A POTENTIAL OF Acacia saligna (Wattle) WOOD AS RAW MATERIAL FOR PARTICLE BOARD PRODUCTION

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Acacia saligna provides multi-functions such as production of particle board. However, quantitative information on the physico-mechanical properties of particle board made from A. saligna is scarce. This study evaluated the physico-mechanical properties of A. saligna particle board. Physico-mechanical properties of boards were evaluated with respect to standard board characteristics. Physical properties of panel thickness, mass, density, moisture content, water absorption and thickness swelling at 24 hrs differed between A. saligna board and standard board, but thickness swelling at 2 hrs did not. The mean density, mass, thickness and moisture content of the A. saligna panel was 612.64 kg.m⁻³, 12.61 kg, 6.99 mm and 3.99% respectively. The internal panel bond length-wise (1.99 N mm⁻²) and width-wise (2.53 N mm⁻²) with significant differences of A. saligna panel were higher than the standard. The average width-wise bending strength (8.58 N mm⁻²) was higher than the standard, and length-wise (10.86 N mm⁻²) it was not different from the standard. In general, the panel has low board mass and moisture content that make it good panel. However, higher panel water absorption, thickness of swelling and internal bond strength and lower bending strength of the panel was not highly preferable by the end user. Therefore, this study recommended that further study is needed on the amount of binding agent to make an appropriate strength class. In addition to this, it is recommended to evaluate additional board characteristics such as checking pH, resin content and flake (particle) geometry.

Keywords: Particleboard, A. saligna, Physical, Mechanical

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INTRODUCTION
Particle board is defined as a panel product manufactured from lignocellulosic materials, primarily in the form of discrete particles, combined with some suitable binder chemicals and bonded together under heat and pressure (Maloney 1977, Haygreen and Bowyer 1998). The primary difference between particleboard and other reconstituted wood products, such as waferboard, oriented strand board, medium density fiberboard, and hardboard, is the material used in its production (Haygreen and Bowyer 1998). The major types of particles used to manufacture particle board include flakes, wafers, chips, powdery particles of wood produced by sawing, strands, slivers, and a mass of fine, softwood shavings (Maloney 1977, Haygreen and Bowyer 1998). Technically it is possible to make particle boards from many species of wood in almost any form, regardless of board qualities and economic considerations. There are a lot of tree and shrub species that have been used for particle board such as Paulownia tomentosa, Virola spp., Terminalia superba, and Pericopsis elata (Vital et al 1974), Eucalyptus grandis (Mehra 1978), Acacia saligna, Conocarpus erectus, Melia azedarach and Phoenix dactylifera (Hegazy and Aref 2010), Acacia salicina, Conocarpus erectus, Ficus altissima, Lepidochrysops glauca, Pithecellobium dulce, Tamarix aphylla and Juniperus procera (Nasser 2012), Neolamarckia cadamba (Lias et al 2014) and Acacia seyal and Acacia nilotica (Elbadawi et al 2015).

In Ethiopia particle board companies rely on eucalyptus as the main sources of raw material, and there is a need to increase the supply of wood available with alternative species. An option is the use of new and fast-growing wood species obtained in natural forest stands and woodlots, and A. saligna is a promising candidate species, with wide distribution in Ethiopia (Bekele-Tesemma and Tengnäs 2007).

A. saligna is a very adaptable and fast-growing evergreen shrub or tree native to Western Australia (Midgley and Turnbull 2003). In Ethiopia, this species grows in dry and moist lowland and dry midland agro-climatic zones and in many soil types, but it prefers medium loam texture and well-drained soils (Bekele-Tesemma and Tengnäs 2007). It grows in two forms: a multi-stemmed, thornless and spreading shrub, and a single stemmed tree, growing to a height of about 10 meters (Bein et al 1996). The bark of this tree varies from smooth and grey to red-brown in small branches to dark grey and fissured in older trees (Bein et al 1996, Van Wyk and Van Wyk 1997, Bekele-Tesemma and Tengnäs 2007). The species is classified as an invasive species in South Africa and Botswana (Le-Maitre et al 2002).

In Australia and many other countries around the world, it is used extensively for soil stabilization, animal fodder (leaves) (Midgley and Turnbull 2003, Tanär and Asefa 2009), for fuel and timber (Midgley and Turnbull 2003), for making particle board, charcoal, and agricultural tools (Michaelides 1979). The species is also used as bee forage, as an ornamental tree, a shade, a windbreak and live fence, and gum used for food preservative (Bein et al 1996).

Using A. saligna as an alternative to eucalyptus in the production of particle boards may provide good panel (Hegazy and Aref 2010). Experimental stands of A. saligna have shown great potential for silviculture (coppicing and pruning) practices, and the characteristic low density, shine colored wood of the species are important technological necessities for production of particulate wood panels (Oliveira et al 2016). Here, we evaluate the quality of particle board panels manufactured with wood from A saligna.

MATERIALS AND METHODS
Raw materials
We used A saligna wood growing on area exclosure of Abreha weatsibeha and Freweini for the production of three-layer bonded particle board panels. The characteristics of A. saligna tree with age of (3-4 year), DBH range from 15-21 cm and Height range from 2.5 – 4.5 m were used. Trees were felled and cut into approximately 1 m logs using a chainsaw. Logs were left to air dry, Commercial urea formaldehyde in solution (48 kg m$^{-3}$) was used as an adhesive.

Preparation of particles
The produced particles or materials (chip and flake) were screened using laboratory sieves to remove the outsize, fines and other impurities. The particles or materials passed through 6 mesh sieves (3.36 mm) were used for the core layer. However, the particles or materials passed through 12 mesh sieves (1.68 mm) were used for surface layers (Figure 1).
Figure 1: particle board processing diagram

Board manufacturing
Particles were oven dried at 105±2°C to reach about 2.3% recommended moisture content. The particles were mixed with urea-formaldehyde resin using a laboratory type blender for about 10 minutes. Immediately thereafter, the mixed particles pass through V-belt into a wooden forming frame on a caul plate (Maloney, 1993). Then, the frame was removed and the mat was pressed at a maximum pressure of 29 MPa and 220 °C for at least 72 seconds 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. Seventy-two boards were manufactured from 16 m³ A. saligna wood. The manufactured board size was 1.22 by 2.44m with 8 mm thickness and its target density was 700 kg m⁻³. The ratio of three-layer particle board surface-core-surface weight was 27:40:26%. Resin type was applied using urea-formaldehyde with resin solid content 65±1%, viscosity 300-500 CPS and PH value minimum 7. For hardener, ammonium chloride (25% of solid content) was also used with paraffin wax liquid content (60%). Mat moisture content was 9% (Haygreen and Bowyer 1998).

Testing methods
Mechanical properties: Internal bond (IB) and bending strength (BS) of the panels were measured using Universal Testing Machine (Zwick/Roel) (Model 3382) in accordance to the American Standard. Bending strength (BS) and internal bond (IB) was measured in Oromia Forest Enterprise.

\[
BS (N/mm^2) = \frac{Load_{max} (N)}{\text{Thickness (mm)} \times \text{Width (mm)}}
\]

(Cai and
Dimensional Properties: Thickness swelling (TS) and Water absorption (WA) of the panel were evaluated after immersion in water for 2 hrs to test WA and 2 and 24 hrs to test TS and carried out as specified by the European standard, then were taken out and weighed. The results of WA and TS after 2 and 24 hrs were expressed as a percentage of the original state.

\[
\text{Density (kg/m}^3\) = \frac{\text{Average mass (kg)}}{\text{Average Volume (m}^3\)}  \quad \text{(Eq 1)}
\]

\[
\text{TS} (\%) = \frac{T_{\text{out (mm)}} - T_{\text{in (mm)}}}{T_{\text{in (mm)}}} \times 100 \quad \text{(Chiang et al 2014)}  \quad \text{(Eq 2)}
\]

\[
\text{WA} (\%) = \frac{M_{\text{out (kg)}} - M_{\text{in (kg)}}}{M_{\text{in (kg)}}} \times 100 \quad \text{(Chiang et al 2014)}  \quad \text{(Eq 3)}
\]

\[
\text{MC}_{\text{oven}} (\%) = \frac{M_{\text{in (kg)}} - M_{\text{out (kg)}}}{M_{\text{out (kg)}}} \times 100 \quad \text{(Reeb and Milota 1999)}  \quad \text{(Eq 4)}
\]

Where: \(TS\) = Thickness swelling, \(T_o\) = Final thickness, \(T_i\) = Initial thickness, \(WA\) = Water absorption, \(M_o\) = Mass out, \(M_i\) = Mass in, \(MC_{\text{oven}}\) = Oven dry moisture content, \(BS\) = Bending strength, \(Load_{\text{max}}\) = Maximum exerted load.

Statistical analysis: To evaluate the mechanical and physical (dimensional) properties of the particle board panel made from \(A.\) saligna wood, the American Society for Testing and Materials - ASTM D 1037 standard (ASTM 1988) was used. The average values observed for the physico-mechanical properties were compared with the average required by the norm of the American National Standards Institute - ANSI 208.1 (ANSI 1993) For all cases, the data obtained was assessed through one sample T test \((p < 0.05)\) using R Software V 3.4.4 to determine if mechanical and physical properties of the particle board differed from the standard board values.

RESULTS AND DISCUSSION

Physical (dimensional) characterization

Chip and flake moisture content and density: Overall, the average moisture content of chip and flake was 22 and 24\% respectively, and the density was 304 and 127 kg m\(^3\), respectively (Figure 2; Table 1). The moisture content of the chip and flakes of \(A.\) saligna was lower by 68\% and 65\% than from the standard, and the density of chip and flakes of the \(A.\) saligna board was also lower by 8\% and 36\% respectively. The chip and flake of \(A.\) saligna wood is characterized by its hygroscopic nature (Kollmann and Cote 1968). The hygroscopic behavior of wood describes the adsorption and desorption of moisture to maintain equilibrium depending on the surrounding climate in particular relative humidity and temperature (Kollmann and Cote 1968). Changes in the moisture content below the fiber saturation point (28 – 30\%) affect the physical, mechanical and rheological properties of the material, like shrinking and swelling and the strength values (Kollmann and Cote 1968, Siau 1984, Skaar 1988).
Figure 2: Chip and flake moisture content and density, thickness of swelling, internal bond and bending strength
Table 1: Moisture content and density of Flake and chip of *A* saligna.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Norms</th>
<th>Acacia saligna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip MC (%)</td>
<td>70</td>
<td>22.02 (±1.20) ***</td>
</tr>
<tr>
<td>Flake MC (%)</td>
<td>70</td>
<td>24.24 (±1.57) ***</td>
</tr>
<tr>
<td>Chip Density (Kg m⁻³)</td>
<td>330</td>
<td>303.68 (±2.83) ***</td>
</tr>
<tr>
<td>Flake Density (Kg m⁻³)</td>
<td>200</td>
<td>127.12 (±7.23) ***</td>
</tr>
</tbody>
</table>

Data expressed as mean ± SD. The stars indicate the significance of a one-sided t-test with comparison to a standard

Panel Thickness and Mass: The average thickness and mass of the panel were 6.99 mm and 12.61 kg respectively (Figure 3; Table 2), and the panel made from *A. saligna* had 12.6% lower thickness (P<0.05) and 24.5% lower mass (P<0.05) than the standard. This may be due to low content of moisture and density of both chip and flake of the material.

Board density: Density is one of the parameters that shows the better mechanical properties of particle board. Influence of board density on the flexural strength properties of bending strength and internal bond when density increases can cause the higher compaction ratio in the board (Lias et al 2014). The average value of bulk density measured for *A. saligna* panels was 0.613 g cm⁻³ (Figure 3; Table 2). A board made from *A. saligna* was lower by 12.5% in density from the standard industrial panels (P<0.05). However, the panels were classified as medium density panels, which refer to panels with a bulk density between 0.60 and 0.80 g cm⁻³ (Oliveira et al 2016). The panel bulk density of *A. saligna* was higher than the panel bulk density of *Sequoia sempervirens* (0.32 g cm⁻³) and *Pinus taeda* (0.50 g cm⁻³) (Iwakiri et al 2014).

Table 2: Density, mass, thickness and moisture content of panels made from *A* saligna.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Norms</th>
<th>Acacia saligna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board Density (Kg m⁻³)</td>
<td>665 - 735</td>
<td>612.64 (±55.21) ***</td>
</tr>
<tr>
<td>Board Mass (Kg)</td>
<td>16.2 - 17.2</td>
<td>12.61 (±0.46) ***</td>
</tr>
<tr>
<td>Board Thickness (mm)</td>
<td>7.76 – 8.24</td>
<td>6.99 (±0.61) ***</td>
</tr>
<tr>
<td>Board Moisture Content (%)</td>
<td>2.5 - 8</td>
<td>3.99 (±1.09) *</td>
</tr>
</tbody>
</table>

Data expressed as mean ± SD. The stars indicate the significance of a one-sided t-test with comparison to a standard.

Panel moisture content: Panel moisture content of *A. saligna* was lower by 24% than the standard but not significantly different (Figure 3; Table 2). This may be due to the type of additives used for panel production; for example, the chemical formula of the urea-formaldehyde adhesive used in the manufacture of particle board panels made from *A. saligna* is different from that being used. A second reason may be the chemical composition of the raw material, as *A. saligna* in general presents higher values of extractives and this chemical compound may lead to decreased moisture content of panels (Maloney 1993). The panel moisture content (3.99%) of *A. saligna* panel was lower than the Eucalyptus grandis (8.3%) and rice husk (8.6%), (Melo et al 2009).

Water absorption: The effect of *A saligna* wood species on the water absorption of the three-layer particle board panels after 24 hrs soaking water tests was highly significant (P<0.05). The water absorption values of the particle board samples for 24 hrs water immersion ranged from 61.47 to 221.08% (Figure 3 and Table 3). This variability may be due to the orientation of particle and the mixture of the chemicals and material, which was higher than those of *Sequoia sempervirens* and *Pinus taeda* (range between 26.3 and 55.4%), (Iwakiri et al 2014), *Conocarpus erectus* (46.0% and 63.3%), Hegazy and Aref (2010), *Tamarix aphylla* (35.91-50.79%), Nazerian et al (2011) and some evergreen Mediterranean hardwood species (*Quercus coccifera*, *Quercus ilex*, *Arbutus unedo*, *Phillyrea latifolia*, *Erica arborea*, range (42.1-78.3%), Barboutsis and Philippou (2007). A possible reason for the high *A. saligna* water absorption values could be the low density of the material. The other possible reason is,
in accordance with which the A. saligna panels with lower compaction ratio had higher values of water absorption. According to Moslemi (1974), panels with a lower compaction ratio have a less closed structure which contributes to easy entry of water.

**Thickness swelling:** The three-layer particle board panels had thickness swelling values ranging from 7.55 to 16.90% (average 12.39%) and 12.66 to 24.45% (average 18.19%) after 2 and 24 hrs water soaking, respectively (Figure 2 and Table 1). The 2 hrs values did not differ significantly (P>0.05) from the maximum thickness swelling requirements of 10% for 2 hrs immersion of the standards. However, the 24 hrs values were significantly (p<0.05) higher than the 24 hrs standard values of 10% and, this would not satisfy the thickness swelling requirement for the standard. The differences in thickness swelling of the produced particle boards may be attributed to the chemical composition of wood (Akgül and Tozluoğlu 2008, Nemli et al 2009). Lower compaction increases water penetration into the particle board and consequently, the water needs a shorter time to diffuse into the particles and panel (Chiang et al 2014). In addition, thickness swelling is influenced by the geometry of particles, their structure and the presence of many voids in the boards that allow internal swelling as well (Sotannde et al 2012).

**Mechanical characterization**

**Internal bond:** Internal bonding is one of the most important for the qualitative characterization of the particle boards. This parameter indicates how significant was the interaction performed between the particles and the adhesive used (Melo et al 2014), and is directly related to all the other physico-mechanical properties evaluated in this study. The panels made from A saligna attained the higher internal bond value in both length and width wise (1.99 and 2.53 N mm$^{-2}$, Figure 2; Table 3). The industrial panels made from A saligna were significantly higher in both lengthwise (P<0.05) and widthwise (P<0.05) testing activities by 468.6% and 622.9% respectively compared to the standard. The internal bond of A. saligna was higher than the Eucalyptus grandis (0.24 N mm$^{-2}$), Bambusa vulgaris (0.22 N mm$^{-2}$), and Oryza sativa (0.04 N mm$^{-2}$) (Melo et al 2014). The higher average value of internal bond for the panels made from A saligna may be due to the higher amount of adhesive available per particle, low moisture content (Winistorfer and Dicarlo 1988) and higher resin content (Rathke et al 2012).

**Bending strength:** The bending strength of the three-layer particle board panel in widthwise was lower (P<0.05) by 38.7% than the standard, but lengthwise bending strength was not significantly different (P>0.05) (Figure 2, Table 3). This may be due to the physical and anatomical characteristics of this material as well as the associations between these factors and variables of panel production.
Figure 3: Board thickness, mass, density, moisture content and water absorption at 24 hrs
CONCLUSIONS

A. saligna panel possesses good physical (dimensional) and mechanical properties in terms of light density of flake and mass of panel, the low flake moisture content and the low moisture content that make it a good panel for making furniture and for construction. However, the high-water absorption, thickness swelling, and internal bond make the panels be not highly preferred by end users. Therefore, to improve the less preferable characteristics, the manufacturer could use hydrophobic chemicals to minimize the high-water absorption and thickness swelling, adding adequate number of binding agents (urea formaldehyde, melamine formaldehyde, phenolic formaldehyde and melamine urea formaldehyde) to have preferable internal bond strength of the panel, and adding enough amount of binding agents and producing fibrous flakes to have good bending strength panel. We recommend to explore physical and mechanical qualities of mixed wood particle boards, especially A. saligna and Eucalyptus globulus, and also to explore qualities of alternative panel thicknesses (e.g., 13 – 18 mm). In addition to this, other measurements, such as pH, moisture content, resin content and flake (particle) geometry should be explored.

ACKNOWLEDGEMENTS

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Table 3: Internal bond, bending strength, thickness swelling and water absorption of panel made from A. saligna

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Norms</th>
<th>Acaia Saligna</th>
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<tbody>
<tr>
<td>Internal Bond (N mm⁻²)</td>
<td>Lengthwise</td>
<td>0.33 – 0.37</td>
</tr>
<tr>
<td></td>
<td>Widthwise</td>
<td>0.33 – 0.37</td>
</tr>
<tr>
<td>Bending Strength (N mm⁻²)</td>
<td>Lengthwise</td>
<td>13.3 – 14.7</td>
</tr>
<tr>
<td></td>
<td>Widthwise</td>
<td>13.3 – 14.7</td>
</tr>
<tr>
<td>Thickness Swelling (%)</td>
<td>2 hrs</td>
<td>8 - 12</td>
</tr>
<tr>
<td></td>
<td>24 hrs</td>
<td>8 - 12</td>
</tr>
<tr>
<td>Water Absorption (%)</td>
<td>24 hrs</td>
<td>20 - 40</td>
</tr>
</tbody>
</table>

Data expressed as mean ± SD. The stars indicate the significance of a one-sided t-test with comparison to a standard.


