



Milling Characteristics and Nutritional Quality of Paddy Rice Processed Using Biomass Powered Stove

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Abstract: Milling and nutritional quality of rice processed using wood and rice-husk briquette powered biomass stove was investigated. There was significant difference ($p \leq 0.05$) in milling attributes of the processed rice among volumetric air flow rates. There was no significant difference ($p \geq 0.05$) in the milling attributes of the processed rice between the treatments. The L-values ranged from 60.20 to 62.40 with the least values at 0.18 m³/s and 0.20 m³/s and the highest value at 0.25 m³/s. The percentage head rice (HR) ranged from 98.50 to 98.83% which were fairly the same. The lowest and highest values of (HR) were obtained at 0.25 m³/s and natural air flow. Milling recovery (MR) ranged from 68.21 to 68.60% with the highest values at 0.25 m³/s and the least value at natural air flow. Similar trends were observed for milling attributes with exception of chalkiness that remained constant for all treatments. The values for other quality parameters of the milled rice showed that fire wood and briquette recorded fairly similar values, although, briquette recorded higher values in some cases with the exception of chalkiness that showed exactly the same trend at different treatments. The carbohydrate content of the rice processed using briquette was higher than those processed using fire wood and most of the other quality indices such as protein, ash which is an indication of presence of mineral elements were higher for briquettes compared with fire wood. The results revealed that powering the stove was advantageous since the quality indices of the rice were enhanced.

Keywords: Biomass Stove, Milling, Nutritional Quality, Rice Husk Briquette, Wood

1. Introduction

Rice is the seed of the monocot plant of the genus *Oryza* and of the grass family *Poaceae* (formally *Graminae*) which includes twenty wild species and two most cultivated ones are *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice). *Oryza sativa* is the most commonly grown species throughout the world today. Rice has been considered the best staple food among all cereals and is the staple food for over 3 billion people, constituting over half of the world's population [1]. Similarly, various authors such as [2, 3] etc. reported that rice is an important cereal grain which feeds nearly half of the world's population and that rice is usually consumed as a whole grain after cooking, and in a regular Asian diet, can contribute for 40 to 80% of the total calorie intake.

Despite its widespread consumption irrespective of geographic and ethnic barriers, there are number of factors that influence the consumers' preference [4, 5]. The appearance (size, colour, etc.) of rice grain is among such factors that influences consumers' choice. In addition to physical appearance, the nutritional quality of rice can be affected during processing. For example, the carbohydrate content of parboiled rice samples is higher than that of non-parboiled samples [6]. As the rice grains are heated, it gives rise to the gelatinization of the starch component which makes the grain to expand thus filling up the surrounding air spaces. The primary component of rice is starch, and its hydration begins with diffusion of water into the grain and is completed by gelatinization [7]. Similar irreversible changes in protein, fat, ash etc. and mineral content occur during rice processing (steeping, steaming and milling).

Rice is largely consumed as cooked, milled whole kernels,

which are produced by de-hulling and milling processes, by removing the most outer layers of the rough rice kernel. During the rice milling process, portions of damaged, chalky, and broken rice kernels are usually separated and rice eventually graded based upon several criteria, among which is the percentage of broken kernels in milled rice [8]. These processes cause series of changes that affects both the milling and nutritional qualities of rice. Therefore, this work seeks to investigate the effect of fuel type and airflow rates on the milling and nutritional quality of rice paddy processed using powered biomass stove.

2. Materials and Methods

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

2.1. Hydration Studies

The modified [9] method was adopted. Pre-cleaned paddy (10 g) 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. 10 g of paddy samples were placed in 500 ml beakers as described above. 100 ml of boiling water was added to each beaker. Duplicate samples were withdrawn at 2 hours interval for 24 hours 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, 50 kg, was soaked in boiling water at 90°C - 96°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 30 min.

2.2.2. Steaming Condition

The method described by [10] was used to steam the rice. Steaming was done at temperature 90°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. Milling Characteristics

2.3.1. Milling Degree

The degree of milling was determined using the method described by [11]. This was computed based on the amount of bran removed from the brown rice. The husk of the paddy was removed using laboratory huller, SATAKE model THU35B. The percent milling degree was estimated using the equation:

$$\% \text{ milling degree} = \text{wt of milled rice} / \text{wt of brown rice} \times 100 \quad (1)$$

2.3.2. Milling Recovery

Milling recovery was carried out using Abrasive Whitener (Polisher), SATAKE model SE1008. The dehulled samples were fed into the machine and polished for one minute. Percent milling recovery was computed by dividing the weight of milled rice recovered by the weight of the paddy sample as follows:

$$\% \text{ milling recovery} = \text{wt of milled rice} / \text{wt of sample} \times 100 \quad (2)$$

2.3.3. Percentage Head and Broken Rice

Percentage head rice and broken grain was determined using grain grader, SATAKE model TY54X. The broken grains were separated from whole grains. Percentage head rice and broken were computed using the equations:

$$\% \text{ head rice yield} = \text{wt of whole grain} / \text{wt of sample} \times 100 \quad (3)$$

$$\% \text{ broken} = \text{wt of broken grain} / \text{wt of sample} \times 100 \quad (4)$$

2.3.4. Chalkiness

The visual rating of the chalky proportion of the grain was determined using SATAKE model KU120. The measurement was done based on the Standard Evaluation System scale. The percentage chalky grain was calculated using the equation:

$$\% \text{ chalky grain} = \frac{\text{wt of chalky grains}}{\text{wt of paddy samples}} \times 100 \quad (5)$$

2.3.5. Colors Values

A color meter (CR-300, Minolta Co, Ltd, Tokyo, Japan) was used to measure the lightness and color value of whole kernel milled rice utilizing the $L^* a^* b^*$ uniform color space procedure. The value of L^* expresses the lightness value, a^* and b^* are the red/green and yellow/blue coordinates of the $L^* a^* b^*$ color space system. The instrument was calibrated with a standard white plate having L^* , a^* and b^* values of 90.10, -1.80 and 3.10, respectively. Each measurement was replicated ten times and the average value was considered. The color value (B) of parboiled rice was calculated using the following formula

$$B = \sqrt{(a^*)^2 + (b^*)^2} \quad (6)$$

2.3.6. Percentage Proximate Composition

The proximate composition of the rice was determined using the oven method described by standard official methods of analysis of the [12]. The total percentage carbohydrate content was determined by the difference method as described by [13].

2.3.7. Determination of Mineral Elements in Rice

Zinc, Calcium, sodium, magnesium, manganese, iron and potassium were determined by atomic absorption spectrophotometric method, while phosphorous was determined by molybdate method [12].

2.4. Statistical Analysis

Multiple replicates were analyzed per sample and the data generated was subjected to statistical analysis using analysis of variance (ANOVA) test.

3. Results

3.1. Combined and Main Effects of Volumetric Air Flow Rate and Fuel Type on the Milling Attributes of Paddy Parboiled Using Powered Biomass Stove

Table 1 shows the combined (average) effect of volumetric air flow rate on milling attributes of the paddy. There was significant difference ($p < 0.05$) in milling attributes of the

processed rice among volumetric air flow rates. There was no significant difference ($p < 0.05$) in the milling attributes of the processed rice between the treatments. The L-values ranged from 60.20 - 62.40 with the least values at 0.18 m³/s and 0.20 m³/s and the highest value at 0.25 m³/s. The percentage head rice (HR) ranged from 98.50 - 98.83% which were fairly the same. The lowest and highest values of (HR) were obtained at 0.25m³/s and natural air flow. Milling recovery (MR) ranged from 68.2 to 68.60% with the highest values at 0.25 m³/s and the least value at natural air flow. Similar trends were observed for milling attributes with exception of chalkiness that remained constant for all treatments. On the other hand, significant difference ($p < 0.05$) was observed in the milling attributes of the rice with L* value for briquettes higher (61.49) compared to the fire wood with L* value of (60.69). The values for other quality parameters of the milled rice showed that fire wood and briquette recorded similar values, although, briquette recorded higher values in some cases.

Table 1. Combined (Average) Effect of Volumetric Air Flow Rate and Fuel Type on the Milling Attributes of Paddy Parboiled Using Powered Biomass Stove.

VFR (m ³ /s)	L*	a*	b*	B	HR	BK	MD	MR	CHALK	UN
ANA	61.50	0.14	17.80	17.80	98.83	1.170	89.60	68.21	0.00	0.60
0.18	60.20	0.43	16.90	16.91	98.70	1.330	89.91	68.36	0.00	0.71
0.20	60.20	0.21	16.60	16.60	98.70	1.330	89.45	68.46	0.00	0.42
0.25	62.40	0.39	18.03	18.03	98.50	1.500	89.65	68.60	0.00	0.70
LSD	0.0122	0.0122	0.012	0.013	0.432	0.0447	0.441	0.010	*	0.080

ANA= average natural air flow; L* scale: Light vs. dark where a low number (0-50) indicates dark and a high number (51-100) indicates light; a* scale: Red vs. green where a positive number indicates red and a negative number indicates green; b* scale: Yellow vs. blue where a positive number indicates yellow and a negative number indicates blue; B= Yellow vs. blue; HR=% head rice; BK=% broken rice; CHALK= chalkiness/whiteness; MD=%milling degree; MR=% milling recovery; UN= unfilled grain; the analysis was done in 5 replicates

Table 2 shows the main effect of volumetric air flow rate and fuel type on the milling attributes of the paddy. There was significant difference ($p < 0.05$) in the milling characteristics of the rice at different volumetric air flow rates and fuel types. The L* values ranged from 59.10 to 63.34. The highest L* value was obtained when briquettes were used at natural air flow and the least value at 0.20 m³/s for fire wood. The B-values ranged from 16.42 to 18.22. The highest B-value (18.22) was obtained at 0.25 m³/s for wood and the least value (16.42) for wood at 0.20 m³/s. The percentage head rice ranged from 98.33 to 99.00% when wood was used at natural air flow with the highest value at

0.25 m³/s with the least value. The percentage head rice (HR) ranged from 98.33 to 99.00%. The lowest and highest values of (HR) were obtained at 0.25 m³/s for wood and natural air flow for wood as well. Milling recovery (MR) ranged from 67.93 to 68.90% with the highest values at 0.25m³/s for wood and the least value at natural air flow for briquettes.

The values for other quality parameters of the milled rice showed that fire wood and briquette recorded fairly similar values, although, briquette recorded higher values in some cases with the exception of chalkiness that showed exactly the same trend at different treatments.

Table 2. Main Effect of Volumetric Air Flow Rate and Fuel Type on the Milling Attributes of Paddy Parboiled Using Powered Biomass Stove.

FT	VFR (m ³ /s)	L*	a*	b*	B	HR	BK	MD	MR	CHALK	UN
W	N. A	59.70	0.10	17.80	17.80	99.00	1.00	89.30	67.93	0.00	0.73
B	N. A	63.34	-0.10	17.72	17.72	98.70	1.33	89.90	68.50	0.00	0.40
W	0.18	61.14	0.44	16.72	16.73	98.70	1.33	89.80	68.23	0.00	0.30
B	0.18	59.34	0.42	17.04	17.04	98.70	1.33	90.03	68.50	0.00	0.70
W	0.20	59.10	-0.04	16.42	16.42	98.70	1.33	89.33	68.43	0.00	0.37
B	0.20	60.10	0.46	16.74	16.75	98.70	1.33	89.60	68.50	0.00	0.47
W	0.25	62.30	0.64	18.22	18.23	98.33	1.67	89.30	68.20	0.00	0.63
B	sss0.25	62.50	-0.14	17.84	17.84	98.70	1.33	90.00	68.90	0.00	0.70
LSD		0.0010	0.009	0.0173	0.007	0.612	0.0633	0.624	0.13	*	0.11

L* scale: Light vs. dark where a low number (0-50) indicates dark and a high number (51-100) indicates light; a* scale: Red vs. green where a positive number indicates red and a negative number indicates green; b* scale: Yellow vs. blue where a positive number indicates yellow and a negative number indicates blue; B= Yellow vs. blue; HR=% head rice; BK=% broken rice; CHALK= chalkiness/whiteness; MD=%milling degree; MR=% milling recovery; UN= unfilled grain; the analysis was done in 5 replicates

3.2. Combined (Average) and Main Effects of Volumetric Air Flow Rate and Fuel Type on Proximate Composition of Paddy Parboiled with the Powered Biomass Stove

Table 3 shows the combined (average) effect of the volumetric air flow rates and the fuel types on the proximate composition of the paddy processed using the powered biomass stove. There was significant difference ($p < 0.05$) in the proximate composition of the processed paddy with exception of ash among the different volumetric air flow rates. The carbohydrate content of the samples was 73.93, 73.00, 72.23 and 73.35% at natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s. The average carbohydrate of the rice when processed with briquette was higher (74.41%) than fire

wood (72.83%).

Protein contents were 9.69, 9.73, 10.81 and 10.51% for natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. The average protein content for wood was lower (9.17%) than briquette (11.20%). The moisture content of the samples was 10.84, 11.75, 10.76 and 10.40% for natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. On the other hand, the average moisture content for the rice samples for wood was lower (10.74%) compared to briquette (11.13%). Similar trends were observed for fibre and energy content of the paddy with the exception of ash where similar values were obtained for both volumetric air flow rates and fuel types.

Table 3. Combined (average) Effect of Volumetric Air Flow Rate and Fuel Type on Proximate Composition of Paddy Parboiled with the Powered Biomass Stove.

VFR (m ³ /s)	Protein	CHO	Fat	Moisture	Fibre	Ash	Energy
N. A	9.69	73.93	2.35	10.84	3.10	2.25	355.59
0.18	9.73	73.00	2.70	11.75	2.85	2.50	354.23
0.20	10.81	72.23	3.10	10.76	3.10	2.20	360.06
0.25	10.51	73.35	3.25	10.40	2.50	2.20	364.67
LSD	0.045	0.045	0.12	0.012	*	0.12	0.012

VFR= volumetric air flow rate; N. A= natural air flow; LSD= least significant difference; CHO= carbohydrate.

Table 4 shows the main effect of the volumetric air flow rates and the fuel types on the proximate composition of the paddy processed using the powered biomass stove. There was significant difference ($p < 0.05$) in the proximate composition of the paddy processed using the powered biomass stove. The protein content at natural air flow for wood was lower (8.72%) than briquettes (10.65%); 8.56% for wood and 10.90% for briquettes at 0.18 m³/s; 9.91% for wood and 11.71% for briquettes at 0.20 m³/s; 9.48% for

wood and 11.53% for briquettes at 0.25 m³/s;

The carbohydrate content of the rice paddy processed using the powered biomass stove was higher (74.46%) for wood compared to briquettes (73.39%) at natural air flow; 74.02% for wood and 71.93% for briquettes at 0.18 m³/s; 73.10% for wood and 71.36% for briquettes at 0.20 m³/s; 72.06% for wood lower than 74.64% for briquettes at 0.25 m³/s. Similar trends were observed in the remaining macronutrients determined.

Table 4. Main Effect of Volumetric Air Flow Rate and Fuel Type on Proximate Composition of Paddy Parboiled with the Powered Biomass Stove.

Fuel Type	VFR (m ³ /s)	Protein	CHO	Fat	Moisture	Fibre	Ash	Energy
Wood	N. A	8.72	74.46	2.50	11.32	3.00	2.40	355.22
Briquette	N. A	10.65	73.39	2.20	10.36	3.20	2.10	355.96
Wood	0.18	8.56	74.02	2.90	11.82	3.00	2.70	354.64
Briquette	0.18	10.90	71.93	2.50	11.67	2.90	2.30	353.82
Wood	0.20	9.91	73.10	3.10	11.09	2.80	2.50	359.94
Briquette	0.20	11.71	71.36	3.10	10.43	3.40	2.51	360.18
Wood	0.25	9.48	72.06	3.20	10.28	2.40	2.40	365.28
Briquette	0.25	11.53	74.64	3.30	10.51	2.60	2.60	364.06
LSD		0.063	0.063	0.17	0.017	*	0.17	0.017

VFR= volumetric air flow rate; N. A= natural air flow; LSD= least significant difference; CHO= carbohydrate.

3.3. Combined (Average) and Main Effects of Volumetric Air Flow Rate and Fuel Type on the Mineral Composition of Paddy (µg/100g) Parboiled Using Powered Biomass Stove

Table 5 shows the combined (average) effect of the volumetric air flow rates and the fuel types on the mineral composition of the paddy processed using the powered biomass stove. There was no significant difference ($p > 0.05$) in the zinc (Zn) content of the processed paddy at natural air

flow and 0.18 m³/s. The zinc value at natural air flow and 0.18 m³/s was 0.19 µg/100g, while at 0.20 m³/s and 0.25 m³/s were 0.62 µg/100g and 0.57 µg/100g indicating significant difference ($p < 0.05$) in the zinc (Zn) content of the rice among volumetric air flow rates. The average zinc content for wood was higher (0.46 µg/100g) compared to briquettes (0.33 µg/100g).

There was significant difference ($p \leq 0.05$) in the Phosphorus (P) content of the processed paddy at different volumetric air flow rate. The values were 151.00 µg/100g,

223.50 µg/100g, 193.50 µg/100g and 194.00 µg/100g at natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. On the other hand, the average phosphorus content for wood was higher (197.50 µg/100g) compared to 183.50 µg/100g for briquettes.

There was significant difference ($p \leq 0.05$) in the sodium (Na) content of the processed paddy at different volumetric air flow rate. The values obtained were 141.00 µg/100g, 135.50 µg/100g, 127.00 µg/100g and 129.50 µg/100g at natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. On the other hand, the average sodium content for wood was lower (1327.75 µg/100g) compared to 133.75 µg/100g for briquettes.

There was no significant difference ($p \geq 0.05$) in the manganese (Mn) content of the processed paddy at different volumetric air flow rates with exception at volumetric air flow rates of 0.20 m³/s and 0.25 m³/s. The values obtained were 0.001 µg/100g, 0.004 µg/100g, 0.005 µg/100g and 0.001 µg/100g at natural air flow, 0.18 m³/s, 0.20 m³/s and

0.25 m³/s respectively. On the other hand, the average manganese content for wood was lower (0.0038 µg/100g) compared to 0.005 µg/100g for briquettes.

There was significant difference ($p \leq 0.05$) in the magnesium (Mg) content of the processed paddy at different volumetric air flow rate with exception at natural air flow and 0.18 m³/s. The values of (Mg) obtained were 146.05 µg/100g, 147.00 µg/100g, 157.10 µg/100g and 143.50 µg/100g at natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. On the other hand, the average magnesium content for wood was higher (153.50 µg/100g) compared to 143.32 µg/100g for briquettes.

The Potassium (K) content of the rice samples processed varied significantly ($p > 0.05$) at different air flow rates and fuel types. The values obtained for (K) were 207.00 µg/100g, 191.50 µg/100g, 217.50 µg/100g and 183.00 µg/100g at natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. The potassium contents for wood and briquette was 167.50 and 232.00 µg/100g.

Table 5. Combined Effect of Volumetric Air Flow Rate and Fuel Type on the Mineral Composition of Paddy (µg/100g) Parboiled Using Powered Biomass Stove.

VFR (m ³ /s)	Zn	P	Na	Mn	Mg	K	Fe	Ca
N. A	0.19	151.00	127.00	0.001	146.05	207.00	140.00	32.00
0.18	0.19	223.50	129.50	0.002	147.00	191.50	210.00	36.00
0.20	0.62	193.50	135.50	0.001	157.10	217.50	220.00	39.50
0.25	0.57	194.00	141.00	0.002	143.50	183.00	170.00	31.50
LSD	0.024	1.22	1.22	0.011	1.06	1.224	0.011	1.20

VFR=Volumetric air flow rate (m³/s); N. A= natural air flow; the analysis was done in 5 replicates

There was significant difference ($p > 0.05$) in the Iron (Fe) content of the samples as shown in Table 6. The (Fe) content recorded was 140 µg/100g, 210 µg/100g, 220 µg/100g and 170 µg/100g at natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. The average Iron contents for wood and briquette was 201 µg/100g and 180 µg/100g. There was significant difference ($p > 0.05$) in the Calcium content of the samples as shown in Table 6. The (Ca) obtained were 32.00 µg/100g, 36.00 µg/100g, 39.50 µg/100g and 31.50 µg/100g at natural air flow, 0.18 m³/s, 0.20 m³/s and 0.25 m³/s respectively. On the other hand, the average Calcium contents of the samples processed using wood and briquettes

were 37.25 µg/100g and 32.25 µg/100g. Table 6 shows the main effect of volumetric air flow rates and fuel types on the mineral composition of the rice processed using the powered biomass stove. There was significant difference ($p \leq 0.05$) in the mineral composition of the processed rice among the different volumetric air flow rate and fuel type. The zinc (Zn) content ranged from 0.023 µg/100g to 1.12 µg/100g. The highest value obtained was 1.12 µg/100g at 0.25 m³/s when wood was used whereas the lowest value (0.023 µg/100g) was recorded for briquette under the same condition. Similar trends were observed for the remaining minerals such as potassium (K), sodium (Na), etc.

Table 6. Combined Effect of Volumetric Air Flow Rate and Fuel Type on the Mineral Composition of Paddy (µg/100g) Parboiled Using Powered Biomass Stove.

FT	VFR (m ³ /s)	Zn	P	Na	Mn	Mg	K	Fe	Ca
W	N. A	0.24	110.00	142.00	0.001	156.00	250.00	140.00	36.00
B	N. A	0.13	192.00	140.00	0.001	136.10	164.00	140.00	28.00
W	0.18	0.24	230.00	134.00	0.001	147.00	160.00	210.00	38.00
B	0.18	0.13	217.00	137.00	0.001	147.00	223.00	210.00	34.00
W	0.20	0.22	270.00	126.00	0.002	160.00	145.00	230.00	42.00
B	0.20	0.20	117.00	128.00	0.001	154.20	290.00	210.00	37.00
W	0.25	0.20	180.00	129.00	0.001	151.00	115.00	220.00	33.00
B	0.25	0.23	208.00	130.00	0.001	136.10	251.00	120.00	30.00
	LSD	0.034	1.7	1.7	0.002	1.501	1.70	0.0165	1.70

FT= fuel type, B= briquette, W= wood; VFR=Volumetric air flow rate (m³/s); N. A= natural air flow; the analysis was done in 5 replicates

4. Discussion

4.1. Physical Properties of Parboiled Rice

4.1.1. Colour of Milled Rice

Significant difference ($p \leq 0.05$) was observed in the colour parameters (L^* , a^* , b^* and B) of rice between natural air flow and forced convection (Table 1). The L^* value indicates the degree of whiteness (50-100) and darkness (0-49), according to Hunter's scale [14]. There was no significant difference ($p \geq 0.05$) between $0.18 \text{ m}^3/\text{s}$ and $0.20 \text{ m}^3/\text{s}$, but was significantly higher ($p \leq 0.05$) at $0.25 \text{ m}^3/\text{s}$. Therefore, the colour of the milled rice in this work was whitish in nature. The highest L^* value recorded was at $0.25 \text{ m}^3/\text{s}$, hence increasing the air flow of the powered stove is more favorable for improvement of the color of parboiled rice than under natural convection. Increasing air flow improved parboiling temperature and favored gelatinization of the starch and disruption of the protein bodies which expanded and occupied all the air spaces in the endosperm during parboiling thus making the parboiled paddy to become more translucent and glassy. as reported by [6]. These findings are in agreement with the report of [15] who recorded L^* values ranging from 55.99 to 67.19.

The other colour parameters for the rice (a^* , b^* and B values) followed the same trends as L^* values, showing significant ($p \leq 0.05$) difference between natural air flow and forced convection and highest values obtained at $0.25 \text{ m}^3/\text{s}$. The a^* values indicate the degree of redness (0.14 - 0.43) because it is a positive integer, b^* values indicates yellowness (16.60-18.03) because the values were all positive integer, while B^* indicates translucence (16.60-18.03) according to Hunters scale [14]. The result indicates that the color of the parboiled paddy was improved as air flow was increased to the stove, showing best values at $0.25 \text{ m}^3/\text{s}$. Therefore powered stove can be adopted to improve the quality of locally processed rice.

There was significant difference ($p \leq 0.05$) in the color attributes between fuel types (Table 2). The L^* value varied significantly ($p \leq 0.05$) between fuel types at every level of air flow, the colour parameters were significantly higher and brighter when briquettes were used than fire wood. The values showed irregular variation i.e. the variation in a -value does not follow a definite pattern. The findings in this work were in agreement with results reported by [16]. The b -values ranged from 16.42 - 18.22 in the treated rice samples using briquettes and firewood, thus following the same trend observed in L^* for the fuel types. Both the treated samples and the control were yellowish in colour. According to [16, 17], this is due to maillard type non-enzymatic browning during storage of the paddy after harvest.

The B -values of the rice ranged from 16.42 to 18.23. The use of briquettes and firewood affected the color of the milled rice. Color of parboiled brown rice changed from white to yellow when both briquettes and firewood were used as energy source for parboiling. [17] observed similar trends in B -values of parboiled rice. The findings revealed that

briquette was good substitute for fire wood because the colour of the milled rice was not affected by the source of fuel used.

4.1.2. Percentage Head Rice

There was no significant effect ($p \geq 0.05$) in the percentage head rice (HR) between natural air flow and forced convection as show in Table 1. The percentage head rice (HR) ranged from 98.50% to 98.83%. The highest percentage head rice was obtained at natural air flow but since it was not significantly different ($p \geq 0.05$) from the forced convection, powering the stove at higher volume of air flow would be better than using natural air flow in order to minimize the cost of energy utilization for economic reasons. The HR obtained in this work was higher than those reported by [16] who recorded 50.92% - 84.46%.

Similarly, there was no significant ($p \geq 0.05$) difference in the percentage head rice (HR) due to fuel types as shown in Table 2. Both fuel performed well in terms of percentage head rice (HR). The values for percentage head rice obtained in this work (98.33 - 99.00%), were higher than those recorded by [17]. The authors reported head rice yield values ranging from 54% to 71% for all three rice varieties. The higher values in this work might be attributed to the soaking and steaming at the suitable conditions provided by powered stove. The use of powered stove enhanced effective heat generation which improved the gelatinization process hence HR quality [18]. The results indicated that briquettes can be used in place of fire wood in rice processing using powered stove since it performed satisfactorily in terms of HR.

4.1.3. Percentage Broken Rice

There was significant difference ($p \leq 0.05$) in percentage broken rice (BR) between natural air flow and forced convection, with more percent broken rice at natural air flow (Table 1). However there was no significant difference ($p \geq 0.05$) between $0.18 \text{ m}^3/\text{s}$ and $0.20 \text{ m}^3/\text{s}$. The low percentage broken rice (BR) observed with increase in air flow rate to the stove is an indication of good milling quality which was probably due to uniform distribution of heat for steaming, leading to improved gelatinization of the grains and minimized grain breakage during milling operation [18].

There was significant ($p \leq 0.05$) difference in percentage broken rice (BR) at natural air flow but there was no significant difference ($p \geq 0.05$) at forced convection between fuel types as shown in Table 2. The (BR) ranged from 1.00 to 1.33%. The percentage broken grain is an important quality factor for general acceptability of rice by consumers. The lower the percentage broken rice, the more the consumers preferred the rice. It can be deduced that using briquette is a good alternative for fire wood in rice processing, since fuel type did not significantly affect percentage broken grains.

4.1.4. Milling Degree

There was no significant difference ($p \geq 0.05$) in the milling degree (MD) with changes in volumetric air flow rates as show in Table 1. The milling degree ranged from 89.45% to

89.91%. The MD trend did not follow definite pattern, nevertheless, for economic reasons, higher air flow rate is preferred since the desired results were obtained faster and at reduced cost. The result obtained indicated a better milling degree compared to the findings of [17] who reported lower values ranging from 62 to 68%. The better MD was probably due to varietal difference and conditions of parboiling among other factors [19].

There was no significant difference ($p \geq 0.05$) in the milling degree as a result of a fuel types as shown in Table 2. Briquettes performed excellently as it had higher milling degree than fire wood and this gives indication that it is a good substitute for fire wood in rice processing using powered stove.

4.1.5. Milling Recovery

There was significant difference ($p \leq 0.05$) in milling recovery (MR) between natural air flow and forced convection as shown in Table 1. The milling recovery ranged from 68.21 to 68.60%. The (MR) increased with increase in volumetric air flow rate. The lowest MR was at natural air flow while the highest was at $0.25 \text{ m}^3/\text{s}$. From the results, it is evident that higher air flow rate is better for processing rice using powered stove as this improves on the milling recovery.

Table 2 also shows the main effect of fuel type on the milling recovery (MR). There was significant difference ($p \leq 0.05$) in milling recovery (MR) between briquettes and firewood. The milling degree ranged from 67.93% to 68.90%. At every volume of air flow, briquette performed significantly ($p \leq 0.05$) better, with higher milling rate than fire wood. The result obtained is in the range of that by [20] who reported the MR of 66% to 68%. Based on this observation, it is unquestionably clear that briquettes can suitably substitute fire wood used for rice processing using powered stove.

4.1.6. Chalkiness

There was no significant difference ($p < 0.05$) in chalkiness between natural air flow and forced convection as shown in Table 1. The degree of chalkiness irrespective of volumetric air flow rate was 0.00% for all the treatments. Powering of the stove showed no effect on the chalkiness of the rice.

Similarly, Table 2 shows the main effect of fuel type on the chalkiness of the rice processed using the powered stove. The fuel types showed no effect on the chalkiness of the milled rice. Chalkiness value is another factor that influences the price of parboiled rice. Several researchers have reported that the temperature and period of soaking and steaming significantly influence chalkiness of parboiled rice [9, 17, 18]. In this regard, briquettes can adequately serve as substitute fire wood to reduce indiscriminate falling of trees for rice processing.

4.2. Proximate Composition of the Paddy

4.2.1. Carbohydrate Content

There was significant difference ($p \leq 0.05$) in the

carbohydrate contents of the milled rice between natural air flow and forced convection as shown in Table 3. The average carbohydrate content of the processed rice ranged from 72.23 to 73.93%. There was no defined trend in the values with respect to changes in air flow rate. The carbohydrate content recorded in each case was appreciably satisfactory in comparison with those recorded by other authors such as [13] who reported values of 75.37 to 76.37%; but lower than those reported by [21] who reported 76.92 to 86.03% of carbohydrate.

As shown in Table 4, the rice samples contained reasonable quantities of carbohydrates ranging from 71.36 to 74.64%. The carbohydrate content of the processed rice was higher with wood than briquettes. The values for carbohydrate were less than those reported by [21], 76.92 to 86.03%; similarly, they were lower than the values of 75.37 to 76.37% reported by [13]. This low carbohydrate content may be attributed to high moisture content of rice in this work (10.40 - 11.75%) compared to that of the authors (8.86 - 9.23%), since proximate composition of the rice was expressed as relative percentage [21]. The relative high percentage carbohydrate contents of the rice samples show that briquettes are good source of energy for rice processing using powered stove.

4.2.2. Protein Content

There was significant difference ($p \leq 0.05$) in the protein content of the processed rice between natural air flow and forced convection as shown in Table 3. The values ranged from 9.69 to 10.81%. The protein content of the rice generally increased with an increase in volume of air flow although the value obtained at $0.25 \text{ m}^3/\text{s}$ was lower (10.51%) than at $0.20 \text{ m}^3/\text{s}$ (10.81%). Thus powering the stove has positive effect on the protein content. The variations in the protein content among air flow rate might not be unconnected with the fact that the starch granules might behave differently under varying conditions. Based on these results, the use of powered stove does not have adverse effect on the quality of rice as far as protein content is concerned because the trend was erratic.

As shown in Table 4, the samples had protein ranging from 8.56 to 11.71%. There was significant difference ($p \leq 0.05$) in the protein content of the processed rice between fuel types. The protein contents were generally higher when briquettes was used compared to fire wood and this might be due to variations in starch component following irreversible changes such as retrogradation and gelatinization as the rice was subjected to heat treatment. The protein values in this work are higher than the report of [22] who reported protein content of 6.22% - 7.86% for indigenous and foreign rice varieties in Nigeria. The results of this study are in agreement with earlier results reported by [13] who analyzed the proximate composition of rice in Ebonyi State. [23] observed that the protein of parboiled rice ranged between 7.94 and 9.46%. Also [24] reported that the protein content of parboiled rice ranged from 6.83% to 8.69%. The high protein content in this work may be attributed to the relative amounts

of the other macronutrients. The higher percentage of protein recorded in briquettes makes it better than fire wood.

4.2.3. Moisture Content

There was significant difference ($p \leq 0.05$) in the moisture content of the processed rice between natural air flow and forced convection as shown in Table 3. Air flow rate significantly ($p \leq 0.05$) affected the moisture content of the processed rice. The average moisture content of the rice ranged from 10.40% to 11.75%. The lowest moisture content was recorded at 0.25 m³/s. The moisture content of the rice has direct link with the time spent during parboiling/steaming as more time was spent at lower air flow rates, it was logical for the grains to absorb more water thereby increasing the relative percentage of the moisture in the final milled rice. Therefore, it can be deduced that powering the stove have positive effect by lowering the moisture content. High moisture would favour activities of micro-organisms therefore causing spoilage [22]. Based on the results, the biomass stove should be powered during rice processing with high air flow rate since that is also advantageous from the perspective of cost. Therefore, it is suggested that rice is processed at higher volumes of air flow rate to achieve low moisture content as well as reduce cost of energy utilization.

As shown in Table 4, the samples had moisture content ranging from 10.28 to 11.67%. The moisture content was higher for fire wood compared to briquettes at every given volumetric air flow rate. The higher moisture content observed for fire wood is connected with the lower heat utilization and prolonged parboiling /steaming time [21, 25]. Since using briquettes gave lower moisture content, it can serve as substitute for fire wood for rice processing using powered stove to achieve storage stability [22].

4.2.4. Fiber Content

There was significant difference ($p \leq 0.05$) in the fiber content of the processed rice between natural air flow and forced convection as shown in Table 3. The average fiber content of the processed rice ranged from 2.50% to 3.10%. The trend did not follow definite pattern in relation to the rate of air flow. The fiber content recorded in each case was higher than those reported by [23], who recorded values between 0.29 to 0.73% and that of [22] 1.5 to 2.0%. However, it was in the range reported by [13] and [26] as 1.93 to 4.3%. This difference might be attributable to varietal difference. This suggests that high air flow rate to powered stove can be used to reduce time and energy requirement during processing and cooking and achieve high fibre.

As shown in Table 4, the samples have fiber ranging from 2.40 to 3.40%. The values recorded did not show definite trend with fuel type. Therefore, briquettes can be used in rice processing as alternative to fire wood since higher fiber content was observed when briquettes was used in the powered stove.

4.2.5. Fat Content

There was significant difference ($p \leq 0.05$) in the fat content of the processed rice between natural air flow and forced

convection as shown in Table 3. The fat content increased with increase in air flow rate and ranged from 2.35% to 3.25% and this probably was due to non-leaching of fats in the water as more time spent would favour leaching of the fat [27]. Hence high volume of air would enhance the relative fat content of the rice. Therefore, powering the stove enhanced fat content of the milled rice.

Similarly, there was significant difference ($p \leq 0.05$) in the fat content of the processed rice between fuel types as shown in Table 4. The fat content ranged from 2.20% to 3.30%, although, the variation was erratic and did not follow definite pattern. The result of this work was higher than those reported by [23] who reported fat content of rice to be between 0.57 and 0.85%; the higher fat content perhaps is an indication of good milling process which was limited removal of fat during milling and polishing. It has been reported that milling of rice removes the outer layer of the grain where most of the fats are concentrated [27]. The results of this study revealed that briquettes compared favourably with fire wood. Therefore, briquettes are good alternatives to fire wood for rice processing using powered stove.

4.2.6. Ash Content

There was significant difference ($p \leq 0.05$) in the ash content of the processed rice between natural air flow and forced convection as shown in Table 3. Although there was no significant difference ($p \geq 0.05$) in the ash content of the rice between 0.20 m³/s and 0.25 m³/s but difference existed between 0.18 m³/s and other flow rates. The ash content ranged from 2.20% to 2.50%. The trend did not follow definite pattern rather it was erratic. The ash content recorded in each case was higher than those reported by [23] who recorded ash content between 0.55 and 0.97% in some local varieties of rice investigated.

Similarly, there was significant difference ($p \leq 0.05$) in the ash content of the processed rice between fuel types as shown in Table 4, although the variation was irregular as neither fire wood nor briquettes showed consistent trend. The ash content ranged from 2.10 to 2.70%. The values obtained were higher than those recorded by [23], who reported ash content of rice between 0.55 and 0.97%. Higher values obtained in this study may be due to improved steaming and parboiling conditions occasioned by the use of powered stove. The parboiling process promotes an increase in ash, compared to the white rice (of 30%) as reported by [28], and this was attributed to the migration of mineral salts during the soaking and boiling. The parboiled whole-rice usually has higher levels of ashes and proteins. Also the degree of polishing after milling, can affect the content which removes the surface layers of the grain, particularly germ and bran, where there is a higher concentration of ashes and proteins [24].

4.3. Mineral Composition of the Paddy

4.3.1. Zinc Content

There was significant difference ($p \leq 0.05$) in zinc content of the rice between natural air flow and forced convection as

shown in Table 5. However, there was no significant difference ($p \geq 0.05$) between natural air flow and volumetric air flow rate of $0.18 \text{ m}^3/\text{s}$. The zinc content of the samples ranged from 0.19 to $0.62 \text{ }\mu\text{g}$. The variations were irregular in nature, showing no defined trend with air flow rate. However, the highest zinc value ($0.62 \text{ }\mu\text{g}$) was obtained at $0.20 \text{ m}^3/\text{s}$. The volumetric air flow rates have significant effect on the zinc content of the processed rice; hence using higher air flow rates is suggested to reduce cost for energy utilization.

Similarly, there was significant difference ($p \leq 0.05$) in zinc content of the rice between fuel types as shown in Table 6 and this difference was not defined with respect to fuel type. The rice samples contained zinc content ranging from 0.12 to $0.24 \text{ }\mu\text{g}$. The values obtained were within the same range ($0.13 - 0.22 \text{ }\mu\text{g}$) published by [29]. Therefore, it can be said that briquettes can be used favorably as substitute for fire wood in rice processing.

4.3.2. Phosphorus Content

There was significant difference ($p \leq 0.05$) in phosphorus content of the rice between natural air flow and forced convection as shown in Table 5. The phosphorus content of the samples ranged from 151.00 to $223.50 \text{ }\mu\text{g}$. The variation observed did not follow definite trend in terms of the volume of air flow supplied. Such variations was observed by [30] who carried out comparative analysis of the chemical nutrient composition of selected local and newly introduced rice varieties grown in Ebonyi State of Nigeria.

Similarly, there was significant difference ($p \leq 0.05$) in phosphorus content (P) of the rice between fuel types as shown in Table 6. The phosphorus content ranged from 110.00 to $270.00 \text{ }\mu\text{g}$. The trend observed with respect to the values of P was not defined with respect to fuel type. These findings are consistent with those obtained by [31] who carried out a research to investigate the physiochemical and mineral composition of rice.

4.3.3. Sodium Content

There was significant difference ($p \leq 0.05$) in sodium content of the rice between natural air flow and forced convection as shown in Table 5. The sodium content of the samples ranged from 127.00 to $135.50 \text{ }\mu\text{g}$. The values increased with increase in volumetric air flow rate and this probably can be attributed to leaching [32]. The longer time spent at lower volume of air compared to higher volumetric air flow rate may have increased the possibility of leaching, hence the observed results. Using high air flow rate is important to improve the Sodium content of the parboiled rice using powered stove.

Similarly, there was significant difference ($p \leq 0.05$) in sodium content of the rice between fuel types as shown in Table 6. The variation in sodium with respect to fuel type ranged from 126.00 to $142.00 \text{ }\mu\text{g}$ and did not follow a defined pattern with fuel type. The values are in agreement with those obtained by [29] who reported in the range of 121.00 to $145.00 \text{ }\mu\text{g}$. Values for briquettes were higher probably due to shorter processing time as more Na might

have leached when the samples were heated for prolonged period of time using fire wood. Therefore using briquettes in rice processing as a substitute to fire wood would help a great deal in enhancing Na content.

4.3.4. Manganese Content

There was no significant difference ($p \geq 0.05$) in manganese content of the rice between natural air flow and forced convection as shown in Table 5. Manganese content of the samples ranged from 0.001 to $0.002 \text{ }\mu\text{g}$. The manganese content showed erratic pattern and did not follow definite order and as such the variations cannot be attributed to air low rate.

Similarly, there was no significant difference ($p \geq 0.05$) in manganese content of the rice between fuel types as shown in Table 6. The manganese content varied between 0.0010 and $0.0020 \text{ }\mu\text{g}$ due to fuel type. The values obtained were less than those obtained by [29] who reported values of about $2 \text{ }\mu\text{g}$. The lower values might be as a result of leaching during steaming and soaking processes as well as varietal difference.

4.3.5. Magnesium Content

There was significant difference ($p \leq 0.05$) in magnesium content (Mg) of the rice between natural air flow and forced convection as shown in Table 5. The trend was erratic and did not follow a definite order, showing dependence on air flow rate. Magnesium content of the samples ranged from 143.50 to $157.10 \text{ }\mu\text{g}$.

Similarly, there was significant difference ($p \leq 0.05$) in magnesium content of the rice between fuel types as shown in Table 6. The Magnesium content ranged from 136.10 to $160.00 \text{ }\mu\text{g}$. Although, wide range was observed for the Mg, the values obtained did not show any trend with fuel type. The result was higher than those reported by [29] who reported values ranging from $70-80 \text{ }\mu\text{g}$. Higher values obtained in this work might not be unconnected with varietal difference and improved processing conditions such as soaking, steaming and milling using powered stove.

4.3.6. Potassium Content

There was significant difference ($p \leq 0.05$) in potassium content (K) of the rice between natural air flow and forced convection as shown in Table 5. The trend was erratic and did not follow a definite order. Potassium content of the samples ranged from 183.00 to $217.50 \text{ }\mu\text{g}$. Based on the observed trends, the volumetric air flow rate has no direct bearing on the K content of the milled rice.

As shown in Table 6, the rice samples contained Potassium (K) ranging from 115.00 to $290.00 \text{ }\mu\text{g}$. The result was higher than those reported by [29] who reported values of $105-160 \text{ }\mu\text{g}$. The higher K values obtained for briquettes probably was due to short processing time when briquettes was used in relation to fire wood thereby reducing the amount of K leached. It can be deduced that briquettes can be used in rice processing instead of fire wood.

4.3.7. Iron Content

There was significant difference ($p \leq 0.05$) in iron (Fe)

content of the rice between natural air flow and forced convection as shown in Table 5. The trend did not follow a definite pattern and thus it is clear that the volumetric air flow rate had no direct bearing on the (Fe) content of the rice.

Similarly, there was significant difference ($p \leq 0.05$) in iron (Fe) content of the rice between fuel types as shown in Table 6. The rice samples contained iron ranging from 120 to 230 μg for firewood and briquettes. The wide range of values obtained perhaps was due to effect of soaking on the starch granules. The values obtained were less than those obtained by [29] who reported values of about 600 μg and this may not be unrelated to varietal differences [32].

4.3.8. Calcium Content

There was significant difference ($p \leq 0.05$) in calcium (Ca) content of the rice between natural air flow and forced convection as shown in Table 5. The trend of the calcium content was not definite. Calcium content of the samples ranged from 31.50 to 39.50 μg . Therefore, the choice of processing rice does not depend solely on the volumetric air flow rate but rather this should be determined as a composite function of other processing parameters.

Similarly, significant difference ($p \leq 0.05$) in calcium (Ca) content of the rice between fuel types was observed as shown in Table 6. The Calcium ranged from 30.00 to 42.00 μg for fire wood and briquettes. The values recorded showed irregular trends with respect to fuel types. The values obtained for minerals in this work are slightly higher than the values obtained by [33]. This slight difference might be as a result of fertilizer application, rate of parboiling and the amounts of soil nutrients all of which affect the mineral contents of rice. [32] reported that as greater amount of rice bran are removed from grain during milling and polishing, more vitamins and minerals are lost. Also [34] reported that milling decreases minerals content of rice.

5. Conclusion

The milling characteristics of the rice processed using the powered biomass stove was satisfactory as the values obtained were within the range published by other researchers. The nutritional assessment of the rice processed using the powered biomass stove revealed that the stove did enhance some quality factors such as protein, ash etc. The minerals of the milled rice were enhanced due to reduction of leaching as less time was spent during steaming.

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