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Physical and Mechanical Properties of Three-Layer Particleboard Manufactured from the Tree Pruning of Seven Wood Species

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Abstract: This study was carried out to investigate the feasibility of using tree prunings of seven wood species available in Saudi Arabia to manufacture three-layered resin-bonded particleboard. The wood species used were *J. procera* as softwood species collected from Al-Baha region, southwest of the kingdom and six hardwood species *viz., A. salicina*, *C. erectus, F. altissima, L. glauca, P. dulce* and *T. aphylla* collected from different sites of Riyadh city during year 2011. Boards were pressed at target density level of 750 kg m^{-3} and the resin content for core and surfaces was 8 and 10%, respectively based on oven dry weight. The press conditions were 150 °C, 3.5 MPa and 8 min. Mechanical properties in static bending (MOR and MOE), tensile strength perpendicular to board surface (IB) and screw holding power were determined. In addition, water absorption and thickness swelling were also determined after 2 and 24 h water immersion. Chemical constitutents of wood had the highest effects on the properties of the produced particleboard. Results indicated that the suitability of waste material to manufacture high-quality particleboards with high strength and dimensional properties and points to a need of future research along that line. Additional treatments might be needed such as coating surface with melamine-impregnated paper or chemical modification of particles to improve the panel quality especially their dimensional stability.

Key words: Tree punning · Particleboard · Mechanical properties · Dimensional stability · MOR · MOE

INTRODUCTION

Saudi Arabia is a poor country in natural forests where the forest area is about 2.1 million ha equivalent to 1.3% of the area of ??the Kingdom [1], So the Kingdom depends on imported wood and its products to meet the demands of the population. This puts great pressure on the balance of government payments, where the value of imports of wood-based panels is 476.8 US$ million in 2010, of which about 20.5 million US$ of particleboard and wood fiber [2]. Growing concern about the environment has led to change of forest management practices, resulting in significant reduction in wood harvest from national forests in the midst of growing demands [3]. Constantly increasing population resulted in higher escalating demand for wood in the sector of forest product industry. Consumption of wood products is annually increasing although other competitive materials such metals and plastics are available. The world wood production by weight is twice than that of steel and 15 times that of plastics [4].

One of the most important wood-based composites is particleboard, which is made from wood or lignocellulosic material particles glued with binder (adhesive) under pressure and temperature. Urea-formaldehyde is the most economic and useful adhesive because of its low cost and easy production [6]. There are many applications of particleboard i.e., floor, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops and desk tops [6, 7]. Throughout the world, Sellers [8] reported that the demand for wood composite products has increased substantially. The world consumption of wood-based panels was 263.7 million m^3 in the year 2011 and 1.25 million m^3 in the Kingdom of Saudi Arabia [2]. Particleboard panels form about 57% of the total production of wood-based panels, which is growing annually at a rate of 2 to 5% [9]. The total production of particleboard by year is expected to be 41.63 million m^3 in Europe and 33.08 million m^3 in North America [10].

Growing social demands for various wood-based panel products leads to the continuous efforts to find new

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wood resources as an alternative to solid wood from natural forests [11-16]. The use of non-timber resources, wood wastes and agricultural residues are a way of saving wood [15, 17]. In order to overcome the wood shortage and to meet the future demand of wood products, studies have been conducted to utilize non-wood materials, agricultural residues, fast growing tree, low-grade wood species and/or underutilized wood species in the forest industry as raw material components for wood-based composite production in several countries. A wide variety of these raw materials have been studied, such as almond shell [5], wheat straw and corn pith [6], kiwi stalks [7], hazelnut husk [14], waste grass clippings [15], tomato stalks [16], rhododendron [17], peanut husk [19], underutilized low-quality raw materials [20], palm leaves midribs [18,21], cotton stalks [11, 22-23], castor stalks [24], peanut hull [25], eggplant [26], wheat straw [27], betel palm [28], bagasse [23, 29], date palm branches [30], flax shiv [31], rice straw [32] and kenaf core [33]. Overall studies pointed to the viability of utilizing of these lignocellulosic materials in forest industries. In Saudi Arabia, with its poor timber resources, pruning of street trees could be a form of suitable cheap secondary resource.

A large quantity sheds huge quantity of plant biomass annually from seasonal street trees pruning as an essential agricultural practice. In developing countries most of these residues are mostly ploughed into the soil or burnt in the field [16, 25], however, in developed countries these residues are used to produce wood composites such as pulp, particleboard and medium density fiberboard [17, 20]. However, in Saudi Arabia most of these residues are eliminated by incineration or thrown away as refuse by costly conventional methods and could be considered as a serious of environmental pollution [13]. On the other hand, the need of raw materials for industrial and constructional expansion has placed much demand on the converted forest products. Using of these pruning residues for particleboard production may reduce the import expenses.

Although, there are no accurate estimates in the Kingdom about the residues resulted from the pruning of woody trees, enormous quantities of *Conocarpus erectus*, *Ficus altissima* and *Pithecellobium dulce*, yields huge biomass annually through seasonal pruning as regular agricultural practice to achieve the purposes of these plantations in public gardens and streets in different engineering forms. No data were available in this field about the average of these tree residues.

Tamarix aphylla (Athel) is one of forest trees, fast growing, drought resistant and salt-tolerant species, planted throughout the Kingdom. This wood species constitutes a renewable resource that could be used as a source of wood raw material required in several local uses [34]. During the last three decades, many multipurpose tree species, i.e. *Acacia salicina* and *Leucaena leucocephala* were imported into the country and planted for biomass production as fast-growing tree species [35-36]. These trees are used as supplement to fuel wood and fibrous raw materials. However, the suitability of the wood resulted from these trees to manufacturing of wood-based panels is still not defined.

Juniper (*Juniperus procera* Hochst. Ex Endl.) is a coniferous evergreen forests grows in pure and/or mixed stands in the southwestern mountainous region of Saudi Arabia at elevations higher than 1500 m above sea level [37]. For more than three decades, it has been reported that juniper forests are suffering from serious decline and deterioration in the form of die-back [38-39]. Abo-Hasan [37] reported that the current available volume of timber in the southwest that about 0.5% of tree plantation area in the Kingdom is ready for cut and/or thinning annually, which yields a volume ranging from 55,000 to 70,000 ton. These residues if properly managed could provide a reasonable supply of timber for wood

To meet the growing demand for wood, the most effective ways are the establishment of fast-growing tree plantations, using the underutilized tree species and fibrous agricultural residues [17]. So that, research in Saudi Arabia has been carried out in the Plant Production Department, College of Food and Agricultural Sciences, King Saud University, on a wide variety of fast-growing species [18, 35, 40]. Most of previous studies in Saudi Arabia dealt with composite boards made from some fast-growing wood species and/or agricultural residues were directed towards the manufacture of homogenous particleboards [18, 41]. However, no studies have been done to investigate the properties of three-layer particleboard made from these residues.

As a part of a large project of exploring the possibility of utilizing agricultural residues, wood wastes and prunings trees in Saudi Arabia, this study was undertaken to evaluate the basic properties of three-layer particleboards from seven wood species grown through out Saudi Arabia. Accordingly, the objectives of this study were to investigate the feasibility of using the pruning tree residues of seven wood species for production three-layer particleboard bonded with urea-formaldehyde adhesive and to compare their properties to the minimum property requirements specified in the commercial standards for mat-formed particleboards.

MATERIALS AND METHODS

Raw Materials: Pruning residues of seven wood species produced from street trees growing in Riyadh city were used in this study as lignocellulosic raw materials to manufacture three-layer UF-bonded particleboard panels. Six of those are hardwood species (*Acacia salicina, Conocarpus erectus, Ficus altissima, Leuceana glauca, Pithecellobium dulce* and *Tamarix aphylla*) collected from Riyadh region during 2011. The seventh one is softwood species *viz., Juniperus procera* were collected from the branches of juniper trees growing in Al-Baha region, southwest of the kingdom. The characteristics of these species and their descriptions are listed in Table 1. Commercial urea-formaldehyde in solution (50% resin solid content) was used as an adhesive.

Preparation of Particles: Lignocellulosic raw materials were ground using a Laboratory hammermill. The produced particles were screened using Laboratory sieves to remove the oversize, fines and other impurities. The screen analysis of the seven raw materials is presented in Table 2. The particles passed through 10-mesh sieve and retained on 40-mesh sieve were used for core layer. However, the particles passed through 40-mesh sieve and retained on 80-mesh sieve were used for surface layers. Dimensions and slenderness ratio of particles used for particleboard production are given in Table 3.

Table 1: Characteristics of the pruning residues of the seven wood species

Remarks	Species	Height (m)	Diameter (cm)	Age (year)	SG	MC* (%)
Acacia salicina	9.65	13.5	10-12	0.561	8.45	Branches without bark
Conocarpus erectus	15.7	11.9	10-12	0.653	6.39	Branches with bark (10-12%)
Ficus altissima	19.3	26.5	20-25	0.460	9.65	Branches without bark
Leuceana glauca	13.4	17.6	10-12	0.530	6.41	Branches without bark
Pithecellobium dulce	12.8	14.3	10-12	0.532	8.79	Branches without bark
Tamarix aphylla	32.2	35.7	30-35	0.600	15.16	Branches with bark (7-11%)
Jupirus procera	18.5	28.9	20-25	0.507	6.47	Branches from dead trees without bark

Each value is an average of 3 trees. SG is specific gravity and MC is moisture content. Each value is an average of 10 samples and *after air-drying and before processing.

Table 2: Screen analysis of the particles of the eight wood species used

Fraction (mesh)*	*A. salicina*	*C. erectus*	*F. altissima*	*L. glauca*	*P. dulce*	*T. aphylla*	*J. procera*
F > 10	11.02	10.77	0.82	8.45	2.71	11.91	6.75
10> F>20	13.00	14.90	7.49	11.52	17.66	26.64	12.64
20> F > 40	39.10	34.90	32.31	40.23	37.77	30.00	44.15
40 > F > 60	14.81	22.50	14.44	14.69	22.15	16.11	15.32
60 > F > 80	6.34	6.30	16.24	11.47	6.57	5.34	10.75
80 > F	15.73	10.58	18.70	13.64	13.14	9.99	10.39

*Average of four fraction analysis.

Table 3: Dimensions and slenderness ratio (L/W) of the particles

		Particles 10/20 mesh			Particles 20/40 mesh			Particles 40/60 mesh		
Wood species	N	Length	Width	L/W	Length	Width	L/W	Length	Width	L/W
A. salicina	86	4.01	1.22	3.29	3.01	0.98	3.07	2.09	0.62	3.37
C. erectus	79	3.62	1.12	3.23	2.61	0.86	3.04	1.89	0.52	3.63
F. altissima	85	6.23	1.42	4.39	2.86	0.68	4.21	2.30	0.48	4.79
L. glauca	85	5.87	1.39	4.22	3.09	0.82	3.77	1.96	0.43	4.55
P. dulce	85	5.62	1.42	3.96	2.68	0.77	3.48	2.03	0.45	4.51
T. aphylla	73	4.43	1.25	3.54	2.72	0.91	2.99	1.88	0.46	4.09
J. procera	82	5.92	1.25	4.74	2.88	0.70	4.34	1.67	0.38	4.62

N is the number of the measured particles.

Chemical Analyses of Woody Materials: Based on oven-dry weight, the percentage of total extractive of wood samples was determined according to the ASTM D1105-84 [42]. The contents of the cellulose, hemicelluloses and lignin were then determined for each wood species using wood meal free-extractive and based on oven-dry weights, according to the methods described by Nikitin [43], Rozmarin and Simonescu [44] and ASTM D1106-84 [45], respectively. However, ash content was determined based on the oven-dry wood meal weight [46]. In addition, solubilities of wood in cold water, hot water and 1% NaOH solution were carried out according to ASTM D1110-84 [47], TAPPI T1m-84 [48] and ASTM D1109-84 [49], respectively.

Board Manufacturing: Particles were oven dried at 105±5°C to reach about 3% moisture content. Constant weight of particles was weighted to obtain the target density of 0.75 g cm^{-3}. The particles were mixed with urea-formaldehyde resin using a Laboratory-type blender for about 6 minutes. Immediately, the mixed particles were hand-felted into a wooden forming frame on a caul plate. Thereafter, the frame was removed and the mat was pressed at a maximum pressure of 3.5 MPa and 150 °C for 8 minutes including one minute closing time using Carver Laboratory press, model 2699. The boards were then conditioned at 65±5% relative humidity and 20°C to reach equilibrium moisture content. Three boards were manufactured for each wood species (21 boards in total). Other manufacturing variables of resin-bonded particleboard in this study were:

- Board size: 30 by 30 cm by 13 mm in thickness.
- Target density: 750 kg m^{-3}.
- Three-layer particleboard, face-core-back weight ratio: 25:50:25%.
- Resin type: commercial urea-formaldehyde with resin solid content 50%.
- Resin solid content based on oven-dry weight of the mixture: core 8% and surface 10%.
- Hardener: ammonium chloride (1% of solid resin).
- No wax was added.
- Mat moisture content: 13%.
- The boards were not sanded.

Mechanical Properties: Three-point static bending, tensile perpendicular to board surfaces and screw withdrawal tests of the particleboards were carried out using Instron Testing Machine (Model 3382) in accordance to the American Standard [50] with some modifications due to the limited size of boards. Modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB) and screw holding power (SHP) were recorded. After static bending test, the specimens of density and moisture content were cut from the ends of the bending specimens and they were prepared and determined according to ASTM D-1037 [50].

Dimensional Stability Properties: Water absorption (WA), thickness swelling (TS) and linear expansion (LE) of the boards were evaluated from equilibrium condition to water soak condition after immersed in water for 2 and 24 h and carried out as specified by the European standard [51]. The test specimens were immersed in a water bath at room temperature for 2 h, then were taken out and weighed. The samples were then soaked again to complete 24 h immersion time. The results of WA, TS and LE after 2 and 24 h were expressed as a percentage of the original state.

Experimental Design and Statistical Analyses: The analysis of variance (ANOVA) was applied using randomized complete design (RCBD) to find out the statistical differences in the physical, mechanical and dimensional properties of the particleboard. A Duncan multiple range test at 5% level of probability was conducted to study the significance of the differences among species using Statistical Analysis System [52].

RESULTS AND DISCUSSION

Mechanical Properties: The analysis of variance (ANOVA) of the modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) and screw holding power (SHP) of the produced particleboard made from the pruning trees of the seven wood species is presented in Table 4. In addition, the average values and standard deviations of those mechanical properties are given in Table 5. It can be seen from the ANOVA that the effect of wood species on all the mechanical properties of produced particleboards is highly significant. As shown in Table 5 the mechanical properties of the three-layer particleboard were highly differed among the seven wood species.

It can be noted from Table 5 that particleboard manufactured from *J. procera* had the highest MOR value (18.29 MPa) followed by *P. dulce* (16.13 MPa). The lowest MOR value (12.71 MPa) was reported with board produced from the tree pruning of *T. aphylla*, followed by *C. erectus* (13.89 MPa) without any significant differences

Table 4: Analysis of variance for physical and mechanical properties of particleboard

Source of Variation	d.f.	Mean square: Physical Properties: Density	CR	MOR	Mechanical Properties: MOE	IB	SHP
Species	6	0.00033**	0.0712**	9.40**	225991.3**	0.060**	318641.2**
Error	35	0.000099	0.00034	0.69	3936.4	0.0066	4147.5
Total	41						

** Highly significant.

Table 5: Physical and mechanical properties of UF-bonded particleboard

Wood species	Physical properties: Density (g.cm^{-3})	CR	Mechanical properties: MOR (MPa)	MOE (MPa)	IB (MPa)	SHP (N)
Acacia salicina	0.773^{A}(0.009)	1.378^{D}(0.02)	15.91^{B}(0.57)	2.608.7^{B}(149)	0.700^{B}(0.07)	1599.0^{C}(80)
Conocarpus erectus	0.750^{B}(0.005)	1.152^{F}(0.01)	13.89^{C}(0.90)	2254.0^{D}(233)	0.523^{CD}(0.10)	1686.1^{C}(166)
Ficus altissima	0.749^{B}(0.010)	1.628^{A}(0.02)	15.72^{B}(0.51)	2418.3^{C}(239)	0.660^{BC}(0.07)	1894.2^{B}(151)
Leuceana glauca	0.763^{AB}(0.010)	1.440^{C}(0.02)	15.77^{B}(0.38)	2636.7^{B}(126)	0.800^{AB}(0.12)	1893.6^{B}(88)
Pithecellobium dulce	0.765A^{B}(0.015)	1.439^{C}(0.03)	16.13^{B}(0.96)	2558.0^{B}(174)	0.683^{B}(0.10)	2066.6^{A}(173)
Tamarix aphylla	0.773^{A}(0.014)	1.288^{E}(0.03)	12.71^{C}(1.57)	2189.3^{D}(184)	0.503^{D}(0.07)	1184.9^{D}(178)
Jupirus procera	0.770^{A}(0.009)	1.519^{B}(0.02)	18.29^{A}(0.41)	3008.7^{A}(166)	0.904^{A}(0.06)	2160.1^{A}(149)
EN 312-4 (1996)	-	-	11.5	1.60	0.35	350

Each value is the average of three specimens. Values given in parentheses are standard deviations.
Means with the same letters in column are not significantly different according to Duncan Multiple Test at $p<0.05$. Whereas, CR is a compaction ratio which calculated as a ratio between board density and wood density and SHP stands for screw holding power.

between them. The MOR values of the boards made, complied with the specifications of European standard [53]. They fulfilled the requirement for general purpose boards for use in dry conditions (Type p1), for interior fitments (including furniture) for use in dry conditions (Type p2). They also met the requirements for non-load bearing boards for use in humid conditions (Type p3) and for load bearing boards for use in dry conditions (Type p4).

Regarding to MOE values, it is clear from Table 5 that there were large variations among the seven particleboard panels produced, which ranged between 2189.3 and 3008.7 MPa for boards made from *T. aphylla* and *J. procera*, respectively. MOE values of the entire Laboratory fabricated board types were higher than the maximum requirements (2000 Mpa) specified by the EN 312 [53]. Some values were slightly higher than values were reported in previous research results of a similar nature.

It is clear from Table (5) that the panels made from *J. procera* attained the highest IB value (0.90 MPa), followed by *L. glauca* (0.80 MPa). The panels manufactured from the tree pruning of *T. aphylla* and *C. erectus*, attained the lowest values (0.503 and 0.523 MPa, respectively). However, the IB strength of all the panels exceeded the maximum standard specifications (0.4 MPa) set by EN-312 [53] for general purpose boards, boards for interior fitments as well as boards intended for load and non-load bearing for use in dry and humid conditions. The screw holding power of the three-layer particleboard in the current study ranged between 1184.9 N for *T. aphylla* and 2160.1 N for *J. procera* (Table 5).

Generally, the values of the mechanical properties are in line with previous research results of Gertjejansen [54], Kozlowski *et al.,* [55] and El-Osta *et al.*, [56]. However, the slightly lower values of the mechanical properties of the particleboard made from the tree pruning of *T. aphylla* and *C. erectus* in this study could be attributed to the interaction effect of three factors *viz.,* wood density, geometry or configuration of the particles and the presence of bark. The particles obtained in this work were smaller or lower in quality than that produced by other researchers because these particles were produced using a hammer mill available in our Laboratory [18], whereas others had used a Laboratory ring flaker, which can produce particles of high quality [57]. Firstly, low-slenderness particles (L/W ratio) for *T. aphylla, A. salicina* and *C. erectus* comparing to the other species resulted in the slightly lower MOR, MOE and IB values (Table 3). For example, L/W ratio of large particle (10/20 mesh) for these species ranged from 3.23 to 3.54 while for other species ranged from 4.22 to 4.74. Another reason could be that particleboard made from *T. aphylla* and *C. erectus* incorporate up to 12% bark particles (Table 1). Previous studies concluded that the particleboard made with bark had lower mechanical properties than the particleboard without bark [58-59]. This could be due to the fact that the presence of bark caused higher pH and/or lower absolute acid buffering capacity of wood particles, which could have extended the gel time of UF resin and inhibited the curing of UF [60-61], causing the deterioration of bonding quality between fibers and UF [62]. In addition, the weaker mechanical strength of bark could also contribute to the lower mechanical properties of particleboard with bark [59]. Finally, the high-density of the wood produced from *T. aphylla* and *C. erectus* (0.60 and 0.65 g cm^{-3}, respectively, as shown in Table 1) which resulting in lowering compaction ratio (1.29 and 1.15, respectively) and values of the mechanical properties of the particleboard produces from these species.

The density of the seven wood species used was Laboratory determined based on oven-dry weight and green volume (Table 1) and ranged from 0.46 g cm^{-3} for *F. altissima* to 0.653 g cm^{-3} for *C. erectus*. The compaction ratio (the density ratio between board and wood), therefore, was ranged from 1.15 for *C. erectus* to 1.63 for *F. altissima*. Since all particleboard panels in this work were manufactured at constant conditions (press, temperature and target density), increasing compaction ratio due to decreasing the density of wood species have a generally favorable effect on mechanical properties, resulting in increasing MOR, MOE and IB. These results were in agreement with the finding of Geimer [63] and El-Osta *et al.,* [56]. It can be seen from the results that particleboard manufactured from low-density wood species such as *F. altissima* and *J. procera* had the highest compaction ratios, which resulted in increasing the mechanical properties of those panels as compared with other wood species having high-density raw materials such as *C. erectus* and *T. aphylla*.

The chemical composition of wood is one of the most important factors affecting in the mechanical properties of the produced particleboard [25, 64-65]. Table 6 shows that the seven wood species used in this study were statistically different in all the chemical constituents. These variation might be explained the differences between the produced particleboard. A comparison of the chemical composition of the seven wood species to softwoods and hardwoods is presented in Table 6. It was evident that except *C. erectus* and *T.* aphylla, all chemical constitutes fell within the range of either softwoods or hardwoods. Extractives content ranged from 5.24% for *A. salicina* to 16.28% for *T. aphylla*, while cold water solubility of wood ranged from 3.93 to 12.83%, respectively. The high extractives content and solubilities in cold and hot water of both *C. erectus* and *T. aphylla* may be attributed to the inclusion of bark in the wood mill (Table 1).

Table 6: Chemical composition of wood compared to other plant sources

	Content (%) of					Solubility (%) in	
Wood species	Extractive	Cellulose	Hemicellulose	Lignin	Ash	Cold water	Hot water
A. salicina	5.24	46.58	21.73	31.69	1.02	3.93	4.04
C. erectus	12.08	46.41	20.55	33.04	1.86	7.98	7.85
F. altissima	9.91	48.04	21.61	30.35	3.02	9.24	9.59
L. glauca	5.51	47.14	21.50	31.36	2.38	4.85	4.56
P. dulce	6.08	48.10	22.49	29.43	4.84	5.66	5.85
T. aphylla	16.28	45.49	20.91	33.62	6.40	12.66	12.83
J. procera	6.49	49.74	21.75	28.51	0.87	3.55	4.25
Hardwood^{+}	2-6	45-50	15-35	23-30	0.2-0.5	4-6	2-7
Softwood^{+}	2-8	45-50	20-32	25-34	0.2-0.5	2-3	3-6

* Each value is an average of 5 samples. $^{+}$ Fengel and Wegener [66].

Table 7: Correlation coefficients matrix

	Extractive	Cellulose	Hemicellulose	Lignin	CWS	HWS
MOR	-0.81*	0.96**	0.26^{NS}	-0.93*	-0.83*	-0.82*
MOE	-0.77*	0.82*	0.18^{NS}	-0.60^{NS}	-0.85*	-0.85*
IB	-0.79*	0.80*	0.25^{NS}	-0.63^{NS}	-0.81*	-0.82*
SHP	-0.74*	0.90**	0.55^{NS}	-0.84*	-0.74*	-0.73*

NS Not significant. * Significant at 0.05 level of probability. ** Significant at 0.01 level of probability.

Table 7 shows the correlation coefficients matrix of the chemical constituents of wood and mechanical properties of the three-layer particleboard produced from them. It is clear from this Table that the cellulose content directly correlated with all the mechanical properties, while the extractives content and the lignin content have exhibited highly inverse correlations. This means that increasing cellulose content of wood and decreasing either extractives content or lignin content resulted in increasing the mechanical properties of the particleboard produced. The relationship between MOR and each of cellulose content, lignin content and extractives content are presented in Figures 1 to 3. It is clear from these relations that about 94, 86 and 68% of the total variability in MOR values are attributed to cellulose, lignin and extractives content, respectively. Fengel and Wegener [66] stated that high cellulose content decreases the brittleness of wood, whereas high lignin content increases its brittleness. This result is in agreement with the finding of Nemli *et al.,* [15] who attributed the poor mechanical properties of particleboard with increasing the concentration of grass clippings to the higher contents of holocellulose and alpha cellulose of eucalyptus wood than grass clippings with inverse trend with lignin content. On the other hand, Nemli *et al.,* [64] concluded that increasing concentration of the extractives decreased the mechanical properties of the panels.

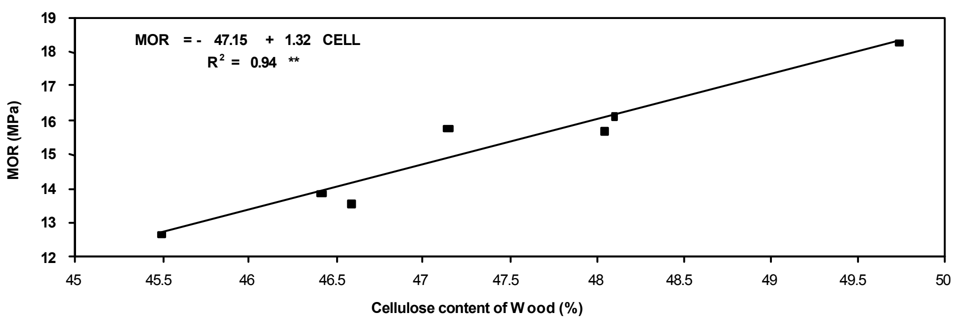

Fig. 1: Relationship between modulus of rupture (MOR) and cellulose content of wood

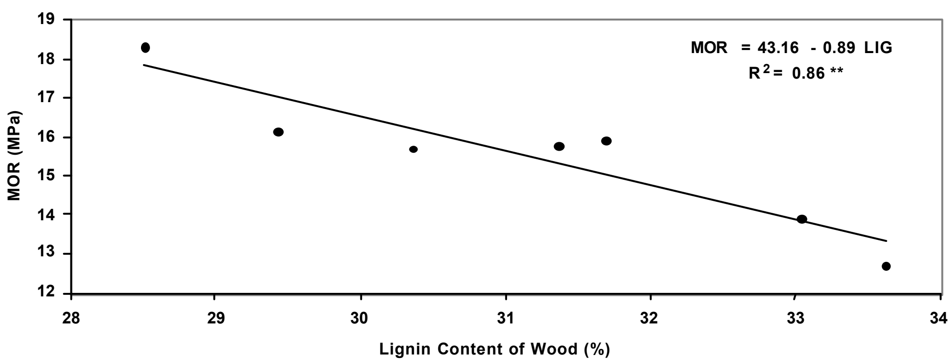

Fig. 2: Relationship between modulus of rupture (MOR) and lignin content of wood

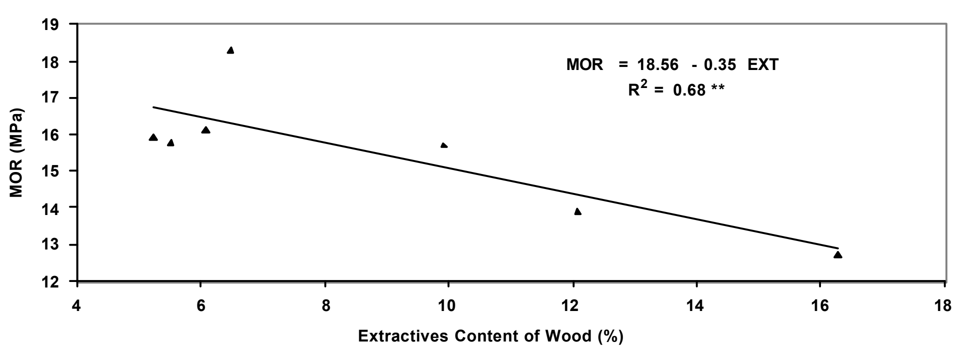

Fig. 3: Relationship between modulus of rupture (MOR) and extractive content of wood.

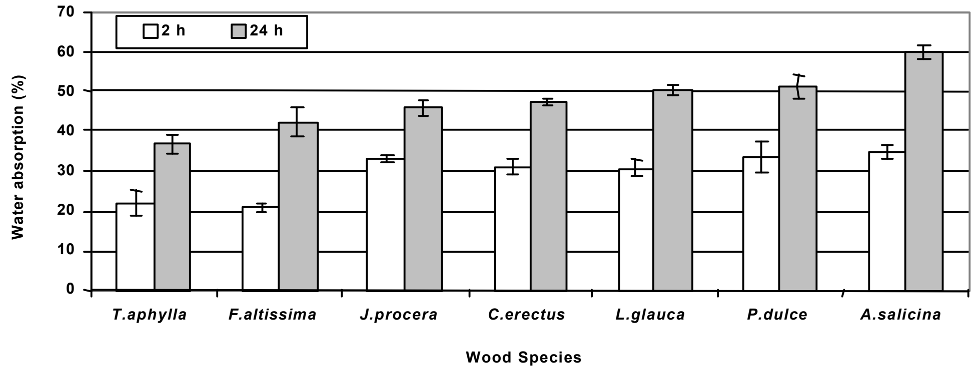

Fig. 4: Water absorption of the three-layer particleboard from the seven species

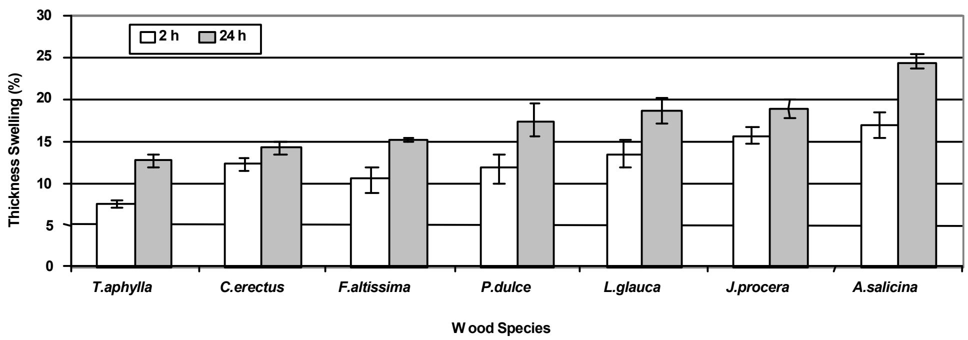

Fig. 5: Thickness swelling of the three-layer particleboard panels from the seven species.

Dimensional stability of the particleboard: The results of the analysis of variance (ANOVA) indicated that the effect of wood species on the dimensional stability properties of the three-layer particleboard panels after 2 and 24 h soaking water tests was highly significant except for LE after 24 h water soaking. The WA values of the particleboard samples for 2 h water immersion ranged from 20.92 to 34.87% (Fig. 4). It was apparent from the results that the lowest value was obtained with particleboard made from *F. altissima* (20.92%) and *T. aphylla* (21.89%) without significant differences between them. The highest WA values after 2 h were recorded with the other five species without any significant differences between them and ranged from 30.61% for *L. glauca* to 34.87% for *A. salicina*. Average WA for 24 h water immersion ranged from 36.66% for *T. aphylla* to 59.83% for *A. salicina* (Fig. 4). There are no standards for WA of particleboard. However, the WA values obtained in the current study were similar or slightly lower than the values reported for the particleboards produced from some wood species. Hegazy and Aref [18] using a board density of 750 kg m^{-3}, reported WA values of 46.0% and 63.3% for *C. erectus* after 2 and 24 h immersion, respectively. Nazerian *et al.*, [67] obtained 25.92-39.31% and 35.91-50.79% for *T. aphylla* after 2 and 24 h immersion, respectively using a target density of 650 kg m^{-3}. However, Zheng *et al.,* [57] using the same species and a board density of 760 kg m^{-3} gave 47.66% and 57.15% for *T. aphylla* after 2 and 24 h immersion, respectively. Barboutis and Philippou [68] reported 11.6-28.8% and 42.1-78.3% for some evergreen Mediterranean hardwood species after 2 and 24 h immersion, using a low board density of 550 kg m^{-3}, respectively.

Depending on the wood species, the three-layer particleboard panels had TS values ranging from 7.55 to 16.90% and 12.66 to 24.45% after 2 and 24 h water soaking, respectively (Fig. 5). The maximum TS requirements according to EN standards are 8 and 15% for 2 and 24 h immersion, respectively [53]. It can be seen that all the TS values of the produced panels after 2 h soaking exceeded (poor) the requirement of the EN standard, except for *T. aphylla* panels which gave an average TS value of 7.55%. The TS values after 24 h water immersion of the panels made from *T. aphylla* (12.66%) and/or *C. erectus* (14.15%) satisfy the TS requirement for general purposes (less than 15%). However, the TS values of the particleboard made from the other wood species, except for *A. salicina* (24.45%) were close to the required level of TS of panels for general purposes [53]. Lower TS obtained by *T. aphylla* could be explained by the compatibility of

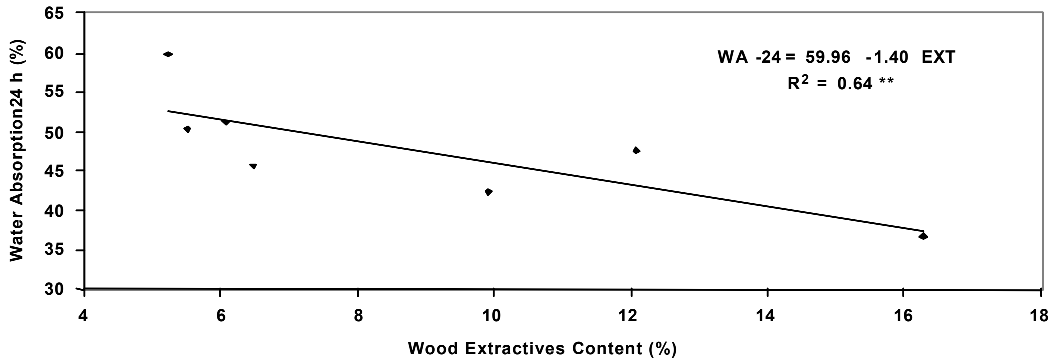

Fig. 6: Wood extractives vers water absorption after 24 h of water immersion

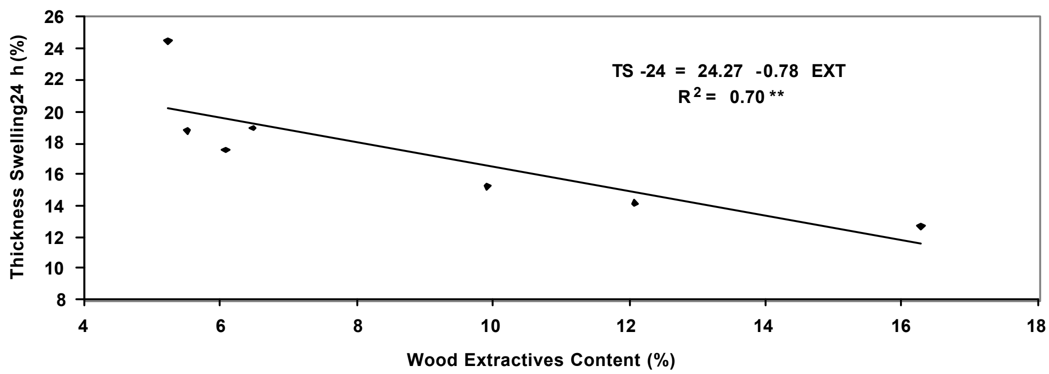

Fig. 7: Wood extractives vers thickness swelling after 24 h of water immersion

furnish and adhesive (UF). Another reason of this result was the presence of bark and more amounts of extractives (16.28% as shown in Table 1) in the Athel wood (*T. aphylla*).

The differences in WA and TS of the produced particleboards may be attributed to the chemical composition of wood [15, 19]. These results were supported by a significant relationship between extractives content of wood and each of WA and TS (Fig. 6 and 7). It can be seen from these Figures that increasing extractives content of wood decreasing the WA and TS of the particleboard produced from this wood. The positive effect of extractives on the resistance to the water and humidity was mentioned in the previous works {59, 69]. On the other hand, it has been reported that some polyphenolic extractives in bark could react with UF to improve the water resistance properties [64].

Generally, the significant differences between the wood species and the slightly higher WA and TS values of the particleboard made from the seven wood species may be attributed to the interaction effect of several factors including the absence of wax and hydrophobic substance in particleboard manufacturing [20], the geometry of the particles obtained in the current study which was smaller or lower in quality than that produced by other researchers [18] and the chemical composition especially extractives, cellulose and lignin contents [15]. To improve the dimensional stability properties of the particleboard produced from these wood species, there are four methods which could be used based on the current practices in the particleboard manufacturing industry [20, 59]. These methods are to add wax (0.5-1%) to the mixture of adhesive and particles [25,29], to decrease "spring-back" effect by reducing the density of the panels [70], to acetylate the particles [71] and to add more bark to the wood furnish however, the lowered mechanical properties need to be carefully considered [59].

The above results suggest that it is completely feasible to produce acceptable and/or high-quality particleboard using those tree pruning residues of the seven wood species. However, in order to achieve a more stable product from such species, the boards may require additional treatments i.e., coating of particleboard surfaces with melamine-impregnated papers [72], increasing resin level [20, 59], using high press temperature and time of post-heat treatments or using acetylation method [73].

CONCLUSIONS

This study was carried out to determine the properties of the three-layer UF-bonded particleboard panels made from suitability the pruning residues of seven wood species growing in Saudi Arabia. Utilization of the tree pruning to manufacture three-layer particleboards will present an alternative resource for particleboard industry and convert these residues into valuable and largely needed products which can play a key role in providing balance between supply and demand. This may help us to solve the problem of raw material shortage for particleboard industry and to prevent some environmental problems caused by burning of these wastes. The results of the current study indicated that the produced three-layer particleboards made from the tree pruning of the seven wood species agreed with the specifications of EN standard and they fulfilled the requirement for general purpose panels for use in dry conditions and for interior fitments (including furniture). Also they met the requirements for non-load bearing boards for use in humid conditions and for load bearing boards for use in dry conditions. Results also showed that the cellulose content of wood had significantly and positively correlated with all the mechanical properties, while the lignin content was highly but inversely correlated. On the other hand, there was a positive significant effect of the wood extractives on the water absorption and thickness swelling of the produced panels. Future studies about optimum conditions of particle geometry, adhesion and pressing conditions are needed to improve the panel quality, especially their dimensional stability properties.

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