

Enhancing the physical properties of briquettes from sawdust of *Piptadenia africana* through combination with *Ceiba pentandra*

Abstract

This study sought to determine the effect of combining sawdust of *Piptadenia africana* with *Ceiba pentandra* on the physical and mechanical properties of briquettes produced at room temperature using low compacting pressure without a binder. Briquettes were produced from a mixture of sawdust of *Piptadenia africana* and *Ceiba pentandra*. Particle size of sawdust used for this study was 1mm or less. The two materials were combined at mixing proportions: 80 : 20, 60 : 40, 40 : 60 and 20 : 80 (*Piptadenia africana* : *Ceiba pentandra*). The results indicated that the relaxed density of briquettes produced from the mixed materials ranged from 534 to 766 kg/m³ whilst that of compressive strength in cleft ranged from 12.46 to 60.28 N/mm. At compacting pressure levels between 30 and 50 MPa, all the briquettes produced from the mixed materials had adequate compressive strength in cleft. The impact resistance index of briquettes from the mixed materials was adequate and ranged from 128 to 500%. The compressive strength in cleft and impact resistance index of all the briquettes produced from the mixed species were better than those produced from *Piptadenia africana* only. Additionally, at 5% level of significance, the relaxed density, compressive strength in cleft and impact resistance index of briquettes were significantly affected by the biomass raw material and compacting pressure. Thus, the addition of sawdust of *Ceiba pentandra* to that of *Piptadenia africana* could significantly improve the physical and mechanical properties of briquettes produced from sawdust of *Piptadenia africana*. Therefore, production of briquettes from mixed timber species should be encouraged.

Keywords: Briquettes, *Ceiba pentandra*, Compressive strength, Impact resistance index, *Piptadenia africana*, Relaxed density

1.0 Introduction

For over a century now densification/briquetting has been one of the technologies used in the conversion of sawdust into a more efficient biomass fuel for heating, cooking and generation of electricity. Briquetting is very useful, in that, it improves the physical strength, enhances the volumetric calorific value up to 500 - 1500 kcal/kg, help reducing volume by 8 - 10 times by increasing density up to about 1000-1200 kg/m³ [1]. It helps in making fuel available for a variety of domestic and industrial applications and turns biomass residues into a cash income for farmers [1]. In order to produce a good quality briquette, the type of raw material and its preparation before pressing is very important. Besides, different briquetting machines require varying optimum conditions of raw materials and process variables to ensure production of good quality briquette [2]. Raw material characteristics that have great effect on briquette quality include moisture content, particle size, material mix, particle density and chemical composition [3]. Additionally, process variables which have effect on briquette's quality are temperature, compacting pressure, preheating of raw material and cooling lines [3].

Previous studies by [4, 5] indicated that briquettes produced from *Piptadenia africana* at room temperature (28°C) using low compacting pressure (compacting pressure $\leq$ 50 MPa) had adequate relaxed density but weak compressive strength in cleft and impact resistance index. Species characteristic of *Piptadenia africana* which predominantly contributed to the low compressive strength in cleft and impact resistance index was its high density (744.89 kg/m³). Species density has been found to negatively correlate with compressive strength in cleft and impact resistance index of briquettes produced at room temperature using low compacting pressure [5]. This is because when sawdust is pressed at room temperature using low compacting pressure it is likely for particles of low density species to reach elastic and plastic deformation. Therefore, enhancing formation of stronger bonds. *Ceiba pentandra* is a

low density species (409.22 kg/m^3) with acid-insoluble lignin and alpha-cellulose content of 24.34% and 41.24% respectively [5].

Previous study by [5] indicated that briquettes produced from sawdust of *Ceiba pentandra* at room temperature (28°C) and low compacting pressure (20 to 50 MPa) without a binder had adequate relaxed density, high compressive strength in cleft and high impact resistance index. Further studies by [6] indicated that the relaxed density, compressive strength in cleft and impact resistance index of briquettes produced from maize cobs was significantly enhanced when maize cobs particles was combined with sawdust of *Ceiba pentandra*. Furthermore, the durability property of wheat straw briquette was enhanced as a result of blending the straw with wood waste [7, 8, 9]. The above research outcome confirms report from other researchers that combination of different biomass materials may enhance the quality characteristics of briquettes produced [10]. In this paper, the researcher report the findings of a study conducted to determine the effect of combining sawdust of *Piptadenia africana* with that of *Ceiba pentandra* on relaxed density, compressive strength in cleft and impact resistance index of briquettes produced at room temperature using low compaction pressure without a binder.

2.0 Materials and Methods

Materials and material preparation

Sawdust of *Piptadenia africana* and *Ceiba pentandra* were used for the study. The two materials were sun dried at an average relative humidity and temperature of 75% and 28°C respectively for between five and seven days. Particle sizes of sawdust used for the study were 1mm or less. The materials were combined at mixing proportions: 80 : 20, 60 : 40, 40 : 60 and 20 : 80 (*Piptadenia africana* : *Ceiba pentandra*).

82 2.1 *Moisture content*

83 The moisture content, on oven-dry basis, of the sawdust was determined in accordance with
 84 [11]. A sample of 2 g of the pure and mixed species of sawdust materials were weighed and
 85 placed in a laboratory oven at a temperature of 103 °C. The samples were dried until the
 86 difference in mass between two successive weighings separated by an interval of two hours
 87 was 0.01g or less. The moisture content of the specimen were then computed as follows:

$$88 \quad \text{Moisture content (\%)} db = \frac{M_1 - M_o}{M_o} \times 100 \quad (1)$$

89 Where, M_1 and M_o were masses (g) of test samples before drying and after oven drying
 90 respectively.

91 2.2 *Briquetting process*

92 A 55.3-mm ID × 52.5-cm height cylindrical mould was used to produce the briquettes. Ninety
 93 grammes of each biomass material was weighed and filled into the mould. The average
 94 moisture content of the biomass materials was 12.11%. A manual hydraulic press with a
 95 gauge and piston was used to press the biomass raw material without a binder to form the
 96 briquettes. A clearance of about 0.1 mm was provided between the piston and the inner wall
 97 of the mould to allow for air escape. The samples were then pressed using the following
 98 predetermined compacting pressure levels: 20, 30, 40 and 50 MPa. The dwelling time for each
 99 pressing was 10 s. This process was repeated for all the biomass materials.

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101

102 2.3 *Physical properties of briquettes*

103 The relaxed density, compressive strength in cleft and impact resistance index of the
104 briquettes were investigated using standard testing methods.

105 2.3.1 *Relaxed density*

106 Relaxed density of briquettes was determined 30 days after removal from the pressing mould
107 in accordance with [12]. The mass of each briquette was determined using a laboratory
108 electronic balance with an accuracy of 0.01g. The diameter and length of each briquette was
109 measured at three points with a Digital Vernier Calliper. Relaxed density (RD) was then
110 computed as:

$$RD \left(\frac{g}{cm^3} \right) = \frac{108000 \times M(g)}{\pi [d_1(mm) + d_2(mm) + d_3(mm)]^2 \times [l_1(mm) + l_2(mm) + l_3(mm)]} \quad (2)$$

111
112 Where, d_1 , d_2 and d_3 were diameters (mm) measured at three different points on the briquettes.
113 L_1 , L_2 and L_3 were lengths (mm) measured at three different points on the briquettes. M (g) is
114 the mass of briquette.

115 2.3.2 *Compressive strength in cleft*

116
117 Compressive strength in cleft of briquettes was determined in accordance with [13] using an
118 Instron Universal Strength testing machine (Norwood, MA, USA) with a load cell capacity of
119 100 kN. The cross-head speed was 0.305 mm/min. A sample of briquette to be tested was
120 placed horizontally in the compression test fixture and a load was applied at a constant rate of
121 0.305 mm/min until the briquette failed by cracking. The compressive strength in cleft was
122 then computed as follows:

$$\text{Compressive strength in cleft} \left(\frac{N}{mm} \right) = \frac{3 \times \text{The load at fracture point (N)}}{[l_1(mm) + l_2(mm) + l_3(mm)]} \quad (3)$$

123 Where L_1 , L_2 and L_3 were lengths (mm) of briquettes at points one, two and three respectively.

124 2.3.3 Impact resistance index

125 Impact resistance index of the briquettes produced was determined in accordance with [14] of
 126 drop shatter test for coal. Five drops were set as the standard. Briquettes were released from a
 127 vertical height of 2 m and allowed to freely fall and impact on a concrete floor. After five
 128 drops, the broken pieces of briquettes were collected and weighed using an electronic balance
 129 with an accuracy of 0.01 g. Only the number of pieces which weighed 5% or more of the
 130 initial weight was recorded for the purpose of calculating the impact resistance index. Impact
 131 resistance index (IRI) was then computed as follows:

$$IRI = \frac{N}{n} \times 100$$

132 Where, N is the number of drops and n is the number of pieces that weighed 5% or more of
 133 the initial weight of briquette after N drops.

134 2.3.4 Water resistance quality

135 Briquette's water resistance quality was determined using [15]. This was done by immersing a
 136 briquette into a container filled with water at room temperature. The time taken for the
 137 briquette to completely disperse in the water was determined using a stop watch. Each
 138 experiment was replicated five times for each biomass material.

139 3.0 Results and discussion

140 3.1 Relaxed density

141 Density is one of the major indices for assessing the combustion, handling and ignition
 142 characteristics of fuel briquettes. **Table 1** indicates the relaxed density of briquettes produced
 143 from sawdust of *Piptadenia africana* and *Ceiba pentandra*, and their combination. The

relaxed density of briquettes produced from a mixture of *Piptadenia africana* and *Ceiba pentandra* ranged from 534 to 766 kg/m³. This could be deemed adequate in that it is consistent with those produced from other hydraulic piston presses. Studies by [3, 16] suggested that briquettes produced from hydraulic piston press are less than 1000 kg/m³ nevertheless they are usually between 300 - 600 kg/m³. The result further shows that at mixing ratio 80 : 20 the relaxed density of all the briquettes produced from a mixture of *Piptadenia africana* and *Ceiba pentandra* were higher than those produced from pure sawdust of *Piptadenia africana* and *Ceiba pentandra*.

Table 1 Relaxed density (kg/m³) of briquettes produced from *P. africana*, *C. pentandra* and their combination using compacting pressure levels from 20 to 50 MPa

Biomass material	Mixing ratio (weight basis)	Compacting pressure			
		20 MPa	30 MPa	40 MPa	50 MPa
<i>C. pentandra</i>	Pure (100%)	523	622	666	716
<i>P. africana</i>	Pure (100%)	567	637	679	741
<i>P. africana</i> : <i>C. pentandra</i>	80 : 20	578	645	701	766
<i>P. africana</i> : <i>C. pentandra</i>	60 : 40	564	626	677	732
<i>P. africana</i> : <i>C. pentandra</i>	40 : 60	560	620	672	730
<i>P. africana</i> : <i>C. pentandra</i>	20 : 80	534	614	654	719

Thus, mixing sawdust of *Piptadenia africana* with *Ceiba pentandra* at a mixing ratio of 80 : 20 could result in the production of briquettes that are denser than those produced from their corresponding pure species. Additionally, with the exception of briquettes produced from mixing ratio of 20 : 80, at compacting pressure levels of 30 and 40 MPa, the relaxed density of all the briquettes produced from combination of *Piptadenia africana* and *Ceiba pentandra* were higher than that of *Ceiba pentandra* only. Thus, combining sawdust of *Piptadenia africana* and *Ceiba pentandra* could enhance the relaxed density and for that matter the heat per unit volume of briquettes produced from *Ceiba pentandra*.

163 The result further indicates that generally for the entire compacting pressure levels, the
 164 briquettes' relaxed density decreased with decreasing amounts of *Piptadenia africana* in the
 165 mixture. This result is supported by a weak significant positive correlation between the
 166 proportions of *Piptadenia africana* in the mixture and relaxed density of briquette produced
 167 (Pearson's $r = 0.218$, $p\text{-value} = 0.026$; $N = 80$; 1-tailed, $\alpha = 0.05$). This trend may be due to the
 168 fact that *Piptadenia africana* is a high density species (744.89 kg/m^3) whilst *Ceiba pentandra*
 169 is a low density species (409.22 kg/m^3). Thus, decreasing the amount of *Piptadenia africana*
 170 in the mixing ratio tends to decrease the density of the raw material. Therefore, leading to
 171 decrease in relaxed density of the briquettes produced. The result further suggest that there
 172 exist a strong positive correlation between compacting pressure and relaxed density of
 173 briquettes (Pearson's $r = 0.964$, $p\text{-value} = 0.000$; $N = 80$; 1-tailed, $\alpha = 0.05$). This trend is due
 174 to the fact that the higher the compacting pressure, the closer the particles of the biomass
 175 materials were packed together due to reduction of the void spaces, therefore leading to the
 176 formation of denser briquettes [17]. Analysis of variance (**Table 2**) indicates that at 5% level
 177 of significance, the biomass material (*Piptadenia africana* and *Ceiba pentandra* and their
 178 combination), compacting pressure and their interactions have significant effect on relaxed
 179 density of the briquettes ($p\text{-value} < 0.05$). The multiple coefficient of determination value (R^2)
 180 and root mean square error (RMSE) of the ANOVA Model were 0.9829 and 9.97
 181 respectively. This suggests that about 98.29% of the variability in the relaxed density of
 182 briquettes produced could be explained by the biomass raw material, compacting pressure and
 183 their interaction.

184

185 **Table 2** ANOVA of effect of biomass material and compacting pressure on relaxed density of
186 briquettes

Source	DF	ANOVA SS	Mean square	F-Ratio	p-value
Biomass raw material	5	25476.142	5095.228	51.28	< .0001*
CP	3	519735.625	173245.2083	1743.64	< .0001*
Biomass material x CP	15	3875.425	258.3617	2.60	< .0026*
Error	96	9538.400	99.3583		

187 *Statistically significant at 0.05 level of significance

188 3.2 Compressive strength in cleft

189 Compressive test tends to simulate the compressive stress due to weight of the top briquettes
190 on the lower ones during storage [18]. The compressive strength in cleft of briquettes
191 produced from mixed species of *Piptadenia africana* and *Ceiba pentandra*, as indicated in
192 **Table 3**, ranged from 12.46 to 60.28 N/mm. With the exception of briquettes produced from
193 mixing ratios 80 : 20 and 60 : 40 and pressed at compacting pressure level of 20 MPa,
194 briquettes produced from the mixed species had adequate compressive strength in cleft, that
195 is, compressive strength in cleft greater than 19.6 N/mm. [19] indicated that briquettes
196 compressive strength in cleft of 19.6 N/mm is adequate for handling or use for domestic fuel
197 purpose. The result further suggests that all the briquettes produced from the mixed species
198 had compressive strength in cleft higher than their corresponding values for *Piptadenia*
199 *africana* only. Additionally, the compressive strength in cleft of briquettes produced from the
200 mixing ratio 20 : 80 (30.18 to 60.28 N/mm) were higher than those produced from both pure
201 biomass materials of *Piptadenia africana* and *Ceiba pentandra*. The implication of this result
202 is that briquettes of significantly improved compressive strength in cleft could be produced at

203 room temperature using low compacting pressure if sawdust of *Piptadenia africana* is mixed
204 with that of *Ceiba pentandra*.

205 **Table 3** Compressive strength in cleft (N/mm) of briquettes produced from *P. africana*,
206 *C. pentandra* and their combination using compacting pressure levels 20 to 50 MPa

Biomass material	Mixing ratio (weight basis)	Compacting pressure			
		20 MPa	30 MPa	40 MPa	50 MPa
<i>C. pentandra</i>	Pure (100%)	29.23	39.26	40.40	44.58
<i>P. Africana</i>	Pure (100%)	5.95	10.13	17.06	21.14
<i>P. africana</i> : <i>C. pentandra</i>	80 : 20	12.46	20.43	27.03	39.66
<i>P. africana</i> : <i>C. pentandra</i>	60 : 40	18.95	27.19	34.87	48.53
<i>P. africana</i> : <i>C. pentandra</i>	40 : 60	27.08	37.08	43.96	56.33
<i>P. africana</i> : <i>C. pentandra</i>	20 : 80	30.18	39.34	46.45	60.28

207
208 A strong significant negative correlation was established between the proportions of
209 *Piptadenia africana* in the mixture and compressive strength in cleft of briquette produced
210 (Pearson's $r = -0.561$, $p\text{-value} = 0.000$; $N = 80$; 1-tailed, $\alpha = 0.05$). This suggests that larger
211 proportions of *Ceiba pentandra* sawdust in the mixture could significantly enhance the
212 compressive strength in cleft of briquettes produced from *Piptadenia africana* sawdust and
213 that the compressive strength in cleft depends on the mixing ratio. This finding is consistent
214 with that of [20]. Studies by [20] on production and characterization of rice husk based
215 charcoal briquettes, found that the mixing ratio of the biomass materials have significant
216 effect on the physical and mechanical properties of briquettes produced. In this study
217 briquettes were pressed using low compacting pressure therefore increasing the proportions of
218 high density species (*Piptadenia africana*) in the mixture inhibited the tendency of the
219 biomass material to undergo plastic deformation. The result also showed a consistent increase
220 in compressive strength in cleft with increasing compacting pressure for briquettes produced
221 from both the pure and the mixed biomass materials. This trend was confirmed by a highly,

significant and positive correlation between compressive strength in cleft of briquettes produced and compacting pressure (Pearson's $r = 0.798$, $p\text{-value} = 0.000$; $N = 80$; 1-tailed, $\alpha = 0.05$). Analysis of variance (**Table 4**) of the effect of biomass material and compacting pressure on the compressive strength in cleft indicates that at 5% level of significance the two variables and their interactions had significant effect on compressive strength in cleft of the briquettes ($p\text{-value} < 0.05$). The multiple coefficient of determination value and RMSE of the ANOVA Model were 0.9698 and 2.7612 respectively.

Table 4 ANOVA of effect of biomass material and compacting pressure on compressive strength in cleft of briquettes produced

Source	DF	ANOVA SS	Mean square	F-Ratio	p-value
Biomass raw material	5	13168.875	2633.7751	345.45	$< .0001^*$
CP	3	9540.080	3180.0266	417.10	$< .0001^*$
Biomass material x CP	15	831.690	55.4460	7.27	$< .0001^*$
Error	96	731.924	7.6242		

*Statistically significant at 0.05 level of significance

Therefore, the biomass material, compacting pressure and their interactions could explain about 96.98% of the variance in the compressive strength in cleft of the briquettes produced. Post hoc multiple comparison of means shows that at 5% level of significance the compressive strength in cleft of briquettes produced from the biomass materials differed significantly ($LSD > 1.7332$) and that those of the mixed species were significantly better than that of *Piptadenia africana* only. It is also worth noting that briquettes produced from mixing ratios 20 : 80 and 40 : 60 (*Piptadenia africana* and *Ceiba pentandra*) had compressive strength in cleft significantly higher than that of *Ceiba pentandra* only.

3.3 Impact resistance index

Briquettes impact resistance index is used to simulate the forces encountered during emptying the products from trucks onto the ground. The impact resistance index of briquettes made from mixed species of *Piptadenia africana* and *Ceiba pentandra* ranged from 128 to 500%. All the briquettes produced had adequate impact resistance index in that according to the Italian standard for briquettes/pallets CTI-R04/5 briquettes durability greater or equal to 97.7% is considered adequate (Italian standard for briquettes/pallets CTI-R04/5 as cited in [21]).

Table 5 Impact resistance index (%) of briquettes produced from *P. africana*, *C. pentandra* and their combination using compacting pressure levels 20 to 50 MPa

Biomass material	Mixing ratio (weight basis)	Compacting pressure			
		20 MPa	30 MPa	40 MPa	50 MPa
<i>C. pentandra</i>	Pure (100%)	200	283	316	350
<i>P. Africana</i>	Pure (100%)	72	137	184	217
<i>P. africana</i> : <i>C. pentandra</i>	80 : 20	128	150	217	250
<i>P. africana</i> : <i>C. pentandra</i>	60 : 40	142	167	250	300
<i>P. africana</i> : <i>C. pentandra</i>	40 : 60	175	200	250	400
<i>P. africana</i> : <i>C. pentandra</i>	20 : 80	200	283	350	500

The result further indicates that for all corresponding compacting pressure levels, the impact resistance index of briquette made from a combination of *Piptadenia africana* and *Ceiba pentandra* were greater than that made from *Piptadenia africana* only. This suggests that addition of *Ceiba pentandra* sawdust to that of *Piptadenia africana* could enhance the impact resistance index of briquettes made from *Piptadenia africana*. Briquettes made from the mixing ratio 20 : 80 had impact resistance index either equal to or more than their corresponding values for *Ceiba pentandra*. This, also suggest that impact resistance index of briquettes produced from *Ceiba pentandra* could be enhanced by introducing 20% of

259 *Piptadenia africana* into *Ceiba pentandra*. Most of the briquettes produced from mixing ratios
 260 80 : 20, 60 : 40, and 40 : 60 had IRI lower than their corresponding values for *Ceiba*
 261 *pentandra*.

262 Correlation analysis between proportions of *Piptadenia africana* in the mixture and impact
 263 resistance index of briquette produced indicates that there exist a moderate significant
 264 negative correlation between the two parameters (Pearson's $r = -0.466$, $p\text{-value} = 0.000$; $N =$
 265 80 ; 1-tailed, $\alpha = 0.05$). This may be due to the relatively high species density of *Piptadenia*
 266 *africana*. Additionally, in view of the fact that briquettes were formed using low compacting
 267 pressure and room temperature (28°C) it was easier to press low density species to reach
 268 plastic deformation therefore enhancing bonding than high density species. Compacting
 269 pressure was also found to be significantly and positively correlated with impact resistance
 270 index (Pearson's $r = 0.655$, $p\text{-value} = 0.000$; $N = 80$; 1-tailed, $\alpha = 0.05$). This finding is
 271 consistent with other research outcomes. Previous studies by [22] on densification behaviours
 272 of oak sawdust, oak mulch, oak bark, oak chips, pine sawdust, cotton wood sawdust, and
 273 cotton wood mulch in the pressure range of 34 to 138 MPa established that increasing
 274 compacting pressure resulted in increased abrasive resistance, impact resistance and
 275 compressive resistance of briquettes. [23] also found that increasing compacting pressure
 276 from 5 to 44 MPa increased the wafer (150-mm diameter) durability rating (based on an
 277 impact resistance test) of grass hay (mixed with 20% alfalfa) from 5 to 91%. The increase in
 278 impact resistance index resulting from increased compacting pressure level could result from
 279 the fact that increase in compacting pressure enhances the formation of different binding
 280 mechanisms in densification. For instance, under high pressure, the natural binding
 281 components such as starch, protein, lignin, and pectin in the feed or biomass materials are

squeezed out of the particles, which contribute to formation of solid-bridge bonds [24, 25]. Additionally increased compacting pressure could enhance bonding through Van der Waal's electrostatic force as well as the formation of stronger inter-locking bonds of the sawdust particles. Two-way ANOVA (**Table 6**) indicates that at 5% level of significance the biomass material and compacting pressure had significant effect on the impact resistance index on briquettes produced (p-value < 0.05).

Table 6 ANOVA of effect of biomass material and compacting pressure on impact resistance index of briquettes produced from sawdust of *P. africana*, *C. pentandra* and their mixture

Source	DF	ANOVA SS	Mean square	F-Ratio	p-value
Biomass raw material	5	449210.942	89842.1883	14.76	< .0001 [*]
CP	3	557825.958	185941.9861	30.54	< .0001 [*]
Biomass material x CP	15	85703.092	5713.5394	0.94	0 .5253 [†]
Error	96	584477.600	6088.3080		

^{*}Statistically significant at 0.05 level of significance; [†]Not statistically significant at 0.05 level of significance **Legend:** DF = Degree of freedom

Nevertheless, the interaction between the biomass material and compacting pressure at 5% level of significance did not have significant effect on the impact resistance index of briquettes produced (p > 0.05). The multiple coefficient of determination (R^2) and the RMSE of the ANOVA Model were 0.6515 and 78.0276 respectively. The implication of R^2 value of 0.6515 is that about 65.15% of the variance in the impact resistance index of the briquettes produced could be explained by the biomass raw material and compacting pressure. Post hoc multiple comparisons of means of impact resistance index of briquettes produced from the biomass materials indicates that even though the impact resistance index for mixing ratio 20 : 80 was the best, it did not significantly differ from that of *Ceiba pentandra* only (LSD <

48.978). However, the impact resistance index of briquettes produced from mixing ratio 20 : 80 was significantly higher than that produced from *Piptadenia africana* only and mixing ratios 40 : 60, 60 : 40 and 80 : 20 (LSD > 48.978). Lastly, at 5% level of significance the impact resistance index of briquettes produced from *Piptadenia africana* only did not significantly differ from that of mixing ratio of 80 : 20 (LSD < 48.978).

3.4 Water resistance quality

The water resistance quality of briquettes produced from the biomass materials (**Table 7**) ranged from 1.01 to 6.63 minutes. With the exception of that produced from mixing ratio of 20 : 80, using compacting pressure 50 MPa for which the water resistance quality was 6.63 minutes, the rest had water resistance quality considered as very low. According to [15] briquettes for which when dipped into water falls into pieces sooner than 5 minutes are considered as having a very low water resistance quality. When the briquette falls into pieces before 15 minutes, it is of a medium water resistance quality, and up to 20 minutes it is of a good water resistance quality. The medium water resistance quality of briquettes produced from combination of *Piptadenia africana* and *Ceiba pentandra* at a mixing ratio of 20 : 80 and low compacting level of 50 MPa provides a breakthrough in the production of briquettes at room temperature using low compacting pressure.

Table 7: Water resistance quality (minutes) of briquettes produced from *P. africana*, *C. pentandra* and their combination using compacting pressure levels from 20 to 50 MPa

Biomass material	Mixing ratio (weight basis)	Compacting pressure			
		20 MPa	30 MPa	40 MPa	50 MPa
<i>C. pentandra</i>	Pure (100%)	2.76	3.19	3.82	4.81
<i>P. africana</i>	Pure (100%)	0.62	0.69	0.69	0.70
<i>P. africana</i> : <i>C. pentandra</i>	80 : 20	1.01	1.29	1.31	1.40
<i>P. africana</i> : <i>C. pentandra</i>	60 : 40	1.17	1.53	1.59	1.76

<i>P. africana</i> : <i>C. pentandra</i>	40 : 60	1.51	2.06	2.28	3.20
<i>P. africana</i> : <i>C. pentandra</i>	20 : 80	2.92	3.38	4.68	6.63

321

322 A two-way analysis of variance indicates that at 5% level of significance the biomass
323 material, compacting pressure and their interactions had significant effect on the water
324 resistance quality of the briquettes produced (p-value < 0.05). The multiple coefficient of
325 determination value and the RMSE of the ANOVA Model were 0.9849 and 0.2088
326 respectively.

327 4.0 Conclusions

328 The results from the study indicates that combining sawdust of *Piptadenia africana* with
329 *Ceiba pentandra* could significantly improve the compressive strength in cleft and impact
330 resistance index of briquettes produced from *Piptadenia africana* at room temperature using
331 low compacting pressure without a binder. The quality of briquettes was significantly
332 influenced by the type and mixing proportion of biomass material used. Briquettes produced
333 from mixing proportions: 80 : 20, 60 : 40, 40 : 60 and 20 : 80 (*Piptadenia africana* : *Ceiba*
334 *pentandra*) using compacting pressure of 30 MPa or more could have adequate compressive
335 strength in cleft. Lastly, increase in proportion of *Piptadenia africana* in the mixture of
336 biomass material could result in decreased compressive strength in cleft and impact resistance
337 of briquettes. Generally, the water resistance quality of briquettes produced from the biomass
338 material used at room temperature using low compacting pressure is low and need to be
339 protected from moisture.

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