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Cooking and Rheological Characteristics of Paddy Rice Processed Using Biomass Powered Stove

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Abstract: An investigation on the cooking and rheological characteristics of paddy processed using wood and rice-husk powered biomass stove was carried out. There was a significant difference ($p<0.05$) in the physical and cooking attributes of paddy among the different volumetric air flow rates. The length of the paddy (LNP) obtained were 6.19mm, 6.23mm, 6.40mm and 6.46mm at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. The least value obtained was at natural air flow while the highest value was obtained at 0.25m^3/s. The average length of the milled rice was higher (6.39mm) for briquettes compared to fire wood (6.25mm). The length/width ratio (LWR) of the paddy were 3.12mm, 3.02mm, 3.15mm and 3.12mm at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. Similar trends were observed for other physical and cooking attributes of paddy rice. The optimum cooking time of the rice ranged from 27.50min to 28.83min,andincreased with increase in air flow rate with the highest value observed at 0.25m^3/s. Similarly, there was a significant difference ($p\leq0.05$) in the peak viscosity between natural air flow and forced convection. The peak viscosity of the samples ranged from 442.06 to 485.94RVU. The peak viscosity increased with increase in air flow rates. Similar trends were observed for other rheological parameters such as trough, setback etc. The results revealed that powering the biomass stove enhanced both the cooking and rheological characteristics of the paddy.

Keywords:cooking, rheological, biomass, air flow rate, optimum, volumetric.

1.0 Introduction

Rice belongs to the family, *Gramineae, Genus; Oryza and species:* sativa L. and *Glaberrima*. It was taken to West Africa in the early 19th century (Jirgi*et al*., 2009). Rice is a staple food for every household in rural and urban areas in most parts of the world particularly in countries like Nigeria. Rice is the staple food for about half of the human race. Presently, rice is the most popular cereal crop in Nigeria in terms of consumption pattern. In some decades past, rice was once reserved for ceremonial occasions in the Nigerian diet (Ekpe and Alimba, 2013). The popularity of rice is derived partly from the rising level of income and the relative convenience with which it can be processed and preserved (Onwuchekwa, 1988). With increasing urbanization, it is expected that the importance of rice would increase.

After harvesting of rice from the farm, the grains are thoroughly cleaned prior to other processing operations such as soaking, steaming, drying and milling in order to obtain acceptable semi-finished product. These units operations have been reported to affect both the income level of processors as well as the cooking and eating quality of the final product. Processing of rice as a means of value-addition has direct implications on the price, cooking and its palatability (Daniel, 2011). The author further revealed that due to heating the starch granules are gelatinized and retrograded as a result various changes occur in rice, which plays an important role in the subsequent processing operations such as storage, milling, cooking, rheological and eating quality.

Rice is used for various food processing applications such as breakfast cereals, snacks, and package mixes, and as a thickener for baby food and sauces (Perdon*et al*., 2001). However, rice processing methods can affect its functionality and the quality of the final product. As a result, tests for rice cooking and rheological properties are important in specific food processing applications. Several researchers such as Dutta and Mahanta, (2012); Danbaba*et al*. (2013) Bergman *et al*. (2001) etc. have reported various factors such as varietal difference, geographic location, processing methods etc. to have influence on the cooking and rheological properties of rice. Notwithstanding, there is little or no information on effects offuel types and rate of heat supplied on cooking and rheological properties of rice. This research is therefore aimed at investigating the effects of fuel types and volumetric air flow rates on the cooking and rheological characteristics of paddy rice processed using powered biomass stove.

2.0 Materials and Methods

Raw rice (*Oryiza sativa*) “FARO 44” was obtained from National Cereal Research Institute Badeggi, Niger State, Nigeria. Rice husk (fuel biomass) were obtained from rice processing centres at Wurukum, *Detariummicrocarpum*was purchased from modern market in Makurdi Local Government Area, Benue State, Nigeria.The materials and apparatus included in the experiments were Pot, Digital thermometer, water, Fuels (wood and rice husk briquettes), weighing balance, stop watch, measuring cylinder and matches.

2.1 Hydration Studies

The modified Bhattacharya and SubbaRao (1966) method was adopted. Pre-cleaned paddy (10g) was placed in 500 ml beakers.The determination of the hydration characteristics for paddy samples parboiled using the powered biomass stove was carried out as follows. 10g of paddy samples were placed in 500ml beakers as described above. 100ml of boiling water was added to each beaker. Duplicate samples were withdrawn at 2h interval for 24h and their moisture content determined as described for the modern laboratory method.

2.2 Parboiling Process

2.2.1 Soaking condition

The drum was filled, closed, the pot filled with water and covered with lid and heated to boiling point. Clean paddy, 50kg, was soaked in boiling water at 90^{o}– 96^{o}C for solubilization and the source of heat withdrawn and quenched. After 6 hours of soaking, the water was drained out. The soaked rice was tempered at ambient temperature for 30min.

2.2.2 Steaming condition

The method described by Kimura, *et al*. (1976) and Bhattacharya, 1985) was used to steam the rice. Steaming was done at temperature 90^{0} C for 15 - 20 min. It was allowed for 25-30 min in the pot.

2.2.3 Drying condition

The steamed rice was then sun dried thinly on woven mats for 2 hours and dried in inside room for 2 days. After drying, samples were stored in polyethylene bags for moisture equilibration and hardness stabilization. The dried rice was analyzed after milling for physical and rheological properties after two weeks.

2.3 Physical Properties

2.3.1 Length, breath, length- breath ratio and thickness:

Length, breath and thickness were determined using a straight edged ruler and micrometer (Miutoyo, Japan) reading to 0.01mm.

2.3.2 1000 grain weight:

Thousand-grain seed weights was determined by counting 100 kernels and weighing them in digital electronic weighing balance and then multiplied by 10 to give mass of 1000 grain.

2.4 Cooking Properties

Cooking properties of the rice samples were determined based on the available standard procedures (Batcher *et al.*, 1956; Singh *et al.*, 2003, 2005).

2.4.1 Minimum cooking time

Rice samples (2 g) were individually taken and cooked around 90°C in distilled water (20 ml) in a boiling water bath. The minimum time required for cooking was estimated by pressing the cooked rice samples between two glass slides (till no white core was left) by removing a few cooked kernels at regular time intervals.

2.4.2 Elongation ratio and length–breadth ratio

Elongation ratio was determined by randomly selecting cooked rice samples and measured for length and was divided by length of uncooked raw samples. Results were reported as elongation ratio. The length-breadth ratio was determined by dividing the cumulative length by the breadth of cooked kernels. A mean of 10 replicates were taken for measurement.

2.4.3 Water uptake ratio

This was determined by using the method described by Batcher *et al.*, 1989; Singh *et al.*, 2003, 2005). Two grams of rice samples were cooked in 20 ml of distilled water for a minimum cooking time in a boiling water bath. After this, the contents were drained and the adhering superficial water present on cooked rice was removed by pressing the samples between filter papers. Cooked rice samples were weighed and the water uptake ratio was calculated (determined as increase in weight of rice samples after cooking).

2.4.4 Gruel solid loss

This was determined using the method described by Batcher *et al.*, 1989; Singh *et al.*, 2003, 2005). Approximately 2 g of rice grains were cooked in 20 ml of distilled water for minimum cooking time. The gruel obtained was transferred to beakers (50 ml) after washing (3-5 times), and the volume was made up with distilled water. Further, the aliquot was evaporated in a vacuum oven (at 110°C) until it was completely dried. The solid obtained were weighed and the percentage of gruel solid loss was calculated.

2.5 Pasting Properties

The Pasting properties of the milled rice flour was studied using the Rapid Visco Analyzer (RVA) (model Super 3, Newport Scientific Pty. Ltd., Australia) according to the procedure described by Noda *et al*. (2001). Sample (3 g) was added to distilled water (25 mL) and placed in the RVA. The suspension was kept at 50°C for 1 minute, heated to 95°C at 13.2 minute, kept at 95°C for 2.7 minutes, then cooled to 50°C at 11.6 min and kept at 50°C for 2 minute. The RVA experiment was performed in triplicates.

2.6 Statistical Analyses

All data were analyzed by the Analysis of Variance (ANOVA) procedure using SAS software version 9.1 (SAS Institute, 1998). Differences were declared statistically significant at $P < 0.05$. Where significant differences were detected, the means were separated by the least significant difference (LSD) at 5 % probability level.

3.0 Results

3.1 Combined and main effects of volumetric air flow rate and fuel type on the physical and cooking attributes of paddy parboiled using powered biomass stove

The combined (average) effect of volumetric air flow rates on the physical and cooking attributes of paddy parboiled using powered biomass stove are presented in Table 1. There was significant difference ($p<0.05$) in the physical and cooking attributes of paddy among the different volumetric air flow rates. The length of the paddy (LNP) obtained were 6.19mm, 6.23mm, 6.40mm and 6.46mm at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. The least value obtained was at natural air flow while the highest value was obtained at 0.25m^3/s. The average length of the milled rice was higher (6.39mm) for briquettes compared to fire wood (6.25mm). The length/width ratio (LWR) of the paddy were 3.12mm, 3.02mm, 3.15mm and 3.12mm at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. Similar trends were obtained for other physical and cooking attributes of paddy.

Table 2 shows the main effect of volumetric air flow rate and fuel type on the physical and cooking attributes of paddy parboiled using the powered biomass stove. There was significant difference ($p<0.05$) in the physical and cooking attributes of paddy among the different volumetric air flow rates and fuel types. The length (LNP) of the paddy ranged from 6.06mm to 6.52mm. The highest value obtained (6.52mm) was at 0.25m^3/s when briquettes were used and the least value of LNP was 6.06mm for wood at natural air flow. Similar trends were observed in the remaining physical and cooking characteristics of the paddy processed using the powered biomass stove.

Table 1: Main Effect of Volumetric Air Flow Rate and Fuel Type on Physical Characteristics and Cooking Attributes of Paddy Parboiled with the Powered Biomass Stove

VFR	LNP	WP	L/WP	TGW	LNC	WTC	TWC	SCW	L/WC	WUR	OCT	MCT	ER
N.A	6.19	2.005	3.12	19.34	9.10	2.88	59.00	0.24	2.93	3.00	27.66	25.66	1.47
0.18	6.23	2.070	3.02	19.34	9.46	2.98	59.00	0.26	3.19	3.04	27.50	25.50	1.54
0.20	6.40	2.062	3.15	19.16	9.50s	2.99	60.00	0.23	3.19	3.10	28.50	26.50	1.49
0.25	6.46	2.085	3.12	19.84	9.51	3.10	60.33	0.29	3.20	3.17	28.83	26.83	1.43
LSD	**0.013**	**0.081**	**0.013**	**0.87**	**0.31**	**0.013**	**0.61**	**0.076**	**0.12**	**0.063**	**0.75**	**0.75**	**0.05**

***Volumetric air flow rate** (m^3/s); N.A= natural air flow; LNP=Length of Paddy; WP= width of Paddy; L/WP=Length/width ratio; TGW= 1000 grain weight; LNC= length of cooked rice; WTC = width of cooked rice; TWC=1000 grain weight of cooked rice (g); SCW=solids in cooking water (g); L/WC= Length/width ratio of cooked rice; WUR= water uptake ratio; OCT=Optimum cooking time (min); MCT= minimum cooking time (Min); WTC=Width of cooked rice; ER= Elongation ratio; the analysis was done in 5 replicates*

Table 2: Combined Effect of Volumetric Air Flow Rate and Fuel Type on Physical Properties and Cooking Attributes of Paddy Parboiled with the Powered Biomass Stove.

FT	VFR	LNP	WP	L/WP	TGW	LC	TWC	SCW	L/WC	WUR	WTC	OCT	MCT	ER
W	N.A	6.06	2.010	3.06	19.67	8.64	63.33	0.35	2.85	3.23	3.16	28.00	25.33	1.37
B	N.A	6.32	2.000	3.17	19.00	9.46	56.67	0.20	3.01	2.97	3.04	27.33	26.00	1.56
W	0.18	6.15	2.010	2.97	19.00	9.34	62.67	0.21	3.13	2.80	2.99	29.33	27.33	1.49
B	0.18	6.31	2.130	3.06	19.67	9.32	55.33	0.20	3.24	3.27	2.99	25.67	23.67	1.59
W	0.20	6.37	2.023	3.08	19.00	9.27	61.33	0.33	3.08	3.10	2.94	31.00	29.00	1.45
B	0.20	6.43	2.100	3.22	19.33	9.65	59.33	0.13	3.29	3.23	3.02	26.00	24.33	1.52
W	0.25	6.39	2.070	3.11	19.67	8.89	58.00	0.33	3.11	2.97	2.89	31.33	29.33	1.38
B	0.25	6.52	2.100	3.12	20.00	9.68	60.00	0.26	3.25	3.03	2.88	26.33	24.33	1.47
	LSD	**0.018**	**0.054**	**0.019**	**1.23**	**0.017**	**0.87**	**0.069**	**0.17**	**0.088**	**0.018**	**1.06**	**1.06**	**0.80**

***FT = Fuel type; W= wood; B= Briquette; VFR=Volumetric air flow rate** (m^3/s); N.A= natural air flow; LNP=Length of Paddy; WP= width of Paddy; L/WP=Length/width ratio; TGW= 1000 grain weight; LNC= length of cooked rice; WTC = width of cooked rice; TWC=1000 grain weight of cooked rice (g); SCW=solids in cooking water (g); L/WC= Length/width ratio of cooked rice; WUR= water uptake ratio; OCT=Optimum cooking time (min); MCT= minimum cooking time (Min); WTC=Width of cooked rice; ER= Elongation ratio; the analysis was done in 5 replicates*

3.2 Combined (average) and Main Effect of Volumetric Air Flow Rate and Fuel Type on Pasting Characteristics of Paddy Parboiled with the Powered Biomass Stove

Table 3 shows the combined effect of volumetric air flow rates on the rheological characteristics of the milled rice. There was significant difference ($p<0.05$) in the rheological characteristics of the processed paddy among different volumetric air flow rates. The peak viscosity of the samples was 442.06, 478.06, 482.25 and 485.94RVU at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. On the other hand, the average peak viscosity for wood and briquette was 463.43 RVU and 480.73 RVU.

From Table 3, Trough viscosity (TRV) of the samples was 262.98, 280.46, 272.23 and 273.35RVU at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. On the other hand, the average trough viscosity for wood and briquette was 273.41 and 272.83 RVU.

The breakdown viscosity (BVDR) was 278.59, 276.70, 266.83 and 278.25RVU at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. On the other hand, average breakdown viscosity for wood and briquette was 272.93 and 278.10RVU.

Setback viscosity (SETV) of the samples was 258.86, 273.48, 271.50 and 259.69RVU at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. On the other hand, the average Setback viscosity for wood and briquette was 268.98 and 269.31RVU.

Final viscosity (FV) of samples was 408.84, 2400.54, 405.25 and 401.96RVU at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. On the other hand, the average Final viscosity for wood and briquette was 403.59 and 404.09RVU.

The pasting temperature (PAT) of the samples was 80.79, 82.31, 79.92, and 79.07°C at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. On the other hand, the average pasting temperature for wood and briquette was 80.96 and 80.06°C.

The peak time (PKT) for the samples was 5.31, 5.47, 5.37 and 5.40min at natural air flow, 0.18 m^3/s, 0.20m^3/s and 0.25m^3/s respectively. On the other hand, the average peak time for wood and briquette was 5.35 and 5.43min respectively.

As shown in Table 4, these was significant difference ($p<0.05$) in the rheological characteristics between fuel types. Although there was no significant difference ($p>0.05$) in the pasting time (PAT) of the rice samples. The rice samples have peak viscosity ranging from 431.67 to 489.40RVU The highest and least peak viscosity recorded when briquettes was used at volumetric air flow rate of 0.25m^3/s and natural air flow.

As shown in Table 4, the rice samples have trough viscosity ranging from 271 to 276.93RVU. The value of trough viscosity has not direct relationship with the flow rate and the source of the fuel.

As shown in Table 4, the rice samples have breakdown viscosity ranging from 265.88 to 280.92RVU. The least value of breakdown viscosity (265.88RVU) was obtained at 0.18m^3/s when wood was used and highest value obtained was (280.92RVU) at natural air flow for wood. The trend of the breakdown viscosity was erratic.

The Final viscosity (FV) of samples ranged from 399.85 to 409.54. The highest value, 409.54RVU, was obtained at 0.25m^3/s and lowest, 399.54RVU for briquettes at 0.25m^3/s. The values obtained showed no direct relationship between fuel source and volumetric air flow rate.

As shown in Table 4, the rice samples have Setback viscosity ranging from 254.34 to 269.45RVU.

The gelatinization temperature (GT) ranged from 76.65 to 83.90°C.The peak time (PKT) ranged from 5.20 to 5.54min respectively.

Table 3: Combined (average) Effect of Volumetric Air Flow Rate and Fuel Type on Pasting Characteristics of Paddy Parboiled with the Powered Biomass Stove

VFR (m^3/s)	PKV	TRV	BRDV	SETV	FNV	PAT	PKT
N.A	442.06	262.98	278.59	258.86	408.84	80.79	5.31
0.18	478.06	280.46	276.70	273.48	400.54	82.31	5.47
0.20	482.25	272.23	266.83	271.50	405.25	79.92	5.37
0.25	485.94	273.35	278.25	259.69	401.96	79.07	5.40
LSD	0.61	0.012	0.012	0.012	0.44	0.44	0.17

VFR= volumetric air flow rate; N.A= natural air flow; LSD= least significant difference; PKV= peak viscosity; TRV= trough viscosity; BRDV= breakdown viscosity; SETV= setback viscosity; FNV= final viscosity; PKT= peak time; PAT= pasting temperature.

Table 4: Main Effect of Volumetric Air Flow Rate and Fuel Type on Pasting Characteristics (*RVU) of Paddy Parboiled with the Powered Biomass Stove.

Fuel Type	VFR (m^3/s)	PKV	TRV	BRDV	SETV	FNV	PAT	PKT
Wood	N.A	452.46	274.46	280.92	256.46	401.50	80.00	5.20
Briquette	N.A	431.67	273.39	270.88	267.25	404.17	81.58	5.42
Wood	0.18	485.56	274.02	265.88	254.34	402.29	80.72	5.40
Briquette	0.18	489.40	276.93	275.45	259.04	406.00	83.90	5.54

Wood	0.20	478.59	273.10	267.46	262.17	400.34	81.63	5.36
Briquette	0.20	485.92	271.36	269.21	259.68	399.85	78.20	5.38
Wood	0.25	466.75	272.06	267.67	268.83	400.25	81.48	5.43
Briquette	0.25	488.13	274.64	270.54	269.45	409.54	76.65	5.36
LSD		**0.51**	**0.017**	**0.0.017**	**0.017**	**0.62**	**0.62**	**0.24**

VFR= volumetric air flow rate; N.A= natural air flow; LSD= least significant difference; PKV= peak viscosity; TRV= trough viscosity; BRDV= breakdown viscosity; SETV= setback viscosity; FNV= final viscosity; PKT= peak time; PAT= pasting temperature.

4.0 Discussion

4.1 Dimension and Cooking Attributes of Parboiled Rice

4.1.1 Length and length/width ratio

The dimensions of the paddy processed at various volumetric air flow rates using the powered biomass stove is presented in Table 1.There was significant difference ($p \leq 0.05$) in the length of paddy (LNP), length/width ratio (L/WP) between natural air and forced convection. The length of parboiled paddy increased with increase in volume of the air supplied. The increment in the length might be attributed to effect of gelatinization of the paddy during parboiling. As adequate heat was supplied, the rice grain acquired the heat needed to maintain a compacted structure making it not to disintegrate during milling (Danbaba*et al.*, 2012). Thus, the length of the paddy was affected by the air flow rates as the quantity of heat supplied varied with the air flow rates. The length of the paddy ranged from 6.19mm to 6.46mm. Danbaba*et al.* (2012) and Jennings *et al.* (1979) classified milled rice length as extra-long (> 7.50 mm), long (6.61 – 7.50 mm), medium (5.51 – 6.60 mm) and short (< 5.50 mm). Based on this classification, therefore, the rice grains from this work can be said to be medium size. Powering the stove as seen in this work is advantageous as it improved the dimensions of parboiled rice.

Similarly, the length of the paddy (LNP) was significantly ($p \leq 0.05$) affected by the fuel types as shown in Table 2. In each case, the LNP was higher for briquettes compared to the wood. The higher LNP obtained from briquette might be attributed to better heat generation and distribution during parboiling and thus effective gelatinization of the starch content of the paddy which reduced the degree of cracking during milling (Sareepuang*et al.*, 2008). Therefore, it can be deduced that briquette can adequately substitute fuel wood and this would reduce significantly the rate of indiscriminate felling of trees. Powering the stove at higher volumes of air flow was preferred when briquettes were used as enormous task was carried out at shorter time than natural air flow and the higher air flow did not significantly affected the dimensions of the paddy processed.

There was significant difference ($p \leq 0.05$) in the length/width ratio (L/WP) between natural air flow and forced convection. The length/width ratio of the paddy ranged from 3.02mm to 3.15mm. The L/WP of the paddy was generally higher for briquettes compared to fire wood. The higher ratios can be attributed to the higher LNP obtained in each case and this might be due to the same factors as stated for the length above. The shapes of milled rice in terms of length-width ratio are slender (> 3.0), medium (2.1–3.0), bold (1.1 – 2.0) and round (< 1.1) (Danbaba*et al.*, 2012; Jennings *et al.* 1979). Therefore, based on above classification, the rice in this work is categorized as slender type. The result of this study is in agreement with the work of Danbaba*et al.*, (2012) who reported grain size and shape of rice varieties as slender. The results in this work showed higher ratio compared to those reported by Unnevehr*et al.* (1992) who observed values ranging from 2.81 to 3.00mm among more than 10 different varieties of paddy.

The size and shape are among the grain characteristics that influence the marketability and commercial viability of rice (Khush*et al.*, 1979). The dimensions obtained were high and within the range of values in literature (Kimura *et al.*, 1993).Therefore, it is evidently clear that briquette is a good alternative for fire wood in rice processing using powered stove.

4.1.2 1000-grain weight

The 1000-grain weight is a useful index in measuring the relative amount of dockage or foreign material in a given lot of rice and the amount of shriveled or immature kernels (Danbaba*et al.*, 2012). This value could be used to estimate the weight contained in holding bins of known volume (Jha, 1999; Simonyan*et al.*, 2007; Danbaba*et al.*, 2012).

There was significant difference ($p \leq 0.05$) in the weight of 1000-grain between natural air flow and forced convection as shown in Table 1. The weight of the processed rice ranged between 19.16g to 19.84g. The values obtained did not follow a definite order yet the highest weight was obtained at 0.25m^3/s. The higher weight obtained might be due to less cracking of the grain during milling and polishing. Therefore, powering the stove is important in rice processing to obtain reasonable high weight after milling.

As shown in Table 2, the 1000-grain weight ranged from 19.00g to 20.00g.From the results of this work, it can be deduced that fuel types did significantly affect the weight of the paddy processed, with briquettes giving higher weights. In the light of the above, briquettes is a good alternative to fire wood. The values obtained were less than the findings of Danbaba*et al*. (2012) who reported 24.40g to 31.4g in *ofada*rice varieties. The difference can be attributed to varietal differences and the time spent during polishing of the rice after milling as well as drying conditions'

4.1.3 Length of cooked rice

The cooking characteristics of the milled rice samples subjected to steaming at various volumetric air flow rates are presented in Table 1.There was significant difference ($p \leq 0.05$) in the length of the cooked rice (LNC) between natural air flow and forced convection. The length of the cooked rice ranged from 9.10mm to 9.51mm. The length of the cooked rice increased with increase in volumetric air flow. The length of cooked rice has direct bearing on its attractiveness as long grain cooked rice tend to stand wholly than shorter grain cooked rice. The length of the cooked rice followed the same trend with the LNP. Values obtained in this work are higher than those reported in literature (Danbaba*et al*., 2012 and Unnevehr*et al.*,1992). The higher values in this work might be attributed to the effective soaking and steaming as adequate heat was supplied by the powered stove. The use of powered stove enhanced effective heat generation and improved the gelatinization process which has direct bearing on the degree of grain cracking during milling and polishing (Kimura *et al*., 1993). Therefore, it can be deduced that processing rice at high volume of air flow is important to enhance the length of cooked grain.

The length of the cooked rice vary significantly ($p \leq 0.05$)with fuel type as shown in Table 2. The length of the cooked rice ranged from 8.64mm to 9.68mm. The same trend as milled rice was observed for cooked rice. In each case, briquette performed better than fire wood, giving longer cooked grains. The result in this work is in agreement with those reported by Shayo*et al*., (2006). In light of the above, it is indisputably clear that briquettes are a good alternative to fire wood.

4.1.4 1000-grain weight of cooked rice

There was significant difference ($p \leq 0.05$) in the weight of a 1000-grain of cooked rice while using natural air flow and forced convection, as shown in Table 1. The weight of the cooked 1000-grain rice ranged from 59.00g to 60.33g. The use of powered stove enhanced effective heat generation and distribution during the processes. The weight of 1000-grain increased with increase in air flow rate. This implies that the breakage of the grain during milling and polishing decreased due to effective absorption of heat during steaming. The highest weight was obtained at 0.25m^3/s, therefore, it can be deduced that powering the stove is important to obtain good weight of cooked rice.

There was significant difference ($p \leq 0.05$) in the weight of 1000-grain cooked rice between fuel types as shown in Table 2.The weight ranged from 55.33g to 63.33g. Higher weights were obtained when briquettes was used, and this probably was due to better steaming condition as the amount of heat supplied per kilogramme of paddy depends on the calorific value of the biomass used. Briquettes from rice husk and hard wood sawdust have been reported to have higher calorific values (Gravalos*et al*., 2010). Therefore briquettes performed better in terms of 1000-grain weight of cooked rice and can be suitably used in place of fire wood for rice processing. The values obtained were less than the findings of Danbaba*et al*. (2012) who reported 64.40g to 71.42g in *Ofada*rice varieties. The lower values (weight of 1000 grain) obtained in this work can be attributed to varietal difference and the time spent during polishing of the rice after milling.

4.1.5 Solids in cooking water

There was significant difference ($p \leq 0.05$) inthe amount of solids in cooking water (SCW) between natural air flow and forced convection as shown in Table 1.The weight of the dissolved solids in the cooking waterranged from 0.23g to 0.29g. The amount of dissolved solids in water did not follow definite pattern, therefore the choice of powering the stove during rice processing in terms of solids in cooking water will depend on other factors such as time required for processing, energy requirement and number of laborers. Therefore, based on these other factors, higher volume of air is preferred during rice processing as it would minimize the amount of energy utilization.

As shown in Table 2, the fuel types did significantly ($p \leq 0.05$) affect the amount of solids in cooked water (SCW). The weight of the dissolved solids in cooking water ranged from 0.13g to 0.35g and was lower when briquettes was used compared to fire wood. The amount of (SCW) has direct relationship with the degree of gelatinization; properly gelatinized rice usually have less (SCW) (Danbaba*et al*., 2012) and this might be attributed to the lower (SCW) observed when briquettes were used. In light of the above, briquettes is a good alternative to fire wood in order to reduce SCW.

4.1.6 Length/width ratio of cooked rice

There was significant difference ($p \leq 0.05$) in the length to width (L/W) ratio of the cooked rice between natural air flow and forced convection as shown in Table 1. The ratio varied between 2.80 to 3.29mm for the cooked rice. The increase in the LNP probably was due to optimum processing conditions such as steaming, parboiling thereby enhancing reduction in cracking during milling process. The cooked rice in this study can be classified as medium to slender based on Danbaba*et al*. (2012) and Jennings *et al*. (1979). This is in agreement with the report of Danbaba*et al*. (2012) who observed similar dimensions in cooked O*fada*rice.

Similar trends were observed in Table 2 that shows the main effect of volumetric air flow rates and fuel types on the cooking attributes of the rice. The ratio of length/width of the cooked rice ranged from 2.85 to 3.29. At each given air flow rate briquettes performed better compared to fire wood and this might be due to improved gelatinization process, as this process has direct bearing on the degree of grain cracking during milling and polishing (Kimura *et al*., 1993). From the results of this work, it can be deduced that fuel types did significantly affect the ratio of length/width of the cooked rice. The ratios were generally higher when briquettes was used compared to fire wood. Based on this observation, it is indubitably clear that briquettes can be used as alternative to fire wood in rice processing.

4.1.7 Water uptake ratio

Water uptake ratio is an index of swelling capacity of the grain, the higher the ratio, the better increase during cooking (Sareepuang*et al*., 2008). There was significant difference ($p \leq 0.05$) in the water uptake ratio (WUR) between natural air flow and forced convection as shown in Table 1. The water uptake ratio ranged from 3.06 to 3.17 and this increased with increase in the volume of air supplied. The (WUR) has a direct relationship with the degree of gelatinization (Kimura *et al*., 1993) and the increase might be attributed to better gelatinization. WUR (swelling index) is an important quality factor that attracts consumers to make choice of any given rice, therefore, higher air flow rate should be used when powering the stove.

As shown in Table 2,water uptake ratio ranged from 2.97 to 3.27. The WUR was higher for briquettes compared with fire wood at every given air flow rate and this might be attributed to better absorption of water during parboiling because the amount of water absorbed during parboiling is directly proportional to the WUR during cooking (Odenigbo*et al*., 2014). This finding is in agreement with the report of Danbaba*et al*. (2012) who observed similar trends during cooking of *Ofada*rice varieties. On the other hand the ratio of water uptake as reported by Odenigbo*et al*. (2014) was slightly lower (2.69) which can be attributed to varietal difference and the length of storage. In the light of the above, it can be deduced that briquettes is a good alternative to fire wood.

4.1.8 Optimum cooking time

There was significant difference ($p \leq 0.05$) in the optimum cooking time (OCT) between natural air flow and forced convection as shown in Table 1.The optimum cooking time of the rice ranged from 27.50min to 28.83min. The optimum cooking time increased with increase in air flow rate with the highest value observed at $0.25m^3/s$. In the chemistry of starch, the higher the volume of water absorbed during boiling and subsequent drying, the longer the time that is needed for the same dried product to re-absorb the same quantity of water (Danbaba*et al*., 2012). The implication of this is that more time would be needed during cooking of the rice at higher air flow. Therefore, in terms of optimum cooking time, lower air flow is suggested to minimize time and energy required during preparation of the rice as meal.

As shown in Table 2, optimum cooking time ranged from 25.67min to 31.00min. In each case the optimum cooking time for rice that was processed using briquettes was lower than those obtained when fire wood was used. This probably was due to longer time spent when fire wood was used for parboiling. The longer the parboiling time, the longer the optimum time required during cooking. The findings are in agreement with those of Parnsakhorn and Noomhorm (2008). Cooking time depended on several factors, not only parboiling process, but rice variety and storage time (Parnsakhorn and Noomhorm, 2008; Odenigbo*et al*., 2014).

4.1.8 Minimum cooking time (MCT)

There was significant difference ($p \leq 0.05$) in the minimum cooking time (MCT) between natural air flow and forced convection as shown in Table 1. The minimum cooking time (MCT) ranged from 25.50min to 26.83min. The minimum cooking time decreased with increase in air flow rate, thus lower cooking time was obtained at high air flow rate due to longer time spent when the rice was processed at lower air flow rates. Therefore, it can be deduced that high air flow is preferred to minimize time spent during cooking of rice for meals. High air flow rate of $0.25m^3/s$ should be used in rice processing to minimize energy utilization.

As shown in Table 2,minimum cooking time ranged from 23.67min to 29.00min. The minimum cooking time for the rice processed using briquette was less than the value obtained for wood and perhaps was due to longer time spent when the rice was processed at lower air flow rates. Thus, it can be deduced that the paddy processed using briquette requires less time during cooking and lower cooking time leads to less fuel and energy consumption during cooking. From the results of this work, it can be deduced that fuel types did significantly affect minimum cooking time of the rice and in each case briquettes had lower MCT compared to fire wood. In light of the above, briquettes is a good alternative to fire wood.

Several researchers reported lower cooking time. Odenigbo*et al*. (2014) reported 17.9 min to 19.7 min.; Singh *et al*. (2005) reported MCT between 13 to 24min on 23 milled rice varieties in India. Similarly, Bocevska*et al*. (2009) reported MCT of 17.5 to 22.5 min for milled rice varieties. The difference in the MCT possibly was due to varietal difference and other factors such as the use of powered stove.

4.1.9 Elongation ratio

There was significant difference ($p \leq 0.05$) in the elongation ratio (ER) between natural air flow and forced convection as shown in Table 1. The elongation ratio of the rice ranged from 1.43 to 1.54. The ER did not follow definite pattern as indicated by the results. This finding is in agreement with the work reported by Odenigbo*et al*. (2014) on elongation ratio of 1.48 to 1.56.

Similarly, as shown in Table 2, there was significant difference ($p \leq 0.05$) in the ER between fuel types. The higher ratios obtained for briquettes might be attributed to longer LNP as shown in the results. From the results of this work, the paddy processed using briquette had better elongation ratio.Thus, it can be deduced that is a good alternative to fire wood in rice processing.

4.2 Rheological Characteristics

4.2.1 Peak viscosity

Rheological characteristic is a phenomenon that occurs during cooking following gelatinization of rice starch, involving swelling of molecular components from granules (Atwell *et al*., 1988).Table 3 shows the rheological characteristics of the milled rice. There was significant difference ($p \leq 0.05$) in the peak viscosity between natural air flow and forced convection. The peak viscosity of the samples ranged from 442.06 to 485.94RVU. The peak viscosity increased with increase in air flow rates. The increase might be due to shorter time spent during parboiling at higher air flow rates leading to higher temperatures at short time intervals (Danbaba*et al*., 2012). Higher peak viscosity is a positive quality index of parboiled rice. High peak viscosity has been reported to be important parameter in the choice of material used for preparation of stiff dough products. Also, high peak viscosity is an indication of high water-binding capacity and ease with which starch granules are disintegrated and it is often correlated with final product quality (Tran *et al*., 2001; Thomas and Atwell, 1999). Since the highest peak viscosity was obtained at $0.25m^3/s$. from the results of this work, the use of powered stove at higher air flow rate is good during rice processing.

As shown in Table 4, the rice samples have peak viscosity ranging from 431.67 to 489.40RVU. There was significant difference ($p \leq 0.05$) in peak viscosity between fuel types. The value of peak viscosity has direct relationship with the source of the fuel. The highest peak viscosity recorded was at air flow rate of $0.25m^3/s$ when briquettes were used. These values are higher than those reported by Danbaba*et al*. (2012) who recorded mean viscosity of 124.53 BU. Higher values of peak viscosity were recorded with briquettes. Therefore, it is a good replacer for firewood.

4.2.2 Trough viscosity

There was significant difference ($p \leq 0.05$) in the trough viscosity (TRV) between natural air flow and forced convection as shown in Table 3. Trough viscosity (TRV) of the samples ranged from 262.98 to 280.46RVU. The trough viscosity did not follow definite order. Therefore in terms of TRV, there is no preference between convective and natural air flow

Similarly, significant difference ($p \leq 0.05$) in the (TRV) was observed between the fuel types as shown in Table 4. The TRV varied from 271 to 276.93RVU with respect to air flow. The values obtained showed no definite pattern and as such the choice of fuel type would be determined by other factors such cost of fuel etc. The values in this work are higher than those reported by Danbaba*et al*. (2012) who recorded mean viscosity of 124.53 BU. The variation might be due to varietal difference as well as storage conditions of the grains prior to processing. In addition, the higher (TRV) value recorded was probably due to series of irreversible reaction/process such as starch retro-gradation and gelatinization. Trough viscosity (TRV) is the point at which the viscosity reaches its minimum during either heating or cooling process. PV is usually followed by a breakdown to minimum (trough viscosity) as a result of starch granules deformation and leaching during exposure to high temperature and shear (Danbaba*et al*., 2012).

4.2.3 Breakdown viscosity

Breakdown viscosity measures the tendency of swollen starch granules to rupture when held at high temperaturesand continuous shearing, and this is used to measure the relative stability of the starch on heating (Patindol*et al*., 2005). There was significant difference ($p \leq 0.05$)in the breakdown viscosity (BVDR) between natural air flow and forced convection as shown in Table 3. The breakdown viscosity (BVDR) ranged from 266.83 to 278.59RVU. The trend did not follow definite order; therefore, the use of powered stove should be based on other factors.

Similarly, there was significant difference ($p \leq 0.05$)in the breakdown viscosity (BVDR) of the processed rice between fuel types as shown in Table 4. The BVDR ranged from 265.88 to 280.92RVU based on fuel type. Tran *et al*. (2001) in a study comparing the physicochemical properties of different rice varieties rated the cultivars with the highest breakdown value as the most palatable. The breakdown viscosity reported by Danbaba*et al*. (2012) was lower than the values recorded in this study. The higher values obtained in this study probably was due to varietal difference and other processing methods.

4.2.4 Setback viscosity

There was significant difference ($p \leq 0.05$) in the Setback viscosity between natural air flow and forced convection as shown in Table 3. Setback viscosity (SETV) refers to the increase in viscosity from minimum to the final value and has been correlated with the texture of various end products. From Table 3, the SETV ranged from 258.86 to 273.48RVU. The trend for setback viscosity did not follow particular order and indicating non influence of air flow on the parameter.

As shown in Table 4, the Setback viscosity ranged from 254.34 to 269.45RVU for firewood and briquettes. There was significant difference ($p \leq 0.05$) in the setback viscosity between fuel types. The result of setback viscosity obtained in this study was higher than those reported by Danbaba*et al*. (2012) with mean value of 122.34BU. The results of this work agreed with the findings in studies by Noosuk*et al*. (2003) who reported similar range of value 265.32RVU.

4.2.5 Final viscosity

There was significant difference ($p \leq 0.05$) in the Final viscosity (FNV) between natural air flow and forced convection as shown in Table 3. Final viscosity (FNV) ranged from 240.54 to 408.84RVU. The final viscosity of the rice showed erratic pattern, therefore, other quality parameters should be the determining factors in the choice of stove.

As shown in Table 4, the rice samples had Final viscosity ranging from 399.85 to 409.54RVU for fire wood and briquettes. There was significant difference ($p \leq 0.05$) in the final viscosity between fuel types.The FNV is the most commonly used parameter for determining a particular starch based sample quality. It gives an idea of the starch to gel after cooking (Danbaba*et al*., 2012). The results obtained showed no definite behavior therefore, briquettes can be used as substitute for fire wood in rice processing.

4.2.6 Pasting temperature

Pasting temperature (PAT) which is also referred to as gelatinization temperature (GT) indicates the range of temperature wherein at least 90% of starch granules swell irreversibly in hot water with loss of crystalinity and birefringence (Cruz and Khush, 2000). It is the measure of the paste hardening on cooling. The PAT in this work ranged from 79.07 to 82.31^{o}C. The trend was not dependent on volume of air flow. The variation observed in the (PAT) might be attributed to irregular changes in the behavior of the starch granules as the heating process differs.The results of this work support the findings of Danbaba*et al*. (2012) who reported the values ranging from 78.90 to 82.64^{o}C. PAT is an indication of the amount of swelling power of rice samples and usually this is related to the amylose content of sample (as reported by various researchers such as Martin and Smith, 1995; Loh, 1992; Jennifer and Les, 2004).

There was significant difference ($p \leq 0.05$) observed among the treatments as shown in Tables 3 and 4. The (GT) obtained in this work ranged from 76.65 to 83.90^{o}C and was higher than the values reported by Danbaba*et al*. (2012) and Cruz and Khush, (2000) 55 to 70^{o}C. The degree of gelatinization is directly related to the water uptake ratio (Manuful*et al*., 2004) and it explains the variation in GT recorded in this work because WUR varied. Gelatinization temperatures were affected by the source of the wood and the volumetric air flow rates. Therefore processing rice at higher air flow rate using briquettes as source of fuel is most preferred.

5.0 Conclusion

The cooking properties of the rice processed using the powered biomass stove was satisfactory as the values obtained were within the range published by other researchers. The rheological characteristics of the rice processed using the powered biomass stove showed that the swelling capacity as well as the palatability of the milled rice was enhanced.

6.0 References

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