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ARTÍCULO

Some physical and mechanical properties of particle boards produced from industrial wood chips and Scots pine (*Pinus sylvestris*) cones

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Abstract:
This study investigated the potential use of Scots pine cones as an alternative raw material to larch wood chips for particle board production. Due to the increasing scarcity of forest resources, exploring alternative raw material for the forest industry has gained importance in in recent years. Particle boards were produced in laboratory conditions by blending industrial wood chips with Scots pine cones in varying proportions (25 %, 50 %, 75 % and 100 %) and usingr urea formaldehyde glue. The adhesice mixture contained 55 % urea formaldehyde glue and 33 % ammonium chloride as a hardener. Te production parameters included a press temperature of 150 °C, a press time was 7 minutes, and a press pressure of 2,4 MPa to 2,6 MPa. The resulting boards had a thickness of 16 mm and a density ranging from 730 kg/m^3 to 740 kg/m^3.
Tests for thickness iswelling, water absorption, , bending strength, modulus of elasticity and tensile strength perpendicular to the surface were conducted. Results showed that the physical and mechanical properties of the boards containing up to 25 % Scots pine cone met the required standards.

Keywords: Larch chip, mechanical properties, particle board, physical properties, pinus sylvestris, raw material, scots pine cone, wood chips

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Introduction

With the acceleration of industrial production, it has become even more imperative to reduce the pressure on forests, to use raw material resources more efficiently, and to develop and disseminate environmentally friendly Technologies (Guler and Ozen 2004).

With the increase in population in our country, the need for raw materials in the furniture and plate industry is increasing. There is a great need to fulfill traditional needs such as agricultural wastes, animal feed, cultivated mushrooms, fertilizer production. However, in order to meet the ever-increasing need in the plate industry, it seems that various technologies related to the evaluation of these lignocellulosic products can be developed and supported instead of printing on forests (Guler 2015a).

Forest secondary wastes, top and branch residues left in nature after tree felling, bark, roots, chips, cones, lignocellulosic wastes, bushes, straw-straw etc. can be divided into classes such as. Forestry secondary waste is mostly left in the environment where it was cut or used as fuel. Studies have reported that tree bark, hazelnut shells, pine cone waste and various lignocellulosic wastes can be easily used instead of normal wood flour (Avcı 2015).

Kalkan *et al.* (2021) report in their study that Scots pine is one of the pine species widely distributed in Turkey, its length is between 20 m and 40 m, and it produces seeds every 2-3 years. Additionally, it is reported that the length of the Scots pine cone varies between 2,5 cm and 7 cm. In the study by Ganenko *et al.* (2006) in which the extractive composition of Scots pine cones was examined, the cones were first kept in ethanol, and then this solution was extracted first with chloroform and then with butanol. While dehydroabietinic acid and a sterol fraction were detected in the chloroform extract, it was reported that (-) catechin, shikimic acid and β-sitosterol glucopyranoside were found in the butanol extract. In the study conducted by Eberhardt and Young (1996), it was reported that the polysaccharide compositions of Scots pine cones in Turkey are similar to coniferous trees. The chemical compositions were reported to be galactose (5,1 %), glucose (59 %), xylose (4,5 %) and mannose (31,4 %). He also reported that pine cones have a guayasyl and hydroxyphenyl lignin structure similar to wood.

Micales *et al.* (1994) chemical analysis (Table 1) and resin acid ratios of Scots pine cones are given (Table 2).

Table 1: Chemical analysis of Scots pine cone.

Chemical	Content* (%)
Glucose	46,2
Mannose	24,6
Galactose	0
Xylose	3,5
Arabino	0
Klason lignin	2,8
Acid soluble lignin	0,7
Ash	0,4
Ethanol/tolüene extractives	6,4

*Sugars and lignin given as a percentage of extractive-free wood.

Table 2: Resin acids in fresh and oxidized Scots pine cones.

Resin acid	Content (%)	
	Fresh	Oxidized
Pimaric acid	16,7	18,3
Sandaracopimaric acid	6,5	8,7
Levopimaric acid	3,6	0,9
Palustric acid	1	5,2
Isopimaric acid	7,9	7,2
Abiatic acid	13,4	8,6
Dehydroabiatic acid	11,8	47
Neoabiatic acid	23	4,1

Bal and Ayata (2020) reported that the sapwood of the larch (*Pinus nigra* J.F.Arnold) tree is wide, its heartwood is narrow and very resinous. On the other hand, they stated that the appearance of annual rings was clear and soft. It has been reported that the radial expansion of larch wood is 6,57 %, its volumetric expansion is 14,23 %, its tangential expansion is 7,19 %, while its radial contraction is 5,69 %, its tangential contraction is 7,12 % and its volumetric contraction is 12,40 %. They reported that cellulose in larch wood was 48,27 %, extractive substance content 8,71 %, holocellulose 64,27 %, α-cellulose 40,10 % and lignin 34,32 %. On the other hand, they reported that hot water solubility was 8,68 %, cold water solubility was 7,42

%, ash content was 0,60 % and 1 % NaOH solubility was 19,75 % (Sanıvar and Zorlu 1980, Kardas 2014, Akyurek 2019, Var and Kardas 2017, Cavuş *et al.* 2019).

Bal and Ayata (2020), in her study on the mechanical properties of larch wood, They determined the humidity as 9,77 %, the air-dry density as 508 kg/m^3, the bending strength as 118,7 MPa and the modulus of elasticity as 97,89 MPa.

The situation, which started years ago with the production of mud-brick composites (adobe) by mixing wheat or rice stalks with mud, continues today by combining wood or lignocellulosic materials with inorganic materials (Moslemi 1999, Guntekin 2009, Cavdar *et al.* 2012).

31,5 % of the raw material resources for the production of lignocellulosic composite materials in the world are provided from agricultural sources. This rate is too large an amount to be underestimated. Research on performance characteristics for the use of agricultural resources in plate production has continued to increase day by day. Straw-based particleboard trials have been conducted in North America and medium and high density particleboard made of rice husk in the Middle East. As a result, these productions started mass production as the performance properties on particle board gave positive values. In later years, researchers used sugar cane, bamboo, kenaf, wheat stalk, cotton stalk, hazelnut shell, corn stalk, etc. They examined the possibilities of using annual plants in plate production (Arslan *et al.* 2007, Tascioglu *et al.* 2018).

The raw material problem in the particleboard industry is increasing. Many countries have started to explore different sources of raw materials. In addition to the increase in consumption in parallel with the world population, the scarce and insufficient raw material resources cause an increase in costs. It has become imperative to evaluate resources economically and rationally. All kinds of raw materials with lignocellulosic structure are evaluated in the production of particle board panel.

With the increase in demand and production for boards, industrial wastes such as sawdust, planning waste and cover board as alternative raw material sources to wood chips used as raw materials are involved in the production of boards between 10 % and 30 %. Alternative sources used by some researchers for particle board production are given in Table 3.

Table 3: Alternative sources used by some researchers for particle board production.

Alternative Sources	Researchers
Corn stalk, cotton stalk, pepper stalk, wheat stalk, sunflower stalk	Guler and Ozen 2004, Bektas *et al*. 2005, Alma *et al*. 2005, Guler *et al*. 2006, Oh and Yoo 2011, Bektas *et al*. 2020
Peanut, hazelnut husk, peanut shell, yellow pine	Guler *et al*. 2009, Mankowski and Laskowska 2021
Sugarcane, hemp grass, flax, hemp, kenaf	Jianying *et al*. 2003, Kalaycıoglu and Nemli 2006
Licorice root, rice pad	Yang *et al*. 2003, Guler 2015b
Coconut skin and fiber	Khedari *et al*. 2003, Khedari *et al*. 2004
Needle leaves, pine cones	Nemli and Aydın 2007, Buyuksari *et al*. 2010
Kiwi pruning waste, grass waste, tea waste, vine waste	Nemli *et al*. 2003, Nemli *et al*. 2009

Particle boards have both smooth and large surfaces. On the other hand, these materials can be easily combined with nails, screws and various adhesives (Ozsoylu and Istek 2015, Istek *et al.* 2017).

Particle boards are easy to process, they do not have defects such as knots, rots and fiber curls that are seen in solid wood materials, and they are relatively inexpensive. Since particle boards have these features, there has been a huge increase in production (Gunduz and Masraf 2005).

The geometry of the wood chip is effective on the physical and mechanical properties, surface quality and processing properties of particle boards. The most suitable blade direction for particle board is parallel cutting, perpendicular to the fiber direction. Parallel cutting, where the blade direction is inclined towards the fiber direction, can also be applied in the same way. As the thickness of the chip increases, the amount of thickness increase as a result of soaking in water also increases. As the chips are oriented within the plate, the resistance properties of the plate may change (Gunduz and Masraf 2005).

In particle board production, as the chip sizes decrease, it causes more adhesion and denser surfaces depending on the surface area. The bending elasticity values of particle boards produced in 3 layers are higher than particle boards produced in single layers. On the other hand, the internal adhesion resistance is higher in single-layer particle board. In addition, bending and elastic resistances vary depending on the surface density (Istek *et al.* 2017).

The specific gravity of the wood used in particle board production should be neither too high nor too low. Wood density should not be less than 400 kg/m^3 and not more than 700 kg/m^3 (Gunduz and Masraf 2005).

In the study, the suitability of Scots pine cones as an auxiliary raw material in the production of particle board based on high amounts of wood (larch chip) was examined. Using Scots pine cones in industries with higher economic value instead of burning them will also help solve the raw material problem. As a result of being used as a source of raw materials, the pressure on forests will be reduced.

Materials and methods

Scots pine (*Pinus sylvestris*) cones were obtained from the Scots pine urban forest in Gümüşhane region. The production of the boards was carried out at Düzce University Faculty of Forestry. Scotc pine has its widest geographical distribution in Turkey in the Black Sea Region. Forest villagers collect pine cones and use them as fuel.

In the study, Scots pine cones were first dried and then finely chipped in the chipping machine. Later, larch chips were added to this process with two different chipping processes. In the first chipping process, the average thickness of the outer layers (top-bottom) of the plate was between 0,8 mm and 1,5 mm, while in the second chipping process, the average thickness for the middle layer was between 1,5 mm and 3 mm. The mixture was made by blending pine cones and larch chips in certain proportions (Table 4). All chips were dried in the drying oven at 70 °C to ensure their moisture content was between 1 % and 3 %. The amounts of chip mixture and glue used for board production were determined separately for the outer and middle layers. The amount of chips determined for each layer was weighed and then the gluing phase started.

Table 4: Test panels.

Panels Type	Industrial wood chips (%)	Scots pine cone (%)
F	100	0
G	75	25
H	50	50
I	25	75
K	0	100

40x40 cm forming frame and 16 mm thick wedges were used in the preparation of the plate draft. The targeted density in the plate was determined as 730 kg/m^3. Urea formaldehyde glue was used at 10 % of the completely dry chip weight. A total of 10 plates were produced, 2 of each plate type. Single-layer sheets were produced with the press temperature of the trial sheets being 150 ^{0}C, the press time being 7 minutes, the press pressure being between 2,4 MPa and 2,6 MPa and the sheet thickness being 16 mm. The produced sheets were kept in the air conditioning room at 20 °C and 65 % relative humidity for three weeks in accordance with the TS 642 (1997) standard, and then the necessary samples were prepared from these sheets for trials, TS EN 326-1 (1999). The properties of urea formaldehyde glue are given in Table 5.

In the study, TS EN 312 (1999) standard (particle boards-properties) was used for physical and mechanical tests. The physical properties of the produced boards are density TS EN 323 (1999), humidity amount TS EN 322 (1999), 2 h and 24 h thickness increase rate and water intake amount TS EN 317 (1999); Modulus of rupture and modulus of elasticity in bending of the mechanical properties of the boards were determined in accordance with TS EN 310 (1999) and internal bond strength to the surface TS EN 319 (1999). Ten test specimens were used for the determination of physical and mechanical properties. All the data were statistically analyzed by using the analysis of variance (ANOVA) and Duncan’s mean seperation tests.

Table 5: Properties of the urea formaldehyde (UF).

Properties	UF
Solid (%)	55±1
Density (kg/m^3)	1200
pH	8,5
Viscosity (cps)	160
Ratio of water tolerance	10/27
Reactivity	35
Free Formaldehyd (%)	0,15
33 % NH_4CI content (max, %)	1
Gel point (100 °C)	25-30
Storage time (25 °C, max day)	90
Flowing point (25 °C)	20-40

Results and discussions

The average indensity and moisture values of the panel groups are shown in Table 6. The number of sample samples was 20 for density and 6 samples were used for moisture determination.

Table 6: Density and moisture content in the plates.

Panel Groups	Moisture (%)	Density (kg/m^3)
F	0,734 (0,061)*	668 (0,153)
G	0,738 (0,038)	730 (0,347)
H	0,730 (0,050)	782 (0,366)
I	0,738 (0,563)	689 (0,636)
K	0,743 (0,041)	766 (1,018)

*Standard deviation values are shown in parentheses.

The findings of the water absorption and thickness swelling of the test plates are given in Table 7 and Figure 1.

In the analysis of variance of the findings obtained in laboratory experiments on particle boards, it was determined that the production conditions had effects on water uptake and thickness increase.

The highest thickness increase was found to be 44,03 % in G group plates and the lowest was 23,69 % in F control group plates. The results of the analysis of variance showed that the difference between the groups was significant with a probability of error of 0,001 % (Table 7, Figure 1). In the Duncan test results, the difference between all groups was determined to be significant with a margin of error of 5 % (Table 7, Figure 1). The thickness increase is given as 14 % for 24 hours in the standards TS-EN 312 (1999). However, since these values were exceeded for 2 hours, a 24-hour soaking test was not performed.

Table 7: Thickness swelling (TS) and water absorption (WA) test results of ANOVA and Duncan's mean separation tests of particleboards produced from cones and industrial wood chips.

Physical properties	Board type	Soaking time (min)	Mean (%)	Std dv	X_{min}	X_{max}	P
Thickness swelling (TS)	F	2	23,69a	5,68	22,59	29,54	0,001
	G	2	44,03b	7,02	33,40	57,90	0,001
	H	2	39,46c	8,18	25,33	57,60	0,001
	I	2	36,34d	7,86	24,65	53,11	0,001
	K	2	39,42c	7,67	28,24	50,49	0,001
Water absorption (WA)	F	2	53,28a	8,63	38,20	69,25	0,001
	G	2	72,29b	4,77	57,40	78,23	0,001
	H	2	63,40c	5,02	53,35	72,49	0,001
	I	2	51,70d	6,50	39,10	67,90	0,001
	K	2	63,55c	5,61	40,55	73,52	0,001

Mean values are the average of 20 specimens. X_{min}: Minimum value; X_{max}: Maximum value; P: Significance level (for ANOVA); a,b,c,d Values having the same letter are not significantly different (Duncan test).

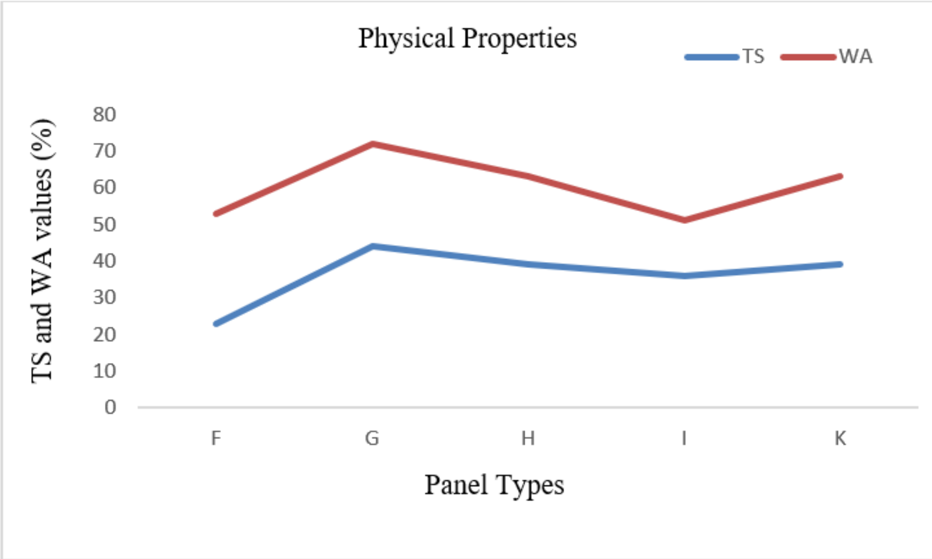

Figure 1: Effect of water uptake (2 h) and thickness swelling on plate drafts (2 h).

In the amount of water uptake, values parallel to the thickness increase were obtained and were found to be between 51,70 % and 72,29 % for 2 hours. According to the results of variance analysis, the difference between the groups was found to be significant with a probability of error of 0,001 %. According to the Duncan test results, the difference between the plate groups was determined to be significant with a margin of error of 5 % (Table 7, Figure 1). In his studies with tobacco stalks and tea factory waste, Kalaycıoglu (1992) found that the water absorption rate of the boards was between 60 % and 71 % for 24 hours, and the thickness increase was between 22 % and 37 %. In their study with peanut hulls, Guler and Buyuksari (2011) found water absorption of 43,43 and thickness swelling of 15,74 after 2 hours of soaking in water for the particle board produced with a density of 796 kg/m^3, while they found water absorption of 77,57 and thickness swelling of 25,71 after 24 hours of soaking in water. Aras (2014) reported in his study that there was a significant increase in the water intake of the boards with the use of pine cones. It has been stated that boards produced from pine cone chips are not suitable for use in places where high bending strength is required, but they are suitable for use as load carriers in humid environments. It has been reported that the inclusion of low percentages of cone chips in production can both improve technological features and contribute to reducing the use of wood chips in today's world where raw material supply is difficult.

In general, the increase in thickness and the amount of water intake may be higher due to the high porosity in the panels produced from scots pine cones. In addition, low temperature drying process was applied after this scots pine cone was shredded. However, it can be said that the water intake and thickness increase are slightly higher than expected. In addition, water absorption and thickness increase can be reduced by using hydrophobic materials such as paraffin at a certain rate during the production of these boards.

The findings of the modulus of rupture, modulus of elasticity and internal bond strength to the surface of the test panels are given in Table 8 and Figure 2.

In the analysis of variance of the findings obtained in laboratory experiments on particle boards, it was determined that production conditions had effects on modulus of rupture, modulus of elasticity in bending and tensile strength perpendicular to the surface.

Table 8: The mechanical properties of particleboards made from Industrial wood (Black pine chips) and Scots pine cones and the test results of ANOVA and Duncan's mean separation tests.

Mechanical properties	Board Type	Mean[a]	Std dv	X_{min}[b]	X_{max}[c]	P[d]
MOR (MPa)	F	11,98a	1,025	10,43	13,44	0,001
	G	10,73b	1,343	8,58	12,84	0,001
	H	6,75c	0,730	5,54	8,89	0,001
	I	5,74c	1,002	4,98	7,57	0,001
	K	4,54d	0,606	3,94	5,22	0,001
MOE (MPa)	F	2174,73a	264,01	1697,21	2472,11	0,001
	G	1759,62b	330,85	1225,32	2138,20	0,001
	H	1243,33c	129,55	989,10	1406,50	0,001
	I	1036,43d	153,25	958,30	1298,10	0,001
	K	950,71e	102,74	821,46	1130,14	0,001
IB (MPa)	F	0,496a	0,026	0,476	0,641	0,001
	G	0,352b	0,028	0,285	0,433	0,001
	H	0,300c	0,030	0,213	0,376	0,001
	I	0,284cd	0,026	0,197	0,326	0,001
	K	0,203e	0,014	0,110	0,230	0,001

MOR= modulus of rupture; MOE= modulus of elasticity; IB= internal bond strength. Mean values are the average of 10 specimens. X_{min}: Minimum value; X_{Max}: Maximum value; P: Significance level (for ANOVA); a,b,c,d,e Values having the same letter are not significantly different (Duncan test).

Modulus of rupture is one of the important factors affecting the place of use, and it changes significantly with the specific mass of the panel and the amount of glue in the particleboard (Istek *et al*. 2018). According to TS-EN 312 (1999), it has been reported that the bending strength of particleboards produced for general purposes used in dry conditions is at least 11 MPa. The lowest value in modulus of rupture was obtained in K group boards (4,54 MPa) and the highest in F group boards (12 MPa). According to the results of the analysis of variance, the difference between the groups was found to be significant with a probability of error of 0,001 % (Table 8, Figure 2). The bending resistance varies depending on the density of the board and the glue usage rate. As the scots pine cone usage rate increased, the bending resistance decreased. In this case, more than 25 % of the Scots pine cones should not be used in the board. On the other hand, the boards are produced as a single layer and the rate of glue usage can be increased. There is a similarity between the particle boards produced from sunflower, tea factory wastes, tobacco and cotton stalks produced by different researchers (Ors and Kalaycıoglu 1991, Kalaycıoglu 1992). On the other hand, Aras *et al.* (2016) investigated the fire performance and rot resistance properties of particle boards produced using pine cones. In addition, Aras *et al.* (2014) determined the bending strength of the boards produced from 100 % pine nut cones at a density of 70 kg/m^3 as 5,02 MPa. In this study, the modulus of rupture of the boards produced as 100 % monolayer was determined as 4,5 MPa. It can be assumed that similar results were obtained. In their study with peanut hulls, Guler and Buyuksari (2011) found the bending strength of particleboard produced with a density of 796 kg/m^3 as 10,40 MPa.

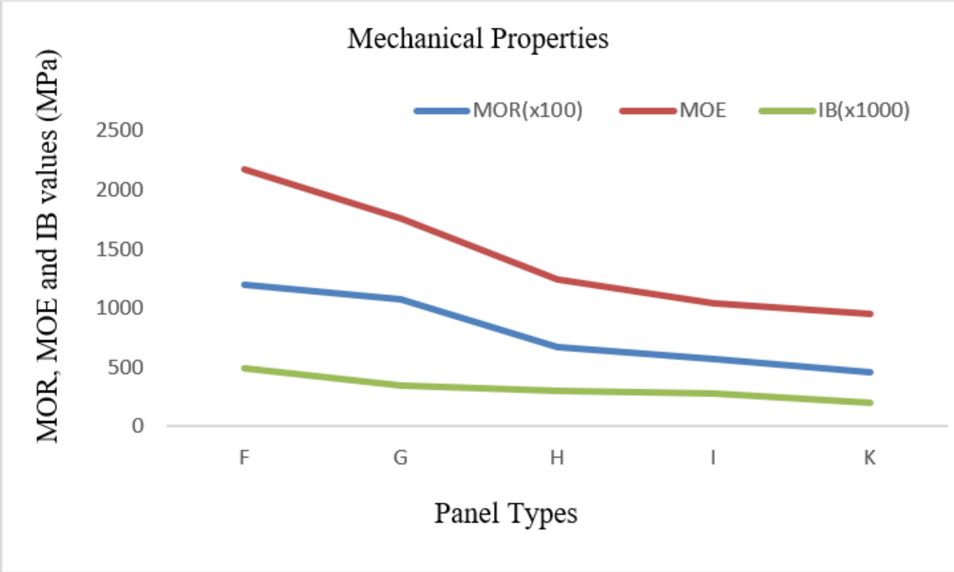

Figure 2: Effect of plate drafts on modulus of rupture (MOR) modulus of elasticity (MOE) and internal bonding (IB).

Modulus of rupture tests were carried out according to the principles specified in TS EN 310 (1999). The modulus of elasticity data obtained in the experiments between 950,71 MPa and 2174,73 MPa show parallelism with the bending strength values (Table 8, Figure 2). In TS EN 312 (1999), the minimum value given for the modulus of elasticity in bending is 1600 MPa, and it can be stated that the data obtained from the plates produced with the addition of more than 25 % of scots pine cones are not in accordance with the standards. In their study with peanut hulls, Guler and Buyuksari (2011) found the elasticity modulus in bending of particle board produced at a density of 796 kg/m^3 as 1485,2 MPa. Arslan (2008) produced red pine cone reinforced panels at two different temperatures and three different glue ratios. It was reported that as the temperature of the plate groups increases, the resistance values of the plates increase and their thickness increases decrease. It has been reported that as the amount of glue increases, the bending strength of the boards first increases and then decreases. Aras *et al.* (2014) determined the modulus of elasticity as 970 MPa in the boards produced from 100 % pine nut cones with a density of 70 kg/m^3. In this study, the modulus of elasticity was determined as 950,71 MPa in the boards produced as 100 % monolayer, which is similar.

The internal bond strength to the surface varied between 0,203 MPa and 0,496 MPa, and it appears to decrease in parallel with other mechanical properties as the cone rate increases (Table 8, Figure 2). The internal bond strength to the surface in particleboards has been determined as at least 0,24 MPa in TS-EN 312 (1999). Accordingly, it has been observed that the tensile strength of the plates produced perpendicular to the surface is up to 75 % in accordance with the standard values for general purpose boards, but a mixture of pine cones up to 25 % is suitable for uses including furniture. Arslan (2008) produced red pine cone reinforced panels at two different temperatures and three different glue ratios. It is reported that as the amount of glue increases, the tensile strength perpendicular to the surface increases and the thickness increase decreases. In addition, it was reported that the tensile strengths perpendicular to the surface of all pine cone-based board groups were above TS EN standards, and their bending strengths and thickness increases showed values far from the standards. In their study with peanut hulls, Guler and Buyuksari (2011) found the tensile strength perpendicular to the surface of particle board produced with a density of 796 kg/m^3 as 0,40 MPa. Aras *et al.* (2014) determined the internal bond strength values to the surface as 0,97 MPa in the plates produced from 100 % pine nut cones.

Conclusions

In the statistical analysis of the physical and mechanical properties of the test panels, it can be concluded that the panels meet the standards when incorporating up to 25 % Scots pine cones.

Coating the particleboard surface with laminated or wood veneer sheets positively impacts the board'sresistance properties. Studies (Chow *et al.* 1986) indicate that bending strength increases when particleboard are covered with veneer sheets. Therefore, covering the boards produced with

Scots pine cones using wooden or laminatedsheets enhances their physical and mechanical properties.

Panels made with Scots pine cones and similar raw material sources may not be suitable for applications requiring high resistance properties. However, when produced with lightweight and sufficient resistancecharacteristics, they can serve , as effective insulation material for indoors use. Cobnsequiently, incorporating 25 % Sscots pine cones, classified as forest waste, into the production of particleboards for general purposes and indoor environments offers a sustainable and viable raw material option.

Authorship contributions

S.K.: Conceptualization, data curation, formal analysis, investigation, methodology, resources, software, supervision, validation, visualization, writing – original draft, writing – review & editing. C.G.: Conceptualization, data curation, methodology, resources.

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