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# Design, fabrication and testing of batched grain beverages processing machine

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Ibrahim MG,[1] Gbabo A[2]

[1]Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic, Nigeria
[2]Department of Agricultural and Bioresources Engineering, Federal University of Technology, Nigeria

**Correspondence:** Ibrahim MG, Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic P. M. B. 55, Bida, Niger State, Nigeria, Email ganaibro74@yahoo.com

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## Abstract

Grain beverages are indigenous food product in most developing countries. In Nigeria, the production method is still at the basic level of using separate equipment for each operation. The research work was conducted to develop a batched grain beverages processing machine capable of integrating blending of soaked grains, mixing the slurry and extracting the aqueous liquid together. Some physical and mechanical properties of soya beans, sorghum and maize essential to the design of the machine were determined. 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 water tank, outer casing, connecting pipes, temporary milled starch/milk tank, machine frame, detachable cover, cover screw handle, perforated basket, blending blade, perforated drum cover, muslin cloth inner casing (blending casing), inner casing cover, detachable cover, electric motor of 7.5Hp, pulleys, central shaft, V- belt and perforated drum teeth Assembly. The results of testing of the machine using soya beans revealed that highest blending efficiency of 81.11% from combination of blade with contact area of 1.32x10-3m2, speed of blending of 1100rpm and blending time 540sec while the lower value of blending efficiency of 52.85% was obtained from combination of blade with contact area of area of contact of 6.8x10-4m2, speed of blending of 1000rpm and blending time 420sec. The results of analysis of variance ANOVA also revealed that all the experiment factors have positive significant effects ($p \leq 0.05$) on the blending efficiency. The results of optimization of the machine functional parameters; blade area of contact, blending time and speed of blending carried out with goal of maximizing the blending efficiency produced values of 1.16x10-3m2 for blade contact area, blending time of 660seconds and speed 1200rpm with corresponding blending efficiency of 80.34% and desirability of 97.30%. The machine capacity and cost of production are 150 liters per hour and $396.93 respectively.

**Keywords:** beverages, blending, efficiency, extraction, grain, machine, central composite rotatable design

## Introduction

Grain beverages are processed from legumes and cereals such as soya beans, maize, rice, sorghum, millet among others.[1,2] They are rich sources of vitamins, minerals, carbohydrates, fats, oils, and protein. Grains beverages include soya milk, grain milk, *ogi* and *kunu* products among others. These beverages are among the most widely consumed food products in many developing countries and play very important role especially in the socio-economic and health promoting aspect of the people. It is in recognition of this fact that the federal and various state governments are encouraging the establishment of cottage industries to process these products by utilizing local raw materials to supplement the production capacity of the giant industries. The development of appropriate technology in the country for processing grains beverage in the agricultural sector cannot be over looked. According to Gbabo et al.[1] the basic methods of grain beverage production are traditional and the modern methods. The traditional method was reported by Gana et al.[3] to be tedious, time taking and predispose the product to contamination. On the other hand Fayose[4] reported that the industrial method involved the use of equipments which are sophisticated to operate and maintain by small and medium scale processors. Generally, the processing unit operations involved in grains beverage production are almost similar despite the method employed. It comprised of the following major unit operations: cleaning, steeping, wet milling, wet sieving, mixing and cooking. Among these processing operation, wet milling, mixing and wet sieving greatly affect the quality of the final product produced. A lot of research work has been conducted on design of equipments for size reduction of grains, and on design of mechanical sieving equipments. However, very few work were conducted on development of machine that integrate these operations together and finished in one go.[3] It was reported by Shakiru et al.[5] that available equipments used for wet milling of grains include burr mill, plate mill, disc mill and hammer mill. These equipments are generally made from mild steel materials which can easily become rusted and cause contamination of food material, thereby reducing the quality of the product. According to Fellows,[6] Earle[7] these equipments are difficult to disassemble for sanitation and cleaning operation. Foyose[4] reported that the production steps of grains beverage are carried out in separate stages using different equipment, which makes the process tedious, time consuming and predisposed the product to contamination. In addition, the few existing wet sieving machines are only available in large scale industries which are too sophisticated to operate and maintain by local processors. An automated grain beverage processing machine that is 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 was developed by Gana et al.[3] However, the machine was observed to have some shortcomings which include no provision of alternative source of power as such the machine cannot be use in rural area where there is no source electricity. Also sometime the machine stop suddenly when in operation due to power sag, that is decrease in the voltage level below the designated level for a duration of up 1minute,[8] this sometime occur when the 5 hp electric motor is switch on by the control system. The problem of power sag may be peculiar to only some Africans countries like Nigeria where the power supply is inadequate. Therefore this research into development of batch grain beverage processing machine is therefore set out to achieve both blending of grains, mixing of the slurry with water and sieving of the milk in order to alleviate some of these difficulties and shortcomings associated with the existing grains beverage production machine.

## Materials and methods

### Materials selection

Stainless steel material was selected for the construction of component parts of the machine that have direct contact with the beverages due to its high resistance to corrosion. A 2-inches angular iron was used for the construction of the machine frame in order to give a rigid support and ensure stability of the machine when in operation.[1]

### Material preparation

In designing an appropriate grain beverage processing machine, it was paramount to determine some physical and mechanical properties of some selected grains such as sorghum, maize and soya beans. The engineering properties of grains are pre-requisite in designing an equipment for handling, storage, mechanical extraction of oil and other processes.[3,9,10] This experiment was essential to the design of the machine as the results obtained served as reference data used in the design of various component of the machine. It also aided determination of capacity of the machine, force required to caused rupture, angle of hopper in order to have free flow of the materials. In addition it assisted in selection of size of hole on the perforated basket and also expected output of the machine when processing different type of grains.[11,12]

### Sample preparation for determination of engineering properties

The experiments were carried out at the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida. The guinea corn (SSV 98001), maize (SAMMAZ 38) and soya bean (TGX 1954-IFXTGX 1835-10E) were obtained from Niger State Agricultural Mechanization Development Authority, and the samples were cleaned to remove unwanted materials before soaking at room temperature for the recommended time of 12hours for soy bean and 36 hours for guinea corn and corn.[13] One hundred samples of each of the grains were randomly selected for the experiment. The selected engineering properties determined include; thickness, width, and length. Others are volume, filling angle of repose, linear limit, bioyield point rupture point. The moisture content of the grains was determined using a digital microprocessor moisture meter with model number MC7821, as described by Simonya et al.[14] The linear dimensions; thickness, width and length of the seeds were determined using a micrometre screw gauge with Model number 436-2SM. The measurement was made with accuracy of 0.001cm as reported by Mohammed.[15] The grains volume was determined as reported by Simonya et al.[14] by using a standard container. The volume of the container was measured and taken as the volume of grain contain in the container.

Filling or pilling angle of repose of the grains is the angle it made with the horizontal, at which the grains will stand when pilled. It was obtained with the aid of open container of 16cm and 26cm diameter and height respectively. A container with 35cm diameter was filled with the grain after positioning it on a rose round plat form. The container was removed gradually until the grain formed shaped of a cone. The height of the shaped cone was measured and the angle was computed as reported by Ozguven et al.[16]

In determining the visco-elastic behaviour of this biomaterial under application of force, a compressive test was performed. The force and deformation at the time of rupture of the grain samples were obtained by placing the grain samples between the base plate and the plunger head of California Bearing Ratio (CBR) machine. The machine was operated in accordance with American Standard of Agricultural Engineers[17] and Ardebili et al.[18]

### Machine description

The developed machine (Figures 1-4) consists of the outer casing with diameter of 0.29m and it is mounted on machine frame made up of 0.075m angle iron assembly. An out let valves made up of two 0.038m diameter pipe each was fitted to the bottom side of the casing in order to allow outflow of separated liquid (milled starch) from the tank to the temporary milled starch tank. A drain valve was also fitted at the bottom of the casing for easy draining of the extracted residue. The perforated Drum is smaller in size (0.264m) than the outer casing with permissible clearance of 0.026m between them. It has a teeth assembly with wire brush at its base. The wire brush prevents bigger particles from blocking the sieve hole at the tank outlet. Perforated Drum cover of the machine has a pipe with a bearing at the centre, the pipe allows inflow of water into the system during separation and also prevents the drum from getting in contact with the outer casing while in rotation. Muslin cloth was attached to frame made from stainless sheet. The sieve cloth is lined in both walls of the perforated drum. The muslin cloth frame has cover with stainless steel pipe at the center, through which water flow into the system. The inner casing (blending casing) is only used during blending operation. It prevents the blending blade from tearing the sieving cloth and also minimizes the amount of water living the system during blending operation. The inner casing cover is also made from stainless sheet with 18mm bolt and nut at the centerfor easy adjustment of the cover, depending on the quantity of grains fed into the machine. The blending blades these are interchangeable sets of 2mm blades assembly. 8mm bolts and nut were used to tighten the blade assembly (Figures 1-4).

The drive and driven assembly consists of an electric motor of 7.5Hp with its pulley and the central shaft with its pulley. The motor and the central shaft are connected by a V-belt. The perforated drum teeth assembly consists of 4 teeth joined to a pipe through which the central shaft passes. The pipes have two 8mm bolts and nuts that hold the central shaft during separation (sieving) operation. The water tank used was a calibrated transparent rubber bucket; it serves as source of water for separation operation after blending and also during cleaning of the machine. It was designed in such a way that the water goes into the system through a nozzle and a pipe when required by opening the valve. Temporary milled starch tank s made from stainless sheet with two inlet valves, one outlet valve and a drain valve at the base for easy cleaning. The machine frame was made up of 0.0762m angle iron. Its main function is to hold the water tank, blending, separation, drive and driven assemblies in position and stabilizethe system during operation.

**Figure 1** AutoCAD drawing of the developed machine.

**Figure 2** The developed machine.

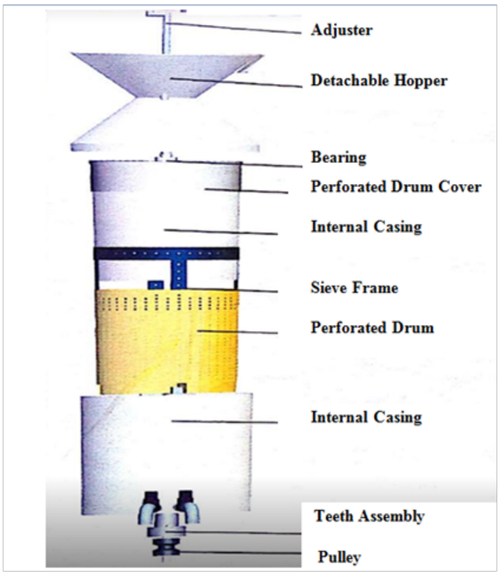


**Figure 3** Exploded view of internal part of the machine.

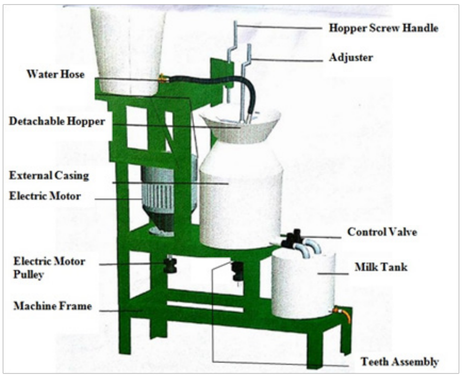


**Figure 4** Side view of the machine.

## Machine working principle

The feed cover was unscrewed and swung aside for the blade to be fixed and tightened to the central shaft. On the other hand, the muslin cloth was then fixed inside the perforated drum, while the internal casing was fixed insisde the muslin cloth frame. The material (grains) to be blended was then fed into the internal casing of the machine before fixing and adjusting the internal casing cover as shown in Figures 5, Figure 6.

**Figure 5** Feeding of grains into the machine.

**Figure 6** Processed milk from the machine.

 

The cover was then swung back to its appropriate position and screwed. The two nuts that tighten the perforated drum teeth assembly to the central shaft were then loosened in order to allow the central shaft to rotate with only the blending blades that beat and cuts the material fed into fine particle. The system is then connected to the sources of electricity and water is intermittently added during the operation in order to accelarate the blending process. The cover screw was then unscrewed and swung away. The blending casing and it's adjustable cover are removed and the covers of the sieve frame and perforated drum are then fixed.

The sieving operation was achieved by tightening back the two nuts to the central shaft, in order to allow the rotation of the perforated drum and central shaft together.Water is released into the system from water tank mounted on the side of the machine frame. Due to centrifugal force generated, the milled starch/milk is seperated from the paste by passing through the sieve (muslin cloth) and collected in the collection tank. The system was allowed to run for 30 seconds before switched off when water in the water tank has reached the desired level. The outletvalve of the starch tank is opened and milled starch/milled is then received as shown in Figure 5. The cover is then unscrewed and swung for the residue to be packed out, and the system cleaned for the next operation.

## Design calculation

**Machine power requirement:** The power required by the sheanut shelling machine to achieve effective blending and sieving g was determined as reported by Khurmi et al.[19]

$$P = \frac{2\pi N \times \tau}{60} \quad (1)$$

$$\tau = F \, d \quad (2)$$

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

$$\omega = \frac{2\pi \times N}{60} \quad (4)$$

$$M = (M_s + M_G + M_{wt} + M_{TPb} + M_{TT} + M_{EBH} + M_P + M_{MF} + M_{FC}) \quad (5)$$

where $P$ is power required by the machine (watts), F is the total force (N), $V$ is the velocity of perforated drum (m/s), $\tau$ is the Torque generated (Nm), $M$ *is* total mass of the centrifugal basket and its content (kg), ω is angular speed of the centrifugal basket (rpm), $M_G$ is mass of grain(kg), $M_{wt}$ is mass of water (kg), $M_{BK}$ is mass of blending blade with highest mass(kg), $M_P$ is mass of the pulley(kg), $M_{TPb}$ is mass of the perforated drum, with the teeth housing and its cover (kg), $M_{TT}$ is the total mass of the teeth assembly(kg,), 'd$_{bs}$ is the diameter of the drum/blade (m), $g$ is acceleration due to greavity, $M_{EBK}$ is mass of external bearing with its housing (kg), $M_{Mf}$ is mass of muslin cloth frame (kg), $M_{FC}$ is mass of frame cover (kg), π is constant, $N$ *is* revolution per minute.

**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 et al.[20]

$$\ddot{a}_b = \frac{M_t \omega^2 r}{ðDh_b} = \frac{M_t \omega^2 D}{2ðDh_b} \quad (6)$$

$$\ddot{a}_b = \frac{M_t \omega^2}{2ðh_b} d \quad (7)$$

Where $\ddot{a}_b$ is the stress on the walls of the conical perforated basket in N $M_t$=total mass of the basket assembly (Kg), ù = the angular velocity (Rpm), $h_b$ = the height of the basket (m), d =the diameter of the basket (m), ð = constant (3.14)

**Expected thickness of 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 et al.[20]

$$t_{bs} = \frac{\ddot{a}_b d_b}{2S_s} \quad (8)$$

Where $t_{bs}$ = expected thickness of the basket (m), ä = stress that is developed and acts on the wall of the conical basket (KN), $d_b$ = diameter of conical centrifugal basket (0.5m), $S_s$ = shear stress of stainless steel used for construction of the basket

**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 et al.[20]

$$M_t = \frac{60W}{2ðN} \quad (9)$$

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

**Design of the central shaft:** The diameter of the central shaft was mputed using the equation reported by Khurmi et al.[19]

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

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

**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 et al.[20] as:

$$J = \frac{ðds^4}{32} \quad (11)$$

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

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**Summary of design calculation:** The summary of design calculation carried out is presented in Table 1 & Table 2.

**Cost analysis of the developed machine:** The cost of construction of the automated grains beverage 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 the machine. It was computed as 20 % of the material price.[21]

**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.[21]

Total Cost of material= **₦143,890**

**Labour (Lc):** This is taken as 20% of the material cost=20/100x**143,890**= ₦ 28,778.

**Overhead Cost (Oc):** The overhead cost is taken as 10% of the material cost, which is

**Overhead cost=**10/100x**143,890**=₦ 14,389

Total Cost of Fabrication (Tc): Material cost+labour cost+overhead cost

**Tc=143,890**+28,778+14,389=₦ 187,057.

Therefore, the total cost of construction of the machine was ₦ 187,057

**Testing of the machine:** The performance of the batched grain beverages processing machine was evaluated in accordance with procedures reported by Gana et al.;[3] Gbabo et al.;[1] Gaffa et al.[13] The grains were cleaned and sorted to remove unwanted materials before soaking at room temperature of 27°C for the recommended time of 12hours for soy bean and 36hours for guinea corn and corn[13] before processing using the developed machine as shown in Figure 4. Two sets of experiments were carried out to investigate the machine performance. In the first experiment effects of blending time on blending efficiency of the machine was examined where as in the second experiment effects of blade cross sectional area, speed of blending and blending time were examined. The experiments were carried out at the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida, Nigeria.

**Design of experiments:** The experimental design was designed as a function of machine parameters of blade cross sectional area, blending time and speed of blending (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 Gana et al.;[1] Tran et al.[22] and Anuonye[23] and is presented in Table 3. 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 (centre points: six replications) as 20[22–24] and the design is shown in Table 4. The objective function here was to minimise the effects of unexpected variability in the observed response. Blending efficiency was considered as the response in this case.

## Statistical analysis

Design expert software package (version7.0.0) 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.[25]

$$Y = \hat{a}_0 + \sum_{g=1}^{N} \hat{a}_g x_g + \sum_{g=1}^{N} \hat{a}_{gg} x_g^2 + \sum_{g<f} \sum \hat{a}_{gf} x_g x_f \qquad (12)$$

where Y = the response (paste expelling efficiency), $\beta_0$=the intercept coefficient, $\beta_g$=the linear terms, $\beta_{gg}$=the squared terms, $\beta_{gf}$=the interaction terms, $x_g$ and $f_g$ and 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 blending efficiency.

### Determination of machine performance

The machine performance determined based on blending efficiency.

**The blending efficiency:** This is the measure of the degree by which the grains are reduced in size and was determined as reported by Nwagwe et al.[26]

$$E_B = \left( \frac{A - W}{MT - W} \right) \times 100 \qquad (13)$$

where, $E_B$=the blending efficiency (%), A=the amount of the material passing through the sieve (kg), MT=the total weight of the material feed into the machine (kg), W=the amount of water used (kg)

## Results and discussion

The results of the physical and mechanical properties of the grains are presented in Tables 1-3. The properties are the thickness, width, length, volume, filling angle of repose, linear limit, bio-yield and rupture point. These properties were important in the design of the machine.[27] The mean major diameter, minor diameter and the intermediate diameter of the soya beans seed at 20 % moisture content were 12.56mm, 7.23mm and 5.11mm respectively, for sorghum were 5.25mm, 4.67mm and 3.68mm respectively and respectively 12.08mm, 9.64mm and 5.56mm for corn. The volume of the grains was $26 \times 10^{-4} m^3$, $4.64 \times 10^{-4} m^3$ and $40 \times 10^{-4} m^3$ for soya beans, sorghum and corn respectively. The volumes are vital factor to be considered in the design of volume of the internal casing and blending chamber.

The filling angles of reposes of the grains were 27.28°, 32.62° and 24.21° for soya beans, sorghum and maize respectively. The various properties measured are considered important in the design and serves as useful tools for the developed machine most especially the blending blade, perforated basket and the internal casing.

The average values of forces and the corresponding deformation at linear limits of the grains were 0.89kN and 18.20mm respectively for soya beans, 1.15kN and 6.9mm respectively for sorghum and 1.72kN and 5.8mm respectively for maize. Bioyield point in biomaterials is an

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indication of initial cell rupture in the cellular structure of the materials. Table 1 shows the average values of forces and the corresponding deformation at bioyield of the grains as 1.44kN and 23.66mm respectively for soya beans, 1.65kN and 9.11mm respectively for sorghum and 2.28kN and 7.54mm respectively for maize.

Rupture point is the point on the force-deformation curve where the material ruptures. The force at this point is the minimum required to break the materials. Table 1 shows the average values of force and the corresponding deformation at rupture of the grains as 2.04kN and 31.47mm respectively for soya beans, 2.34kN and 12.39mm respectively for sorghum and 2.89kN and 9.87mm respectively for maize..

**Performances testing of the machine:** The machine was designed, fabricated and the results of the performance testing are presented in Figure 7 & Table 4.

**Result of the first testing:** The effect of blending time on blending efficiency of the various grains is presented in Figure 7. Blending dehulled white maize for 900seconds has the highest blending efficiency of 85.56%, while blending the same dehulled white maize for 360seconds has lower blending efficiency of 43.23%. The least blending efficiency of 36.23% was obtained from processing sorghum for 360seconds.

From Figure 7, the highest values of blending efficiency range from 67.32% to 85.56% while the least blending efficiency range between 36.23%- 47.24%. The highest value of 85.56% was obtained from blending decupled white maize for 900seconds and the least blending efficiency of 36.23% was obtained from blending sorghum for 360seconds. While the grains were blended for short duration of 360seconds soya beans has the higher blending efficiency of 47.24%. This could be as result of its softness but as the blending operation continues the viscosity of soya milk slurry also increases as such this offer resistance to cutting effects of the blade.

**Result of the second testing:** The result of interaction between the experimental factors, blade cross sectional area, blending time and speed of blending with blending efficiency was presented in Table 4. The highest blending efficiency of 81.11% was obtained when the soya beans sample was processed with blade with area of contact of $1.32 \times 10^{-3} m^2$, speed of blending of 1100rpm and blending time 540sec while the lower value of blending efficiency of 52.85% was obtained when the sample was processed with blade with area of contact of $6.8 \times 10^{-4} m^2$, speed of blending of 1000rpm and blending time 420sec.

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 blending efficiency were determined as reported by Anuonye[23] and Aworanti et al.[28] The significant model terms were identified at 95% significance level.

The model F-value of 79.36 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 blade cross sectional area, blending time and speed of blending were significant model terms with P-values of<0.0001 each. It can be clearly observed that blade area of contact had more significant effect ($p \leq 0.05$) on blending efficiency with coefficient of estimate of 6.86.

The coefficient of determination R value of 0.9931 indicated that the model was able to predict 99.31% of the variance and only 0.69% of the total variance was not explained by the model. Predicted R-Squared value of 0.9595 was in reasonable agreement with the Adjusted R–Squared of 0.9738 which indicated that the experimental data fitted better.[29] Adequate Precision value of 33.23 was above the desirable minimum value of 4 was reported by Salam et al.,[30] this indicated that the model can be used to navigate the design space. The regressed blending efficiency model equation is given as

$$E_{EF} = 64.42 + 6.86A + 2.86B + 4.12C + 0.29AB + 1.29AC - 1.20BC + 1.96A^2 + 0.30B^2 - 0.56^2 \quad (15)$$

where, $B_{EF}$=Blending efficiency (%), A=Blade area of contact($m^2$), B=Speed of blending (rpm), C=Blending time (secs)

The model equation was improved by removing insignificant model terms. Factors with values lesser than 0.1000 were significant model terms (A, B, C, AC, BC, $A^2$), and the model was reduced to equation 16 from equation 15, in order to improve it.[25]

The fitted blending efficiency model equation is given as

$$E_{EF} = 64.42 + 6.86A + 2.86B + 4.12C + 1.29AC - 1.20BC + 1.96A^2 \quad (16)$$

All the variables A, B and C in the model have positive co-efficient implying a direct proportionality. That is independent increase in A, B and C increased the blending efficiency. The model equation obtained was simulated and the blending efficiency was observed to be within the experimental range. From Table 4 the actual values of blending 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 blending efficiency at various operating condition.

The response surface and contour plot for blending efficiency with respect to blending time and speed of blending are shown in Figure 7 respectively. The blending efficiency increased from 55% to 66.25% with increased in blending time from 420sec to 660sec. This could be as result of more number of beatings and cutting of the grains when blended for 660 seconds. This observation is in line with the result of an earlier study[31] where blending efficiency was found to be affected by blending time and volume of the material loaded into blender. Also the blending efficiency increased from 55% to 64% with increased in speed of blending from 1000rpm to 1200rpm. The high blending efficiency observed with speed of 1200rpm could be as result of increased in centrifugal force with corresponding shear force, more number of impacts and beating that caused more cutting effect of blade on the grains. Thus, both the blending time and speed of blending have significant effects ($p \leq 0.05$) on blending efficiency of the machine.

The response surface and contour plot for blending expelling with respect to blending time and blade area of contact are shown in Figure 7 respectively. The blending efficiency increased from 57% to 61.76% with increased in blending time from 420sec to 660seconds. This could be as result of more number of beatings and cutting of the grains during blending for 660seconds. Also the blending efficiency increased from 55% to 69% with increased in blade area of contact from 0.00068m to 0.00116m. The high blending efficiency observed with blade with higher area of contact could be as result of more contact between the blade and the grains.

**Table 1** Summary of calculated values

| S/N | Parameter | Calculated value |
|---|---|---|
| 1 | Expected volumetric capacity of the Machine | $0.283m^3$/8hr/day (0.1179 $m^3$ per batch) |
| 2 | Maximum Mass of Material to be processed at a Time 1Kg | (0.1179$m^3$ per batch) |
| 3 | Mass of Blade Assembly | 0.454kg |
| 4 | Mass of the Internal Casing | 1.982kg |
| 5 | Mass of the Perforated Drum | 6.623kg |
| 6 | Mass of the Perforated Basket Teeth | 2.35kg |
| 7 | Central Shaft Diameter | 0.02m |
| 8 | Mass of the central shaft | 1.00kg |
| 9 | Expected Thickness of Basket Wall to Withstand the Stress | 0.001m |
| 10 | Twisting Moment | 23 Nm |
| 11 | Second Polar Moment Area the Shaft | $1.5 \times 10^{-8} m^4$ |
| 12 | Angular velocity (ω) | 136.15 rev/min |
| 13 | Highest Centrifugal Force Generated | 59.74KN |
| 14 | Torque (τ) | 41.06 Nm |
| 15 | Power required for blending Sorghum | 1.862kw |
| 16 | Power required for processing sorghum | 4.3Kw |
| 17 | Length of V-Belt Required for Power Transmission | 0.0875m |
| 18 | Angle of contact between belt and machine pulley | U1 = 181.15° |
| 19 | Angle of contact between belt and electric motor pulley | U2 = 178.85° |

**Table 2** Cost of materials used in construction of the machine

| S/no | Component | Material | Specification (mm) | Qnty | Unit price (N) | Qnty price (N) |
|---|---|---|---|---|---|---|
| 1 | Shaft | Stainless Steel | 20x40 | 3 | 600 | 1800 |
| 2 | 1 mm Stainless Sheet | Stainless Steel | 1200x2400 | 1 | 50,000 | 50,000 |
| 3 | 3 inch Angle bar Iron | Mild Steel | 75x2400 | 2 | 7500 | 15,000 |
| 4 | 2 inch Angle bar Iron | Mild Steel | 50x1200 | 1 | 2000 | 2000 |
| 5 | 1 inch Angle bar Iron | Mild Steel | 25x1200 | 1 | 1000 | 1000 |
| 6 | 20 gauge Metal Sheet | Mild Steel | 600x1200 | 1 | 1500 | 1500 |
| 7 | Pulley | Cast Iron | 50, 56, 73 and 87 | 4 | 800 | 3200 |
| 8 | Bearing | Cast Iron | ISI NO 6306 | 3 | 600 | 1800 |
| | | | ISI NO 6204 | 2 | 300 | 6000 |
| 9 | V-belts | Rubber | A-29, A-31, A-32 | 3 | 200 | 6000 |
| 10 | Paints | | 2 Tins | 2 | 1200 | 2400 |
| | | | 6x40 | 12 | 20 | 240 |
| 11 | Bolt & Nuts | Mild Steel | 14x400 | 3 | 1000 | 3000 |
| | | | 16x400 | 1 | 1500 | 1500 |
| 12 | Flat bar | Mild Steel | 20x120 | 1 | 500 | 500 |
| 13 | Electric Motor | | 7.5 hp | 1 | 30,000 | 30,000 |
| 14 | Electric Wire | Copper | 4x90 | 10 | 500 | 5000 |
| 15 | Pipe Adaptor | Galvanize Iron | 37.5 | 2 | 1250 | 2500 |

Table Continued

| S/no | Component | Material | Specification (mm) | Qnty | Unit price (N) | Qnty price (N) |
|---|---|---|---|---|---|---|
| 16 | Valve | Galvanize Iron | 18.75 | 2 | 750 | 1500 |
| 17 | Plug Valve | Galvanize Iron | 37.5 | 2 | 200 | 400 |
| 18 | Clip | Mild Steel | | 2 | 50 | 100 |
| 19 | Electrode | Stainless | E 10 | 31 | 150 | 4650 |
| | | | E 12 | 150 | 20 | 3000 |
| 20 | Rubber Seal | Rubber | | 2 | 100 | 200 |
| 21 | Rubber Bucket | Rubber | | 1 | 600 | 600 |
| Total | | | | | | N143,890 |

**Table 3** Physical and mechanical properties of soya beans, sorghum and maize at 20% moisture content

| Properties | Soya beans | Sorghum | White corn | | |
|---|---|---|---|---|---|
| M.D (mm) | 12.56±1.32 | 5.25±0.72 | 12.08±1.21 | | |
| I.D (mm) | 7.23±1.19 | 4.67±0.11 | 9.64±1.02 | | |
| MN.D (mm) | 5.11±0.48 | 3.68± 0.73 | 5.56± 1.23 | | |
| V ($m^3$)X$10^{-5}$ | 26 ±6.5 | 4.64±1.12 | 40.2± 6.1 | | |
| F.A.R (Deg) | 27.28±2.21 | 32.62±3.51 | 24.21±0.78 | | |
| **Mechanical Properties** | | | | | |
| | **Linear Limit** | | **Bio-yield Point** | | **Rupture Point** |
| | **Force(kN)** | **Deformation(mm)** | **Deformation(mm)** | **Force(kN)** | **Deformation(mm)** |
| Soya beans | 0.89 | 18.2 | 23.66 | 2.04 | 31.47 |
| Sorghum | 1.154 | 6.9 | 9.11 | 2.34 | 12.39 |
| Maize | 1.72 | 5.8 | 7.54 | 2.89 | 9.87 |

Note: M.D, major diameter, I.D, intermediate diameter, MN.D, minor diameter, V, volume, FAR, filling angle of repose.

**Table 4** Results of interaction between the blade area of contact, speed of blending and blending time on blending efficiency

| Std. ord | Run ord. | Blade area of contact ($10^{-5}$X$m^2$) | Speed of blending (rpm) | Blending time (secs) | Blending efficiency (%) | Predicted values for blending efficiency (%) |
|---|---|---|---|---|---|---|
| 7 | 1 | 68 | 1200 | 660 | 64.21 | 63.47 |
| 2 | 2 | 116 | 1000 | 420 | 63.21 | 63.22 |
| 11 | 3 | 92 | 931.82 | 540 | 60.43 | 60.45 |
| 12 | 4 | 92 | 1268.18 | 540 | 69.06 | 70.07 |
| 18 | 5 | 92 | 1100 | 540 | 65.86 | 64.42 |
| 5 | 6 | 68 | 1000 | 660 | 60.97 | 60.73 |
| 19 | 7 | 92 | 1100 | 540 | 62.12 | 64.42 |
| 13 | 8 | 92 | 1100 | 338.19 | 55.57 | 55.91 |
| 8 | 9 | 116 | 1200 | 660 | 80.89 | 80.34 |
| 17 | 10 | 92 | 1100 | 540 | 65.32 | 64.42 |
| 6 | 11 | 116 | 1000 | 660 | 76.65 | 76.43 |
| 20 | 12 | 92 | 1100 | 540 | 65.92 | 64.42 |
| 3 | 13 | 68 | 1200 | 420 | 60.71 | 60.2 |

Table Continued

| Std. ord | Run ord. | Blade area of contact ($10^{-5}Xm^2$) | Speed of blending (rpm) | Blending time (secs) | Blending efficiency (%) | Predicted values for blending efficiency (%) |
|---|---|---|---|---|---|---|
| 15 | 14 | 92 | 1100 | 540 | 63.62 | 64.42 |
| 4 | 15 | 116 | 1200 | 420 | 72.4 | 71.91 |
| 16 | 16 | 92 | 1100 | 540 | 63.85 | 64.42 |
| 9 | 17 | 51.64 | 1100 | 540 | 57.79 | 58.44 |
| 14 | 18 | 92 | 1100 | 741.82 | 69.09 | 69.78 |
| 10 | 19 | 132.36 | 1100 | 540 | 81.11 | 81.5 |
| 1 | 20 | 68 | 1000 | 420 | 52.85 | 52.67 |

**Table 5** Results of analysis of variance (ANOVA) of the machine performance

| Source | Sum of squares | Coefficient estimate | Standard error | F Value | p-value Prob>F | R- square | |
|---|---|---|---|---|---|---|---|
| Model | 1075.003 | 64.41883 | 0.500366 | 79.35757 | <0.0001 | 0.986192 | Significant |
| A-Blade cross sectional area | 641.9096 | 6.855855 | 0.331982 | 426.4763 | <0.0001 | | |
| B-Speed | 111.6234 | 2.858921 | 0.331982 | 74.16109 | <0.0001 | | |
| C-Blending Time | 231.9949 | 4.121582 | 0.331982 | 154.1344 | <0.0001 | | |
| AB | 0.678613 | 0.29125 | 0.433755 | 0.450861 | 0.5171 | | |
| AC | 13.28701 | 1.28875 | 0.433755 | 8.827716 | 0.014 | | |
| BC | 11.44811 | -1.19625 | 0.433755 | 7.605975 | 0.0202 | | |
| $A^2$ | 55.42748 | 1.961151 | 0.323175 | 36.82528 | 0.0001 | | |
| $B^2$ | 1.277056 | 0.297683 | 0.323175 | 0.848459 | 0.3787 | | |
| $C^2$ | 4.457433 | -0.55615 | 0.323175 | 2.96146 | 0.116 | | |
| Lack of Fit | 3.667789 | 5 | 0.733558 | 0.322197 | 0.8803 | | not significant |

The optimization of the machine functional parameters; blade area of contact, blending time and speed of blending was carried out using numerical technique in rsm with the goal of maximizing the blending efficiency. The ramp of the optimization process is shown in Figure 8 with optimum values of $1.16x10^{-3}m^2$ for blade area of contact, blending time of 600secs and speed of 1200rpm. On the other hand blending efficiency and desirability of 80.32% and 0.973 respectively were also obtained.

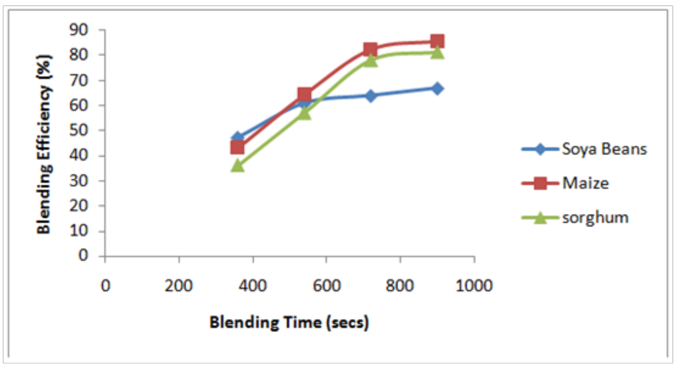


**Figure 7** Relationship between Blending Efficiency and Blending Time at constant blending speed of 1200rpm using blade with contact area of 1.32×10-3m2.

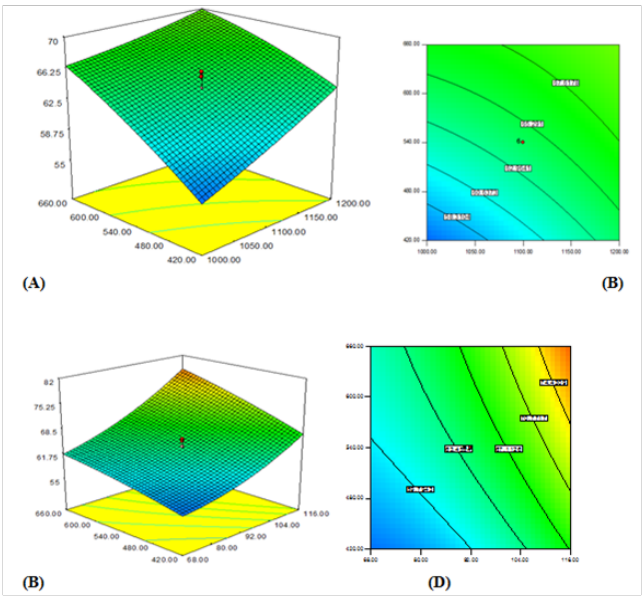


**Figure 8** Response surface for blending efficiency with respect to blending time and speed of blending.

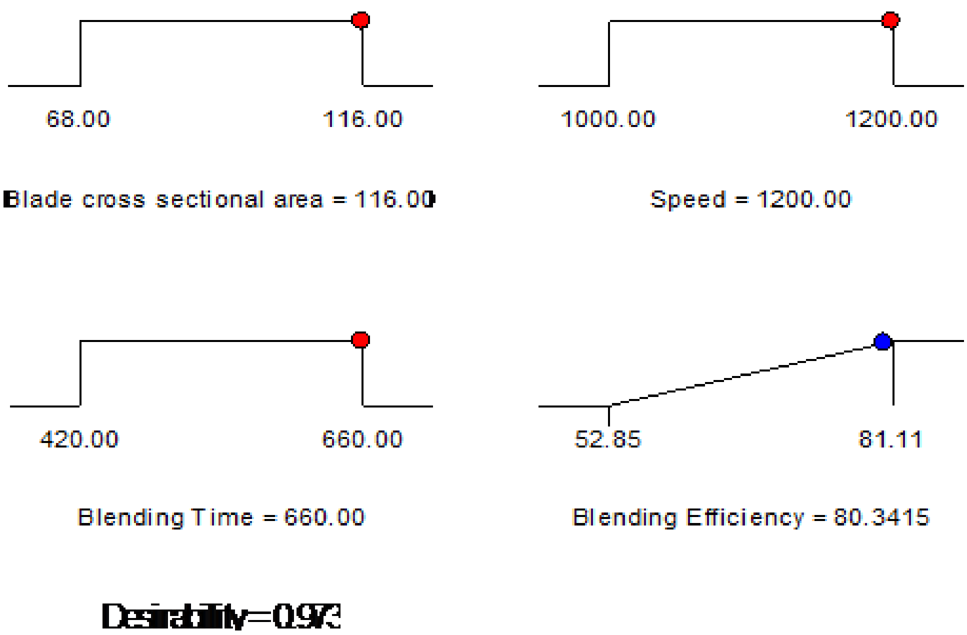


**Figure 9** Ramp for optimization of the blending efficiency.

## Conclusion

Some physical and mechanical properties of soya beans, maize and sorghum were determined and used in the design of the machine to minimize economic losses. The average value of the major, minor and intermediate diameters of the soya beans seed at 20% moisture content were 12.56mm, 7.23mm and 5.11mm respectively, for sorghum were 5.25mm, 4.67mm and 3.68mm respectively and respectively 12.08mm, 9.64mm and 5.56mm for corn. The volume of the grains were 26x10$^{-4}$m$^3$, 4.64x10$^{-4}$m$^3$ and 40x10$^{-4}$m$^3$ for soya beans, sorghum and corn respectively. The filling angles of reposes of the grains were 27.28°, 32.62° and 24.21° for soya beans, sorghum and maize respectively. The average values of forces and the corresponding deformation at linear limits of the grains were 0.89kN and 18.20mm respectively for soya beans, 1.15kN and 6.9mm respectively for sorghum and 1.72kN and 5.8mm respectively for maize. The average values of forces and the corresponding deformation at bioyeild of the grains were 1.44kN and 23.66mm respectively for soya beans, 1.65kN and 9.11mm respectively for sorghum and 2.28kN and 7.54mm respectively for maize. The average rupture force and the corresponding deformation at rupture of the grains were 2.04kN and 31.47mm respectively for soya beans, 2.34kN and 12.39mm respectively for sorghum and 2.89kN and 9.87mm respectively for maize.

The batched grain beverages processing machine designed, fabricated and tested. The total cost of construction of the machine was $396.927. Test results of the machine using soya beans soaked for 12hours and 36hours for sorghum and maize under room temperature of 27°C produced highest blending efficiency of 81.11% from combination of blade with contact area of 1.32x10$^{-3}$m$^2$, speed of blending of 1100rpm and blending time 540sec while the lower value of blending efficiency of 52.85% was obtained from combination of blade with contact area of area of contact of 6.8x10$^{-4}$m$^2$, speed of blending of 1000rpm and blending time 420sec. The results of analysis of variance ANOVA also revealed that all the experiment factors have positive significant effects ($p \leq 0.05$) on the blending efficiency. The results of optimization of the machine functional parameters; blade area of contact, blending time and speed of blending carried out with goal of maximizing the blending efficiency produced values of 1.16x10$^{-3}$m$^2$ for blade contact area, blending time of 660seconds and speed 1200rpm with corresponding blending efficiency of 80.34% and desirability of 97.30 %.

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## Conflict of interest

The author declares no conflict of interest.

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