DEVELOPMENT OF A RICE CLEANER CUM GRADER FOR COTTAGE INDUSTRY PROCESSORS IN NIGERIA

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ABSTRACT

The consumption of locally processed rice in Nigeria has been on the increase because of its high nutritive values and favourable government policies. There have been issues with the wide acceptability of this product as a result of the physical quality of the milled rice. A high percentage of broken grains and impurities are the issues of major concern associated with the traditional methods of processing rice. This work examines some physical and aerodynamics properties of five varieties of rice, used for the design of the developed machine. The machine utilises three reciprocating sieves with a blower revolving of 240 rpm to produce air velocity of 4.6 ms^{-1} for separating the contaminants. For an effective grading, apertures diameter of 3, 5.5 and 7 mm were selected for the bottom, intermediate and top sieves of the machine. Parboiled milled rice produced from single-pass steel huller was fed into the machine and tested at tilt angles of 2, 3, 4, 5 and 6° for the intermediate sieve at

blower inclinations of 0 and 5°. The results obtained showed the spherical mean of range 2.85 to 3.45 mm, with sphere city existing within 0.41 to 0.50 and terminal velocity from 4.81 to 6.36ms^{-1}. The machine has cleaning efficiency that ranged from 63.97 – 85.38%, with FARO 44 having the highest. The efficiency of grain grading was from 71.78 - 94.29% and the highest was obtained in ITA 150 at a blower inclination angle of 5°. The capacity obtained from the machine ranged from 1000 – 1200 kghr^{-1}. Better machine performance was obtained at blower inclination of 5°except for FARO52. The adoption of this machine after milling has upgraded cottage processed rice quality from grade 2 to grade 1.

1. INTRODUCTION

Rice is a widely grown crop in Nigeria that has become a structural component of the populace diet. Rice consumption has increased steadily over the last decade as a result of population growth and rapid urbanization. Locally produced rice has been known to be highly delicious and is gradually becoming a national delicacy gaining prominent in eateries and social functions; however, some of the physical quality of milled rice is usually poor. They are characterized with a high percentage of impurities like husk and stones as well as undersize and broken grains which reduce its economic value and makes it difficult to compete favourably with imported ones [1-2]. The low-level technology input in rice processing for cottage industry has contributed to drudgery and poor physical quality of Nigerian rice, thereby limiting sustainable food chain[3-4]. However, the demand for consumption of locally produced rice has been on the increase [5-6]

Milled rice obtained from the cottage processors utilizing a steel huller (Engleberg type) a single pass huller and polisher known for its high breakages of paddy. Milled rice is usually winnowed manually by local processors to separate the grains from the contaminants. This procedure is tedious and time-consuming and a substantial quantity of dockages, small stones and brokenremains mixed with the rice in the end. [7]. The rice has not been graded and they are not well cleaned. This explains why most local rice available in the market is characterized bya high percentage of breakages and some impurities which attracts low prices in the markets; these could be as low as half to a third of head rice value [8-9].A cleaner/grader need to be incorporated for further cleaning after milling operations.[10] accomplished the separation of stones and other contaminants with a combination of oscillating sieves variable directional air stream at 160 r/min. [11] designed and developed a second sieving and grading machine for chick pea which attained an overall cleaning efficiency of 84% with a use of four sieves vibrated at 200 rpm. Also,[12] improved on an appropriate technology cereal cleaner designed by [13] and obtained a higher cleaning efficiency of 71% for paddy than 61% when vibration occurred at 240 rpm instead of 300 to 350 rpm. Several cleaning and grading machines have been produced by companies like Satake, Alvan Blanch and several others, but this was developed with local contents to be less expensive and affordable for cottage processors in Nigeria.

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2. MATERIALS AND METHODS

2.1. Design Considerations

The design adopted some concept as suggested by [14] that separation and cleaning should use a continuous force field rather than a gravitational force and must be accompanied within a minimum space. Also, a positive means of supplying kinetic energy to the crop material is required to loosen the bulk kernels which are firmly lodged inside the straw mass. [15]) stated that mechanical methods of separating rice from foreign materials depend on the differences in such characteristics as size, shape and specific weight. [16] suggested that orientation of particles as well as the combined effect of frequency and amplitude of oscillation, the screen slope,and hanger angle and the friction between particles and screen should be considered for screen sizing. Particle movement on a sieve surface is by vibration and follows procedure suggested by [11].

Grain size determination is important in the design of screen opening. [17] suggested that grains can be best assumed spherical and their spherical mean can be obtained by taking the geometric mean of their mutually perpendicular axes and sphere city is the percentage of the ratio of the spherical mean and the major diameter. [18] stated that horizontal air stream with air speed of $4 – 6$ ms^{-1} was sufficient to separate paddy from other threshed materials.

40 whole milled rice samples were randomly selected from each of the various rice varieties (ITA 150, FARO 44, FARO 52, NERICA 1 and *IGBEMO*1 – *local cultivar*) having moisture content from 12 to 13.6% w.b. and the axial dimension of three axes (major, intermediate and minor axes were measured in three replicates using a digital vernier caliper. (Mutoyo, Japan; $0 – 150 \pm 0.01$ mm). The data was used to calculate the estimated spherical mean (geometric mean) and sphericity in equations (1)and (2)as suggested by [17].

The geometric mean$D$; $\quad D = \left(L \times W \times T \right)^{1/3}$ (1)

The sphericity of paddy θ (%); $\theta = \dfrac{\left(L \times W \times T \right)^{1/3}}{L} \times 100$ (2)

where, D = diameter of hole, mm; L = major diameter, mm; W = intermediate diameter, mm;

T = minor diameter, mm

Geometric characteristics of milled rice and the various contaminants have been determined with a view to effect separation, Also the milled rice were classified according to [19-20]. A grain classification technique used by [11] was adopted to group the spherical mean of the milled rice by a relative frequency distribution. Light weight materials shall be blownoff by air blast, while heavier straws and stalk slide over the top and intermediate screens as over tailings. Whole grains (L ≥ ¾ original length) shall be separated from stones and broken grains by bottom screen inclination and vibrations.

The terminal velocity of the five varieties of rice was determined with a wind column apparatus as described by [21] and the coefficient of friction of the rice varieties on galvanized steel and stainless steel was determined using a laboratory slope-meter apparatus following the procedure described by [11] and angle of repose of the rice varieties according to [22].

2.2. Design for the Rice Cleaner cum Grader

The cleaner cum grader was designed to be portable utilizing electric motor (or Internal combustion engine) sourceto clean and grade milled rice into whole grains and broken grains

which shall be collected in different receptacles and will also blow away light impurities with the aid of air blast from the blower while heavy over tailings will fall towards the air exit of the blower. The machine had been designed using relevant engineering principles and theories. Figure 1 shows the isometric diagram of the machine.
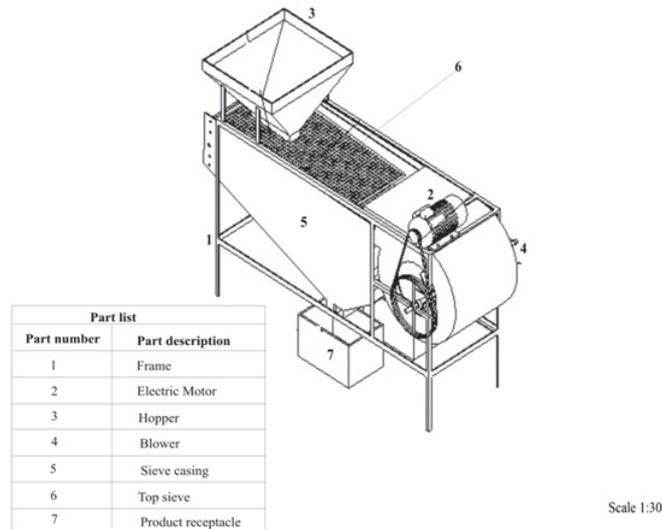

Part list	
Part number	**Part description**
1	Frame
2	Electric Motor
3	Hopper
4	Blower
5	Sieve casing
6	Top sieve
7	Product receptacle

Scale 1:30

Figure 1: The isometric diagram of the rice cleaner cum grader. [7]

2.2.1. Sieve Characteristics and Sieve Mechanism

The sieves were characterized by parameters such as the type of holes, the effective size of opening and co-efficient of opening. Circular opening was selected for all the sieves and the diameter of each sieve was the effective size of opening, hence the co-efficientof opening, $C_o$is the ratio of open area to total area was taken as 40% for the top and intermediate sieves while 90% was chosen for the bottom sieve to allow effective separation of broken grains from the whole kernels [13] and sieves aperture were selected using [11] criterion for relative frequency distribution for size interval of five varieties of chickpea.

For circular sieves,

$$C_O = \frac{3\pi}{2} \frac{D^2}{[D+d]^2} (3)$$

where, D = diameter of hole, mm and d = distance between two successive holes, mm.

The basic requirement for grain separation is that there must be grain movement on the sieve surface towards the lower end of the sieve in a vibration mode. The sieve to and fro motion is effected by an eccentric connection to a power source. The sieves as a result of the eccentric drive connection to the casing experience horizontal oscillation and small vertical motion. The combined motion ensures that the grains move or slides down from the screen and at the same time bounces to give the whole bulk a stir.

The sieve motion ensures the grains hops or slides down from the sieves in order to give the whole bulk a stir. Screen and hanger angles are provided to ensure efficient separation. Figure 2 shows the screen movement in two extreme positions. The side view of the machine is shown in plate 1. All the three sieves were positioned inside the sieves casing with the upper sieve fixed at 2°, lower sieve at 15° while the intermediate sieve could be varied at 1°intervals between 2° and 6°. The front view of the machine in plate 2 shows the three sieves and the deflector.
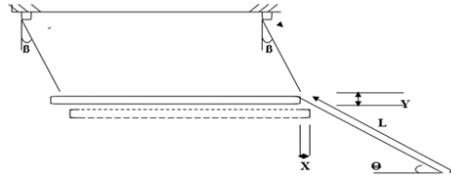
Figure 2: Position of connecting rod at two extreme points

where

ß = hanger angle^0; Θ = screen angle ^{0}; L = Crank length, m; Y = vertical displacement, m;
X = Horizontal displacement, m.

Plate 1: Side view of the cleaner grader

Plate 2: Front view of the cleaner grader showing deflector in between the middle and bottom sieves

2.2.2. Power Requirement

The theoretical power requirement for oscillation of the sieve assembly can be approximated by summation of power required for the movement in the vertical and horizontal direction and was determined using equations 4 to 8 [11]

For vertical

$$HP_1 = \frac{W_s \times N \times 2 \times Y}{4500}$$

(4)

For horizontal

$$HP_2 = \frac{W_s \times N \times 2 \times X \times \mu}{4500} \qquad (5)$$

where,

W_s = Weight of reciprocating unit with materials on it (320 kg); N= Speed, 240 r/min;

X = Horizontal displacement, m; Y = vertical displacement, X tan 15^0, m;

μ = Co efficient of friction between hinges, 0.3 [22]

$$HP_1 = \frac{320 \times 240 \times 2 \times 6.7 \times 10^{-3}}{4500} = 0.22 hp \qquad (6)$$

$$HP_2 = \frac{320 \times 240 \times 2 \times 2.5 \times 10^{-3} \times 0.3}{4500} = 0.26 hp \qquad (7)$$

Available power for blower, HP_b

$$HP_b = HP - (HP_1 + HP_2) \qquad (8)$$

$$HP_b = 2 - (0.22 + 0.26) = 1.52 hp$$

2.3. Cleaning and Grading Machine Specification

The cleaner grader specification at the time of construction is as shown in Table 1.

Table 1: Cleaner - grader components specification

Machine particulars	Specification
Overall length	2060 mm
Overall width	500 mm
Overall height	1350 mm
Support frame	1500 mm x 500 mm x 1000 mm
Machine capacity	1000 – 1200 kgh^{-1}
Power requirement	1.5 kw with 1450 rpm electric motor
Power transmission	A 56 V belt & pulley: Ø 360 mm,60mm
Fan shaft	Ø 25.5 mm
Fan housing	Ø 560 mm
Fan blade	6, 230 mm x 320 mm
Airflow channel inlet	Ø 280 mm
Airflow channel outlet	180 mm x 360mm
Sieve dimension	38 x 95 mm
Sieve apertures	Ø 3mm, 5.5mm & 7 mm
Sieve inclination	Bottom 15° Intermediate 2,3, 4,5 & 6° Top 2°
Connecting rod length	600 mm
Eccentric radius	25 mm

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2.3. Milled Rice Cleaning and Grading

The milled rice (feed)obtained from the single pass rice mill was fed into the cleaner/grader through the hopper for further separation, this machine vibrates its sieve assembly which contains three sieves of aperture sizes diameters of 3, 5.5 and 7mm at 240rpm. The bottom and top sieve tilt angles were maintained at15and 2° respectively while the intermediate sieve was varied between 2 and 6° at 1° intervals to determine the extent of cleaning during the experiment. However, the blower inclination was varied between 0 and 5° to the horizontal as shown in Plate 3. All the sieves were fixed inside the sieve casing suspended by four hangers with a hanger angle of 5° and received oscillating motion by an eccentric drive of 25 mm obtained from the fan shaft. Milled rice were fed into the hopper with a gate opening set at 6mm to allow for effective distribution and enoughresident time over the sieves for through separation and grading. The milled rice was sorted into four categories, namely; light materials away from the top sieve, over tailings sliding over the lower ends of the two upper sieves, broken / undersized/small stones and whole kernels into receptacles located at opposite sides of the machine. Final separation of the rejects and product obtained from the receptacles into a whole and broken grains were done with a 2mm square sieve mesh. Grains with 3/4 or more length were regarded as the whole kernel while those shorter were taken as broken [18]. For purposes of evaluation, the following terms and nomenclature were adopted for the separation efficiency as used by [12-13]. Method for separation processes is shown in equations 9 to 12

1. Efficiency of separating whole grain - E_{GR}

$$E_{GR} = \left(\frac{GP}{GP + GR} \right) \times 100$$

(9)

2. Efficiency of separating materials other than grain (MOG) - E_{BC}

$$E_{BC} = \left(\frac{BR}{BR + BP} \right) \times 100$$

(10)

3. Cleaning Efficiency

$$E_T = \frac{E_{GR} \times E_{BC}}{100}$$

(11)

4. Efficiency of grading of whole grain in products

$$E_G = \left(\frac{GP}{GP + BP} \right) \times 100$$

(12)

Plate 3: Blower assembly at 5° inclination to the horizontal

3. RESULTS AND DISCUSSION

3.1. Grain Size Characteristics

The axial dimension, spherical mean and the sphericity of milled rice by variety were presented in Table 2. The length has the greatest nominal diameter followed by width and thickness in all the rice varieties. ITA 150 and FARO 44 were slender grains having L/W ≥ 3.0 while other varieties are bold grains and L/T ranged from 3.26 to 4.26 which is greater than 2.0 hence justifying the incorporation of vertical motion on the vibrating sieves as suggested by [11] for improved separation.

Table 2: Axial dimension, spherical mean and sphericity of milled rice by variety (N = 40)

Parameter		Rice variety				
		ITA 150	**FARO 44**	**FARO 52**	**NERICA 1**	***IGBEMO* 1**
L	Mean ± S.D.	7.22 ±0.98	6.69±0.52	7.26±0.74	5.93±0.72	6.21±0.55
	Range	5.33-8.77	5.51-7.57	5.91-9.07	4.46-7.16	5.36-7.95
W	Mean ± S.D.	2.20±0.11	2.28±0.15	2.34±0.14	2.39±0.16	2.50±0.24
	Range	1.93-2.47	2.09-2.85	2.07-2.59	2.15-2.68	1.94-2.97
T	Mean ± S.D.	1.68±0.14	1.64±0.14	1.71±0.16	1.82±0.10	1.67±0.16
	Range	1.29-1.98	1.36-2.18	1.43-2.16	1.59-2.07	1.39-2.00
D	Mean ± S.D.	2.99±0.22	2.92±0.15	3.07±0.16	2.95±0.17	2.96±0.22
	Range	2.42-3.35	2.63-3.50	2.84-3.39	2.65-3.25	2.60-3.52
Ψ	Mean ± S.D.	0.41±0.04	0.44±0.03	0.42±.03	0.5±0.05	0.48±0.03
	Range	0.38-0.50	0.40-0.51	0.37-0.49	0.43-0.62	0.40 - 0.54

L=Major diameter, mm; W = Intermediate diameter perpendicular to L, mm; T = Minor diameter perpendicular to L and W, mm; D = Spherical mean, mm; Ψ = sphericity

From data collected on the spherical mean, Microsoft Excel was used to determine the overall spherical mean to be 3.05 mm and grain classification technique as used by [9] was adopted to group all the spherical means of the parboiled milled rice. This is as shown in Table 3 and a 3.00 mm diameter aperture with 90% co-efficient of opening was selected for the bottom sieve of the grader to separate whole kernels from broken/undersized ones.

Table 3: Classification of frequency spherical mean of all varieties of parboiled milled rice

Spherical Mean ≤ (mm)	Relative Frequency (%)	Cumulative (%)
2.60	2	1.11
2.80	24	14.44
3.00	54	44.44
3.20	51	72.78
3.40	37	93.33
3.60	11	99.44
3.80	1	100.00

3.2. Terminal Velocity for the Rice Varieties

The terminal velocity for the various rice varieties were presented in Table 4.

Table 4: Terminal velocity of whole kernel milled rice by variety

Variety	ITA 150	FARO 44	FARO 52	NERICA 1	IGBEMO 1
Terminal Velocity (ms^1)	5.41±0.28	5.15±0.31	5.28±0.29	5.44±0.23	5.71±0.19

Table 4 shows the mean values of terminal velocity of milled rice. The terminal velocity of the whole kernel ranged from 5.15 to 5.71 ms^{-1} and broken grains from 3.18 to 5.51 ms^{-1} while damaged kernel were observed to range from 2.60 to 4.5 ms^{-1}. An air velocity of 4.6 ms^{-1} used by the machine is adequate for separation of good grain from light contaminants and damaged kernels in the milled rice of all the varieties as it exceeds the speed of 3.05 ms^{-1} recommended by [23]. However, the overlap of terminal velocities of whole and broken kernels requires agitation of sieves for further separation. Small stones present as contaminants in milled rice cannot be separated with air blast as their terminal velocities have been determined to range from 11 to 14 ms^{-1} [20]. Moving air cannot be used to effect a separation between milled rice and heavy contaminants like stones other criteria like the size and specific gravity differences between them will be required.

3.3. Co-efficient of Friction and Angle of Repose for the Parboiled Milled Rice Varieties

The co-efficient of static friction obtained for all the parboiled milled rice varieties values ranged from 0.36 to 0.37 radians on mild steel and was from 0.24 to 0.25 radians on stainless steel with standard deviation from the average being ± 0.006 in both cases. This implies that the rice cultivars will conveniently slideover the sieves during cleaning/grading. The higher values observed for kernels contact on the mild steel over the stainless steel was as a result of the smoother surface of the stainless steel, however, the mild steel material was selected for cost-effectiveness. The steepest sieve was fixed at an inclination of 15[o] and was 5.9[o] less than the angle of friction on milled rice. This satisfies the requirement that sieves must be placed at an angle 4 – 8[o] less than the angle of friction of rice grains for effective motion [11].

The angle of repose was observed to range from 28.7 to 29.8[o] on mild steel and 28.1 to 29.4[o] on stainless steel. The class range was less than 2[o]. An angle of slope of 36[o] was chosen as suitable for the hopper inclination to allow easy flow of the milled rice into the machine from a milled steel hopper. This satisfies the observation of [25] that hopper inclination should be 8 to 10[o] greater than the angle of repose of grain for gravity discharge.

3.4. Machine Efficiency

The machine was evaluated for it cleaning and grading capability. The separation of whole grain from broken grains and other contaminants was also evaluated. Cleaned milled rice and materials other than whole grains were collected at various receptacles, weighed and recorded foranaverage of three replicates investigated. Using equations 9to 11, the effect of tilt angle to the grading efficiencies were presented in Figure 3 and 4.
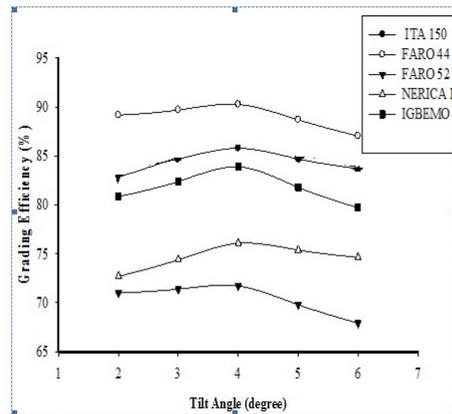
Figure 3: Efficiency curves for grain grading of parboiled rice at 0° blower inclination

Grading efficiency (E_G) of parboiled rice at 0° blower inclination ranged from 67.9 to 90.3% and the highest was obtained in FARO 44. The general trend in all the varieties investigated was that as the tilt angle increases, the E_G increases. It reached the peak at a tilt angle setting of 4° and thereafter a decline was observed. All the rice varieties have different efficiency curves. This implies that rice variety has influence on the grading efficiency of the machine. The HRY and the broken grains/chaff obtained during milling were significantly different ($p<0.05$) and as the grains were fed into the machine, different E_G results. Three distinct categories of curves were observed, FARO 44 and FARO 52 had a slight increase or gentle gradient as the tilt angle increase until 4° which later decreases with a steep gradient, while NERICA I and ITA 150 had E_G with a steep gradient as tilt angle increases to 4° then a gradual decrease beyond it. *IGBEMO* I had rather a steady gradient increase towards tilt angle of 4° and decrease beyond it. These differences can be attributed to the significantly different ($p<0.05$) properties of shape factor, spherical mean and sphericity in the rice variety as well as the output of the rice huller.

The following quadratic equations generated from the efficiency curves in Figure 3 describe the relationship between the selected tilt angles and the E_G ($p<0.05$) at 0° blower inclination.

$$E_{gITA150} = 7.794 + 3.711x - 4.606x^2 \quad (R^2 = 0.91) \tag{13}$$

$$E_{gFARO44} = 8.453 + 3.205x - 4.664x^2 \quad (R^2 = 0.96) \tag{14}$$

$$E_{gFARO52} = 6.666 + 3.711x - 4.867x^2 \quad (R^2 = 0.97) \tag{15}$$

$$E_{gNERICA1} = 6.539 + 4.664x - 5.221x^2 \quad (R^2 = 0.95) \tag{16}$$

$$E_{gIGBEMO1} = 7.202 + 5.924x - 7.765x^2 \quad (R^2 = 0.92) \tag{17}$$

where, x = Tilt angle (^{0})

The R^2 from the above regression models were high and it ranged from 0.91 to 0.97 indicating that change of tilt angle has strong effect in the determination of E_G in the machine performance.
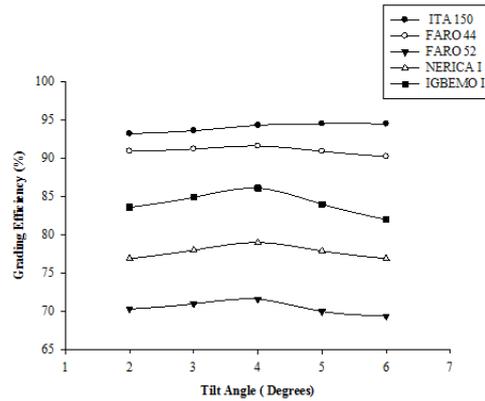
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Figure 4 Efficiency curves for grain grading of parboiled rice at 5^0 blower inclination

From figure 4, the efficiency curves for parboiled rice varieties at 5^0 blower inclination shown; the E_G ranged within 69.4 to 94.5%. The highest grading values were obtained in ITA 150 at 6° tilt angle while all other rice varieties had peak performance at a 4° tilt angle with the E_G decreased beyond this point. The E_G in ITA 150 was different from other varieties as it increases gradually as the tilt angle increases from 2° until a maximum was obtained at 6°. In *IGBEMO*1there were remarkable increases in the performance of the machine at 5° blower inclination than at 0° as minimum E_g moved from 67.9 to 71.6% and maximum E_G from 90.4 to 94.5%. This can be attributed to an increase in the effect of drag force on free falling materials from the hopper as well as particle orientation to the air stream [4]

The following quadratic equations describing the relationship between the selected tilt angle and the Eg ($p < 0.05$) at 5° blower inclination were generated.

$$E_{gITA150} = 9.132 + 1.093x - 7.28x^2 \quad (R^2 = 0.97) \tag{18}$$

$$E_{gFARO44} = 8.852 + 1.601x - 2.214x^2 \quad (R^2 = 0.93) \tag{19}$$

$$E_{gFARO52} = 6.678 + 2.463x - 3.429x^2 \quad (R^2 = 0.82) \tag{20}$$

$$E_{gNERICA1} = 7.148 + 3.59x - 4.5x^2 \quad (R^2 = 0.92) \tag{21}$$

$$E_{gIGBEMO1} = 7.586 + 5.247x - 7.071x^2 \quad (R^2 = 0.93) \tag{22}$$

where$x$ = Tilt angle (^{o})

The R^2 from the above regression models were high and it ranged from 0.82 to 0.97 indicating that change of tilt angle has a strong effect in the determination of Eg in the machine performance.

4. CONCLUSION

The physical and aerodynamic properties of the rice varieties evaluated showed that the variety of rice had a significant effect on the size characteristics of milled rice. The cleaning/grading equipment was developed with local content to improve the physical quality of Nigerian milled rice for enhanced price value. This machine incorporation into rice processing at cottage industry can function as a secondary processing equipment. The bottom sieve of 3 mm diameter was able to screen out broken and other undersized foreign materials. Milled rice quality was upgraded from grade 2 to grade 1 in all the varieties. The production

cost of the prototype was 850USD. Commercializing this machine will be a viable tool for improved small-scale rice processing in the country.

REFERENCES

[1]   FAO. FAO Rice conference. http://oryza.com/africa/nigeria/index.html. 2004

[2]   Adisa A. F.,.Eberendu,N. O,Aderinlewo, A. A. and. Kuye, S. I. Performance evaluation of a developed rice-processing machine.Journal of Agricultural Engineering,506: 2016, 171-176.

[3]   Adewunmi, J. K.,Olayanju, T. M. A and Adewuyi, S. A. Support for Small Rice Threshers In Nigeria. A- DFID/PROPCOM, Nigeria Project. Available from: http://www.propcommaikarfi.org/wp-content/uploads/2013/08/23-Support-for-small-rice-thresher-in-Nigeria--07.pdf.2007.

[4]   Okunola, A. A. and Bamgboye,A. I. Development of a rice cleaning and grading machine CIGR Section VI International Technical Symposium Towards a sustainable food chain process Nantes, France. April 11 - 16. http//www:impascience.eu/CIGR/510proceedings/013_sessions2.3postharvest.pdf?2011.

[5]   GAIN. Global Agricultural Information Network. Nigerian Grain and Feed Regional Rice Annual Report No. 11015. 2011.

[6]   Oyeleye,O. The continued rise in trice production in Nigeriawww.thisdaylive.com/articles//the-continous-rise-in-rice-production-in-nigeria/181713.2014

[7]   Okunola, A. A. Development of a cleaning and grading machine to improve quality of milled rice (Qryza sativa L.) A Ph. D Thesis in the department of Agricultural and Environmental Engineering of the University of Ibadan, Nigeria. Available on http://80.240.30.238/handle/123456789/680/ui_thesis_okunola_a.a._development_2011_full_work.pdf?2011

[8]   Lu, R and Siebenmorgen T. J. Correlation of head rice yieldto selectedphysical and mechanical properties of rice kernels. Trans. America Soc. of Agricultural Engineers 38. 3, 889 -894. 1995

[9]   Lyolds, B. J., Crossen A. G. and Siebenmorgen T. J. Evaluation of two methodsfor separating head rice yield from brokens head rice yield determination. Applied engineering in Agriculture 17.5,643 – 648. 2001

[10]   Ogunlowo, A. S and Adesuyi, A. S. Design and construction of a rice destoner Agricultural Mechanization Asia, Africa and Latin America30(1):1999, 20-24.

[11]   Tabatabaeefar, A. Aghagoolzadeh, H. and Mobli, H. The Design and Development of an Auxillary Chick Pea Second Sieving and Grading Machine Agricultural Engineering International: The CIGR EJournal, Vol. V, 2003.

[12]   Okunola A. A., Igbeka J. C. and Arisoyin, A. G. Development and evaluation of a cereal cleaner. Journal of Multidisciplinary Engineering Science and Technology2(6):2015, 1587 – 1593.

[13]   Igbeka, J. C. An appropriate technology cereal cleaner.Agricultural Mechanisation in Asia, Africa and Latin America.15(2): 1984, 67-70.

[14]   Kewal, K. P. Combine separation and cleaning device – Design Conceptions. Trans.American Soc. of Agricultural Engineers 19(6):1976, 1025-1028.

[15]   Henderson, S. M. and R. L. Perry. Agricultural Process Engineering.Westport Connecticut:3rdEd. AVI. Publishing Company Inc. 1976.

[16]   Harrison, H. P. and A. Blecha. Screen Oscillation Aperture Size – Sliding Only Trans.American Soc. of Agricultural Engineers 26(2):1983, 343-348.

[17]   Moshenin, N, N. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers. , 1986: 20-89.

[18]   Kashayap M. M. and Pandya, A. C. Air velocity requirement for winnowing operations. Journal of Agricultural Engineering Research 11(1):24–32.1986

[19]   Shultz, M. J. Mordern processing and milling of rice. Proceedings Association of operative millers. Louisville., 7627 – 7631. 2001.

[20]   Sampang, R.L.Paddy and milled rice grading. In physical grain characteristics of paddy / milled rice and its grades and standards. http://www:fao.org/docrep/x5048e/x5048E02.htm, 2008.

[21]   Adegbulugbe, T. A. Selected physical properties of three varieties of cowpea (Vignaungulculata (L) Walp) as influenced by environmental factors and moisture content. A Ph.D. thesis in the department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria2004.

[22]   Joshi D.C., Das, S. K. and Mukherjee, R. K. Physical properties of pumpkin seeds. Journal of Agricultural Engineering Research 54(3):1993, 219 – 229.

[23]   CMTI. Machine tools design handbook. Central Machine Tool Institute. Bengalore, India: Tata Mcgraw Hill, 1982.

[24]   German, R. F. andLee, J. H. A. Grain separation on an oscillating sieve as affected by air volume and frequency. Transactions A.S.A.E. 12(6):1969, 883-885.

[25]   Micheal A. M. and Ohja, T. P.Principles of Agricultural Engineering. Gordon and Breach publishers, New York 1987, 115 – 187.