# Properties of Particleboard Produced from Red Pine (*Pinus brutia*) Chips and Lavender Stems

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The usability of lavender stems along with red pine chips was investigated as raw materials in the production of particleboard. Medium-density particleboard was manufactured using urea formaldehyde glue at three different ratios for five different mixture groups containing lavender stems and red pine chips. Some physical and mechanical properties of the boards were investigated. According to the statistical studies of the results, decreasing the ratio of lavender stems between board groups reduced the thickness swelling value. The internal bond strength, bending strength, and elastic modulus values of all board groups (%10-12 glued) were above the minimum values set by the TS-EN-312 standard for general purpose particleboard. According to these results, either lavender stems alone or together with red pine chips are suitable for use as a new raw material for particleboard manufacturing.

*Keywords: Waste of lavender plants; Red pine chips; Urea formaldehyde glue; Particleboard; Mechanical properties*

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## INTRODUCTION

Particleboards are board materials produced as panel shapes by compressing glued or non-glued lignocellulosic fibrous materials (wood, sawdust, *etc*.) by means of hydraulic presses (Hofstrand *et al*. 1984). The products are used as partition walls or floor and wall coverings in the construction sector (Kozlowski and Helwig 1998).

The manufacture of modern particleboards goes back to early 19th century. The production started with the utilization of planer shavings and sawdust and continued with the use of logs of all kinds. The demand for wood in the forest product industry has grown over the years with increasing population and new application areas, which has caused a significant pressure on standing forest resources. Moreover, these events have stimulated a rise in the price of wood as a raw material. This has motivated people in the forest industry and the scientists studying in this field to find alternative biomasses or raw materials. Therefore, alternative fibers such as agrofibers and other plant fibers, recycling, more efficient conversion technologies, and new products will play an important role in the wood fiber supply/demand map of the future.

The use of agricultural waste materials (agrofibers) as a raw material in the manufacture of composites was one of the solutions that came to the minds of many researchers. The use of these materials may benefit both the environment and socioeconomic development since these waste materials are mostly ploughed into the soil or burnt in the field. Studies have been conducted to find the suitable agrofibers for composite manufacturing (Bektaş *et al.* 2005). Some of the agrofibers studied so far are cotton and hemp stalks (Kollmann 1966), groundnut shell (Jain *et al*. 1967), bagasse

(Mitlin 1968; Turreda 1983), grain-wheat straw (Mosesson 1980; Han *et al*. 1998), bamboo (Rowell and Norimoto 1998), tea plant waste (Nemli and Kalaycioğlu 1997; Yalinkiliç *et al*. 1998; Filiz *et al*. 2011; Batiancela *et al*. 2014), sunflower stalks (Khristova *et al*. 1998; Bektaş *et al*. 2005), vine branches (Ntalos and Grigoriou 2002), castor stalks (Grigoriou and Ntalos 2001), corn stalks (Güler *et al*. 2001), wheat straw and corn stalks (Wang and Sun 2002), kiwi branches (Nemli *et al*. 2003), peanut shell (Batalla *et al*. 2005), almond shells (Gürü *et al.* 2006), agricultural waste (Arslan *et al*. 2007), giant reed (Garcia-Ortuna *et al*. 2011), kenaf (Xu *et al*. 2013), kenaf and rubberwood (Abdul Halip *et al*. 2014), sunflower seed husks (Cosreanue *et al*. 2015), and hazelnut husk (Avcı *et al*. 2013).

Some of these wastes have a hard and crusty structure (like nuts and peanut shells), some have thin and soft structure in the shape of stalks (like sunflower, wheat, barley, rice straw), and some have hard and woody structure in the shape of trimmed tree branch (like apple and grape branches). It is known that these structural differences change physical and mechanical properties of particleboards dramatically. Scientists have investigated the usability of many herbal wastes in the production of particleboards by considering fibrous structure of these herbal wastes similar to raw wood material and reached significant results.

Zhang *et al.* (2011) reported that they could produce particleboards from wheat straw that met minimum international standards by adding emulsifiable pMDI to urea formaldehyde glue at different ratios. Batiancela *et al.* (2014) reported that they could produce general-purpose particleboards from waste tea leaves with *Paraserianthes falcataria* (moluccan sau) wood pieces at a ratio of 20 to 50% with 8% glue. Guler *et al.* (2008) reported that they could produce 3-layer general purpose particleboards from chips obtained from peanut branches by mixing them with 25% of black pine chips. Guler *et al.* (2006) reported that they could produce 3-layer general purpose particleboards with chips derived from red pine and sunflower stalks at different ratios by mixing with UF glue. Li *et al.* (2010) reported that they could produce particleboards that are appropriate to the characteristics of the M-2 class of American standards by using rice straws in different geometries.

According to these studies, with the combination of wood chips, modification of agrofibers, and the addition of some moisture repellant, it is feasible to produce particleboard from the wastes of agricultural crops having the physical and mechanical properties as required by related standards. Several countries utilize agrofibers for the production of particleboard or other composite panels. So far there are at least 30 plants that utilize agricultural waste materials in the production of particleboards around the World (Bektaş *et al.* 2005).

Turkey faces the problem of limited raw wood materials due to the reduction of forest areas, as in many other countries. Turkish scientists as well as scientist around the world continues to research the availability of the production of particleboard to solve this problem.

The leaves of the lavender plant are used for the cosmetic industry after the harvest in Kuyucak Village of Keçiborlu District of Isparta Province, Turkey. However, approximately a 1700-decares field is being utilized for lavender farming in Turkey, generating roughly 1000 to 2000 tons of waste lavender stalks every year (Anonymous 2015).

In this study, the usability of waste lavender stems was investigated in the production of particleboard industry as a raw material; the utilization of such a raw material in combination with other woody species available in the country could yield benefits both economically and environmentally.

## EXPERIMENTAL

### Materials and Methods

Red pine chips, UF glue, and 20% ammonium chloride solution were obtained from Isparta Orma Company (Turkey). Waste lavender stems, which were dried under natural weather conditions, were obtained from Kuyucak Village of Keçiborlu District of Isparta, Turkey. Waste lavender chips (LP) and red pine chips (RP) were dried in oven at a temperature of 102± 3°C and humidity of 2% to 3%.

The chemical analysis performed by Suleyman Demirel University (S.D.U.) Industrial Engineering Labratories is shown in Table 1, the characteristics of the UF adhesive are shown in Table 2, and the experimental ratios used for manufacturing are given in Table 3.

**Table 1.** Chemical Analysis of Waste Lavender Stems and Red Pine Chips

| Chemical Analysis | Method of Analysis | Type of chip | |
|---|---|---|---|
| | | LP | RP |
| Amount of inorganic material | Burn at 525 °C | 0.042 | 0.0086 |
| pH (acidic 1-7/basic 8-14) | pH measurement | 5.89 | 4.83 |
| Holocellulose | Chlorite (%) | 83 ± 2 | 70 ± 2 |
| Lignin | Klason (%) | 12 ± 3 | 27.3 ± 3 |
| Cellulose | 17.5% NaOH solution (%) | 55 ± 5 | 48.5 ± 5 |
| Extractives | Ethanol solution (%) | 10 ± 3 | 7 ± 3 |

To eliminate some impurities such as sugar, as shown in Table 1, all wood chips first were allowed to sit in 1% NaOH solution for 24 h, then washed again with water and finally dried in an oven in the first drying conditions. The sugars that are found in the chemical structures of particleboards have potential to prevent the adhesion of particleboards with resin,

**Table 2.** Characteristics of Urea Formaldehyde Adhesive

| Density (g/cm$^3$) | pH at 25 °C | Solution (%) | Viscosity Din/cPs 25 °C | Gelling period (s at 100 ºC) | Time of Fluidity (s) | Use period (day) | Free $CH_2O$ (max.%) |
|---|---|---|---|---|---|---|---|
| 1.27 to 1.29 | 7.5 to 8.5 | 65 ± 1 | 150 to 200 | 25 to 30 | 20 to 30 | 60 | 0.19 |

LP, RP, and UF glues were weighed on precision scales and mixed homogeneously before being used in gluing to form the mixture groups. The mixture was then compressed by cold pressing in a mold with a rectangular section before the hot-pressing process. The properties related to the hot-pressing machine and the boards are given in Table 4. After being removed from the hot press and cooling, the boards were cut to dimensions of 50 mm by 50 mm, according to TS-EN-325 (1999), and to 50 mm by 300 mm, according to TS-EN 326-1 (1999). Then, they were prepared for experimentation by scaling them with a caliper (Mitutoyo, P&G Industrial Co., Ltd., China) with a sensitivity of 0.01 mm convenient with EN-325 (1999).

**Table 3.** Chip and Glue Amounts for Experimental Groups

| Board Group | Mixing ratio of chips (%) | | Glue ratio (%) |
|---|---|---|---|
| | Red pine | Lavender stem | |
| A | 100 | 0 | 6 |
| | | | 10 |
| | | | 12 |
| B | 75 | 25 | 6 |
| | | | 10 |
| | | | 12 |
| C | 50 | 50 | 6 |
| | | | 10 |
| | | | 12 |
| D | 25 | 75 | 6 |
| | | | 10 |
| | | | 12 |
| E | 0 | 100 | 6 |
| | | | 10 |
| | | | 12 |

**Table 4.** Properties of Hot-Press Machine and Boards

| Press temperature (°C) | Pressure (N/mm$^2$) | Duration (min) | Board edge size (cm) | Thickness (mm) | Number of boards per group |
|---|---|---|---|---|---|
| 150-155 | 2.5-3 | 4 | 31x35 | 12 | 15 |

The thickness swelling of the experimental particleboards after soaking in water for 24 h was determined in accordance with EN-317 (1996). The boards, measured from their four corners, were placed into a container filled with clean and stable water with a pH value of 7 at 20±1 °C. The boards did not touch the bottom or top of the container or each other and were situated 25±1 mm below the top of the container. The increase in thickness of the boards was calculated using Eq. 1 after removing them from the water and drying their surfaces .

$$TS = W_s - D_s / D_s x100 \tag{1}$$

In Eq. 1, *TS* is the thickness swelling of the test samples (%), $W_s$ is the thickness of the test samples after being soaked in water (mm), and $D_s$ is the thickness of the dry test samples (mm).

The bending strength and modulus of elacticity of the particleboards were determined in accordance with EN-310 (1996). The thicknesses were measured from the intersection points of the corners, whereas the widths were measured from the middle point of the lengths and determined by an experimental device , in accordance with TS-EN-325 (1999). During the load test experiments, a universal testing device (Zwick/Roell Z050, Germany) with a 5000-kg capacity was used, and the load was applied at a constant rate (6 mm/min). A load was applied at a constant rate throughout the experiment. The flexural strength of the experimental samples based on the maximum force values was calculated according to Eq. 2 with 1% sensitivity. The bending amounts were determined with 1% accuracy through the mid-points, and the modulus of elasticity was calculated in accordance with Eq. 3,

$$MOR = 3L_{\max} \times D / 2w \times t^2 \tag{2}$$

$$MOE = L \times D^3 / 4w \times t^3 \times d \tag{3}$$

where *MOR* is the bending strength (N/mm²), $L_{\max}$ is the maximum load at the breaking point (N), *D* is the distance between supports (mm), *w* is the width of the sample (mm), *t* is the thickness of the sample (mm), *MOE* is the modulus of elasticity (N/mm²), *L* is the load applied under the elasticity limit (N), and *d* is the deformation occuring against the load in the sample (mm)

The internal bond strength (*IB*) of the particleboards was determined in accordance with EN-319 (1996). The dimensions of the boards were measured by a caliper gauge, then glued to an aluminum apparatus with adhesive; after completion of the adhesion, a uniform force was applied to the boards until the breaking point, where all the boards were connected to the gripping nozzles of the test device in the pulling direction vertical to the surface. The tensile strength of the boards vertical to the surface was calculated in accordance with Eq. 4 using the obtained maximum force values,

$$IB = L_{\max} \div A \tag{4}$$

where *IBS* is the internal bond strengths (N/mm²), $L_{\max}$ is the maximum force at the breaking point (N), and *A* is the cross-sectional area of the test sample (mm²).

Data for each test were statistically analyzed using the SPSS 20.0 software program. The analysis of variance (ANOVA) was used ($\alpha \leq 0.05$) to test for significant difference between factors. When the ANOVA indicated a significant difference among factors, the compared values were employed to Duncan test to identify which groups were significantly different from other groups.

## RESULTS AND DISCUSSION

The average and standard deviation values of thickness swelling, bending strength, internal bond strength, and modulus of elasticity of the various experimental groups are given in Table 5.

As indicated in the table, the average thickness swelling values were found to be highest (84.26%) in group E particleboards with 6% glue and lowest (36.14%) in group A particleboards with 12% glue. Bending strength values were found to be highest (14.66 N/mm$^2$) in group A particleboards with 12% glue and lowest (6.86 N/mm$^2$) in group E particleboards with 6% glue. Modulus of elasticity values were found to be highest (1712 N/mm$^2$) in group A particleboards with 12% glue and lowest (1024 N/mm$^2$) in group E particleboards with 6% glue. The internal bond strength values were found to be highest (0.51 N/mm$^2$) in group A particleboards with 12% glue and lowest (0.10 N/mm$^2$) in group E particle boards with 6% glue.

**Table 5.** Average and Standard Deviation Values of Thickness Swelling, Bending Strength, Internal Bond Strength, and Modulus of Elasticity of Various Experimental Groups

| PG | GR % | X | | | | S | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | TS % | MOR $N/mm^2$ | IB $N/mm^2$ | MOE $N/mm^2$ | TS | MOR | IBS | MOE |
| A | 6 | 57.18 | 9.81 | 0.23 | 1284.20 | 1.420 | 0.045 | 0.005 | 4.816 |
| | 10 | 47.16 | 12.21 | 0.47 | 1664.00 | 1.091 | 0.081 | 0.008 | 2.915 |
| | 12 | 36.14 | 14.66 | 0.51 | 1712.20 | 1.099 | 0.059 | 0.010 | 4.024 |
| | T | 46.82 | 12.22 | 0.41 | 1553.46 | 8.965 | 2.050 | 0.128 | 198.167 |
| B | 6 | 69.10 | 8.74 | 0.20 | 1255.8 | 0.522 | 0.040 | 0.011 | 3.420 |
| | 10 | 49.12 | 13.62 | 0.43 | 1642.00 | 0.644 | 0.070 | 0.013 | 2.23 |
| | 12 | 39.72 | 14.28 | 0.47 | 1687.80 | 0.325 | 0.022 | 0.007 | 2.588 |
| | T | 52.64 | 12.21 | 0.36 | 1528.53 | 12.688 | 2.558 | 0.121 | 200.573 |
| C | 6 | 71.14 | 8.46 | 0.16 | 1234.40 | 0.251 | 0.031 | 0.010 | 3.781 |
| | 10 | 51.36 | 12.14 | 0.39 | 1631.00 | 0.246 | 0.050 | 0.005 | 2.549 |
| | 12 | 49.14 | 13.64 | 0.45 | 1653.00 | 0.368 | 0.079 | 0.010 | 3.535 |
| | T | 57.21 | 11.41 | 0.33 | 1506.13 | 10.241 | 2.252 | 0.126 | 199.129 |
| D | 6 | 76.14 | 7.94 | 0.12 | 1198.20 | 0.092 | 0.071 | 0.008 | 5.449 |
| | 10 | 55.02 | 11.92 | 0.36 | 1616.20 | 0.106 | 0.087 | 0.013 | 3.701 |
| | 12 | 48.02 | 12.98 | 0.41 | 1631.60 | 0.171 | 0.054 | 0.008 | 3.435 |
| | T | 59.72 | 10.94 | 0.30 | 1482.00 | 12.373 | 2.246 | 0.131 | 207.860 |
| E | 6 | 84.26 | 6.86 | 0.10 | 1023.60 | 0.169 | 0.044 | 0.005 | 3.209 |
| | 10 | 62.12 | 11.54 | 0.35 | 1603.20 | 0.040 | 0.034 | 0.010 | 3.834 |
| | 12 | 60.44 | 12.64 | 0.37 | 1611.20 | 0.104 | 0.048 | 0.008 | 5.069 |
| | T | 68.94 | 10.34 | 0.27 | 1412.66 | 11.235 | 2.595 | 0.122 | 284.813 |
| T | 6 | 71.56 | 8.36 | 0.16 | 1199.24 | 9.095 | 0.988 | 0.050 | 94.17 |
| | 10 | 52.95 | 12.28 | 0.40 | 1631.28 | 5.408 | 0.724 | 0.058 | 21.603 |
| | 12 | 46.69 | 13.64 | 0.44 | 1659.16 | 8.634 | 0.776 | 0.047 | 37.609 |
| | T | 57.07 | 11.43 | 0.33 | 1496.56 | 13.175 | 2.400 | 0.132 | 220.034 |

**X:** Average; **S:** Standard deviation; **PG:** Particleboards Group; **GR:** Glue Ratio **T:** Total

Table 6 shows the results of multiple variance analyses conducted to see whether there are significant differences detected between experimental groups.

According to the variance analysis in Table 6, the differences between all experimental groups are significant at 0.05% level in terms of mixture and glue ratio. The results of the Duncan test to determine the importance of the smallest differences between the groups that have significant relationships are presented in Tables 7 and 8.

**Table 6.** Variance Analysis of Thickness Swelling, Bending Strength, Internal Bond Strength, and Modulus of Elasticity

| S | D.V | Sum of Squares | df | Mean Square | F | P < 0.05 |
|---|---|---|---|---|---|---|
| **Corrected Model** | TS | 12822.838[a] | 14 | 915.917 | 2469.569 | 0.000* |
| | MOR | 426.137[b] | 14 | 30.438 | 9066.227 | 0.000* |
| | IB | 1.295[c] | 14 | 0.093 | 1020.399 | 0.000* |
| | MOE | 3581868.480[d] | 14 | 255847.749 | 18231.431 | 0.000* |
| **Intercept** | TS | 244294.413 | 1 | 244294.413 | 658686.192 | 0.000* |
| | MOR | 9798.596 | 1 | 9798.596 | 2918565.161 | 0.000* |
| | IB | 8.535 | 1 | 8.535 | 94130.882 | 0.000* |
| | MOE | 167976887.520 | 1 | 167976887.520 | 11969849.467 | 0.000* |
| **M** | TS | 4086.531 | 4 | 1021.633 | 2754.608 | 0.000* |
| | MOR | 39.840 | 4 | 9.960 | 2966.677 | 0.000* |
| | IB | 0.188 | 4 | 0.047 | 517.169 | 0.000* |
| | MOE | 174035.947 | 4 | 43508.987 | 3100.403 | 0.000* |
| **G** | TS | 8368.009 | 2 | 4184.005 | 11281.249 | 0.000* |
| | MOR | 375.788 | 2 | 187.894 | 55965.234 | 0.000* |
| | IB | 1.105 | 2 | 0.552 | 6091.074 | 0.000* |
| | MOE | 3324685.520 | 2 | 1662342.760 | 118456.729 | 0.000* |
| **M x G** | TS | 368.297 | 8 | 46.037 | 124.129 | 0.000* |
| | MOR | 10.508 | 8 | 1.314 | 391.251 | 0.000* |
| | IB | .003 | 8 | 0.000 | 4.346 | 0.000* |
| | MOE | 83147.013 | 8 | 10393.377 | 740.621 | 0.000* |
| **Error** | TS | 22.253 | 60 | 0.371 | | |
| | MOR | 0.201 | 60 | 0.003 | | |
| | IB | 0.005 | 60 | 9.067E-005 | | |
| | MOE | 842.000 | 60 | 14.033 | | |
| **Total** | TS | 257139.504 | 75 | | | |
| | MOR | 10224.934 | 75 | | | |
| | IB | 9.835 | 75 | | | |
| | MOE | 171559598 | 75 | | | |
| **Corrected Total** | TS | 12845.091 | 74 | | | |
| | MOR | 426.338 | 74 | | | |
| | IB | 1.301 | 74 | | | |
| | MOE | 3582710.480 | 74 | | | |

**a.** $R^2 = 0.998$ (Adjusted $R^2 = 0.998$) **c.** $R^2 = 0.996$ (Adjusted $R^2 = 0.995$)

**b.** $R^2 = 1.000$ (Adjusted $R^2 = 0.999$) **d.** $R^2 = 1.000$ (Adjusted $R^2 = 1.000$)

*****:Significant; **M:** Mixture; **G:** Glue; **S:** Source; **DV:** Dependent Variable; **S.S:** Sum of Squares

**Table 7.** Duncan Mean Separation Tests for Mixture Ratios

| **Particleboards Group** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| Bending strength (N/mm$^2$) | 12.22$^a$ | 12.21$^b$ | 11.41$^c$ | 10.94$^d$ | 10.34$^d$ |
| Modulus of elasticity (N/mm$^2$) | 1553.46$^a$ | 1528.53$^b$ | 1506.13$^c$ | 1482$^d$ | 1412.66$^e$ |
| Internal bond strength (N/mm$^2$) | 0.41$^a$ | 0.36$^b$ | 0.33$^c$ | 0.30$^d$ | 0.26$^e$ |
| Thickness swelling (%) | 46.82$^a$ | 52.64$^b$ | 57.21$^c$ | 59.72$^d$ | 68.94$^e$ |
| $^{a,b,c,d,e}$ Values having the same letter are not significantly different (Duncan test). | | | | | |

**Table 8.** Duncan Mean Separation Tests for Glue Ratio

| **Glue Ratios (%)** | **6** | **10** | **12** |
|---|---|---|---|
| Bending strength (N/mm$^2$) | 8.36$^a$ | 12.28$^b$ | 13.64$^c$ |
| Modulus of elasticity (N/mm$^2$) | 1199.24$^a$ | 1631.28$^b$ | 1659.16$^c$ |
| Internal bond strength (N/mm$^2$) | 0.16$^a$ | 0.39$^b$ | 0.44$^c$ |
| Thickness swelling (%) | 71.56$^a$ | 52.95$^b$ | 46.69$^c$ |
| $^{a,b,c,}$ Values having the same letter are not significantly different (Duncan test). | | | |

Considering the data given in Table 5, the experiment results related to thickness swelling rates of particleboards after 24 h were found to be negatively associated with reduction of glue amount used in the production process, and positively associated with increased amount of lavender chips. In other words, it can be said that the increased amount of glue used in the production of particleboards proportionately reduced the swelling value, whereas waste lavender chips proportionately increased the swelling value.

Particleboards should have maximum thickness swelling values of 15% and 14% for 24 h immersions for load-bearing and heavy-duty load-bearing applications, respectively (TS EN 312 2005). In general, the observed thickness swelling for particleboards were higher than 14%.

In experimental studies using different agricultural wastes, the thickness swelling values of chipboards after keeping them 24 h in the water are reported to be reaching the highest levels in a similar manner. For example, banana peels 44.8% (Topbaşlı 2013), greenhouse wastes 117% (Karakuş 2007), nut shells 19.6% (Copur *et al.* 2007), cotton stalks 35% (Guler and Ozen 2004), tobacco and tea leaves 60.7% (Kalycioglu 1992), and peanut shells 19.84% (Guler *et al.* 2008) are some of these wastes used in the experiments. 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. Heat teratment, use of phenolic resins, coating of the particleboard surfaces, and acetylating of particles can also improve the water repellency of the panels (Rowell and Norimoto 1988; Guntekin *et al.* 2008; Ayrılmış *et al*. 2009; Guler and Buyuksarı 2011).

According to the elasticity module, internal bond strength and bending strength experiment results, which determine the mechanical properties of particleboards, were found to be positively associated with increased amount of glue used in the production and reduced amount of waste lavender chips (Table 5). The strength created by the chips by sticking to each other with UF glue was instrumental in this change. It was also observed that the amount of inorganic matter and pH values of the waste of lavender chips were also effective parameters for strength and weakness of adhesion.

The standard method TS-EN 312 (2005) recommends a minimum MOE, MOR, and IB values of 1600 N/mm$^2$, 11.5 N/mm$^2$, and 0.24 N/mm$^2$ for the particleboards manufactured for general purpose usages, respectively. According to the results of this study, all particleboards produced with 10 to 12% glue provided the minimum conditions required by the standards. However, it was determined that since pH value and inorganic matter content in lavender chips was greater than the pH value and inorganic matter content in red pine chips, mechanical properties of all particleboards in experiment groups except the group consists of particleboards made of 100% red pine chips were adversely affected by lavender chips. Similarly, mechanical properties of particleboards produced in experimental studies with various agricultural wastes have been reported to be reduced (Bektas *et al.* 2005; Nemli *et al.* 2008, 2009; Guler *et al.* 2008; Ayrilmis *et al.* 2009; Guler and Buyuksarı 2011). 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. These particleboards could be improved by coating the particleboard surfaces. Several resarch efforts showed that coating of the particleboard surfaces can improve mechanical properties of the panels (Lee and Kim 1985; Chow *et al.* 1996; Nemli *et al.* 2003; Nemli *et al.* 2005; Guler and Buyuksarı 2011).

## CONCLUSIONS

In this study, some mechanical, physical, and chemical properties of medium-density particleboards produced with various lavender plant wastes, red pine chip, and glue ratios were determined, and their compliance with EN-312-2 (2005) standards was investigated.

1. According to the statistical assessments of experimental results, an increase in the ratio of waste lavender stems found in the chip mixture increased the thickness swelling in particleboards.
2. The internal bond strength, bending strength, and elastic modulus values of 10 to 12% glued board groups were above the values set by TS EN 312 (2005) standards for general purpose particleboard in dry-condition. The boards having lower mechanical properties tested in this study can be used as insulating material in buildings, because such materials wold not be subjected to any mechanical stress.
3. According to these results, both waste lavender stems alone or together with red pine chips will be able to be used as a raw material in particleboard manufacturing, and waste lavender stems used for this purpose will contribute to a reduction of environmental pollution.

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