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Fuel Characterization of Agro-wastes and Briquettes Produced from Rice Husk, Groundnut Shell and Corncob Blends

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Abstract- The choice of agro waste for the production of briquettes for domestic and industrial cottage utilization depends on the residues' physical and fuel characteristics. This study investigates the physical and fuel characteristics for both the residues and blends of rice hull, groundnut shell and corncob. The residues were subjected to size reduction process and variance analysis was used to establish the influence of each sample blends. Different samples of briquettes were produced by blending rice hull (R), groundnut shell (G) and corncob(C) with different ratios of R:G:C respectively using cassava starch as a binder. The residue' dimensions and densifications of the sample briquettes were determined using standard methods. The results revealed the following ranges of values; For the compressed residues, density (0.075 - 0.099Kg/m3), volume (0.001 - 0.002m3), height (1.0357 - 1.0343m). For the relaxed residues, density (0.049 - 0.210Kg/m3), volume (0.0001 -0.0002m3), height (1.0357 - 1.0343m). The residual density of rice hull, groundnut shell and corncob are 104, 105, and 103 (Kg/m3) respectively. The densification; compressed density (461.22 - 627.24 Kg/m3), relaxed density (285.47 - 393.63 Kg/m3), density ratio (0.56 - 0.66), relaxation ratio (1.52 - 1.79), and compaction ratio (1.46 to 2.01). Blend formulations affected the combustion characteristics of the briquettes, with low moisture briquettes possessing higher calorific values. The briquette formulation containing ratio 50:20:30 of rice hull: groundnut shell: corncob respectively had more positive attributes of biomass fuel such as lower relaxation ratio and high compaction ratio than the control and other formulated briquettes in this study. Generally, significant ($p<0.05$) differences existed between the samples in almost all the parameters.

Keywords- Briquettes, Corn comb, Densification, Fuel Characterization, Groundnut shell, Rice hull.

1 INTRODUCTION

The availability of energy for domestic use in Nigeria continues to pose a formidable challenge, especially with high cost of cooking gas and kerosene coupled with environmental problems associated with firewood (Fiber, 2007; Olorunnisola, 2007). Alternative forms of energy need to be sourced. This has necessitated the need to improve on the use of agro wastes such as rice-husk, corncob and groundnut shell as alternatives. Numerous agricultural residues and wastes generated in Nigeria which could be used to generate heat for domestic and industrial cottage applications are mostly left to rot away. When burnt in the field also result in environmental pollution and degradation. However, a lot of potential energy abounds in these residues (Fiber, 2007).

Among several kinds of biomass, agricultural residues have become one of the most promising choices. Some agricultural wastes such as wood can be directly utilized as fuels. Nevertheless, a majority of them are not suitable apparently because they are bulky, uneven, and have low energy density. All these characteristics make them difficult to handle, store, transport, and utilize in their raw form. Hence, there is the need to subject them to conversion processes in order to mitigate these problems. One of the promising solutions to these problems is the application of briquetting technology (Wilaipon, 2007). This technology involves densification process for improving the handling characteristics of raw materials and enhancing volumetric calorific value of the biomass.

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Fuel briquettes produced under different conditions could have different handling characteristics which could be affected by the raw material properties. If biomass or agro-waste briquettes are to be used efficiently and rationally as fuel, they must be characterized to determine parameters such as the moisture content, density, and heating value among others. The result of these determinations will indicate the positive and negative attributes of the agro waste briquettes. Among the positive attributes of agro-waste briquettes are low moisture content, high crushing strength, high density, slow flame propagation, low ash content, high amount of hydrogen, and substantial heating value.

The fuel properties of agro waste briquettes vary from one type to another, so rice husk, corncob and groundnut shell briquettes are expected to vary in properties. Since briquettes can be made from wide varieties of agro-residues, selection of the best briquettes has to be made based on the one that has better fuel properties or positive attributes. This will go a long way to ensure judicious utilization of these wastes. Therefore, this work characterized rice husk, corncob and groundnut shell which are popular agricultural residues in Nigeria with a view to convert them into biomass briquettes.

2. MATERIALS AND METHODS

Agricultural wastes/residues (rice hulls, groundnut shell and corncobs) utilized in this experiment were obtained from farm waste dumps in Makurdi, Benue State, Nigeria. The residues were chosen because they are produced in large quantity in Nigeria and most often, they are dumped or flared resulting in widespread fire hazards and environmental pollution. Yellow corncob was used because it has lower residual moisture contents (9.64%) than white corncob (9.98%) as reported by Oladeji and Enweremadu (2012).

The rice hull (50kg), groundnut shell (40kg) and corncob 40kg) were air dried under an average room temperature of 26.2^{0}C and relative humidity of 62.4% for ten days in order to reduce the moisture content of the materials to an average of 8.77%. Thereafter the residues were individually chopped into small pieces using a hammer mill (BrookCrompton, Series 2000 Type 8 Lab Mill, England) in order to increase the total surface area, pore size of the material and the number of contact points for inter-particle bonding in the compaction process.

Approximately 0.6mm particle size was utilized using procedure highlighted in accordance with ASAE 424.1 (2003) to determine the chosen particle size. Starch was prepared using the method of Olorunnisola (2007) and 5% by weight of starch was used as binding agent in line with works of Musa, (2007) and Olorunnisola, (2007). The starch was made into gel and added to 1 kg each of samples of corncob, groundnut shell and rice husks separately. The blend of cassava starch gel and the residues were stirred vigorously to ensure a proper mix, which was fed into the mould of a briquetting machine and compressed by a hydraulic press.

The briquetting machine used was an existing one at the Materials Laboratory of the Department of Mechanical Engineering, Federal University of Agriculture, Makurdi, Benue State. The machine was based on hydraulic principle and consists of one mould, where biomass feed stocks were fed. The mould is made of steel pipe of 86.00mm (external diameter), 22.50mm (internal diameter), and 110mm (height) perforated to about 1/3rd of the height and equipped with wooden disks to cover both ends. The mould has a central hole which is believed by many authors to improve the combustion characteristics of the briquette (Chaney, 2010). According to the design of the mould, one briquette was produced per batch. The samples were weighed using digital weighing balance (Camry Model 302) and blended at various ratios at ambient temperature. The mixture was then hand-fed into the mould, covered at both ends with the wooden disks. The briquettes were later ejected after the holding time (i.e., duration of load application of five minutes) was observed as suggested by Olorunnisola (2004). The 3-dimentional matrix method used for the formulations was based on 2-way nested design (Che, 2003; Mohammed, 2005).

The agro residues and densification characteristic of the briquettes were determined for compressed density, relaxed density, density ratio, relaxation ratio and compaction ratio using the method of Oladeji (2010). The dimensions of the briquettes were determined immediately after ejection from the mould using the stereometric method of Oladeji (2010) and American Society of Agricultural Engineering (ASAE 269.4 and 424.1, 2003) standard methods was used for the densifications. Hence the compressed density determined by dividing mass by volume and the briquettes were then sealed in a container for analysis.

3 Results and Discussion

3.1 Blend Residues and Briquette Dimensional Characteristics

The significant effect of the residuals blending ratio ((R:G:C)) used for the briquettes (Table 1) was seen in the parameters analysed. The results of mass, volume and height of compressed residues presented in Table 2 shows that average compressed mass density of the samples ranged from 0.075 to 0.099 (Kg/m^3) with sample 70:00:30 (R:G:C) formulation and the control sample having the lowest value while sample 60:30:10 formulation had the highest value. Also, samples 60:00:40 and 60:20:20 formulations had higher compressed volume than other samples, while the least volume was recorded for sample 70:00:30 and the control sample. However, sample 70:00:30 formulation had a fair higher compressed height than the remaining formulated samples while the remaining formulated samples and the control sample were not significantly ($p>0.05$) different. The close trends noticed in all the samples' height indicated that these samples will have even and faster pyrolysis rate which in turn, will maintain higher normalised burn rate (Chaney, 2010). The central holes cylindrical briquettes produced in this work would make good biomass fuels. This is because central hole acts as an insulated combustion chamber as well as a 'mini-chimney' thereby giving a draught to drive the combustion and thus enhances the performance of the combustion.

The results of mass, volume and height for relaxed densities are shown in Table 3. Sample 80:00:20 formulations had higher relaxed mass than other formulated samples. However, the remaining formulated samples and the control sample were not significantly ($p>0.05$) different. Also, samples with 70:00:30, 60:40:00 formulations and control sample had the least relaxed volume than the remaining formulated samples while the least volume value was found with formulated sample 70:00:30 and the control sample. However, sample containing 70:00:30 formulations had a fair higher compressed height than the remaining formulated samples while the remaining formulated samples and the control sample were not significantly ($p>0.05$) different.

The higher volume noticed in the sample containing 70:00:30 formulations must have accounted for its least mass value. As the height increases, the area of the surface elements towards the top of the central hole, which have a high atmospheric factor, make up a smaller proportion of the total central hole internal surface area. Therefore, the greater the height, the lower the proportion of heat radiated to the atmosphere and thus the faster the pyrolysis rate (Chaney, 2010). A tall cylindrical briquette with a central hole and a low A/V ratio will thus be maintained at a higher normalised burn rate compared to a slab with the same A/V ratio. The closer trends noticed in the relaxed density height indicated even and faster pyrolysis rate which in turn, will maintain higher normalised burn rate in the entire samples (Chaney, 2010). Moreover, increase in volume as a results of spring-up of the samples with little or no variation in the mass would ultimately cause reduction in the density of the samples and it is evident that, the briquette that expands more after extrusion would have the least relaxed density and vice versa (Oladeji and Enweremadu, 2012).

The results of compressed density (Table 4) revealed that there were significant ($p<0.05$) differences between the formulated samples and the control sample. The average compressed density for formulated samples ranged from 461.22 to 627.24 (Kg/m^3) with sample 60:20:20 formulation having the lowest value while sample 60:30:10 formulation had the highest value. The control sample briquette had compressed density of 510.76 Kg/m^3.

The values obtained were within the range reported by Chaney (2010) for material density of biomass that varies enormously, from 100 kg/m^3 for light dry straw, to over 2000 kg/m^3 for highly compressed biomass fuels. Moreover, the compressed densities obtained in this study were in agreement with 524.00Kg/m^3 and 650Kg/m^3 reported by Oladeji (2010) for compressed densities of rice hull and corncob briquettes respectively.It can be noted from the results that, subjecting biomass residues to compaction improves their physical and handling characteristics (Kaliyan and Morey, 2009). Moreover, the relationship between density, mass and volume of the compressed samples could be explained that, the finer the particle is, the less the pore spaces and more mass of the material per given volume, which is good for briquetting (Oladeji and Enweremadu, 2012).

From the results generally, it is evident that the briquetting process has been able to obtain increased density, which is a valuable factor in briquetting. The values of some compressed densities obtained are more than the minimum value of 600 Kg/m^3 recommended by Mani *et al.* (2006) and Gilbert *et al*. (2009). This is better for efficient transportation and safe storage of the briquettes. The results of relaxed density (Table 4) reveal that there were significant ($p<0.05$) differences between the formulated samples and the control sample. The results show that average relaxed density ranged from 285.47 to 393.63 (Kg/m^3) with sample 60:00:40 formulation having the lowest value and

also shared similarities with the sample 60:10:30 formulation while sample 50:20:30 formulation had the highest value. The control sample had relaxed density of 335.38Kg/m^3.

A general decrease in the relaxed density values was observed as compared with the values of the compressed densities for both the formulated and the control samples. This could be attributed to the fact that increase in volume as a results of spring-up of the samples with little or no variation in the mass would ultimately result in reduction in the density of the samples and it is evident that, the briquette that expands more after extrusion would have the least relaxed density and vice versa (Oladeji and Enweremadu, 2012).

Generally, all the relaxed densities obtained are good enough and are in good agreement with the values obtained by Oladeji (2010), where relaxed densities of 224.00Kg/m^3 and 385Kg/m^3 were achieved for briquetting of rice hulls and corncobs respectively. The relaxed density obtained in the sample 50:20:30 formulations appear to be the best. This is because, the higher the value of relaxed density, the higher is the stability of briquettes produced (Yang *et al*., 2005). The results of density ratio (Table 4) reveal that there were significant ($p<0.05$) differences between the formulated samples and the control sample. The results show that average density ratio ranged from 0.56 to 0.66 with samples 60:00:40 and 50:00:50 formulations having the lowest value while control sample had the highest value and also shared similarities with the sample 90:10:00; 70:30:00; 60:40:00; 50:20:30 and 50:30:20 formulations.

Higher value of density ratio indicates a more stable briquette, while lower value indicates high tendency towards relaxation i.e. less stable briquette. The values of relaxation ratio obtained in this study for formulated sample briquettes and the control sample were better and found to be reasonable. The implication of this is that, these briquettes will suffer less damage during transportation and storage (Musa, 2007). The results of relaxation ratio (Table 5) reveal that there were significant ($p<0.05$) differences between the formulated samples and the control. The relaxation ratio values ranged from 1.52 to 1.79 with control sample having the lowest value and also shared similarities with samples 70:30:00; 60:40:00 and 50:20:30 while the sample 50:00:50 formulation had the highest value and not significantly ($p>0.05$) different from sample 60:00:40 formulation.

All the briquettes produced from these formulated samples and the control sample will not crumble during transportation and storage. This is because; the lower the value of relaxation ratio, the higher is the stability of briquettes produced (Yang *et al*., 2005). Generally, all the relaxation ratios obtained are good enough and they are close to the values obtained by Olorunnisola (2007), where a relaxation ratio of between 1.80 and 2.25 was achieved for briquetting of waste paper plus the admixture of coconut husk. The results of compaction ratio (Table 5) reveal that there were significant ($p<0.05$) differences between the formulated samples and the control. The values ranged from 1.46 to 2.01 with sample 90:10:00 formulation having the lowest value while sample containing 60:30:10 formulations had the highest value. This sample 60:30:10 formulation was not significantly ($p>0.05$) different from sample 70:10:20

formulation and also shared similarities with the sample 60:40:00 and 50:50:00 formulations.

Higher compaction ratio implied more void in the compressed materials. A higher value of compaction ratio indicates more volume displacement which is good for packaging, storage and transportation and above all, it is an indication of good quality briquettes (Oladeji and Enweremadu, 2012). Furthermore, the values of compaction ratio obtained in this study compare and compete favorably well with notable biomass residues. For example, compaction ratio of 3.5 was obtained from melon shells (Oladeji *et al.*, 2009). Generally, the formulated sample briquettes and the control sample were better and found to be reasonable. The implication of this is that, these briquettes will suffer less damage during transportation and storage (Musa, 2007).

Table 1. Effect of Selected Agro Wastes on various Parameters

Parameter	Rice Hull	Groundnut Shell	Corncob
Specific Heat Capacity (J/m²/K)	2.49	2.58	3.21
Thermal Conductivity (W/K/m)	3.09	3.01	3.65
Temperature (°C)	28	29	27
Density (Kg/m³)	104	105	103
Moisture Content (%)	7.85	8.02	9.65
Calorific Value (J/g)	64	71	89
Water Boiling Capacity (%)	59	61	66
Fuel Efficiency (%)	69	72	78
Degree of Fuel Efficiency (%)	0.057	0.059	0.063
Controlled Cooking Capacity (%)	49	51	59
After Glow Time (s)	10,020	10,560	10,860
Flame Propagation Rate (cm/s)	7.3	6	6.1
Cooking Time of Yam Slices (min/Kg)	14.17	12.24	10.35
Cooking Time of Rice Grains (min/Kg)	17.32	15.24	13.00

Table 2. Compressed Residues Dimensions

Sample	Blends(R:G:C)	M_{CR} (Kg)	V_{CR}(m³)	H_{CR}(m)
Control	100:00:00	$0.075^{m}\pm0.00$	$0.001^{b}\pm0.00$	$0.0367^{b}\pm0.00$
1	90:10:00	$0.077^{l}\pm0.00$	$0.002^{e}\pm0.00$	$0.0397^{b}\pm0.00$
2	90:00:10	$0.092^{e}\pm0.00$	$0.002^{c}\pm0.00$	$0.0378^{b}\pm0.00$
3	80:00:20	$0.087^{i}\pm0.00$	$0.002^{b}\pm0.00$	$0.0368^{b}\pm0.00$
4	80:10:10	$0.091^{c}\pm0.00$	$0.002^{d}\pm0.00$	$0.0387^{b}\pm0.00$
5	80:20:00	$0.088^{h}\pm0.00$	$0.002^{e}\pm0.00$	$0.0380^{b}\pm0.00$
6	70:00:30	$0.075^{m}\pm0.00$	$0.002^{b}\pm0.00$	$0.0398^{b}\pm0.00$
7	70:10:20	$0.097^{b}\pm0.00$	$0.001^{bc}\pm0.00$	$0.0361^{b}\pm0.00$
8	70:20:10	$0.085^{j}\pm0.00$	$0.002^{bc}\pm0.00$	$0.0371^{b}\pm0.00$
9	70:30:00	$0.096^{b}\pm0.00$	$0.002^{f}\pm0.00$	$0.0366^{b}\pm0.00$
10	60:00:40	$0.095^{c}\pm0.00$	$0.002^{a}\pm0.00$	$0.0410^{a}\pm0.00$
11	60:10:30	$0.085^{j}\pm0.00$	$0.002^{b}\pm0.00$	$0.0377^{b}\pm0.00$
12	60:20:20	$0.080^{h}\pm0.00$	$0.002^{a}\pm0.00$	$0.0390^{b}\pm0.00$
13	60:30:10	$0.099^{a}\pm0.00$	$0.002^{ab}\pm0.00$	$0.0357^{b}\pm0.00$
14	60:40:00	$0.090^{f}\pm0.00$	$0.002^{b}\pm0.00$	$0.0377^{b}\pm0.00$
15	50:00:50	$0.095^{c}\pm0.00$	$0.001^{ab}\pm0.00$	$0.0373^{b}\pm0.00$
16	50:10:40	$0.091^{c}\pm0.00$	$0.002^{a}\pm0.00$	$0.0383^{b}\pm0.00$
17	50:20:30	$0.085^{j}\pm0.00$	$0.002^{ac}\pm0.00$	$0.0383^{b}\pm0.00$
18	50:30:20	$0.090^{f}\pm0.00$	$0.002^{ac}\pm0.00$	$0.0373^{b}\pm0.00$
19	50:40:10	$0.087^{i}\pm0.00$	$0.002^{bc}\pm0.00$	$0.0377^{b}\pm0.00$
20	50:50:00	$0.094^{d}\pm0.00$	$0.002^{i}\pm0.00$	$0.0383^{b}\pm0.00$

Values are means ±SD of triplicate determinations. Means with different superscripts within each column are significantly ($p<0.05$) different.

Key: V_{CR} = Compressed Residue Volume; M_{CR} = Compressed Residue Mass; H_{CR} = Compressed Residue Height.

Table 3. Relaxed Density Dimensions

Sample	Blends(R:G:C)	V_{RD} (m³)	M_{RD} (kg)	H_{RD}(m)
Control	100:00:00	$0.0001^{m}\pm0.00$	$0.049^{b}\pm0.00$	$0.0367^{b}\pm0.00$
1	90:10:00	$0.0002^{e}\pm0.00$	$0.050^{b}\pm0.00$	$0.0397^{b}\pm0.00$
2	90:00:10	$0.0002^{e}\pm0.00$	$0.056^{b}\pm0.00$	$0.0378^{b}\pm0.00$
3	80:00:20	$0.0002^{b}\pm0.00$	$0.210^{a}\pm0.27$	$0.0398^{b}\pm0.00$
4	80:10:10	$0.0002^{i}\pm0.00$	$0.054^{b}\pm0.00$	$0.0387^{b}\pm0.00$
5	80:20:00	$0.0002^{fg}\pm0.00$	$0.056^{b}\pm0.00$	$0.0380^{b}\pm0.00$
6	70:00:30	$0.0002^{m}\pm0.00$	$0.005^{b}\pm0.00$	$0.0343^{b}\pm0.73$
7	70:10:20	$0.0001^{kl}\pm0.00$	$0.059^{b}\pm0.00$	$0.0361^{b}\pm0.00$
8	70:20:10	$0.0002^{ij}\pm0.00$	$0.053^{b}\pm0.00$	$0.0371^{b}\pm0.00$
9	70:30:00	$0.0002^{gh}\pm0.00$	$0.062^{b}\pm0.00$	$0.0366^{b}\pm0.00$
10	60:00:40	$0.0002^{a}\pm0.00$	$0.053^{b}\pm0.00$	$0.0410^{b}\pm0.00$
11	60:10:30	$0.0002^{c}\pm0.00$	$0.051^{b}\pm0.00$	$0.0377^{b}\pm0.00$
12	60:20:20	$0.0002^{d}\pm0.00$	$0.050^{b}\pm0.00$	$0.0390^{b}\pm0.00$
13	60:30:10	$0.0002^{hi}\pm0.00$	$0.061^{b}\pm0.00$	$0.0357^{b}\pm0.00$
14	60:40:00	$0.0002^{m}\pm0.00$	$0.058^{b}\pm0.00$	$0.0377^{b}\pm0.00$
15	50:00:50	$0.0001^{ij}\pm0.00$	$0.053^{b}\pm0.00$	$0.0373^{b}\pm0.00$
16	50:10:40	$0.0002^{d}\pm0.00$	$0.053^{b}\pm0.00$	$0.0383^{b}\pm0.00$
17	50:20:30	$0.0002^{f}\pm0.00$	$0.053^{b}\pm0.00$	$0.0383^{b}\pm0.00$
18	50:30:20	$0.0002^{fgh}\pm0.00$	$0.055^{b}\pm0.00$	$0.0373^{b}\pm0.00$
19	50:40:10	$0.0002^{jk}\pm0.00$	$0.054^{b}\pm0.00$	$0.0377^{b}\pm0.00$
20	50:50:00	$0.0002^{l}\pm0.00$	$0.056^{b}\pm0.00$	$0.0383^{b}\pm0.00$

Values are means ±SD of triplicate determinations. Means with different superscripts within each column are significantly ($p<0.05$) different.

Key: V_{RD} = Relaxed Density Volume; M_{RD} = Relaxed Density Mass; H_{RD} = Relaxed Density Height

Table 4. Compaction Characteristics of the Briquettes

Sample	Blends (R:G:C)	CD (Kg/m³)	RD (Kg/m³)	DR
Control	100:00:00	510.76^{j} ±3.58	335.38^{e}±4.23	0.66^{a} ±0.00
1	90:10:00	464.91^{l} ±6.01	301.41^{i}±2.70	0.65^{ab} ±0.10
2	90:00:10	547.44^{f} ±4.67	334.86^{e}±2.00	0.61^{fgh} ±0.01
3	80:00:20	468.47^{k} ±2.00	294.20^{j}±2.51	0.60^{gh} ±0.00
4	80:10:10	583.75^{e} ±11.50	366.98^{c}±4.63	0.63^{cdefg}±0.00
5	80:20:00	525.40^{hi} ±6.16	325.47^{g}±5.99	0.62^{cdefgh}±0.00
6	70:00:30	512.12^{ij} ±6.45	311.48^{h}±3.51	0.61^{fgh} ±0.01
7	70:10:20	618.38^{ab} ±7.24	381.48^{b}±3.37	0.62^{defgh}±0.00
8	70:20:10	542.08^{fg} ±2.99	339.93^{de}±3.12	0.63^{bcdefg}±0.01
9	70:30:00	597.38^{cd} ±8.98	384.23^{b}±4.88	0.64^{abcd} ±0.00
10	60:00:40	508.28^{j} ±6.75	285.47^{k}±2.88	0.56^{i} ±0.00
11	60:10:30	481.30^{k} ±6.61	288.39^{jk}±2.55	0.60^{h} ±0.00
12	60:20:20	461.22^{l} ±5.21	289.68^{jk}±5.43	0.63^{cdefg}±0.10
13	60:30:10	627.24^{a} ±4.17	384.71^{b}±3.37	0.61^{efgh} ±0.00
14	60:40:00	614.18^{abc}±5.80	393.63^{a}±3.72	0.64^{abcde}±0.00
15	50:00:50	601.93^{cd} ±5.11	336.68^{e} ±6.62	0.56^{i} ±0.01
16	50:10:40	529.74^{gh} ±6.49	314.91^{h}±2.74	0.63^{cdefg}±0.00
17	50:20:30	538.38^{fgh}±8.55	347.25^{d}±4.51	0.65^{abc} ±0.00
18	50:30:20	543.83^{fg} ±22.28	345.00^{de}±4.25	0.64^{abcdef}±0.01
19	50:40:10	546.56^{f} ±11.34	344.24^{de}±3.48	0.63^{cdefg}±0.00
20	50:50:00	611.79^{bcd}±10.00	364.00^{c}±4.59	0.60^{h} ±0.00

Values are means ±SD of triplicate determinations. Means with different superscripts within each column are significantly ($p<0.05$) different.

Key: CD = Compressed Density, RD = Relaxed Density, DR = Density Ratio

Table 5. Relaxation Ratio and Compaction Ratio

Sample	Blends	Parameter	
	(R:G:C)	RR	CR
Control	100:00:00	1.52^{i} ±0.01	1.64^{hi} ±0.01
1	90:10:00	1.60^{defg}±0.09	1.46^{k} ±0.05
2	90:00:10	1.63^{bcde}±0.01	1.75^{e} ±0.02
3	80:00:20	1.65^{bc} ±0.01	1.56^{j} ±0.01
4	80:10:10	1.59^{efgh}±0.01	1.87^{d} ±0.04
5	80:20:00	1.61^{cdef}±0.01	1.68^{ghi}±0.02
6	70:00:30	1.64^{bcd} ±0.01	1.64^{hi} ±0.03
7	70:10:20	1.62^{cdef} ±0.03	1.98^{a} ±0.03
8	70:20:10	1.60^{defgh}±0.01	1.74^{efg}±0.01
9	70:30:00	1.55^{ghi} ±0.00	1.91^{cd} ±0.03
10	60:00:40	1.78^{a} ±0.01	1.63^{i} ±0.02
11	60:10:30	1.66^{bc} ±0.01	1.54^{j} ±0.02
12	60:20:20	1.59^{defgh}±0.01	1.47^{k} ±0.02
13	60:30:10	1.63^{cde} ±0.01	2.01^{a} ±0.02
14	60:40:00	1.56^{ghi} ±0.00	1.92^{abc}±0.02
15	50:00:50	1.79^{a} ±0.01	1.92^{bcd}±0.02
16	50:10:40	1.68^{b} ±0.01	1.69^{fgh}±0.02
17	50:20:30	1.55^{hi} ±0.02	1.70^{efgh}±0.08
18	50:30:20	1.58^{fgh} ±0.05	1.74^{efg} ±0.07
19	50:40:10	1.59^{efgh}±0.02	1.65^{ef} ±0.04
20	50:50:00	1.68^{b} ±0.01	1.96^{abc} ±0.03

Values are means ±SD of triplicate determinations. Means with different superscripts within each column are significantly ($p<0.05$) different.

Key: RR = Relaxation Ratio; CR = Compaction Ratio

4 Conclusion

Blend formulations affected the combustion characteristics of the briquettes, with low moisture briquettes possessing highest calorific values. The briquette formulation containing 50:20:30 of rice hull, groundnut shell and corncob had more positive attributes of biomass fuel such as lower relaxation ratio and high compaction ratio than the control and other formulated briquettes in this study. The results of this work indicate that central holes cylindrical briquettes produced from the three residues would make good biomass fuels and will not crumble during transportation and storage.

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