Development And Evaluation Of A Cereal Cleaner

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***Abstract*—A portable cereal cleaning machine was developed to use forced air from a rotary fan and reciprocating sieve driven by an eccentric shaft for separation of grain from grain-impurity mixture. The machine was constructed from locally sourced materials and capable of being operated with an electric motor or internal combustion engine. Two sieves of 8 mm diameter and 3 x 2 mm^2 oblong apertures were used for the upper and lower sieve respectively. The sieve assembly suspended by hangers experienced horizontal oscillation and small vertical motion thus displacing the grain from its stationary position to effect sorting and cleaning. During the test, the angle of tilt of the sieve was varied between 3 and 8° while the hanger angle and fan speed was maintained at 5° and 240 rpm respectively. The machine optimum performance was 98% product purity at a total separation efficiency of 71 % for Paddy rice at 3° tilt angle. Results indicated that paddy rice could be effectively separated from light materials of much lower terminal velocity and also from heavy materials like stones and leave stalks due to difference in geometrical and aerodynamic characteristics. Whole grains and glumes were successfully separated into different receptacles.**

Keywords—Cereal cleaner, paddy rice, impurities, screen aperture, terminal velocity, tilt angle

I. INTRODUCTION

Cereals like maize, rice, sorghum and millet are principal grain crops grown in Nigeria. Various government programmes embarked upon since inception of National Accelerated Food Production Project (NAFPP) in 1972 has led to increased grain production in Nigeria. In addition the recent Agricultural Transformation Agenda (ATA) has also resulted in significant increase in rice production. It has been reported that the Federal Ministry of Agriculture and Rural Development Growth Enhancement Support so far has helped Nigerian rice farmers to increase their output in rice production from 4.47 million MT in 2010 to 5.43 million MT in 2012 [1, 2].

Foreign materials get into cereals during harvesting, handling and transportation. These unwanted materials must be significantly reduced or completely removed for good market value for grains and their products. Also the quality of flour, bread and macaroni is affected by the degree of cleanliness of seeds that go into this product [3].

In Nigeria until of recent, the demand for consumption of locally produced rice is low. This has been attributed to poor harvesting and post harvest handling method which encouraged the presence of contaminants such as stones, stick, chaff and leave stalk as well as low operational quality of the processing equipment [4, 5].

Many types of processing equipment have been developed and are used in many parts of the world to clean seeds, grains and beans. Most of these machines are expensive and require electricity to operate. These are therefore beyond the reach of majority of our farmers (peasant) who produce more than fifty percent of food crops in Nigeria [6]. The traditional method of winnowing employed by the peasant farmers cannot effectively handle the increased grain production of the country. Hence, there is need to develop cereal cleaner which is portable, low cost and can operate with petrol / diesel engine in rural areas and electric motor in urban areas.

Reference [7] stated that mechanical methods of separating rice from foreign materials depend on the difference in such characteristics as size, shape and specific weight. It has also been observed that chaff -like materials were removed from cereals like wheat, rye and soybeans at air velocity of 3.05 m/s which is less than their terminal velocities [8]. Terminal velocities of some rice varieties grown in the South West of Nigeria were found to exist in the range of their mean values between 5.06 to 5.19 m/s and there were no significant differences among the different varieties [9]. At low feed rate of 22 - 34 kg/min, chaff materials were dispersed by air blast before reaching the upper sieve of a combine [10]. Reference [11] established that at high feed rate in a combination of aerodynamic and mechanical process, grain – impurity mixture form a mat on the sieve rather than been separated.

Orientation of particles as well as combined effect of frequency, amplitude of oscillation, the screen slope, hanger angle as well as the friction between particles and screen is parameters that should be considered for effective screen sizing. Grain size determination is important in the design of screen opening [12]. Grains are best assumed spherical and their spherical mean can be obtained by taking geometric mean of their mutually perpendicular axes and sphericity is the percentage of ratio of the spherical mean and the major diameter [13]. When the value of sphericity is greater than 85 %, circular shaped sieves is sufficient for final separation while those that within 32 to 50 % require an oblong shaped sieve [14]. Optimum tilt angle of sieves for a cereal cleaner occurred between 4 and 5° when operating between 300 and 350 rpm with a cleaning efficiency of 61 % [6].

This machine was designed as a pre - cleaner for paddy rice cleaning and can be operated by electric motor or diesel engine. It cleans and sort grains by the use of reciprocating sieve arrangement in a sieve assembly and air blast from a rotary blower.

II. MATERIALS AND METHODS

A. *Design conception and analysis*

The geometrical characteristics and aerodynamic properties of the various materials of the grain impurity mixture are considered for effective separation in the design of the cereal cleaner. The lightweight materials are blown off by air blast, while the heavier straws and stalk slide over the sieve and fall off as over tailings. The whole grains are separated from broken ones by the sieve arrangement with its vibrating motion. This design adopted some concept that separation and cleaning should use a continuous agitation force rather than a gravitational force and must be accompanied within a minimum space [15]. Also a positive means of supplying kinetic energy to the crop material is required to loosen the bulk kernels which might be firmly lodged inside the straw mass.

Moisture contents of three replicates of the paddy samples were obtained using rapid oven method at 130 ^{o}C for 1 hr. Thirty (30) paddy rice samples were randomly selected from the various rice varieties and the axial dimensions of three axes (major, intermediate and minor) were measured in triplicates using a digital vernier calliper (Mutoyo, Japan).The data was used to calculate the estimated spherical average as suggested by [13]. The average dimension of the whole grains of paddy randomly picked for major diameter (L_1), minor diameter (L_2) and thickness (L_3) were 9.04 mm, 2.82 mm and 1.98 mm respectively. The value of L_1 / L_3 = 4.5 is greater than 2.0 implies that horizontal and vertical displacement will be required for the separation [14]. Also sphericity was determined to be less than 50 %, hence an oblong shaped sieve will be required for the final separation [13,14]. Particle movement determination follows the procedure reported by [6].

B. *Screen characteristics*

Screen are characterised by parameters such as aperture shape, effective size of opening and the co-efficient of opening, C_o.

(a) For circular opening;

$$C_o = \frac{3\pi}{2}\left[\frac{D^2}{\left[D+d\right]^2}\right] \tag{3}$$

Where D = diameter of hole (mm)
d = distance between two successive holes (mm)

(b) For oblong opening;

$$C_o = \left[\frac{DL - 0.22D^2}{D - d\left[L + d_1\right]}\right] \tag{4}$$

Where *L* = length of opening (mm)
D = width of opening (mm)
d_1 = distance between adjacent lateral side (mm)
d = distance between elongated sides (mm)

For efficient screening, *Co* is taken as 40 % [6] screen selection for top screen should be such to drop grains through smallest hole possible and preventing over tailings, while that of bottom screen retain whole grains until channeled into the good receptacle, broken grain and other undersize contaminant passes through it. Screen diameter of 8 mm and a 3 mm by 2 mm oblong opening were chosen for upper and lower screen respectively.

C. *Sieve mechanism*

The sieves / screen were fixed inside the sieve assembly which is suspended by hangers. The hanger angle was fixed at 5° while the upper screen was adjustable from 3 to 8° and lower sieve was fixed at 15°. The screens as a result of eccentric drive connection to the casing experience horizontal oscillation and small vertical motion. The combined motion ensures that the seeds move or slide down from the screen and at the same time hop up to give the whole bulk a stir. Screen and hanger angle are provided to ensure efficient separation.

The connecting rod L, imparts velocities in X and Y directions on the sieve assembly as shown in Fig. 1, the force exerted by the reciprocating assembly on the particle sliding over the screen in horizontal and vertical direction depends upon the position of the screen. Theoretical power requirement for oscillation can be approximated by summation of power required for the movement in the vertical and horizontal directions.

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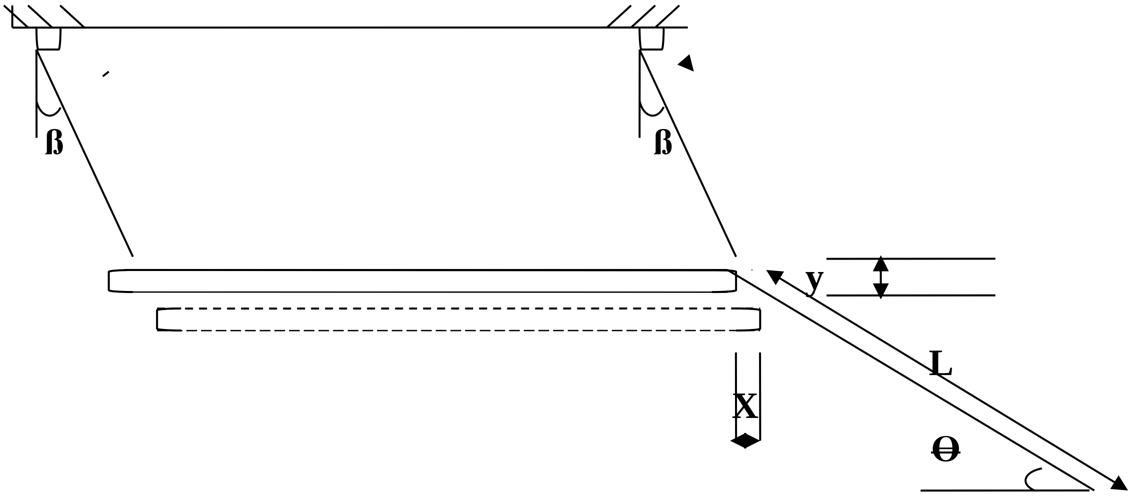


Fig.1 Position of connecting rod at two extreme points

For vertical

$$H_{p_1}| = \left[\frac{W_s x N x 2 x Y}{4,500}\right] \quad (5)$$

For horizontal

$$H_{p_2} = \left[\frac{W_s x N x 2 x X x \mu}{4,500}\right] \quad (6)$$

W_s – weight of sieve assembly and test materials on it (300 Kg)
N - Speed in revolutions per minute, (240 rpm).
Y- Vertical displacement of the reciprocating assembly in meter per stroke, X tan 15^o
X - Horizontal displacement of reciprocating assembly in meter per stroke, 2.5 x 10-^{2} m

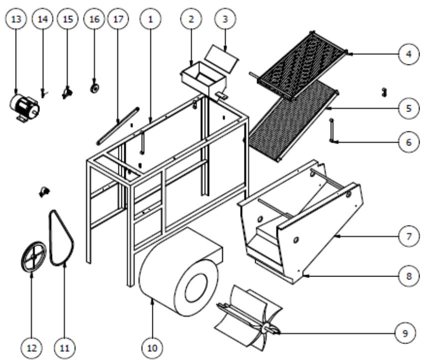
μ - Co-efficient of friction between hinge points (0.4).

From eqn. 5 and 6, Hp_1= 0.2 hp and Hp_2= 0.32 hp
Available power for blower
= Electric motor Hp – (Hp_1+ Hp_2)

= 2.0 - 0.54 = 1.46 hp

D. Basic features of the cereal cleaner

The cereal cleaner is made mainly of galvanised sheet (gauge 14) and 4 cm by 4 cm angle iron. From Fig. 2, the principal components of the machine are shown and it consisted of the seed hopper with its metering device at the base, the sieve assembly and collection units, the fan and its housing unit as well as the supporting frame and the drive components. The cleaner was operated by a 2 hp electric motor mounted blower end of the frame. A continuous feed of grain impurity mixture comes unto the screen through the metering device at the base of the hopper. Separation of chaff, straw and stalk is effected by the blower while the grains are further separated into whole and glumes (undersize materials) by the sieves.



PARTS LIST		
ITEM	QTY	PART NAME
1	1	frame
2	1	hopper
3	1	hopper slide gate
4	1	upper sieve
5	1	lower sieve
6	4	hanger
7	1	chamber
8	1	outlets
9	1	fan
10	1	blower's chamber
11	1	belt
12		driven pulley
13	1	electric motor
14	22	bolt&nut
15	2	bearing
16	2	driver pulley
17	1	connecting rod

Fig. 2.Exploded view of the cereal cleaner

E. Frame and hopper

The frame was constructed from angle iron with joints welded together with gauge 12 electrodes for rigidity. The frame configuration is such that it supports the hopper, the blower and suspends the sieve assembly as well as the drive unit. Plates 1 and 2 shows the front and the oblique view of the cereal cleaner respectively. The hopper has a capacity of 3.55 x 10^{-2} m^3. It is made of flat sheet folded into a rectangular prism, tapering down at the base. The top of the hopper measures 50 cm by 50 cm. A slide gate mechanism was used for metering of grains into the sieve assembly.

F. Cleaning unit

This unit consists of two different sieves of different size openings and a centrifugal fan. The sieves were made from iron sheet with drilled holes at the designed intervals. The upper sieve can be varied from 3° to 8° for efficient separation and the lower sieve was fixed at 15°. A deflector is attached in between the sieves to convey the undersized materials from the top sieve for thorough separation by the lower sieve. The circular sieve is fitted in the top position to take off the large impurities. The oblong bottom sieve has a smaller perforation allowing weed seeds and broken grains to fall though it to the delivery chute for collection to a reject receptacle. The cleaned separated grain passes downward over the bottom sieve and discharge on the opposite side of the machine into product receptacle. A Paddle wheel centrifugal fan was adopted for the machine which has advantage of creating a higher pressure. The fan housing was made from iron sheet cut into a scroll like shape and a 36 cm x 180 cm folded into desired shape was weld on it. Six blades of 32 cm by 16 cm iron sheet were fastened on the fan shaft through solid metal supports. An inexpensive easy -to- built fan housing opens into the sieve assembly through a 36 cm x 18 cm rectangular duct.

Plate 1: Front View of the cereal cleaner

Plate 2: Oblique View of the cereal cleaner

G. Machine specification

The components and the specification of the cereal leaner are listed in Table 1. The fan revolution, sieve slope and opening sizes of the sieves can all be changed on this machine, making it suitable for other crops.

Table1. Machine parameters and their specification

Parameter	Specification
Overall length	2.06 m
Overall width	0.50 m
Overall height	1.35m
Rigid frame	1.50 x 0.50 x 1.0 m
Machine capacity	1068 kg/h
Electric motor	1.5 kW @ 2890 rpm
Pulley diameter	0.36 & 0.06 m
Fan blade size	0.160 m x 0.32 m
Blower airflow channel	0.18 x0.36 m
Upper sieve aperture	Ø8 x 10^{-3}m
Lower sieve aperture	3 x 2 x $10^{-3}$$m^2$
Blower speed	240 rpm
Connecting rod	0.6 m
Eccentricity	2.5 x 10^{-2} m

H. Performance evaluation

Performance of the machine was carried out using paddy rice; it was tested as a pre-cleaner for its ability to separate whole paddy, small grains, glumes, chaff, stalks and tiny stones from grain impurity mixture fed into the machine. Mixtures of known weights of paddy rice (whole grains) and undesirable materials like glumes and straws / stalks were fed into the machine. All the machine parameters such as fan speed, sieves, and sieve slope, eccentricity and tilt angle were set at the appropriate position prior to running the cereal cleaner. The machine was operated until the whole admixture was separated. Four collection points were used namely:

(i) Air passage away from the machine for light chaff, glumes and stalks
(ii) Sieve end near to the fan, for heavy materials (over tailings)
(iii) Receptacle for undersized and broken grains
(iv) Receptacle for whole clean grains

All the materials collected from the collection points except for the whole paddy receptacle are regarded as reject while that of whole paddy is considered as the product.

I. Test results

For purposes of this test the following terms and nomenclature were adopted for the separation efficiency using reference [6] method for separation processes as shown in Figure 2.

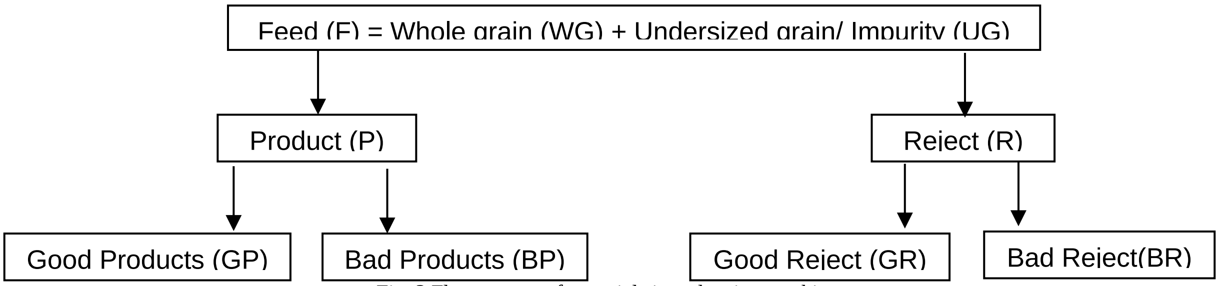


Fig. 3 Flow pattern of materials in a cleaning machine

Table 2: Summary of weights collected at the various receptacles and performance efficiency

Tilt Angle(°)	Feed	WG	UG	GP	BP	GR	BR	E_G%	E_B%	E_T%	P_P%
3	100.7	92	8.7	78.2	1.4	13.8	7.3	85	84	71	98
4	106.8	90.3	16.5	76.6	2.5	13.7	13.6	85	82	70	96
5	120.5	95.7	24.8	83.0	6.2	12.7	18.6	87	75	65	93
6	86.8	70.2	16.6	53.1	2.3	17.1	14.3	76	86	65	96
8	100.7	92.0	8.7	67.0	2.7	25	6.0	73	69	50	96

Machine setting: 240 rpm, 5° hanger angle and 8mm feed gate opening. (Unit:kg)

1. Efficiency of separating whole grain (E_G)

$$E_G = \frac{GP}{(GP+BP)} X100\% \quad (7)$$

2. Efficiency of separating materials other than grain (E_B)

$$E_B = \frac{BR}{(BR+GR)} X100\% \quad (8)$$

3. Total Efficiency (E_T)

$$E_T = \frac{E_G x E_B}{100}\% \quad (9)$$

4. Product purity (P_P) of whole grain in products

$$P_P = \frac{GP}{(GP+GR)} X100\% \quad (10)$$

J. Result and discussion

Table 2 gives the weight of different grades of product collected. From these weights, the various efficiencies and P_P of the products were determined. From the test performed E_G was high, it ranged from 73 to 87 %. The E_T in all the setting varied from 50 to71%. P_p was very high; it ranged from 93 to 98%.

From Fig 4 the effect of tilt angle on whole grain separation (E_G) was constant at 85% for tilt angle of3° and 4° and increased to a peak of 87% at 5° and experienced a sharp gradient of decrease to a value of 76 at 6 ° then gentle gradient 8° to a value of 70 %. This implies a decrease in efficiency as tilt angle increases; a quadratic equation of R^2 of 0.773 describes the trend of the machine performance. Also for the E_B initially decreases gradually as the tilt angle increase from 3 to 5° and then had the peak separation of 86% at 6° before a steep reduction to 69% at 8° tilt angle. A polynomial equation of R^2 of 0.523 described the separation

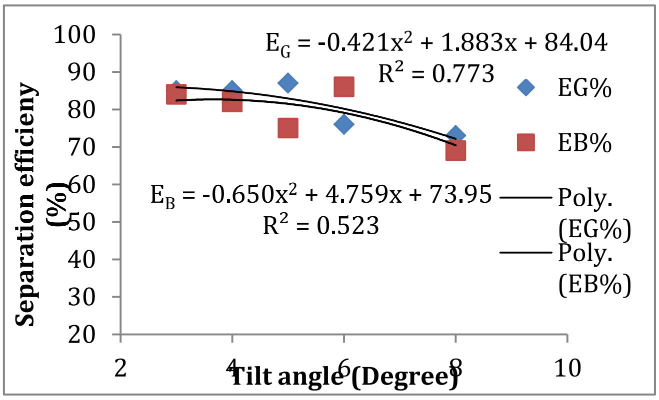


Fig. 4 Effect of tilt angle on Percentage purity and total efficiency

In Fig. 5, the effect of variation of tilt angle on E_T and P_P and can be seen; efficiency curve shows that the E_T was highest at 3° tilt angle. It decreases initially with gentle gradient at successive tilt angle until at 6°where the gradient becomes steep to 8°. This implies that the higher the tilt angle the lower the total separation efficiency. The P_P was highest at 98% at 3° tilt angle and the curve decreases gradually to 93% at 5° and then increases to 96% at 6° and remains constant till 8° tilt angle. The optimum

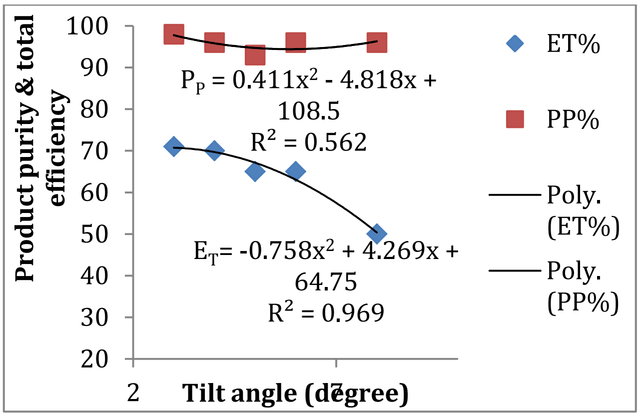


Fig. 5 Effect of tilt angle on Percentage purity and total efficiency

machine performance occurred at 3 and 4° tilt angle having the highest E_T and P_P values. The total efficiency curve trend is best represented by a polynomial equation with a high determination coefficient (R^2) of 0.969 while the product purity curve trend also has a best of fit represented with a polynomial equation with $R^2$of 0.562.

K. Conclusion

From the above result it can be concluded that the optimum tilt angle for paddy rice separation is 3° as it has the highest E_T and p_p. Overall efficiency of machine which ranges from 50 – 71 % which was an improvement on the 20 – 61 % reported by [6] for paddy rice with sphericity of about 40%. Though [14] reported overall efficiency of 84 % with chickpea that has sphericity of about 85 % indicating that higher overall efficiency are obtained where grain shpericity is high. Further cleaning by re-introducing the product into the machine will further increase all the various efficiencies and a near 100 % P_p will be obtained. The cost of production of the prototype was 450 USD. Commercial production of this cereal cleaner will be viable as they shall be utilised by the small scale rice processor in the country.

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