Development and testing of an automated grain drinks processing machine

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Review

Development and testing of an automated grain drinks processing machine

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ABSTRACT

The research work was conducted to develop an automated grain drinks processing machine capable of integrating several operations (blending of soaked grains, mixing the slurry, extracting the aqueous liquid and discharging of the paste out of the machine) together and finished in one go. Fundamental design analysis and calculations were carried out in order to determine and select materials of appropriate strength and sizes for the machine component parts. The major machine parts include hopper, delivery tube, blending chamber, blade, conical centrifugal basket, electric motors and control system. The results of testing of the machine using soya beans revealed that blending efficiency of 85.52% was obtained from combination of 3 blades assembly, basket with half angle of 30° and speed of 1400 rpm. The optimisation of the machine parameters using response surface methodology produced optimum paste expelling efficiency of 94.89% with desirability of 94.3% from combination of 3-blades assembly, basket of half angle of 50° and speed of 1400 rpm. The speed of rotation and basket angle has positive significant effects on the paste expelling efficiency while blade number has insignificant effect. Paste expelling efficiency increase with both increased in speed of rotation and basket angle. The machine capacity and cost of production are 100 L per hour and $ 1670 respectively.

Contents

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1. Introduction

Grain beverages, such as *soya milk, kunu and kunun zaki,* are now having wider acceptability among beverage consumers in Africa (Adebayo et al., 2010). This could be attributed to economic potentials and health benefits associated with production and consumption of these products (Oshoma et al., 2007). The production processes of these beverages are almost similar regardless of the initial type of grains used (Gana et al., 2013). In developing countries, like Nigeria, the production process is faced with some challenges including availability of the right equipment for processing. Nowadays, equipment are mostly made from mild steel material, which can easily become rusted and cause contamination of food materials, thereby reducing the quality of the final product (Gana et al., 2013). Also, the processes are usually carried out in different stages using different equipments, and this makes the entire operation tedious, time consuming and products predisposed to contamination. In addition, the few wet sieving machines are only available in large scale industries and are too sophisticated to operate and maintain by small and medium scale processors (Foyose, 2008).

Another key interest area of this technology is in animal feed product that can be obtained as by product in grain drinks production. By-product of soya milk produced using machine can be obtained at various formulations depending on the processors desire. Soya milk paste is the by-product obtained after extraction of aqueous milk from soya slurry. It contains high percentage of protein and fibre which makes it useful in animal feed formulation and food product production. Foyose (2008) reported some methods employed in extracting paste from milk slurry, including traditional methods of manual sieving, small sieving machine and the industrial centrifuge. According to Simonya et al. (2007), the manual method is tedious, time consuming, results in more loss of nutrients and predispose the product to contamination. Also the small sieving machine has the disadvantage of its batch nature of operation and exposed the materials to contamination since they are mostly made from mild steel materials. On the other hand the industrial centrifuges are sophisticated and difficult to operate and maintain by the small and medium scale processors. Bizard et al. (2013) reported that centrifugal baskets are mostly employed in the separation of liquid and solid phases of mixture in the food processing and chemical production industries. The two types of centrifuge used are batch and continuous centrifuge. The batch type is operated in batch and in this case the cake is removed manually. Unlike in case of the continuous type where the cake is intermittently removed with a knife fixed inside the basket and collected in a vertical chute. One of the advantages of the continuous centrifuge is that drier cakes with lower moisture content of about 65% are produced, compared to 80% obtained from other methods. This type of centrifuge is mostly used where the recovery of solid is desirable (Bizard et al., 2013). However the shortcoming of this system is the incomplete scrapping of the cake from the basket wall as such some quantity of cake remains in the system.

Attempt has been made in the past to address these shortcomings by developing a grain drinks processing machine (Gana et al., 2013). The machine was developed from stainless materials and it combined the major operations of blending soaked grains, mixing of the slurry and aqueous milk extraction in a single unit. However, it was observed that the developed machine also have some deficiencies among which is the separation of the blending, mixing and drink extraction operations into segments. This requires the stoppage of the machine after blending operation in order to engage the perforated drum in rotation with the central shaft for mixing and drink extraction operations. Also, there was problem of attachment and detachment of the external casing cover of the machine before and after blending operation in order to fix in the blending chamber and to feed in the grains into it. In addition, the fixing and removal of the internal casing (blending chamber) from the perforated drum and adjustment of its cover with a plier and spanner, before and after blending operation was time consuming and tedious. Furthermore, the manual packing of the paste after the drink extraction requires the detachment of the external casing cover. All these are time consuming, tedious and make the machine operation complex. Hence, the integration of local method of wet milling of soaked grains, mixing of the slurry, extraction of the aqueous milk and expelling of the paste into a single unit is of immense significance in alleviation of some of the shortcoming associated with the existing grain drinks processing methods.

This was achieved by development of an automated grain beverages processing machine. Therefore the objective of this study is to develop an automated grain drink processing machine that integrate blending of soaked grains, mixing the slurry with water, extraction of the aqueous liquid and expelling of paste out of the machine together and finished in one go. At the same time to also carried out testing of the machine performance.

2. Materials and methods

2.1. Materials selection

Stainless steel (gauge 16) materials were used for construction of component parts of the machine that have direct contact with the beverages because of its high resistance to corrosion. A 50 × 50 mm angular iron was used for the construction of

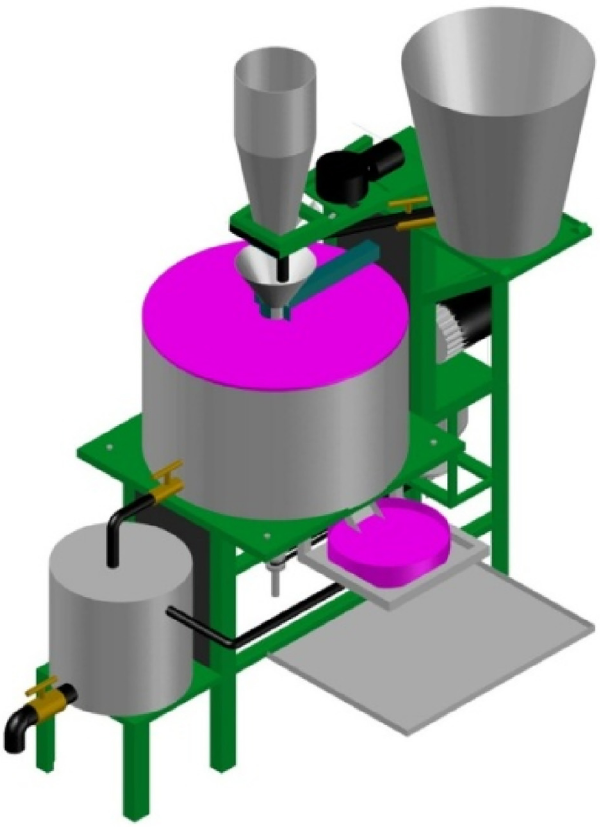

Fig. 1 – AutoCAD drawing of the automated grain drinks processing machine.

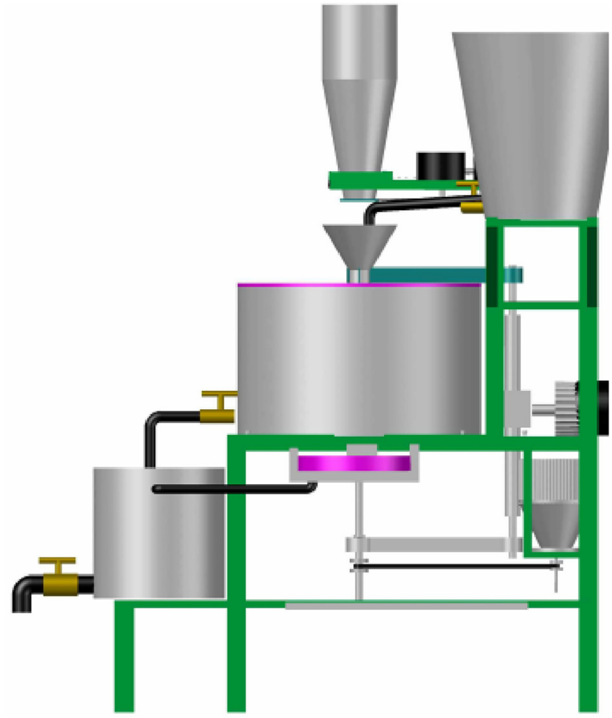

Fig. 2 – Side view of the automated grain drinks processing machine.

the machine frame in order to give a rigid support and ensure stability of the machine when in operation (Gbabo et al., 2012).

2.2. *Machine description*

2.2.1. *Machine components*

The Machine was made up of the following components;

- **Outer casing**: This is made up of stainless sheet gauge 16. It had diameter of 0.65 m, height of 0.40 m and it was mounted on the machine frame made up of 0.50 m angle iron assembly. A liquid out let valve was fitted to the bottom side of the drum in order to allow out flow of extracted aqueous liquid from the tank and paste outlet pipe was also fitted at the bottom of the casing for discharging of expelled paste as shown in Figs. 1 and 5.
- **Conical centrifugal basket**: This is made to have length and half angle of 0.18 m and 30° respectively. Its wall is smooth with perforated openings whose area constituted 20% of the basket wall area, in order to allow fluid drainage and prevent paste losses.
- **Scrapper:** This is attached to the conical basket at the top from outside. It scraps, conveys and discharges the expelled paste from the basket through the discharge outlet as shown in Figs. 2–4.
- **Internal casing:** This is attached to the internal wall of the outer casing. It is cylindrical in shape with its upper side opened in order to allow collection of expelled pastes
- **Hopper:** The grains are fed to the machine through the hopper. It was made up of stainless sheet, and of conical shape as shown in Figs. 1 and 5 .
- **Delivery pipe:** It is cylindrical in shape and conveys the grains directly to the blending chamber; as shown in Fig. 1.
- **Blending chamber (retaining cylinder):** It is made up of stainless sheet (gauge 16) with diameter and height of 0.16 m each. It prevents the materials from spilling over and moving out of the blending chamber till the blending operation is completed. It was attached to the delivery pipe as shown in Fig. 1.
- **Blending blade:** This is attached to the shaft inside the conical basket. The 3-blade assembly consist of 3 horizontal knives at angle of 120° each.
- **Programmable timer:** The control system used was a programmable timer which helps to control devices that operate automatically using time as a parameter. It was designed in such a way that the operating time can easily be varied. It was designed with the following units; power and pre-set units, erasable programmable read only memory, display unit and the relay unit.

2.3. *Design analysis of machine components*

Fundamental design analysis and calculations were carried out in order to determine and select materials of appropriate strength and sizes for the machine component parts.

2.3.1. *Determination of power requirement by the machine*

The power requirement of the machine depend on force in the centrifugal basket with its content, the blending blade, the shaft, machine pulley and the key, and was computed from the equation given by Khurmi and Gupta (2005).

$$P = 2 \times \pi \times N \times \tau/60 \quad (1)$$

$$\tau = F \times r_d \quad (2)$$

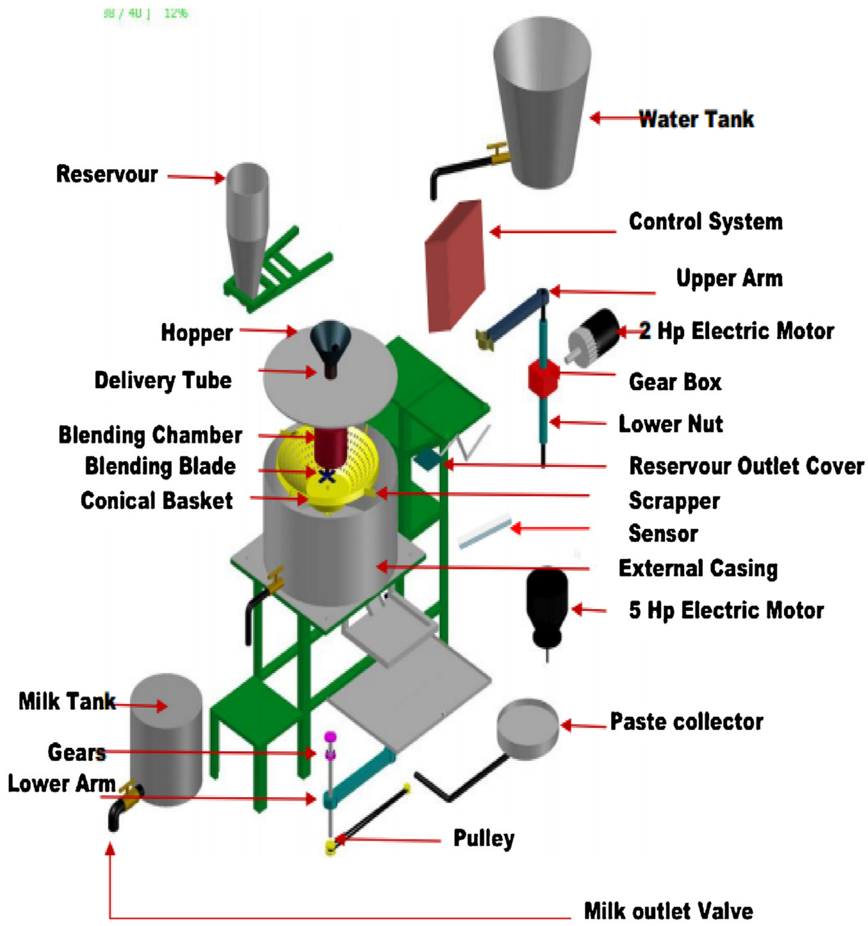

Fig. 3 – Exploded view of the automated grain drinks processing machine.

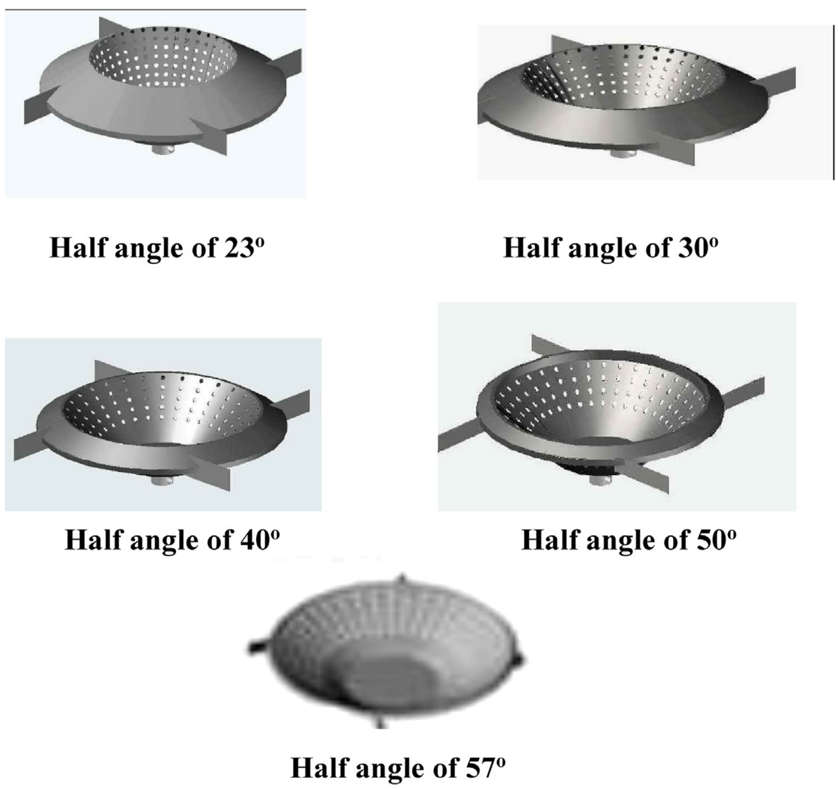

Fig. 4 – Centrifugal baskets used in the study.

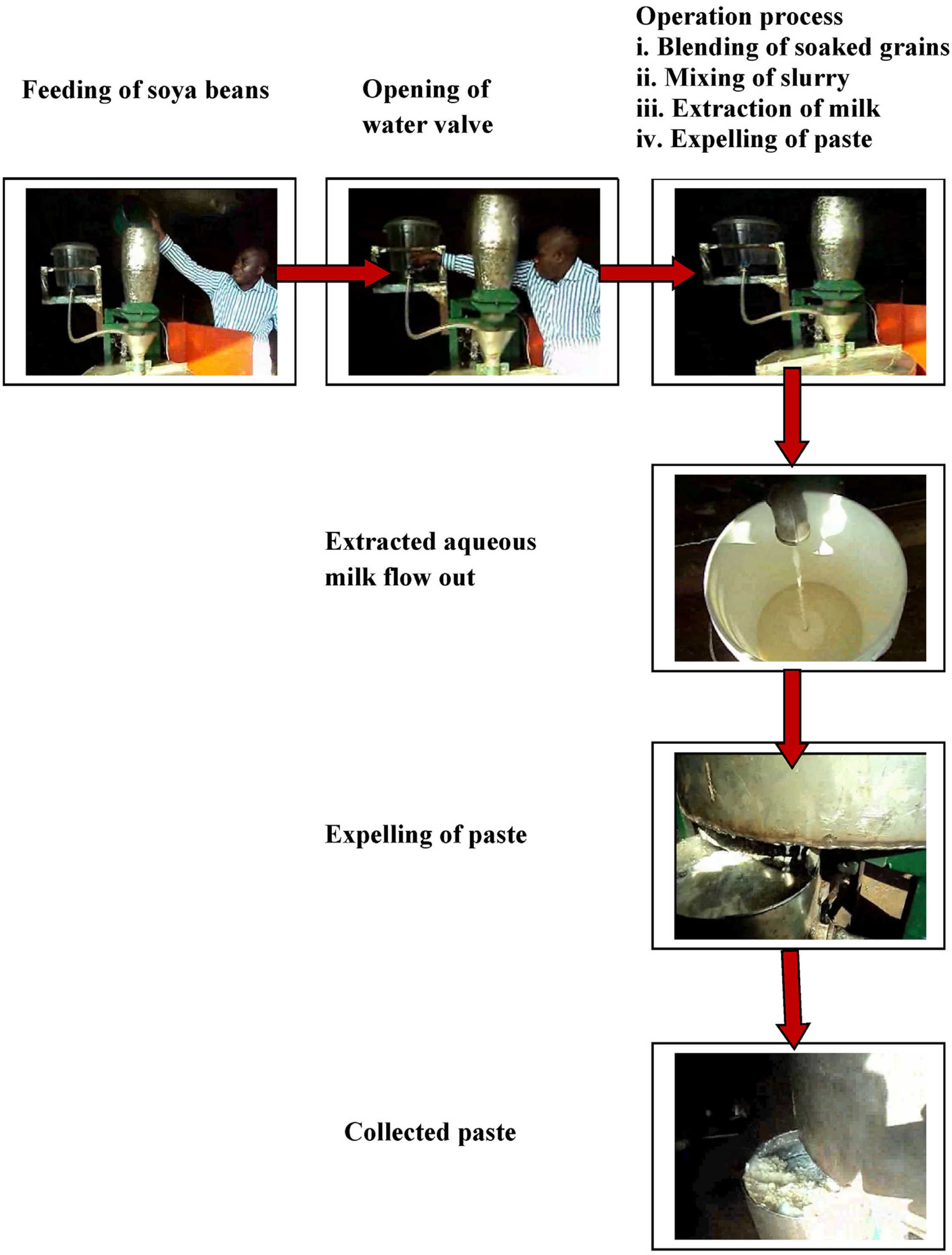

Fig. 5 – Schematic flow chart of mode of operation of the machine.

$$F = M \times r_d \times \omega^2 \quad (3)$$

$$\omega = 2 \times \pi \times N/60 \quad (4)$$

$$M = (M_{CB} + M_G + M_B + M_S + M_P + M_{IS} + M_{WT}) \quad (5)$$

where, P is power required by the machine (watts)

F = the total force (N)

V = the velocity of perforated drum (m/s)

τ = the torque generated (Nm)

M = total mass of the centrifugal basket and its content (kg)

ω = angular speed of the centrifugal basket (rpm)

M_{CB} = mass of the centrifugal basket (kg)

M_G = mass of grain (kg)

M_B = mass of blending blade (kg)

M_{IS} = mass of the internal screen (kg)

g = acceleration due to gravity = 9.81 m/s^2

π = constant,

r_d = radius of the centrifugal basket (m),

N = revolution per minute

2.3.2. *Stress in the conical centrifugal basket*

The stress in the conical centrifugal basket due to the action of the centrifugal force on the wall of the basket was computed in order to assist in the determination of the thickness of the basket. It was determined using the equations reported by Gbabo and Igbeka (2003).

$$\delta_b = M_t\omega^2 r/\pi Dh_b = M_t\omega^2 D/2\pi Dh_b \quad (6)$$

$$\delta_b = M_t\omega^2/2\pi h_b \quad (7)$$

where, δ_b is the stress on the walls of conical perforated basket in Nm^2

M_t = the total mass of the basket assembly (kg)
ω = the angular velocity (Rpm)
h_b = the height of the basket (m)
d = the diameter of the basket (m)
π = constant (3.14)

2.3.3. *Expected thickness of conical centrifugal basket wall to withstand the stress*

The expected thickness of the basket to withstand the centrifugal force to be generated, was computed using the equation reported by Gbabo and Igbeka (2003).

$$t_{bs} = \delta_b d_b/2S_S \quad (8)$$

where, t_{bs} = expected thickness of the conical basket (m)
δ = stress that is developed and acts on the wall of the conical basket (kN)
d_b = diameter of conical centrifugal basket (0.5 m)
S_S = shear stress of
stainless steel used for construction of the basket

2.3.4. *Twisting moment*

The high rotating speed of the shaft which is attached to the conical centrifugal basket is influenced by twisting moment. The twisting moment of the shaft was determined as expressed by Gbabo and Igbeka (2003).

$$M_t = 60W/2\pi N \quad (9)$$

where, M_t = twisting moment (Nm)
N = speed of rotation of the shaft (Rpm)
W = power transmitted (Watt)
π = constant (3.14)

2.3.5. *Design of the central shaft*

The diameter of the central shaft was computed using the equation reported by Khurmi and Gupta (2005).

$$d^3 = 16/\pi S_s \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (10)$$

where, d = expected diameter of shaft (m)
M_t = belt torque moment (Nm)
M_b = bending moment (Nm)
d = diameter of the shaft (m)
K_b = shock and fatigue factor applied to bending moment
K_t = shock and fatigue factor applied to torsional moment
S_S = permissible shear stress of the shaft

2.3.6. *Second polar moment of area of the shaft*

The second polar moment of area of the central shaft is essential in determination of the resistance of the shaft to bending and deflection and was computed as reported by Gbabo and Igbeka (2003) as:

$$J = \pi ds^4/32 \quad (11)$$

where, J = second polar moment of area
d_S = the diameter of shaft (m)

2.3.7. *Summary of design calculation*

The summary of design calculation carried out is presented in Table 1.

2.4. *Cost analysis of the developed machine*

The cost of construction of the automated grains drink processing machine is classified into three namely;

- **Material cost**: The material price, is the price of various component used in fabrication of the machine. Table 2 shows the unit and quantity price of materials used for the construction.
- **Labour cost**: The labour price is the price of services provided at the course of fabrication of the machine. It was computed as 20% of the material price (Gbabo, 2005)
- **Over-head cost**: The cost of feeding during the construction work. It also includes various operating charges involved during the fabrication of the machine. It was computed as 10% of the material price (Gbabo, 2005)

Total cost of material = ₦192,300.
Labour (Lc)
This is taken as 20% of the material cost = 20/100 × 192,300 = ₦ 38,460.
Overhead cost (Oc)
The overhead cost is taken as 10% of the material cost, which is
Overhead cost = 10/100 × 192,300 = ₦ 19,230.
Total cost of fabrication (Tc): Material cost + labour cost + overhead cost
Tc = 192,300 + 38,460 + 19,230 = ₦ 249,990.
Therefore, the total cost of construction of the machine was **₦ 249,990**.

2.5. *Working procedure of the machine*

The conical centrifugal basket with attached screen was fixed inside the external casing and the blending blade was fixed on the shaft inside the basket. The hopper assembly comprised hopper itself, delivery tube and blending chamber fixed inside the machine. The external casing was fixed on the machine frame. Two containers were placed, one at the drink outlet and the other at the paste outlet for collection of extracted drink expelled paste, respectively. The central switch of the machine was connected to source of power and then switches on. Switches for the control unit, 5 and 2 hp electric motors were then switch on. Immediately the 5 hp electric motor commenced operation and a welcome note was displayed on the control system screen (LCD). After that the pre-set buttons was pressed and settings are made by inputting time for disengagement (blending operation) and engagement (sieving operation).

These information was saved by pressing the save button, followed by pressing the auto run switch in order to leave the parameter setting zone. This launched the system into automatic operation mode. The 2 hp electric motor was activated and rotated in anti-clock wise direction thereby, making the upper and lower arm moved downward at the same time. The upper arm holds and brings down the hopper assembly until it touches the base of the basket while the lower arm disengages

Table 1 – Summary of design calculations.

S/N	Parameter	Calculated value
1	Maximum mass of material to be processed at a time 1 kg	1 kg
2	Mass of blade assembly	0.0448 kg
3	Mass of blending chamber	0.00282 m^3
4	Height of the blending chamber	0.185 m
5	Volume of conical centrifugal basket	0.0083 m^3
12	Mass of the conical basket with half angle of 30°	5.83 kg
14	Stress in the conical centrifugal basket	664.48 N/m^2
15	Expected thickness of conical centrifugal basket wall to withstand the stress	1.89×10^{-6} m
16	Twisting moment	23 Nm
20	Mass of the conical screen with half angle of 30°	0.84 kg
22	Mass of the hopper, delivery tube and blending chamber	3.24 kg
23	Central shaft diameter	11 m
24	Mass of the central shaft	0.74 kg
25	Second polar moment area the shaft	1.5×10^{-8} m^4
27	Angular velocity (ω)	13.16 rev per min
28	Centrifugal force	188.25 N
29	Torque (τ)	18.825 Nm
30	Power required by the machine	2.366 kW
31	Selected of electric motor capacity	3.08 kW
32	Power required by the engagement mechanism	0.788 kW
33	Selection of electric motor capacity	1.0244 kW
34	Expected life of the machine	7.3 Years
35	Factor of safety	276

Table 2 – Bill of engineering measurements and evaluations (beme) of the automated grain drinks processing machine.

S/N	Component	Material	Specification (mm)	Qnty	Unit Price (₦)	Qnty Price (₦)
1	Shaft	Stainless steel	20 × 40	3	600	1800
2	1 mm stainless sheet	Stainless steel	1200 × 2400	1	30,000	30,000
3	1 mm screen	Stainless steel	1200 × 2400	1	15,000	15,000
4	2 in. angle bar iron	Mild steel	75 × 2400	2	5000	10,000
5	2 in. angle bar iron	Mild steel	50 × 1200	1	2000	2000
6	1 in. angle bar iron	Mild steel	25 × 1200	1	1000	1000
7	20 Gauge metal sheet	Mild steel	600 × 1200	1	3500	3500
8	Pulley	Cast iron	50, 56, 73 and 87	4	1500	6000
9	Bearing	Cast	ISI NO 6306,	3	600	1800
		iron	ISI NO 6204	2	300	6000
10	V-belts	Rubber	A-32	3	200	6000
11	Paints		2 Tins	2	1200	2400
12	Bolt	Mild	6 × 40	50	20	1000
	&	steel	14 × 400	3	1000	3000
	nuts		16 × 400	1	1500	1500
13	Flat bar	Mild steel	20 × 120	1	500	500
14	Electric motors		5 hp, 2 hp, 0.5 hp	1	55,000	55,000
15	Electric wire	Copper	4 × 90	10	500	5000
16	Pipe adaptor	Galvanize iron	37.5	2	1250	2500
17	Valve	Galvanize iron	18.75	2	750	1500
18	Plug valve	Galvanize iron	37.5	2	200	400
19	Clip	Mild steel		2	50	100
20	Electrode	Stainless	E 10	50	150	7500
			E 12	150	20	3000
21	Ruber seal	Ruber		2	100	200
22	Ruber bucket	Ruber		1	600	600
23	Control timer			1	25,000	25,000
	Sub total				**₦ 147,540**	**₦ 192,300**
24	Labour cost		20% of Sub Total			38,460
25	Over-head cost		10% of Sub Total			19,230
	Grand total					**₦ 249,990** ($ 1670)

Note: Cost of production in 2015.

the basket from the central shaft. The system was designed in such a way that the two components (base of the blending chamber and base of the basket) come in contact almost same time the lower arm touches the lower sensor. This action caused the 2 hp electric motor to be deactivated leading to down ward movement of the lower and upper arms.

The soaked grains are then fed into the machine through the hopper via grain reservoir and immediately the blending operation commenced. This action of blending operation was displayed on the control system screen as machine status: halt. The blending operation continued as shown in Fig. 5. This operation will continue until the inputted blending time elapses and immediately the 2 hp electric motor is reactivated and this time it rotates in clock wise direction. Thereby, lifting the upper arm, this in turns also lifts the hopper assembly from the base of basket. At the same time the lower arm lifted the central shaft up until the gear attached to it mesh with that attached to the basket. Thereby, engaging the basket in rotation with the central shaft for aqueous liquid extraction and expelling of paste from the basket. This action of upward movement of the lower and upper arms is displayed on the control system screen as machine status: up and extraction operation is displayed as machine status: halt. Due to centrifugal force generated, the fluid migrated up along the basket wall. The aqueous liquid is separated from the paste by draining through the pore spaces between the granular material and the perforation on the basket. It is collected at the bottom of the external casing and flows out of the machine through the filtrate outlet as shown in Fig. 5. The paste is expelled out of the basket at the end of the basket wall and collected at the internal screen where is scraped, conveyed and discharged out of the machine through the paste outlet by the scrapper as shown in Fig. 5. The next phase of the operation commences following same sequence. The video clip of working procedure of the machine can be access thorough the link attached (in Supplementary data).

3. Testing of the machine

The performance of the automated grain drinks processing machine was evaluated in accordance with procedures reported by Gbabo et al. (2012) and Gaffa et al. (2003). The soya bean (TGX 1954-IFXTGX 1835-10E) was purchased from Bida central market and the samples were cleaned and sorted to remove unwanted materials before soaking at room temperature of 27 °C for the recommended time of 12 h (Gaffa et al., 2003) before processing using the developed machine as shown in Fig. 5. Two sets of experiments were carried out to investigate the machine performance. In the first experiment effects of speed on blending efficiency of the machine was examined whereas in the second experiment effects of blade type, speed of rotation and basket orientation (half angle) on paste expelling efficiency were examined. The experiments were carried out at the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida, Nigeria.

3.1. *Design of experiments*

In the first testing five levels speeds of 800 rpm, 1000 rpm, 1200 rpm, 1400 rpm and 1600 rpm were used based on an earlier findings by Gbabo et al. (2012) to determine the effects of speed on blending efficiency of the machine. Each of the experiment was replicated three times using Eq. (14) and the results obtained are presented in Fig. 6.

For the second testing, the experimental design was designed as a function of machine functional parameters of blade type (A), basket orientation (B) and speed of rotation (S) (independent variables) using central composite rotatable design (CCRD) of response surface methodology (rsm). In order to obtain the required data, the range of values of each of the three variables (k) was determined as reported by Tran et al. (2010) and Anuonye (2007) and is presented in Table 3.

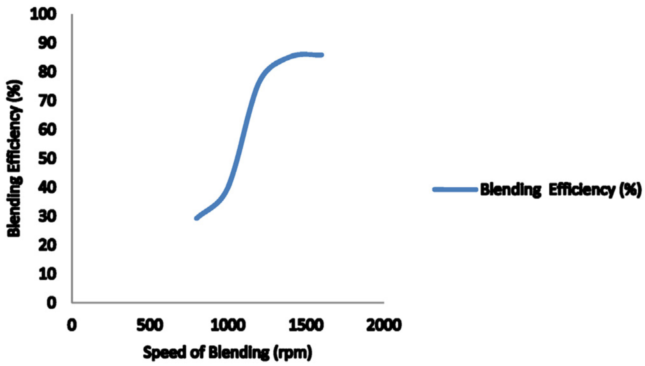

Fig. 6 – Effects of blending speed on blending efficiency of the machine.

For three variables (k = 3) and the five levels (−α, −1, 0, 1 and +α) experiments, the total number of runs was determined by the expression; 2^k ($2^3 = 8$ factorial points) + 2k (2 × 3 = 6 axial points) + 6 (center points: six replications) as 20 (Cukor et al., 2011; Tran et al., 2010; Anuonye, 2007) and the design is shown in Table 4. The objective function here was to minimise the effects of unexpected variability in the observed response. Paste expelling efficiency was considered as the response in this case.

3.2. *Statistical analysis*

Design expert software package (version 7.0.0) was used for the regression and graphical analysis. A quadratic polynomial equation was developed to predict the response as a function of independent variables and their interaction. In general, the response for the quadratic polynomials is described below as reported by Chih et al. (2012):

$$Y = \beta_0 + \sum_{g=1}^{N} \beta_g x_g + \sum_{g=1}^{N} \beta_{gg} x_g^2 + \Sigma_{g<f} \Sigma \beta_{gf} x_g x_f \quad (12)$$

where Y = the response (paste expelling efficiency)
β_0 = the intercept coefficient
β_g = the linear terms,
β_{gg} = the squared terms
β_{gf} = the interaction terms,
x_g and x_f are the uncoded independent variables.

Analysis of variance (ANOVA) was carried out to estimate the effects of main variables and their potential interaction effects on the paste expelling efficiency.

3.3. *Determination of machine performance*

The machine performance determined based on blending efficiency and paste expelling efficiency.

3.3.1. *The blending efficiency*

This is the measure of the degree by which the grains are reduced in size and was determined as reported by Nwaigwe et al. (2012) and Nasir (2005).

$$E_B = (A - W/MT - W) \times 100 \quad (13)$$

where, E_B = the blending efficiency (%)
A = the amount of the material passing through the sieve (kg)

Table 3 – Physical and coded values of the test variable for design of experiment.

Independent variables	Symbol	Codes and levels				
		Extreme low	Lower	Centre	High extreme	Extreme low
Codes		−1.6812	−1	0	+1 +1.6812	−1.6812
Blade configuration	X_1	2	3	4	5	6
Basket crientation	X_2	23	30	40	50 57	23
Speed of basket	X_3	864	1000	1200	1400 1536	864

Anuonye (2006).

Table 4 – Matrix transformation of five level-three factors central composite rotatable design of the experiment.

Run order	Coded X_1	Values X_2	X_3	Real blade configuration	Values basket orientation	Combine speed of blade and basket	Actual paste expelling efficiency (%)	Predicted paste expelling efficiency (%)
1	–	–	–	3	30	1000	46.11	46.94
2	+	–	–	5	30	1000	42.00	42.22
3	–	+	–	3	50	1000	72.15	72.57
4	+	+	–	5	50	1000	94.51	93.88
5	–	–	+	3	30	1400	26.02	24.32
6	+	–	+	5	30	1400	99.07	101.35
7	–	+	+	3	50	1400	96.22	94.90
8	+	+	+	5	50	1400	71.32	71.04
9	−1.682	0	0	2	40	1200	73.14	72.57
10	+1.682	0	0	6	40	1200	75.23	75.37
11	0	−1.682	0	4	23	1200	49.12	49.68
12	0	+1.682	0	4	57	1200	72.14	72.57
13	0	0	−1.682	4	40	864	71.98	72.57
14	0	0	+1.682	4	40	1536	74.23	72.57
15	0	0	0	4	40	1200	71.9	72.57
16	0	0	0	4	40	1200	88.27	87.30
17	0	0	0	4	40	1200	72.14	73.00
18	0	0	0	4	40	1200	40.00	40.91
19	0	0	0	4	40	1200	88.12	86.88
20	0	0	0	4	40	1200	63.12	63.56

Note: X_1 = blade type, X_2 = conical basket orientation, X_3 = combine speed of blade and basket. −1.682 and +1.682 = axial values of X_1, X_2 and X_3 (Anuonye,2006).

MT = the total weight of the material feed into the machine (kg)

W = the amount of water used (kg)

3.3.2. *Paste expelling efficiency*

This is the ability of the conical centrifugal basket to expel paste out of the machine as reported by Gana (2011) and shown in Eq. (14).

$$E_E = (P_a + P_b/P_a + P_b + P_C) \times 100 \quad (14)$$

where, E_E = paste expelling efficiency (%)

P_a = the weight of paste discharged through the machine outlet (kg)

P_b = the weight of paste retained within the machine but not inside the conical basket (kg).

P_c = the weight of paste retained inside the conical basket (kg).

4. Results and discussion

4.1. *Results*

The machine was designed, fabricated and the results of the performance testing are presented in Fig. 6 and Table 4. Fig. 6 represents the results of effects of speed on blending efficiency of the machine. Highest blending efficiency of 85.82% was obtained from speed of 1600 rpm whereas low blending efficiency of 29.23% was obtained from speed of 800 rpm. The result of interaction between the experimental factors, blade configuration, basket orientation and speed of blending with paste expelling efficiency was presented in Table 4. The highest paste expelling efficiency of 99.07% was obtained when the soya beans sample was processed with 4 blade assembly, basket with half angle of 57° (angle of 33° from horizontal) and speed of 1200 rpm while the lower value of expelling efficiency of 26.02% was obtained when the sample was processed with 4 blade assembly, basket with half angle of 23° (angle as 67° from the horizontal) and speed of 1200 rpm as shown in Table 4.

Table 5 – Regresional analysis of response of paste expelling efficiency.

Source	Coefficient of estimate	Standard error	F-value	P-value Prob > F	R-squared	
Model	72.57	0.58	420.53	<0.0001	0.9834	Significant
A-blade confg. (No.)	−0.58	0.381	2.33	0.1579		
B-basket orient. (°)	22.90	0.381	3605.83	<0.0001		
C-speed (r.p.m.)	3.51	0.381	84.72	<0.0001		
AB	0.43	0.50	0.75	0.4071		
AC	−0.36	0.50	0.52	0.4880		
BC	0.14	0.50	0.08	0.7863		
A^2	−0.20	0.37	0.28	0.6108		
B^2	−3.44	0.37	85.98	<0.0001		
C^2	−1.10	0.37	8.75	0.0143		
Lack of Fit			3.688429	0.0892		not significant

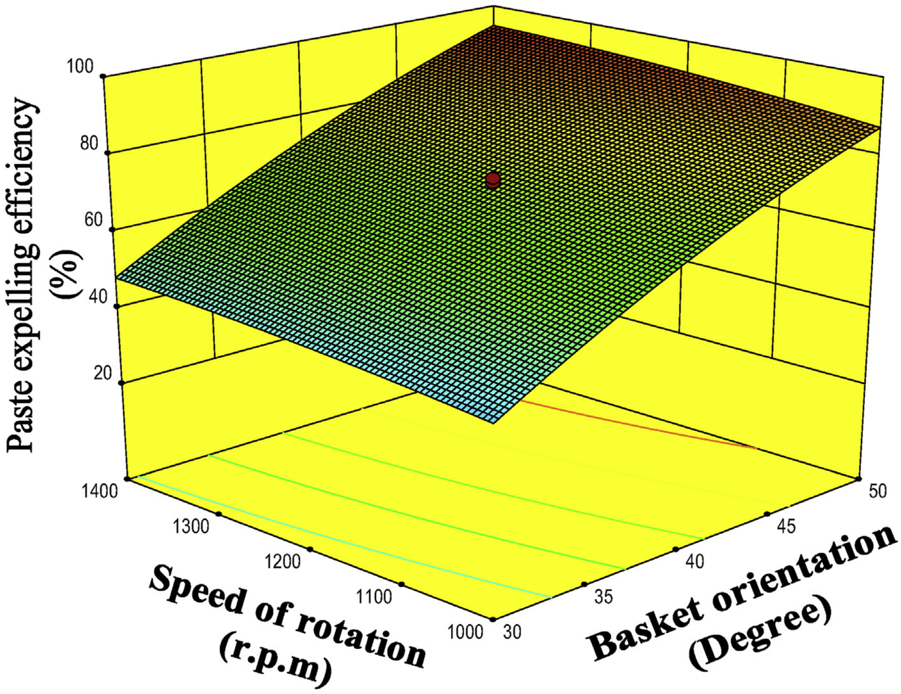

Fig. 7 – Response surface for the paste expelling efficiency.

4.2. *Discussion*

4.2.1. *Effects of speed on blending efficiency*

The effects of blending speeds on the blending efficiency indicated that increasing the speed from 800 rpm to 1600 rpm increased the blending efficiency from 29.23 to 85.82% (Fig. 6). This could be due to increase in impact force, cutting and shearing actions of the blade with increased in rotational speed. This is in agreement with results of similar studies conducted by Jayesh (2009) where decreases in speed of blending decrease the rate of segregation of materials. A significant effect was observed with increasing speed of blending from 800 rpm to 1600 rpm. But almost constant blending efficiency was obtained from blending speed of 1400 rpm (85.16%) and 1600 rpm (85.82%).

4.2.2. *Effects of speed on paste expelling efficiency*

The result of statistical analysis of variance (ANOVA) of the experimental was presented in Table 5. The effects, contribution, model coefficient, test for Lack-of-fit and the significance of the variables and their respective interaction on the paste expelling efficiency were determined as reported by Anuonye (2006) and Aworanti et al. (2013). A quadratic model was statistically significant for the responses. The significant model terms were identified at 95% significance level. The quadratic regression model equation developed to predict paste expelling efficiency with respect to functional machine parameters (independent variables) were given as shown in Eqs. (15) and (16).

The model F-value of 420.53 implies that the model is significant. There was only 0.01% chance that a model F value this large could occurred due to noise. The value of Probability > F less than 0.0500 indicated that model terms were significant. In this case B, C, B^2, and C^2 were significant model terms with P-values of <0.000, <0.0001, <0.0001 and 0.0143 respectively. It can be clearly observed that B had more significant effect on paste expelling efficiency with coefficient of estimate of 22.90. However values greater than 0.1000 implies that the model terms are not significant (that is A, AB, AC, BC, ABC, A^2, A^2B, A^2C, AB^2, AC^2, B^2C, BC^2, A^3, B^3 and C^3 were not significant) and since these terms were insignificant the regressed model was reduced to Eq. (2) (Aworanti et al., 2013).

As reported by Aworanti et al. (2013) the Lack of Fit F-value of 3.69 implies that the Lack of Fit is not significant relative

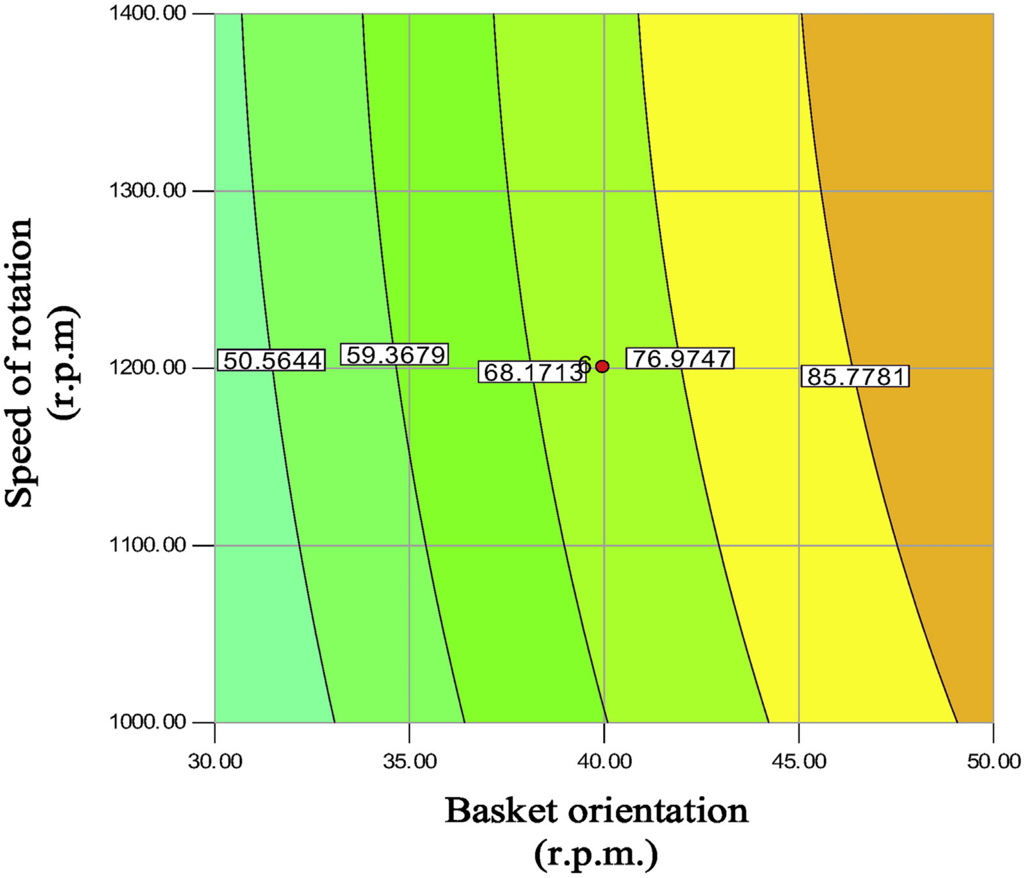

Fig. 8 – Contour plot for response surface of paste expelling efficiency.

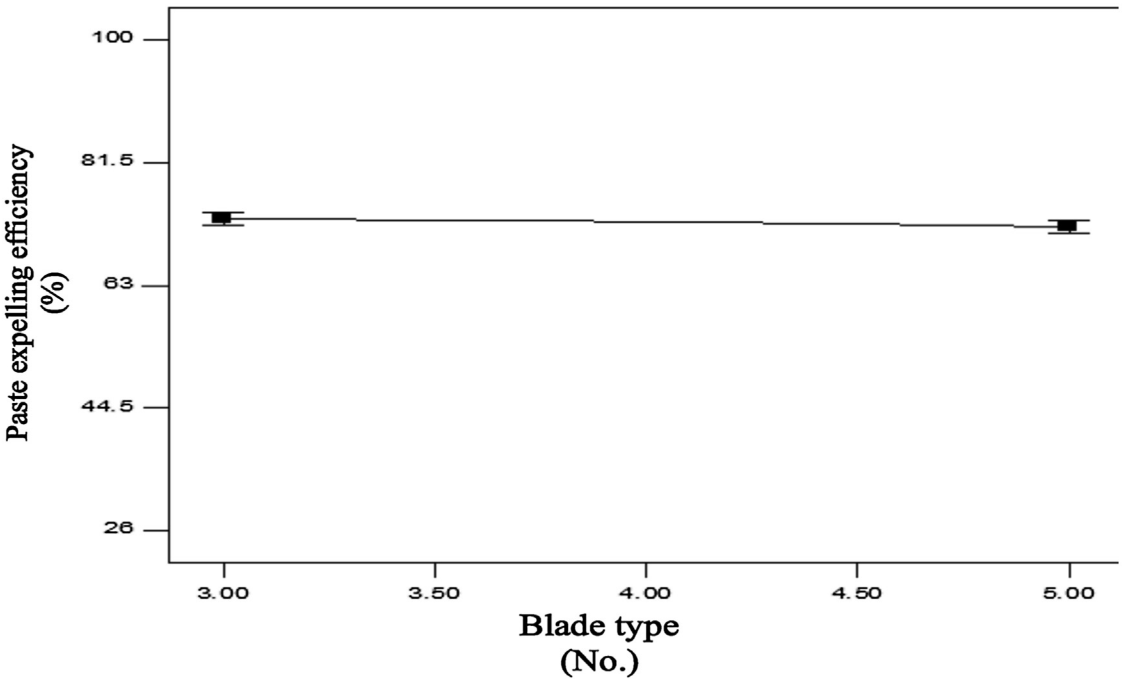

Fig. 9 – Relationship between blade type and paste expelling efficiency.

to the pure error. Also there is 8.92% chance that a Lack of Fit F-value this large could occur due to noise. In general non-significant Lack of Fit was considered good indicative that the model equation can predict the response. The coefficient of determination R value of 0.9917 indicated that the model was able to predict 99.17% of the variance and only 0.83% of the total variance was not explained by the model. Predicted R-squared value of 0.983 was in reasonable agreement with the adjusted R-squared of 0.994 which indicated that the experimental data fitted better (Xin and Saka, 2008). Adequate Precision value of 20.17 is above the desirable minimum value of 4 was reported by Salam et al. (2014), this indicated that the model can be used to navigate the design space.

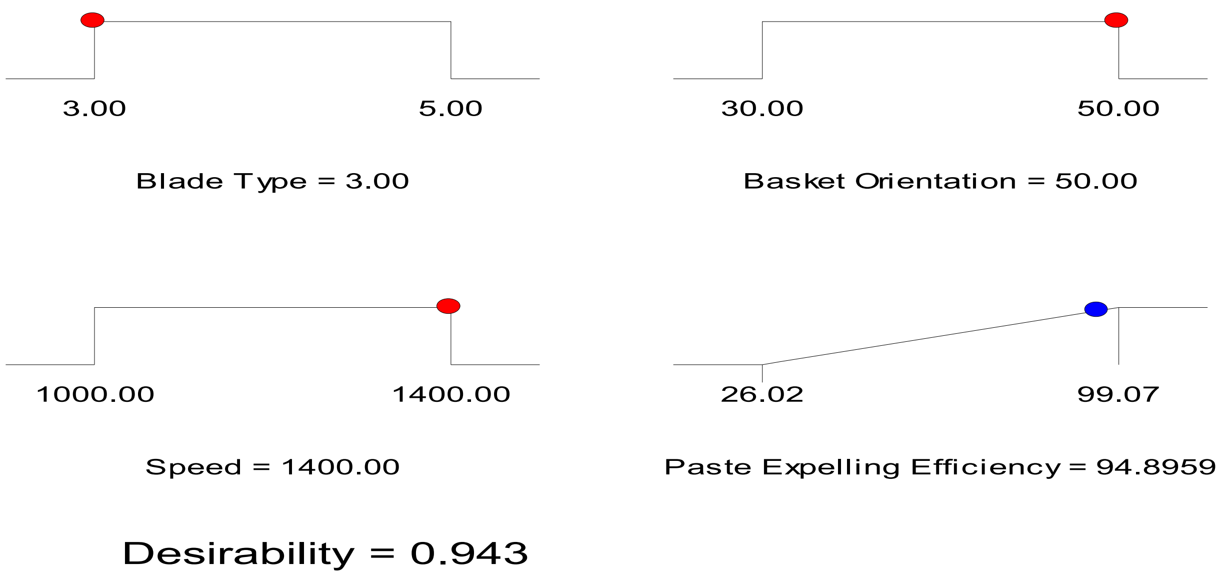

Fig. 10 – Ramp for optimization of machine performance parameters.

The regressed paste expelling efficiency model equation is given as

$$Y_{PE} = 72.57 - 0.58A + 22.90B + 3.51C + 0.43AB - 0.36AC + 0.14BC - 0.20A^2 - 3.44B^2 - 1.10C^2 \quad (15)$$

where, Y_{PE} = paste expelling efficiency (%)
A = blade type (No)
B = basket orientation (°)
C = speed of blending (Rpm)

The model equation was improved by removing insignificant model terms. Values greater than 0.1000 implies that the model terms are not significant (that is A, AB, AC, BC, ABC, A^2B, A^2C, AB^2, AC^2, B^2C, BC^2, A^3, B^3 and C^3 are not significant) and since these terms are insignificant the model was reduced to Eq. (2) from Eq. (1), in order to improve it (Chih et al., 2012).

The fitted paste expelling efficiency model equation is given as

$$\text{Paste Expelling Efficiency (\%)} = 72.57 + 22.90B + 3.51C - 3.44B^2 \quad (16)$$

It is important to add that the variables B and C in the model have positive co-efficient implying a direct proportionality. That is independent increase in B and C increased the paste expelling efficiency.

The model equation obtained was simulated and the paste expelling efficiency was observed to be within the experimental range. From Table 4 the actual values of paste expelling efficiency were observed to be in close agreement with the predicted values. This is an indication to close agreement between the two values validating the need for the model equation to use to determine the optimum paste expelling efficiency at various operating condition.

The response surface and contour plot for paste expelling are shown in Figs. 7 and 8 respectively. The paste expelling efficiency increased from 48% to 94% with increased in basket orientation. This could be due to more slanting of the basket wall with increase in basket half angle which makes it easier for the paste to migrate up. On the other hand the paste expelling efficiency also increased with increased in speed of rotation of the basket.

This could be due to increase in centrifugal force that spins the paste to the wall of the basket at a very high momentum. It was obvious that basket orientation had more significant effects ($P \leq 0.05$) with increase of 46% on paste expelling efficiency. The speed of rotation of the basket had significant effects ($P \leq 0.05$) with increase of 8% on the expelling efficiency. This observation was peculiar with basket with high value of half angle, while for basket with lower value of half angle it was observed that the paste expelling efficiency increased more with increased in speed than with increase in half angle. This could be as result of more slanting of the basket wall at higher degree of half angle which makes it easier for the paste to migrate up even with low speed of rotation. While at lower value of half angle more force was required to force the paste to migrate up along the basket wall. This conform with report of Bizard and Symons (2011) where materials were found to sticks to the wall of conical filters when the half angle of the filters are less than coulomb friction coefficient and required more centrifugal force to be discharge.

From the analysis of variance (ANOVA) conducted blade type was observed to have no any significant ($P \leq 0.05$) effect on the paste expelling efficiency. Also from Fig. 9 there was no any significant ($P \leq 0.05$) difference in paste expelling efficiency with respect to 3-blade assembly and 5-blade assembly. This is clear indication that the blade type has no any significant effect on paste expelling efficiency.

The optimization of the machine functional parameters; blade type, basket orientation and speed was carried out using numerical technique in rsm with the goal of maximizing the paste expelling efficiency. The ramp of the optimization process is shown in Fig. 10 with optimum values of 3-blades assembly, basket half angle of 50° and speed of 1400 rpm. On the other hand paste expelling efficiency and desirability of 94.89% and 0.943 respectively were also obtained.

4.3. *Conclusions*

An automated grain drinks processing machine has been developed and tested. The total cost of construction of the machine was $1670. Test results of the machine using soya beans soaked for 12 h under room temperature of 27 °C using constant combination of 3 blade assembly and basket with angle of 30° gave a blending efficiency and paste expelling efficiency of 85.82% and 99.12% respectively when tested at speed of 1600 rpm. The results of the performance testing also revealed that the blending speed has great influence on the performance of the machine. The interaction effects between the machine parameters showed that paste expelling efficiency increase with increased in speed of rotation from 1000 rpm to 1400 rpm and also with increased in basket orientation from 30° to 50°. The blade type was found to have no any significant effects on paste expelling efficiency.

The developed mathematical models and individual coefficient were found to be significant while the Lack of Fit was insignificant. The experimental values were found to be better with close agreement between predicted R-squared and adjusted R-squared values. The model equations can be used to navigate within the experimental ranges with high adequate precision values of 20.17.

Optimization of the machine parameters carried out using numerical optimization technique by applying desirability function method in rsm produced optimal values 3-blades assembly, basket half angle of 50° and speed of 1400 rpm. Other values obtained are paste expelling efficiency and desirability values of 94.89% and 0.943, respectively.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fbp.2017.04.002.

References

Adebayo, G.B., Otunola, G.A., Ajao, T.A., 2010. Physicochemical, microbiological and sensory characteristics of *kunu* prepared from millet, maize, guinea corn and stored at selected temperature. Adv. J. Food. Sci. Technol. 2 (1), 41–46.

Anuonye, J.C., 2006. Effect of Extrusion Process Variables on Physioco-Chemical, Sensory, Microbial and Storage Properties of Products from Acha (*Digitariaexilis*) and Soybean (*Glycine max* (L.) *Merill*) Flour Blends. Unpublished Thesis on Degree of Doctor of Philosophy in Food Science and Technology. University of Agriculture, Makurdi, Nigeria.

Aworanti, O.A., Agarry, A.O., Ajani, A.O., 2013. Statistical optimization of process variables for biodiesel production from waste cooking oil using heterogeneous base catalyst. Br. Biotechnol. J. 3 (2), 116–132.

Bizard, A.F.M., Symons, D.D., 2011. Flow of wet powder in a conical centrifugal filter, an analytical model. J. Chem. Eng. Sci., 6014–6027 http://www.edc.com.ac.uk/~dds11/.

Bizard, A.F.M., Symons, D.D., Fleck, N.A., Grinwood, G.C., 2013. Design guidelines for granular particles in a conical centrifugal filter. J. Chem. Eng. Res. Des. 91 (2), 348–360.

Chih, W.T., Lee, I.T., Chung, H.W., 2012. Optimization of multiple responses using data envelopment analysis and response surface methodology. Tamkang J. Sci. Eng. 13 (2), 197–203.

Cukor, G., Jurkovic, Z., Sekulic, M., 2011. Rotatable central composite design of experiments versus Taguchi method in the optimization of turning. METABK 50 (1), 17–20.

Foyose, F., 2008. The development of a multipurpose wet food sieving machine. Int. J. Agric. Eng. CIGR X, 1–10.

Gaffa, T.I., Jideani, I.A., Nkama, I., 2003. Traditional production, consumption and storage of *Kunu*—a non-alcoholic cereal beverage. J. Plant Food Hum. Nutr. 57 (1), 73–81.

Gbabo, A., Gana, I.M., Solomon, M.D., 2012. Effect of blade types on the blending efficiency and milk consistency of a grain drinks. Acad. Res. Int. 2 (3), 2223–9944.

Gbabo, A., 2005. Development and testing of rotary dryer for the indigenous cottage sugar industry in Nigeria. J. Sugar Tech 7 (2&3), 57–66.

Gbabo, A., Igbeka, J.C., 2003. Development and performance of a sugar centrifuge. J. Sugar Tech 5 (3), 131–136.

Gana, I.M., 2011. Development and Performance Evaluation of Grain Drinks Processing Machine, Unpublished M. Engineering Thesis. Federal University of Technology, Minna.

Gana, I.M., Gbabo, A., Osunde, Z., 2013. Development of grain drinks processing machine using stainless steel materials. J. Eng. Appl. Sci. 2 (1), 1–9.

Jayesh, T., 2009. V-Blender, Lamar Stone Cypher 76., pp. 841, Retrieved 1st April, 2013 http/www/brigthub.com/./aspr.

Khurmi, R.S., Gupta, J.K., 2005. Machine Design, First Multicolour Edition. Enrasia Publishing House (PVT) Ltd., Ram Nagar, New Delhi-110 055.

Nasir, A., 2005. Development and testing of a hammer mill. AU J. T. 8 (3), 124–130.

Nwaigwe, K.N., Nzediegwu, C., Ugwuoke, P.E., 2012. Design, construction and performance evaluation of a modified cassava milling machine. Res. J. Appl. Sci. Eng. Technol. 4 (18), 3354–3362.

Oshoma, C.E., Aghimien, M.O., Bello, Z.O., 2007. Growth and survival of *Escharichiacoli* in *Kunu Zaki* during storage. World J. Agric. Sci. 5 (40), 494–497.

Salam, K.K., Arinkoola, A.O., Oke, E.O., Adeleye, J.O., 2014. Optimization of operating parameters using response surface methodology for paraffin-wax deposition in pipeline. Pet. Coal, ISSN 1337-7027 Http/www/.vurup.sk/petroleum.coal.

Simonya, K.J., El-Okene, A.M., Yijep, Y.D., 2007. Some physical properties of Samaru Sorghum 17 grains. Agric. Eng. Int. CIGR J. Manuscr. IX, Fp 07 008.

Tran, H.T., Phan, T.C.L., Tran, T.A.T., Ho, T.T., Le, T.V.H., Bui, H., 2010. Using central composite design—response surface methodology to optimize inveratse activity condition for fructose production. Conference Proceedings of Biotechnology for Green Solutions and Sustainable Environment, 82–87.

Xin, L., Saka, S., 2008. Optimization of Japanese beech hydrolysis treated with batch hot compressed water by response surface methodology. Int. J. Agric. Biol. Eng. 1 (2), 239–245.