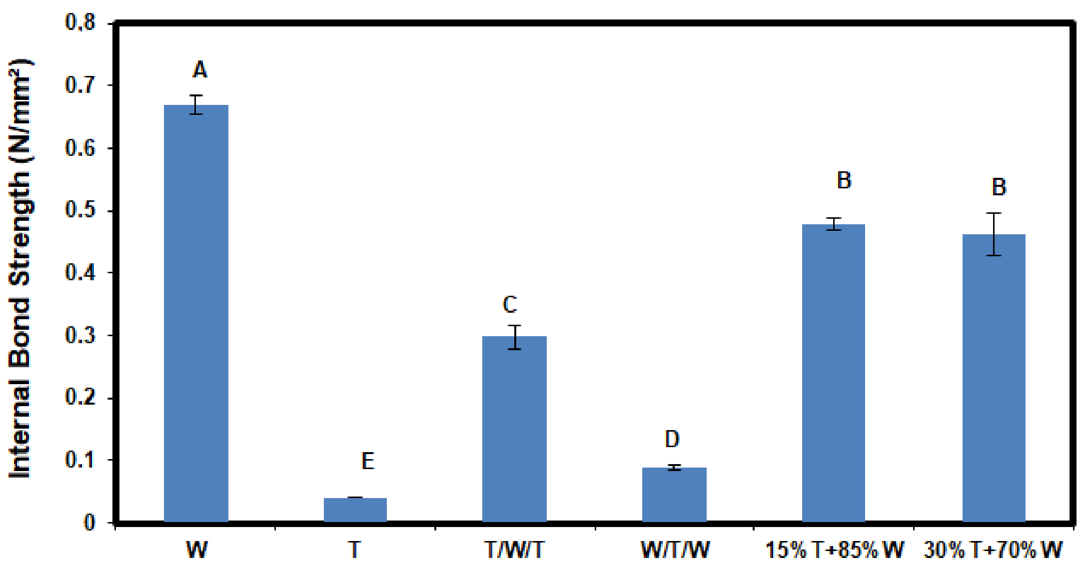

Fig. 3. Bar graphs of internal bond strength

A graph of internal bond strength (IB) is presented in Fig. 3. The IB values of the sample were in the range of 0.04 to 0.67 N/mm². Study showed that panel composition had a significant effect on IB strength values ($P < 0.0001$). Particleboards produced using solely

TLW on the surface layers (T/W/T), core layer (W/T/W), or in all board (T) provided IB strength well below required standard values of 0.35 N/mm^2. The remaining the board types W, %15T+%85W, and %30T+%70 over passed this requirement.

A graph of modulus of rupture is given in Fig. 4. Statistical analyses showed that the panel composition had significant effect on modulus of rupture (P < 0.0001). It achieved the TS EN 310 (1993) standard with the modulus of rupture the value of 12.9 N/mm² of the 15% + 85% W group boards produced. Particleboards produced from infused black tea leaf have low dimensional stability and mechanical properties (Yalınkılıç *et al.* 1998). The addition of wood particles to infused black tea leaves increased the board's MOR (modulus of rupture) value (Batiancela *et al*. 2013).

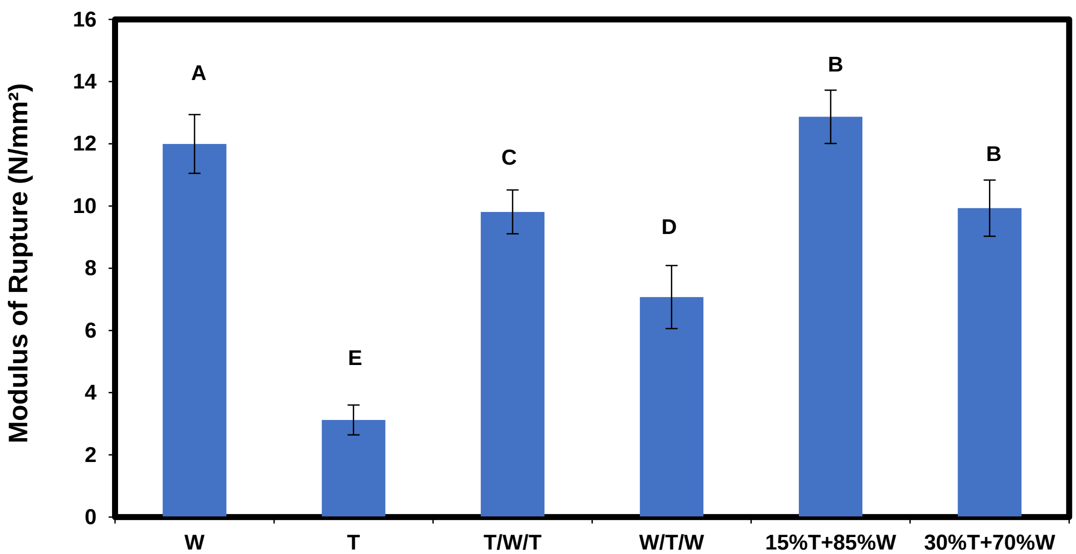

Fig. 4. Bar graphs of modulus of rupture

Modulus of elasticity values are presented in Fig. 5. Results from the statistical analyses showed that panel composition had a significant effect on MOE (P < 0.0001). Higher values were obtained in elasticity modulus of 15%T + 85%W and 30%T + 70 %W group boards compared to other boards groups (Table 2.) The addition of wood particles to infused black tea leaf increased the boards MOE (Modulus of elasticity) value (Lee *et al*. 2022).

The values of WA and TS are presented in Table 2. Considering the 24-h WA and TS values of the particleboard, the 24-h WA and TS values for the T group (tea waste only) could not be measured because they were dispersed in water. It was observed that the W/T/W group received more water after the second hour than the other groups and swelling occurred in its thickness. The reason for this is thought to be the ratio of hygroscopic (cellulose and hemicellulose) substances in the chemical structure of infused black tea leaf waste and wood particle. Particle boards with 100% waste tea leaf have been reported to have significantly lower TS and WA values (June *et al*. 2011).

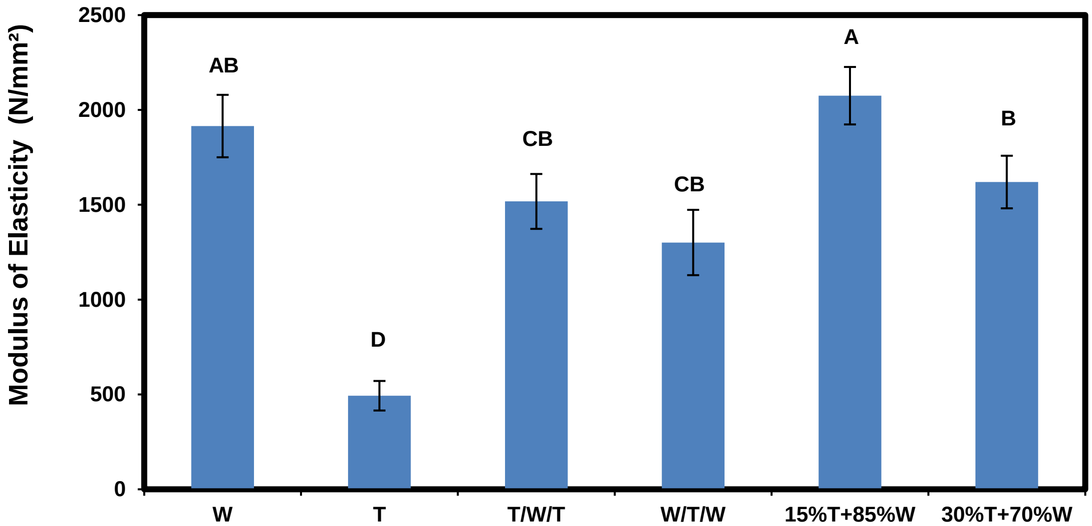

Fig. 5. Bar graphs of modulus of elasticity

In Fig. 6, bar graphs of formaldehyde emission are shown. It was seen that the highest FE was 9.47% in the W group board. Formaldehyde emission amounts were found between 4.28% and 5.99% in other board groups containing infused black TLW. It appears that the infused black TLW had a reducing effect on formaldehyde emission. Tannin and phenolic compounds found in the main ompound of black tea leaves were present at 7% to 14% in dry tea leaves.

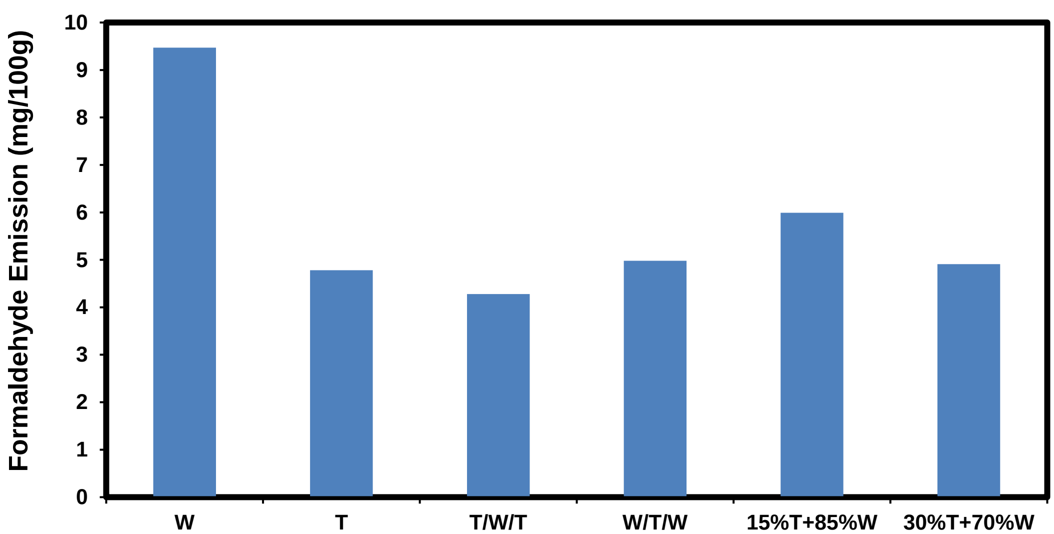

Fig. 6. Bar graphs of formaldehyde emission

In a previous study examining the effects of tannin and chitosan on FE of particleboards, it was observed that the groups added with tannin reduced FE (Çolak *et al.* 2015). As a result of the chemical analysis made on the infused black tea leaf, it was determined that there was 40.3% lignin. In another study, it was found that the use of phenolated kraft lignin in particleboard production reduces the emission of formaldehyde (Younesi-Kordkheili *et al*. 2016). Some tannins can actively react with formaldehyde. Additionally, proteins and amino acids present in tea leaf waste can also react with formaldehyde, as indicated. This chemical interaction can potentially influence the properties of materials incorporating tea leaf waste. This is in accordance with the statement that tea leaf waste can reduce formaldehyde emissions on particleboards (Shi *et al*. 2006).

A graph of density properties is given in Fig. 7. Statistical analysis showed that panel composition significantly affected density ($P < 0.0311$). The densities of the produced particleboards were in the range of 0.66 to 0.75 g/cm^3 (Table 2). When the graphs of boards density was examined, boards densities were at the same range.

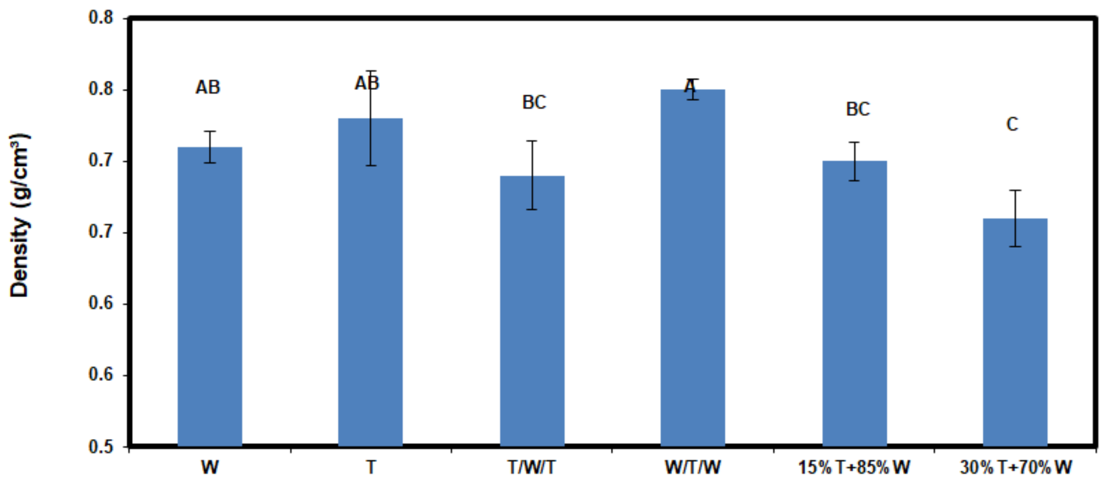

Fig. 7. Bar graphs of density

CONCLUSIONS

In the study, four groups of infused black tea leaf wastes (TLW) were used in surface layers, core layer, and boards with 15%, 30% mixture were formed. In addition, two groups of boards were produced using only wood particle and infused black TLW.

1. Particleboards were successfully produced using infused black TLW and wood flour.
2. Particleboards produced using sole TLW on the surface layers (T/W/T), core layer (W/T/W), or in all board (T) provided IB strength well below the required standard values of 0.35 N/mm^2.
3. The 15% + 85% W group boards produced met the TS EN 310 (1993) standard with the bending strength the value of 12.9N / mm^2.
4. Higher values were obtained in elasticity modulus of 15%T + 85%W and 30%T + 70 %W group boards compared to other boards groups.
5. The water absorption (WA) and thickness swelling (TS) values of the T group boards could not be measured as they are decomposed in water. It was observed that the

W/T/W group received more water after the second hour than the other groups and swelling occurred in its thickness.

6. Formaldehyde emission amounts were between 4.28% and 5.99% in other board groups containing infused black TLW. It appears that the infused black TLW had a reducing effect on formaldehyde emission.
7. The densities of the produced particleboards were in the range of 0.66 to 0.75 g/cm³.
8. The produced particleboards are expected to be used in both interior and exterior construction sectors.

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