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Utilization of locally available binders for densification of rice husk for biofuel production

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Abstract. Sustainability of rice processing depends to a large extent on the utilization of waste by–products generated during the process as biofuel feedstock, biomaterial feedstock or animal feed. Rice husk is an abundant by–product of rice processing that is dumped within the rice processing communities with negative environmental effects. Densification of rice husk into pellets and briquettes using available binders from trees used as firewood, and other agricultural wastes will make it an effective biofuel feedstock that will increase sustainability of rice production. In this study, three locally available binders (*Afzelia africana* aril, de–oiled *A. africana* aril, and groundnut shell) were chemically and physically characterize; and their effectiveness as binders for production of densified rice husk briquettes for biofuel production were studied. The study showed that binder chemical properties affect the permeability and density of the densified rice husk briquettes.
***Keyword**:* rice husk, sustainability, biofuel, densification, *Afzelia Africana* aril, groundnut shell.

Introduction

Densification of rice husk is an important step in making the agricultural biomass a viable feedstock for biofuel production. Raw rice husk is difficult to densify because of its natural characteristic. The outer surface is rough with poor binding qualities; and the inner surface is soft and is composed of esters that make binding difficult.

Utilization of locally available binders will increase effective binding during rice husk densification.

Densification can increase the density of biomass from an initial bulk density of 40–200 kg/m^3 to a final compact density of 600–1200 kg/m^3 [HOLLEY, 1983; MANI *et al.,* 2003; OBERNBERGER and THECK, 2004; McMULLEN *et al.,* 2005, ADAPA *et al.,* 2009; BAKARI and NGADI, 2013].

Densified biomass may be easily handled using standard handling and storage equipment, and it can be easily adopted as fuel feedstock for both thermochemical processes (combustion furnace, gasifiers, pyrolysis reactors) and biochemical processes (i.e. fermentation processes producing biofuels such as bioethanol).

The objectives of this study were to investigate the effectiveness of groundnut shell, whole *A. africana* aril, and de–oiled *A. africana* aril as binders for production of high-quality densified rice husk briquettes

Material and methods

Equipment. Equipment used includes manual hydraulic press, digital scale, Soxhlet, Leco protein analyzer, gas pycnometer and FTIR–ATR spectrometer.

Physical characterization of rice husk. Particle size distribution, bulk density, and particle density analysis were carried out using ASAE standards and gas pycnometry respectively [ASABE BONCIU *et al.,* 2018; BONEA *et al.,* 2018; GROZEA *et al.,* 2017, STOLERU *et al.,* 2016].

Chemical compositional analysis of rice husk and binders. Chemical composition analysis was carried out to determine the protein and fat, using Leco Truspec Analyzer and Soxhlet respectively; and chemical component analysis was carried out using FTIR–ATR [BUTU *et al.,* 2014c. SAMFIRA *et al.,* 2015, BUTNARIU *et al.,* 2015b; BUTU *et al.,* 2014b].

Proximate analysis of rice husk and binders. Proximate composition of the rice husk and binders were determined using American Standard for Testing Material methods [ASTM 1993].

Densification experiments. Pellets were made using manual hydraulic press at die pressures of 42.5, 56.7 and 70.8 MPa; binder ratios of 2.5, 5.0 and 7.5 % and moisture content of 15 % (weight basis).

Full–factorial experimental design with three replicates was used [PUTNOKY *et al.,* 2013, BUTNARIU *et al.,* 2014; BUTNARIU and GIUCHICI, 2011].

Density tests. Density was determined by covering briquettes with paraffin oil of known density and weight submerged in water to determine the volume after weighing [PANWAR 2011; BAKARI and NGADI, 2013, VARDANIAN *et al.,* 2018; STOLERU *et al.,* 2018].

Permeability tests. The water penetration test was carried out by placing the samples in a water bath beaker at room temperature (~22 °C) for 30 seconds and then the rate of absorption or permeability was calculated as a ratio of the weight of the soaked pellet with respect to the original weight [BAKARI and NGADI, 2013, BONEA *et al.,* 2017, PENTEA *et al.,* 2016, STOLERU *et al.,* 2012].

Results and discussion

Characterization of rice husk. Bulk density of the rice husk was 137 kg/m^3 and the particle density was 196 kg/m^3. Geometric mean diameter of the rice husk was 1669 μm. Particle analysis showed that 91.08 % of the rice husk particles were retained by standard sieve 20 (850 μm) and larger (Figure 1).

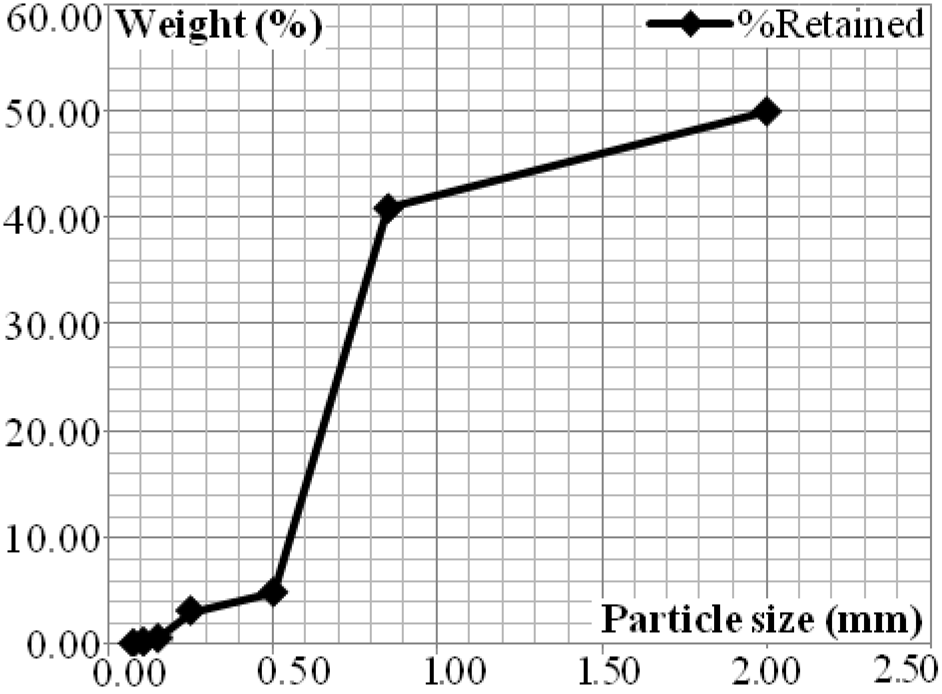

Figure 1. **Particle size distribution of rice husk**

Proximate analysis showed that the average moisture content of the rice husk was 7.630 %, volatile content was 60.571 %, fixed carbon content was 14.414 % and ash content was 25.016 %.

Chemical compositional analysis of the rice husk showed that the protein and fat content of the rice husk were 2.280 % and 0.291 % respectively.

The FT–IR spectrumof the rice husk studied (figure 2) has a broad, strong peak near 3300 cm^{-1}, due to CH stretching vibrations. The strong peak around 1650 cm^{-1} indicated the C=O stretching of a carbonyl group in the sub–Saharan rice husks [BAGIU *et al., 2012*; BUTNARIU and CORADINI, 2012]. The strong peak at around 1025 cm^{-1} indicated the strong presence alcohols [BUTNARIU *et al.,* 2012, STOLERU *et al.,* 2012], carboxylic acids, ethers and esters [LAMBERT *et al.,* 2011].

Also, the secondary peak around 1100–1217 cm^{-1} indicated silica presence in the form of cellulose–silicates [NDAZI *et al.*, 2007] which the proximate analysis ash content confirmed.

Characterization of binders

Groundnut shell (GS). The chemical composition of groundnut shell includes carbohydrates, protein and traces of lipids. Groundnuts shell has high content of cellulose, hemicellulose and lignin. FT–IR spectra of groundnut shell used as a binder in this experiment showed a broad peak between 3600–3000 cm^{-1} that is due to water and OH stretching bands of alcohols, phenols and carboxylic acids [DIMITRIU *et al.*, 2016; GEORGIEVA *et al.*, 2018; BUTNARIU and CAUNII, 2013]. The peak at 2922 cm^{-1} confirms the presence of aromatic and unsaturated aliphatic =CH groups; and the peaks at 1263 cm^{-1}, 1372 cm^{-1}, and 1507 cm^{-1} (figure 3) are characteristics of guajacyl lignin, syringyl lignin and aromatic skeletal vibrations respectively [CHEN, 2005; WEI *et al.*, 2009].

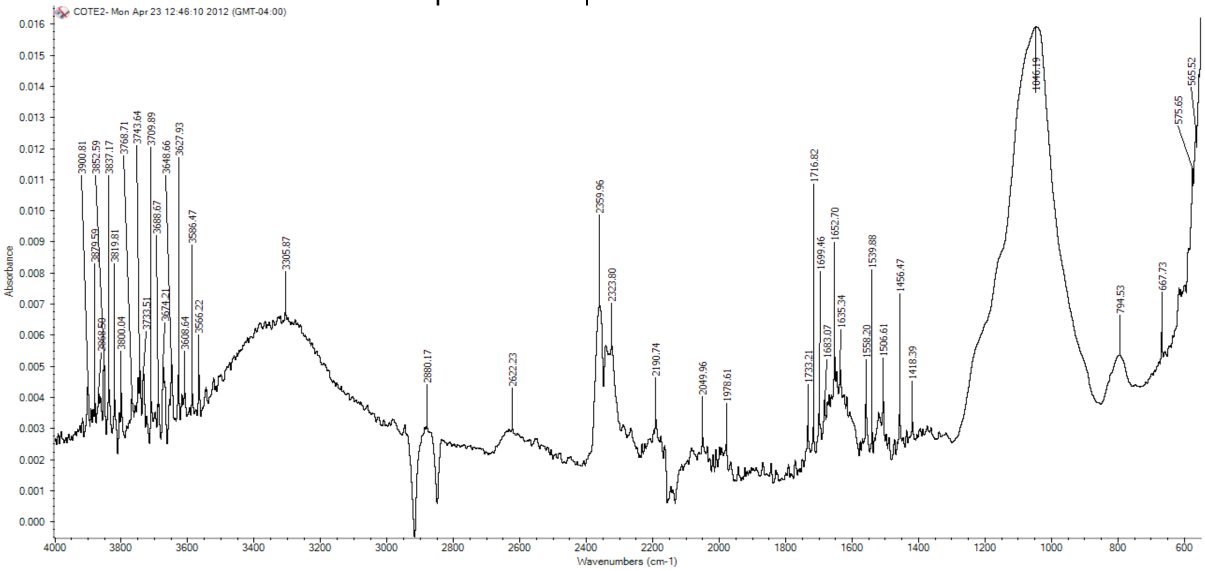

Figure 2. **FT–IR spectrum of rice husk.**

Protein content of the groundnut shell used in this experiment was 5.126% which confirms the broad band observed at 2200 cm^{-1} for the presence of amides [BUTNARIU and SAMFIRA, 2012; IANCULOV *et al.*, 2005, STOLERU *et al.*, 2018].

Fat content was 1.251 %. Proximate analysis results showed that the moisture, volatile, fixed carbon and ash contents were 3.266 %, 79.598 %, 18.400 % and 2.002 %, respectively.

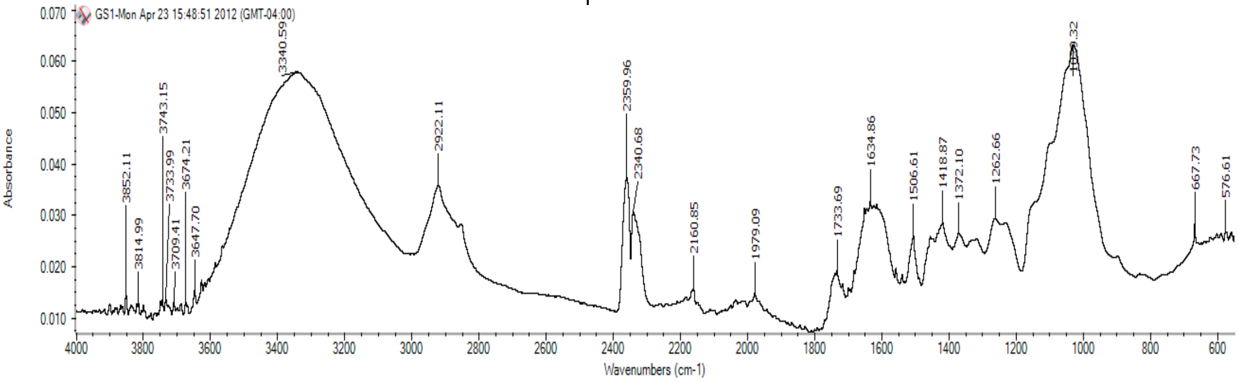

Figure 3. **FT–IR spectrum of Groundnut shell.**

***A. africana* aril whole (AAW)**. *A. africana* aril contains high amount of fat. The fat analysis results showed that the oil content of the aril was 49.13±1.36 %. Protein content was found to be 3.49 %. FTIR spectrum (figure 4) showed a low broad peak at the region between 3600 cm^{-1} and 3000 cm^{-1} indicating the content of carbohydrates and OH vibration [SAMFIRA *et al.,* 2014; BUTNARIU; 2012; BUTU *et al.,* 2014a, STOLERU *et al.,* 2016]. The most significant peaks were at 2920 cm^{-1} and 2851 cm^{-1} which were signatures of asymmetric and symmetric stretching vibrations of CH in methylene. The peaks at 1462 cm^{-1} and 1464 cm^{-1} were due to CH_2 bending. The broad peak between 1462 cm^{-1} and 400 cm^{-1} that have sharp peaks at 1160 cm^{-1}, 1098 cm^{-1} and 718 cm^{-1} peaks indicated the strong presence alcohols, carboxylic acids, ethers and esters. The latter having bands from both C=O and C–O–C groups, but none from the OH group. Gussoni and collab. carried out NMR analysis of *Afzelia cuanzensis* aril and found similar chemical components [GUSSONI *et al.,*1994]. Proximate analysis results showed that the moisture, volatile, fixed carbon and ash contents were 2.768%, 91.069 %, 5.373 % and 3.558 % respectively [VARDANIAN *et al.,* 2018; STOLERU *et al.,* 2018, CAUNII *et al.,* 2015; IANCULOV *et al.,* 2004].

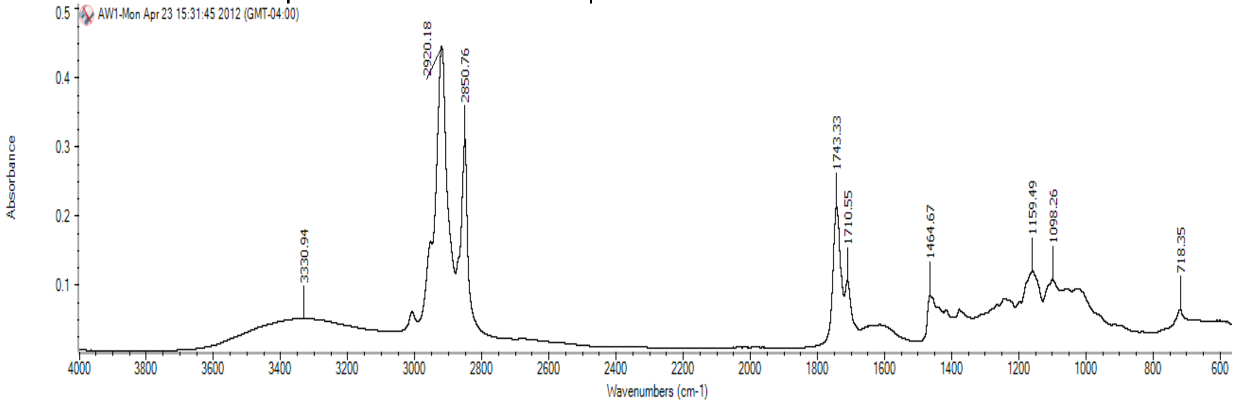

Figure 4. **FT–IR spectrum of *A. africana* whole**

***A. africana* aril de–oiled (AAP)**. The de–oiled aril of *A. africana* contains no fat and has a protein content of 7.42 %. It has the highest protein content of the 3 binders used [PUTNOKY *et al.,* 2013, BUTNARIU *et al.,* 2014; BUTNARIU and GIUCHICI, 2011].

Proximate analysis showed that it has a moisture content of 6.765 %, volatile content of 81.027 %, fixed carbon content of 12.157 %, and ash content of 6.816 %. FTIR spectra (figure 5) of de–oiled *A. africana* showed that it has a significant amount of carbohydrates as well as amide I and II [PETRACHE *et al.,* 2014, BUTNARIU *et al.,* 2014, BARBAT 2013, BUTU *et al.,* 2015].

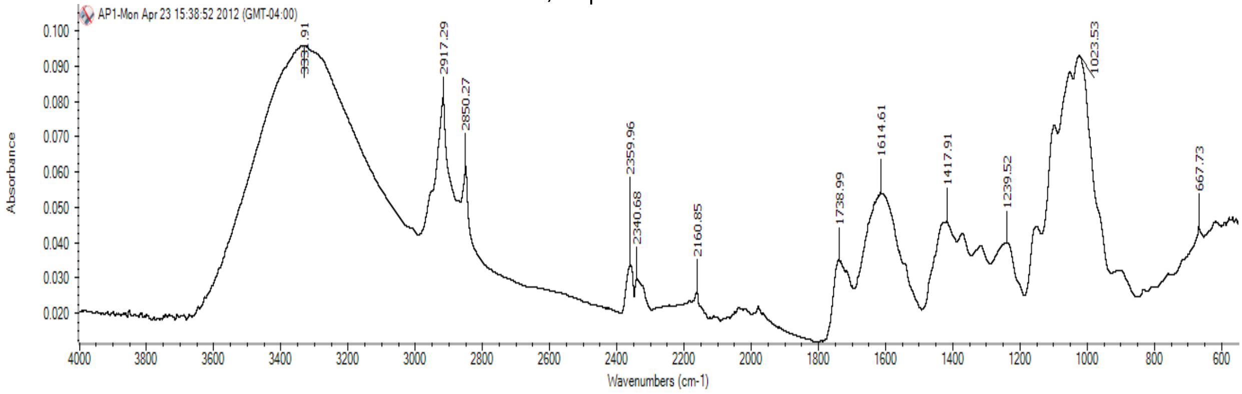

Figure 5. **FTIR spectrum of de–oiled *A. africana***

Effects of binder type, binder ratio and die pressures on permeability. The results obtained showed that the binder type, binder ratio and die pressure determined the water absorption of the briquettes. It was also found that there was variability on the effects of binder ratio within the binders (figure 6).

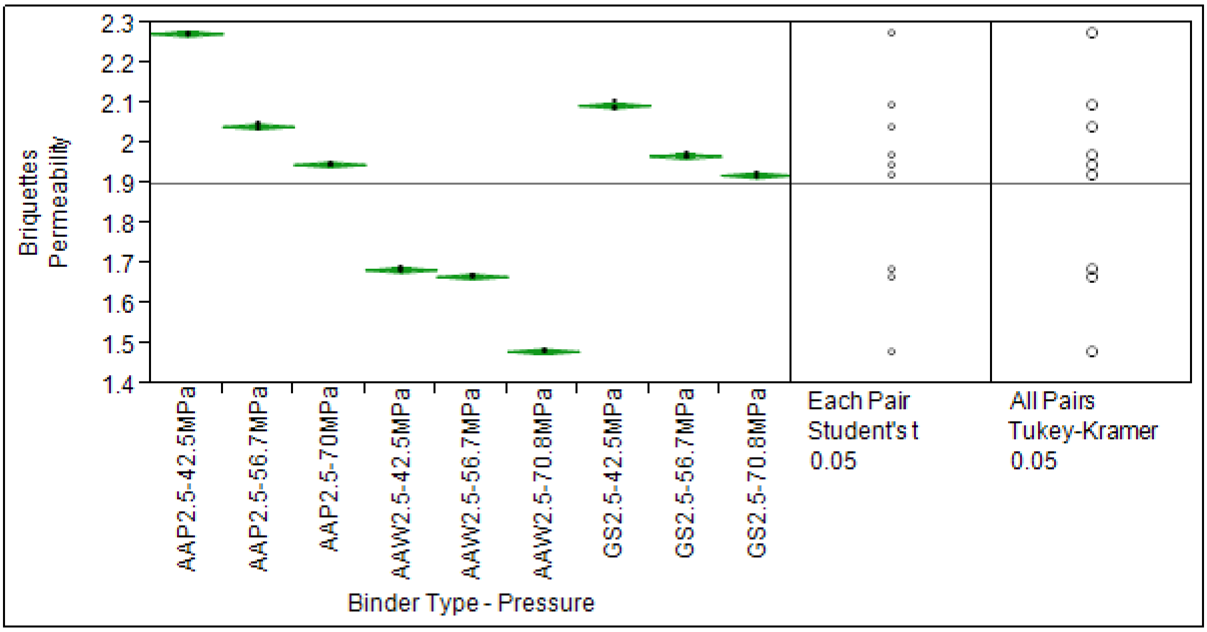

Figure 6. **Effects of process parameters on permeability**

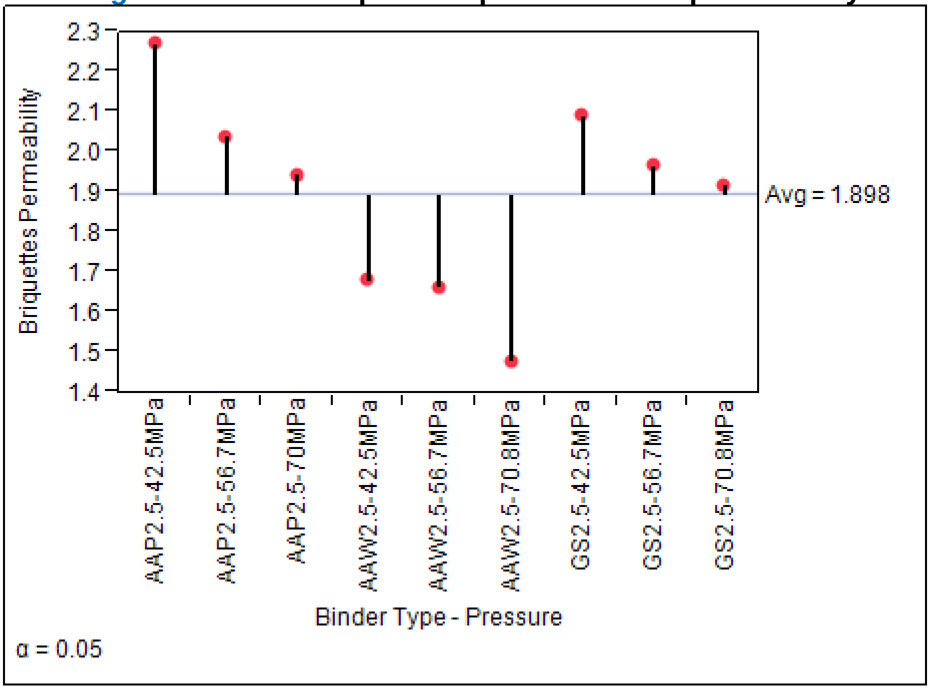

Figure 7. **Comparative analysis of process parameters on permeability**

It was also found that the lipid content of the binders affects the permeability of the briquettes.

The high–lipid whole *A. africana* (AAW) briquettes were more hydrophobic and have lower permeability to water than the low–lipids deoiled *A. africana* aril (AAP) and groundnut shell (GS) bonded briquettes [BUTU *et al.*, 2014c. SAMFIRA *et al.*, 2015, BUTNARIU *et al.*, 2015b; BUTU *et al.*, 2014b].

Effects of binder type, binder ratio and die pressures on density. Statistical analysis showed that binder type, binder ratio and die pressure affect the density of the briquettes (see figures 8 and 9).

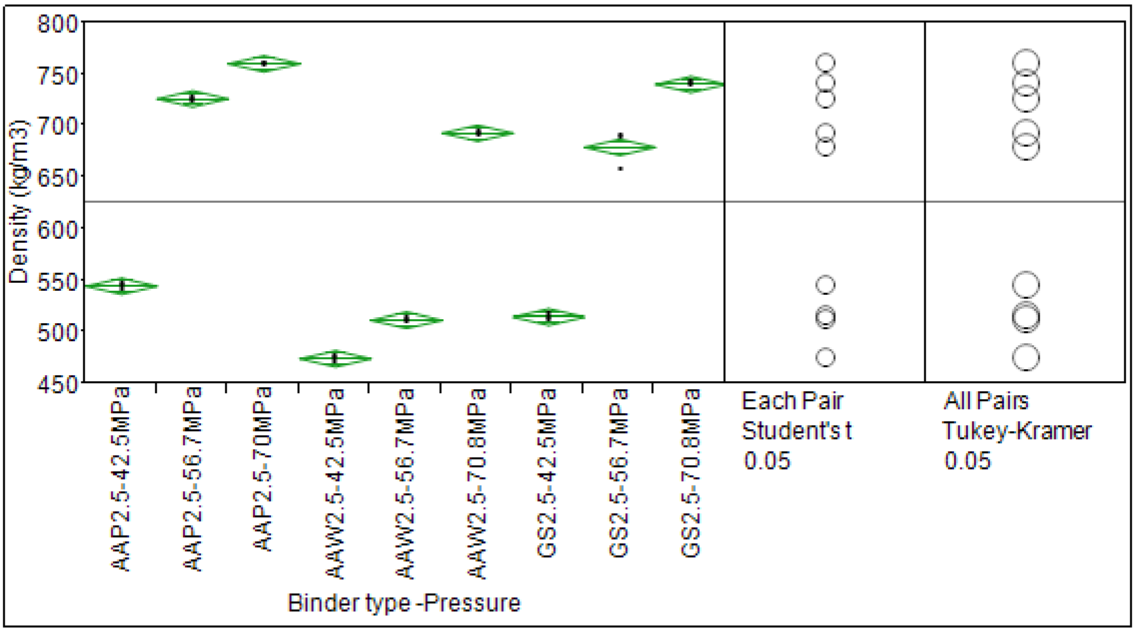

Figure 8. **Effects of process parameters on density**

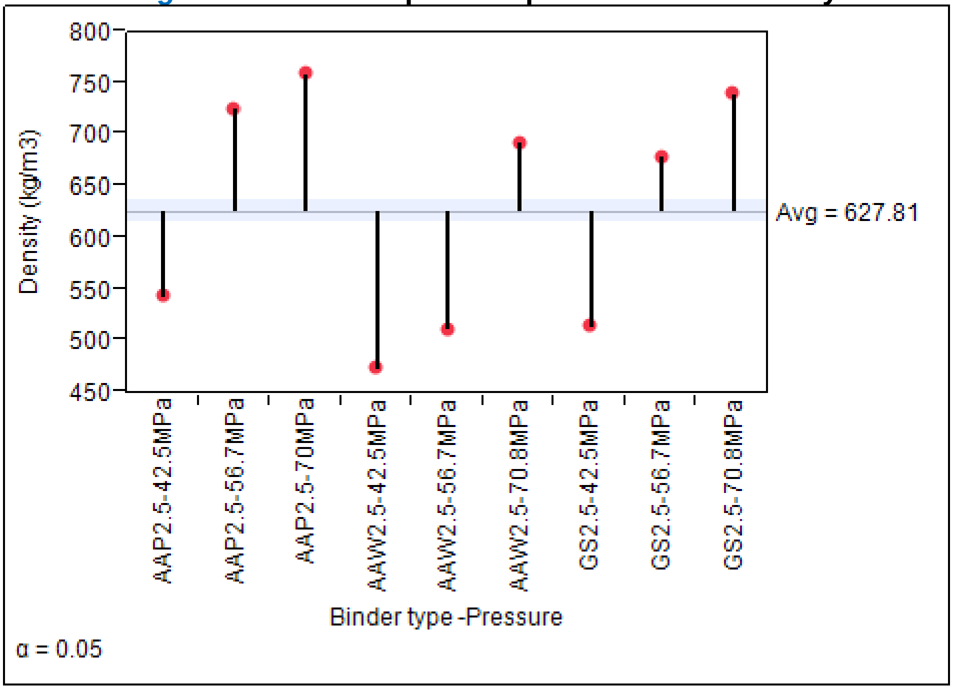

Figure 9. **Comparative analysis of process parameters on density**

It was found that during densification, the densities of rice husk increased from 0.196g/m^3 (196 kg/m^3) to between 513 kg/m^3–765 kg/m^3 with GS as binder; 472–762 kg/m^{3}with AAW as binder [BONEA *et al.*, 2017, PENTEA *et al.*, 2016, STOLERU *et al.*, 2012]; and 542 –786 kg/m^3 with AAP as binder. It was also observed that briquettes of higher densities were obtained at higher die pressure for all the binders [BONCIU *et al.*, 2018; BONEA *et al.*, 2018; GROZEA *et al.*, 2017, STOLERU *et al.*, 2016].

Conclusions

It was observed that: Density of briquettes increased with pressure for all binders; Water permeability was lower at higher pressures and higher binder ratios; Whole *A. africana* aril (AAW) has the lowest permeability, and de–oiled *A. africana* aril (AAP) the highest; Lipid content and interaction between lipid, protein and carbohydrate contents within the binders affects permeability; De–oiled *A. africana* aril (AAP) bonded briquettes have the highest densities; Chemical composition affected the binding properties between binders and the rice husk; Briquettes bonded with hydrophobic binders showed lower water permeability; and Lipid content of binders improved the hydrophobic characteristics of briquettes, but reduced their density.

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