Comparative evaluation of mesh sieve performance of a wet cereal slurry sieving machine

C. N. Anyanwu[1*], C. I. Ibelegbu[2], C. N. Ugwu[2], V. C. Okonkwo[2] and C. A. Mgbemene[3]

(1.Department of Agricultural and Bioresources Engineering/Africa Centre of Excellence for Sustainable Power and Energy Development (ACESPED), University of Nigeria, Nsukka, 410001 Enugu State Nigeria;
2. Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka, 410001 Enugu State Nigeria
3.Department of Mechanical Engineering, University of Nigeria, Nsukka, 410001 Enugu State Nigeria)

Abstract: This paper presents the design, construction and comparative performance evaluation of a cereal slurry sieving machine. For the evaluation, wet slurries of maize, millet and sorghum were each sieved with three sieves of mesh sizes of 1.19 mm, 1.00mm and 0.354mm.The machine performed satisfactorily in the sieving of wet maize slurry, recording an efficiency of 85%. The output capacity was 22.07kgh^{-1}in comparison with 8.82kgh^{-1}achieved in the traditional manual method. The average sieving time for 1kg of maize slurry using the machine was about 2.5 times shorter than in manual sieving. The sieving capacity of the machine was about 2.4 times higher than that of the traditional manual method. The analysis of variance (ANOVA) carried out on the results showed that sieve 1 (mesh size of 1.19mm) was suitable for maize, millet and sorghum slurries. Sieves 2 and 3, with mesh sizes of 1.00mm and 0.354mm respectively, were proved to be significantly better suited for the processing of millet slurry.

Keywords: cereal, slurry, machine design, sieving capacity, mesh size, efficiency.

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1 Introduction

In many African countries, cereals are often consumed in the form of starch meals, which are obtained from the slurries through a manual sieving process that is both time-consuming and labor-intensive. Some of such cereals include maize, millet and sorghum. Maize (*Zea mays*) has been in the diet of many Africans for centuries. Sustainable production and utilization of maize are important steps in enhancing food security and alleviating poverty particularly in West Africa, where it is estimated to provide more than 200 dietary calories each day for over 60 million people (Nweke et al., 1991). Nearly all the grain produce is utilized locally in most West African countries including Nigeria.

In West Africa, cereal slurry processing into *pap* and other foods is very common. Osungbaro (2009) noted that fermented cereal porridges (and gels) were important staple food items for people of the West African sub-region and were also important weaning foods for infants. In spite of this, it is carried out using manual labour, which entails drudgery and oftentimes under poor hygienic conditions. The long man-hours required for manual processing of cereal slurry makes it a very uncomfortable job, reserved for the less privileged.

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***Corresponding author: C. N. Anyanwu,** Ph.D, Department of Agricultural and Bioresources Engineering/ACESPED, University of Nigeria, Nsukka. Email: cosmas.anyanwu@unn.edu.ng. Tel: +2348051980070.

According to Lagunna and Carpenter (1951), considerable nutrient losses take place during steeping, milling and sieving (Osungbaro, 2009). Aminigo and Akingbala (2004), who studied the nutritive composition of *ogi* (*pap*), also confirmed this view. Although these nutrient losses are inevitable because much of the protein in cereal grains is located in the testa and germ, which are usually sifted off during processing (Oke, 1967; Banigo et al., 1974; Chavan et al., 1989), they can be drastically reduced through the use of machine sieving method, while employing the right sieve.

A few researchers have worked on the wet slurry sieving in Nigeria. Simolowo (2011) performed a comparative analysis of the operations of a suction and vibration sieving machine and concluded that the vibration sieving machine was more suitable for sieving operations. They attributed this to the complexity and intricacy involved in designing an appropriate centrifugal pump for the suction sieving machine. Fayose (2008) developed a multi-purpose wet slurry sieving machine, which employed a 0.25hp electric motor and a cam to vibrate the sieve. The sieving capacity obtained using the machine corresponded to household-level processing.

The main objectives of the present study are to design and fabricate an electrically-driven, wet sieving machine for commercial-scale processing of cereal slurry and to evaluate the performance of three different sieves on the fabricated machine using maize, millet and sorghum slurries with respect to sieving efficiency.

2 Cereal production and processing in Nigeria

2.1 Cereal production

The importance of the cereal crops cannot be over-emphasized. According to Dowswell et al.(1996), maize has been put to a wide range of uses more than any other cereal. It has been used as human food, as a feed grain, a fodder crop and for hundreds of industrial purposes because of its broad global distribution, low price relative to other cereals, diverse grain types, and wide range of biological and industrial properties.

Maize is a staple food of great socio-economic importance in sub-Saharan Africa, with per capita production of 40 kgyear^{-1} (IDR, 2014). Cereal production in Nigeria was last put at 19.5MMT in 2010, according to the World Bank. Nigeria has an annual maize production in excess of 9 MMT, and is ranked among the ten largest producers in the world (IDR, 2014). Three cereal crops of sorghum, millet and maize constitute the most important grains produced in Nigeria and are processed in a similar way.

Nigeria is the largest sorghum producer in West Africa, accounting for about 71% of the total regional sorghum output (Ogbonna, 2011). Nigeria's sorghum production also accounted for 35% of the African production in 2007 (Gourichon, 2013). The country is the third largest world producer after the United States and India (FAOSTAT, 2012). However, 90% of sorghum produced by United States and India is destined to animal feed making Nigeria the world leading country for food grain sorghum production. In Nigeria, sorghum, with more than 4.5 MMT harvested in 2010,is the third cereal in terms of production after maize and millet, representing 25% of the total cereal production (FAOSTAT, 2012).

2.2Cerealprocessing

The major unit operations involved in maize starch meal processing (similar to other cereals) in Nigeria include sorting/cleaning, steeping, grinding/extraction and dehydration. Maize has to pass through inspection. It is then coarsely sieved to separate contaminations like stones, cobs, dust particles, foreign grain material and fine material. After cleaning, the maize kernels are stored and then conveyed into steeping tanks.

Well-conducted steeping is an important pre-requisite for high yield and good starch quality. The purified maize kernels are transferred into a tank containing steep water. This step is conducted at 50°C and last about 40 to 50 hours. Steeping tanks are commonly series-connected and operated by the counter flow principle. For optimal steeping conditions, steep-water is kept at pH 4.0 by the addition of sulphuric acid or hydrochloric acid and treated with sulphur dioxide. These conditions guarantee the optimal water absorption of the maize kernel, controlled fermentation by lactic acid bacteria and loosening of the protein matrix. At the same time, steep water causes the softening of the kernels and the release of solubles. The resulting suspension passes through screen cascades for separation from fibre and other maize components.

Unfortunately, most of these processes are carried out manually by a vast majority of the Nigerian populace since the needed machines and tools are not easily affordable and sometimes unavailable at the farm level. The currently available ones were merely fabricated without adequate engineering research. Sieving is a key process in maize processing to pap. Since making cereal production competitive both at the domestic level and for export to world market requires wide research and investment into processing machine design and development, thus the development of sieving machinery is of utmost importance.

2.3 Slurry sieving

A simple definition of sieving is the separation of fine material from coarse ones by means of meshed or perforated vessel. Slurry sieving (sieving in water) or the separation of fines from the coarse portion in an aqueous medium (water) is an indispensable process that is used to extract biopolymers from cereal grains. The water is normally used to negate static charges, break down agglomerates and lubricate near size particles. Wet sieving allows for the washing of starch granules and milk from other particles like fibres and hulls.

Moisture is often applied to the marsh to aid its extraction. In contrast to dry milling, the primary aim of wet milling is to separate and extract the grain biopolymers. The medium of water allows much more milling as heat generation through friction is greatly reduced, and freeing the starch granules from their protein matrix. When carried out manually, wet sieving is energy and time consuming, tedious and back straining.

Due to the presence of water in the wet sieving process, there is a tendency for fermentation to occur. An offensive odour can be generated by fermented products and the resulting acidic water content is both unhealthy and a discouragement to producers. If poorly handled, the wet sieving operation can result in bad quality products, which makes storage very difficult. This reduces the desirable eating quality and suitability of the product for further processing. Some research works have focused on the development of a suitable mechanical system for wet sieving of agricultural products. There are many locally-developed wet sieves in the market particularly for *garri* and cassava marsh sieving (Nweke et al., 1988). However, the majority of these sieves are batch operated and do not incorporate a mixing compartment needed for thorough washing of the milk from the food sample. Also, a wide variety of designs for screens exist and they differ in the complexity of their construction and their efficiency of operation. Basically, rotating, vibrating screens and pusher-type centrifuges are used (Henderson and Perry, 1976; Ihekoronye and Ngoddy, 1985; Asiedu, 1990). In fact, Tabatabaeefar et al. (2003) reported the development of an auxiliary sieving and grading machine (TAG machine) with an efficiency of 84%. However, this machine was meant for cleaning and grading of dry products.

Sieves are effective provided they are made to vibrate (Fellow and Hampton, 1992). The throughput of sieves is dependent upon a number of factors chiefly: the nature and amplitude of the shaking, the methods used to prevent sticking of the sieve, and the tension and physical nature of the sieve material (Earle, 1983). Although a lot of work has been done locally to mechanize the milling and sieving of dry products, it is however observed that no extensive work has been done locally to mechanize the sieving of wet agricultural food products in Nigeria.

3 Materials and methods

3.1 Design considerations and materials

The machine was designed based on the concept that sieving can be achieved by rubbing the cereal marsh on the sieving surfaces comprising the pulverizing unit and the sieving unit. The major factors considered in developing the machine were the strength of the fabrication materials, as well as the properties of the material to be processed. This consideration enabled the determination of the engineering specifications, including the power requirement of the motor, size of the sieve, etc. To achieve good sieving, the physical, mechanical and thermal properties of the materials to be sieved must be considered. These include the particle size, weight, length, surface texture, affinity for liquid and they must be determined for proper sieve analysis. These properties also help in choosing the appropriate sieving processes for different materials and must be taken into consideration in the construction of sieving machine and the determination of sieve size.

Engineering drawing of the machine was made using Autodesk Inventor as drawing interface. The materials used in the fabrication included mild steel, electric motor, pulley, connecting rod mechanism, bolts and nuts, bearing, V-belt, teflon material, sieve material, and welded fins. The equipment used in the performance evaluation of the machine includes weighing scale, water, stop watch and bowls. Maize, millet and sorghum were the materials for the test.

3.2 Description of the machine

The cereal slurry sieving machine is basically powered by an electric motor using belt and pulley system for transmission of motion to a crank mechanism which is attached to a sieving tray. The crank mechanism moves in a reciprocating pattern and transmits its motion to the sieving tray thereby agitating it. The agitation causes pulverized particles of the slurry to fall through the sieve.

Figure 1 shows the isometric projection of the machine. The machine was designed and constructed according to the theoretical design specifications and consists of the following components namely: hopper, mixing compartment, sieving chamber, standing frame, electric motor seat, sieving net, sheaves (pulleys) and the belt. The description of the various components is given here below, while how the dimensions were determined are given in section 3.3.

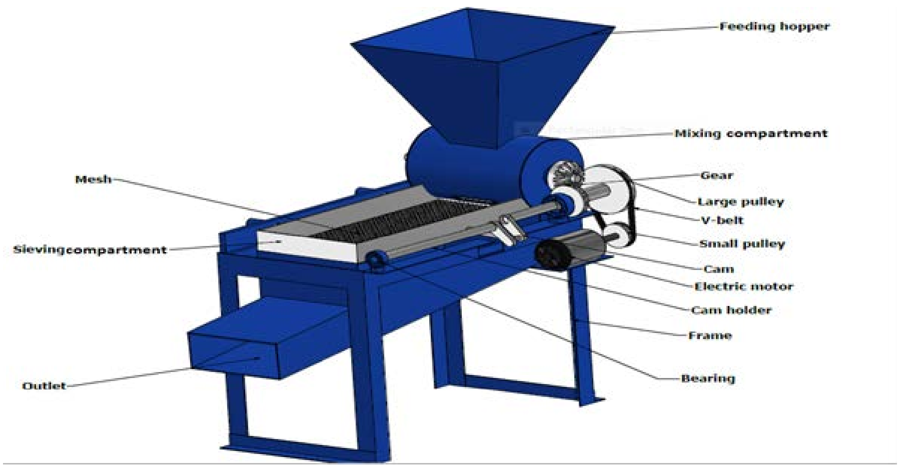

Fig.1 Labeled isometric projection of the machine

Standing frame: This is the main unit of the machine which supports all other components of the machine. It was fabricated from mild steel angle iron of 50× 50×3mm size with dimensions of length of 540mm and width of 335mm. The rectangular frame was firmly fixed together by arc welding. It was made from a high strength material to withstand vibration.

Hopper: This was made from 2mm arc welded mild steel sheet.

Mixing compartment: This comprised a cylindrically shaped compartment, closed at both ends with a Teflon material. A shaft with fins welded onto it ran through the compartment. The shaft is here named the mixing shaft. The fins aid the mixing and moving of the slurry out of the mixing compartment. The mixing shaft has a 90^o bevel gear at one end. This is for transmission of power from an adjoining sieving shaft.

Sieving tray: This consists of a rectangular container 230mm× 520mm× 135 mm in dimension which forms the sieving tray. On the tray, a sieving cloth with a surface area of 230 mm × 520 mm, held all round with wood, is placed. The tray reciprocates by the help of a crank mechanism attached to it. The crank system, which comprised a 25mm diameter drive crankshaft named the sieving shaft with a pulley, is installed at end. The pulley system is connected to the drive electric motor. A 90^o bevel gear is attached between the crankshaft and the pulley to mate with the mixing shaft. A connecting rod connects the sieving shaft to the sieve. The diameter of the connecting rod was 12mm. The bore of the small end of the connecting rod was 15 mm.

Receiving trough: This was made of mild steel welded together for collecting the filtrates.

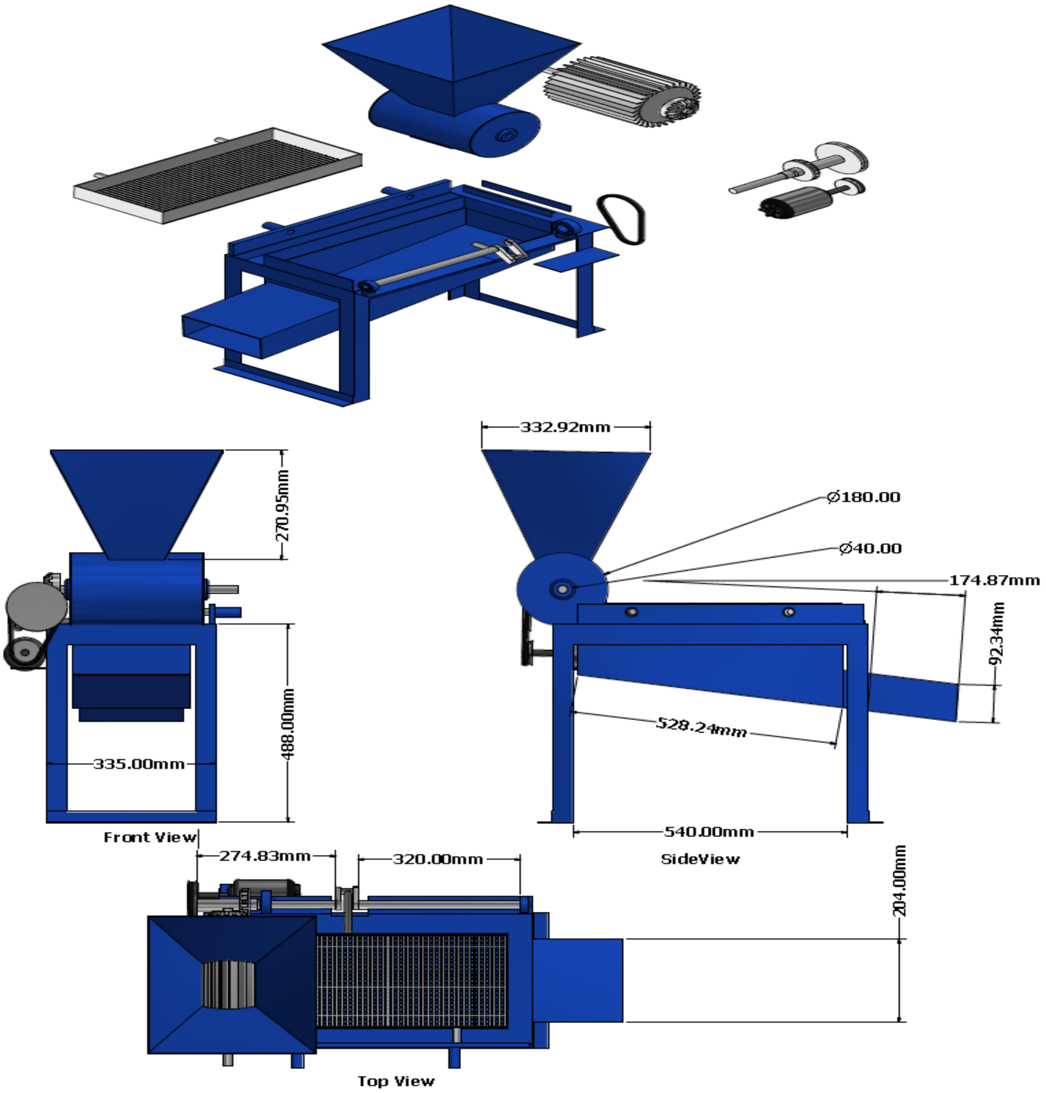

Fig. 3 Assembly drawing showing the dimensions of the machine

Teflon material was used to suspend the mixing chamber's shaft and also to seal the sides of the mixing compartment. The receiving trough is inclined at an angle of 48° and is open at one end. The machine has a single reciprocating sieve which can be easily removed, making it suitable for processing different crops and easy to clean. The shafts are mounted on ball bearings and are driven by a 1hp electric motor. The bevel gears have gear ratio of 1:2 (mixing shaft to sieving shaft). This reduces the speed of the sieve and mixer, transmits 90° angular motion and enables the use of a single electric motor. The filtrate passes through the sieve mesh under the force of gravity into a tray beneath and is collected through an outlet. The exploded parts and assembly drawings of the fabricated cereal slurry sieving machine are presented in Figures 2 and 3 respectively.

3.3 Machine design calculations

In the design, emphasis was laid more on the mixing, reciprocating mechanisms and the transmission system. It was determined that a 1hp motor running at 1750rpm would be suitable for the job the machine will be doing (Hicks, 1998). The machine was designed taking into the consideration that the highest density of marsh to be processed would be 1090kgm^{-3} (Fayose, 2008). This density of maize was observed to be the highest of all the common local diets processed by wet sieving. The shafts sizes, hopper capacity and dimensions, sieve capacity and dimensions, pulley and belt sizes are subsequently determined. For smooth operation of the system, the displacement of the connecting rod mechanism was chosen to be 15.2 mm.

3.3.1 Capacity of the sieve tray

The capacity of the sieve tray was obtained using Equation1:

$$V = BLH \tag{1}$$

Where;V= capacity(m^3)

B= breath(m)

H= height(m)

L = length(m)

The capacity of the sieve was determined to be 0.016 m^3.

3.3.2 Capacity of hopper

The capacity of hopper was calculated using Equation 2.

$$V = 1/3\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)H \tag{2}$$

Where; $A_1 = B_1 L_1$

$A_2 = B_2 L_2$

A_1 = area of the hopper inlet

A_2 = area of the hopper exit

L_1 = length of the top edge of the hopper inlet = 332.9 mm

B_1 = width of the top edge of the hopper inlet = 242.2 mm

L_2 = length of the bottom edge of the hopper exit = 182.3 mm

B_2 = width of the bottom edge of the hopper exit = 105.9 mm

H = height of the hopper = 270.9 mm

The capacity of the hopper was determined to be 0.0126 m^3.

3.3.3 Determination of the crank and mixing shafts diameters

In operation, the crank and mixing shafts will be subjected to combine stresses comprising bending and torsional stresses. The shafts were therefore designed to be solid shafts that could withstand such stresses during operation, and the material specified for their construction was mild steel. As heavy shocks are not involved in this case, the load can be considered as gradually applied. Using the ASME equation for solid shaft as modified from Shigley and Mischke (1989) (Equation 3), the diameters were calculated to be 22.1 mm and 24.3 mm respectively. However, the diameters were uniformly taken to be 25 mm.

$$d^3 = \frac{16}{\pi S_s}\left[\left(k_b M_b\right)^2 + \left(k_t M_t\right)^2\right]^{\frac{1}{2}} \tag{3}$$

Where; d = shaft diameter (mm)

S_s= torsional shear stress (Nmm^{-2})

k_b = Combined shock and fatigue factor applied to bending moment

k_t= Combined shock and fatigue factor applied to torsional moment

M_b = Maximum bending moment (Nmm)

M_b = Maximum torsional moment (Nmm).

3.3.4 Selecting the belt for power transmission

The selection of the belt starts with the determination of the sizes of the sheaves (pulley). The pulley may be called a sheave but when working with V-belts, the term sheave is more appropriate to use. From the relationship, for D_1as the driver (Engineers Edge, 2018):

$$\frac{N_2}{N_1} = \frac{D_1}{D_2}\frac{\left(100 - s\right)}{100} \tag{4}$$

Where; D_1 = diameter of the motor sheave(mm)

D_2 = diameter of the driven sheave(mm)

N_1 = motor sheave speed(ms^{-1})

N_2 = driven sheave speed(ms^{-1})

s = percentage slip

For this selection, it is desired that the driven speed be one third of the motor speed in order to increase the power to the shafts. Thus N_1= 3N_2. We also assumed a no slip condition in the sheaves. Thus s = 0. Due to the space constraint, the allowable center distance between the sheaves, C, was chosen as 370 mm. From Equation4 at the conditions stated above,

$$D_2 = 3D_1 \tag{5}$$

Thus with D_1 = 75 mm, D_2 = 225 mm. However, the available standard sheave size was 205 mm, hence, D_2 was taken as 205 mm throughout the design. The size of the smaller sheave determines the parameters for the belt selection. For a sheave of diameter 75 mm, this implies that the standard V-belt to be used on that sheave belongs to the *A*-section belts (Shigley and Mischke, 1989).

We need to determine if the horsepower chosen for the belt will be suitable for it. The belt horsepower is selected by multiplying the motor horsepower by a service factor (Hicks, 1998). So, we begin by noting that the machine works by agitating the slurry, hence it is classified as an agitator. For an agitator subjected to normal torque situation, the service factor is selected as 1.0. This makes the appropriate belt horsepower to be 1.0hp. Thus, our selected motor horsepower is suitable for the belt. The belt speed can be determined from the relationship given in Hicks (1998) to accommodate the effect of the sheaves on the belt speed. The belt speed, *v*, is given as

$$v = \frac{\pi N_1 (D_1 - 2X)}{60} \tag{6}$$

Where; $2X$ = sheave dimension from the Hicks (1998). According to Hicks (1998), it is safe to start by assuming $2X$ = 3.8 mm for light duty V-belts. Since the sheave effective outside diameter is 75 mm, this initially puts the belt as a 3*L* class belt. The belt speed calculated from Equation6 equals 6.52 ms^{-1}. This speed is acceptable. Shigley and Mischke (1989) stated that V-belts should not be run faster than 25.42 ms^{-1} or much slower than 5.08 ms^{-1}. Although the speed is acceptable, the power capacity needs to be checked if it matches the belt speed. From Table 10 in Hicks (1998), it shows that choosing the belt as a 3*L* rating is unsatisfactory; rather, it is a 4*L* rating. This implies that the appropriate $2X$ value is 0.51 obtained from Table 11 in Hicks (1998). The new belt speed is calculated as 6.40 ms^{-1} which is still within the safe region. This shows that the motor sheave diameter, horsepower and the speed are appropriate for the V-belt.

To compute the belt arc of contact either of the following equations as given by Shigley and Mischke (1989) could be used to determine the angle.

$$\theta_{D_1} = \pi - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \tag{7}$$

or

$$\theta_{D_2} = \pi + 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \tag{8}$$

Where; C is the distance between the sheave centers, θ is the arc of contact in radians, when θ is given as 180° then it is given in degrees. Either of the relations could be used because equation 9 applies.

$$\theta_{D_1} + \theta_{D_2} = 360° \tag{9}$$

From Equation 8, θ_{D1} was determined as 160°.

The pitch length, L_p, of the V-belt is found from the equation (Shigley and Mischke, 1989):

$$L_p = 2C + \frac{\pi}{2}(D_2 + D_1) + \left(\frac{D_2 - D_1}{4C}\right)^2 \tag{10}$$

Inserting the values of the parameters gives L_p as 1,191mm. The available V-belts in the shops were 1,220 mm and width of 12 mm. That suited our design and was therefore used.

3.4 Operation of the machine

To use the machine for sieving, the grain, for example maize, is first soaked for 2-3 days after which it is ground into a paste form. It is then mixed with an appropriate quantity of water to form slurry. The slurry is gradually poured into the hopper and it is gradually introduced into the sieve by a separate collector. The slurry is sieved via the horizontal reciprocating movement of the sieve. After the first run, the chaff on the sieve may not be completely separated from the filtrate and as such, it is collected and another known quantity of water is added before it is sieved again. A mixture of water and the filtrate is collected beneath the sieve via the collector.

3.5 Performance evaluation of the machine

Maize seeds were purchased from Ogbete market in Enugu, Enugu State while the millet and sorghum seeds were purchased at Ogige market, Nsukka also in Enugu State. The cereals were soaked for two days and then ground into paste. About 1kg of the paste was mixed with 1litre of water and sieved with the machine. Another 1kg was mixed with 1litre of water and then sieved using the manual (traditional) process. This was done to compare the performance of the designed machine with that of the traditional method. During the evaluation 0.5kg and 1.1kg of water were added to the machine sieved and manual sieved samples, respectively (see Table 1). In the manual sieving process, grain slurry mixture and sprinkled water were simply allowed to pass through the sieve cloth under natural gravitational force. For the mechanical process, grain slurry mixture was poured into the hopper, mixed in the sieving compartment and moved to the sieving unit where the reciprocating movement of the sieve effected the sieving of the slurry. The following parameters: output capacity, sieving efficiency and sieving capacity were used to evaluate the performance of the machine. Each of the parameters was replicated three times and determined for both the designed slurry sieving machine and the traditional method.

3.5.1 Output capacity

The output capacity of the machine was determined by dividing the weight of the sieved mass with the recorded time of sieving as described by Kudabo et al. (2012)

$$Q_c = W_c / T \tag{11}$$

Where; Q_c = Output capacity (kgh^{-1})

W_c = Weight of the sieved mass (kg)

T = Time of sifting (h).

3.5.2 Sieving efficiency

The sieving efficiency of the machine was determined by dividing the weight of the sieved mash by the initial weight of mash (Kudabo et al., 2012). Slurries of three different cereals, namely maize, millet and sorghum were evaluated using three sieve sizes.

$$\eta = \frac{W_2}{W_1} \times 100 \tag{12}$$

Where; η = Sifting efficiency (%)

W_2 = Weight of the sieved mash (kg)

W_1 = Initial weight of the cereal mash (kg).

The time of sieving was recorded using a stop watch. Sieving flow rates were determined by recording the time taken for different volumes of grain-slurry mixture to pass through the sieve unit as discussed by Simolowo and Nduka (2002).

3.5.3 Sieving capacity

The sieving capacity, C_s(kgm²s^{-1}) is given by Fellows (2003) as:

$$C_s = \frac{Mass\ of\ sample}{Time\ taken\ to\ sieve\ the\ sample / area\ of\ sieve} \tag{13}$$

4 Results and discussion

4.1 Results of performance evaluation of the machine

The average time of machine sieving was about 2.5 times faster than manual sieving. The mass of water added to the slurry before and during the process is shown in Table 1.It also shows that the mass of chaff after sieving was lower for the machine sieved sample. The 50% reduction in water usage during the machine sieving process agrees with the results reported by other researchers (Simolowo and Adeniji, 2009; Simolowo, 2011). The mass of the filtrates before and after water weredrained as 2.8kg and 1.57kg for the machine, and 2.87kg and 1.5kg for the manually sieved samples. The time allowed for the water to drain was 2.5 hours in both cases to enable proper comparison.

Table 2 shows a comparison of the calculated parameters. From the data, it is observed that the output capacity and sieving flow rate were both increased 2.5 times by the machine in comparison with the manual method, while sieving capacity increased 2.4 times. The sieving efficiency achieved with the machine using a mesh size of 1.19mm was 85%, which is a slight improvement over the result of 82% reported by Simolowo (2011).

Table 1 Measured parameters for manual and machine sieving

S/n	Parameter	Manual	Machine
1	Initial mass before adding water (kg)	1	1
2	Initial mass of water added (kg)	1	1
3	Quantity of water added during sieving (kg)	1.1	0.5
4	Time of sieving (min)	10.62	4.27
5	Mass of chaff (kg)	0.23	0.15
6	Total mass of filtrate after sieving (kg)	2.87	2.80
7	Time allowed for water to drain (h)	2.5	2.5
8	Mass after draining (kg)	0.77	0.85

Table 2Calculated parameters for manual and machine sieving

S/n	Parameter	Manual	Machine
1	Output capacity (kgh^{-1})	8.82	22.07
2	Sieving capacity (kgm^2s^{-1})	99.70	238.00
3	Sieving flow rate ($kgmin^{-1}$)	0.099	0.25
4	Efficiency (%)	79.35	85

Since maize has a higher bulk density than many other cereals, the machine will be suitable for processing of other wet cereal slurries without compromising much of its efficiency.

4.3 Results of comparative sieve performance evaluation of the machine

The results of sieve performance evaluation of the machine carried out using maize, millet and sorghum slurries at three treatment levels of sieve sizes are presented in Table 3. The results of sieving efficiencies show that sieve 1 has higher efficiencies for maize and sorghum, whereas sieve 2 has higher efficiencies for sorghum and millet. Sieve 3 gave the highest efficiency with millet slurry. These results were subjected to statistical analysis (Appendices 1-3) using analysis of variance (ANOVA), which showed that there is no significant difference (at 95% confidence level) between the means of the sieving efficiencies obtained using sieve 1. Therefore, sieve 1, with a mesh size of 1.19mm is suitable for maize, millet and sorghum slurries based on the values of Fischer's criterion (F). For sieve 2, since $F_{tab} < F_{cal}$, (at 95% confidence level), there is a significant difference between the means of the sieving efficiencies obtained using sieve 2 for the three crops. It is, therefore concluded that sieve 2 is best suited for millet, but not for maize and sorghum.

Table 3 Values of sieving efficiency (%)

	Experiment1	Experiment 2	Experiment 3	Average	St. Dev	Coeff. Of Variability
			SIEVE 1 (1.19 mm mesh size)			
Maize	98	82	87	89	8.2	9.2
Millet	83	81	79	81	2.0	2.5
Sorghum	87	93	90	90	3.0	3.3
			SIEVE 2 (1.00mm mesh size)			
Maize	72	81	78	77	4.6	6.0
Millet	94	86	90	90	4.0	4.4
Sorghum	78	89	81	82.7	5.7	6.9
			SIEVE 3 (0.354mm mesh size)			
Maize	67	79	71	72.3	6.1	8.5
Millet	99	89	94	94	5.0	5.3
Sorghum	64	76	74	71.3	6.4	9.0

For sieve 3, the tabulated F value (F_{tab} = 5.14), while the calculated value (F_{cal} =14.24) at 95% confidence level. Since the tabulated value is lower than the calculated F value, it means that there is a significant difference between the means of the sieving efficiencies obtained using sieve 3 for the three crops. It is deduced that sieve 3 is best suited for millet, but not for maize and sorghum.

5 Conclusions and recommendations

A vibrating-type cereal slurry sieving machine has been designed, fabricated and tested. The materials of construction, which were sourced locally are easily workable, thereby making the machine cheap and easy to maintain. It performed satisfactorily in the sieving of cereal slurry, recording a sieving efficiency of 85% and output capacity of 22.07kgh^{-1} while sieving maize slurry. It is therefore concluded to be effective and efficient. From the comparative analysis of sieving efficiencies obtained from three different mesh sieve sizes, it is recommended that the appropriate sieves should be employed in handling different cereals since this has an effect on the output. Future research work should be carried out to consider the effect of vibration speed on the sieving efficiency by using a variable speed motor to drive the machine.

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Appendix 1

ANOVA of sieving efficiency using sieve 1

Replicate/Item	Maize	Millet	Sorghum	Row Totals
1	98	83	87	268
2	82	81	93	258
3	87	79	90	256
ΣX	267	243	270	780
n	3	3	3	
$\overline{X}$	89	81	90	
ΣX²	23897	19683	24318	67906
$\frac{(\Sigma X)^2}{n}$	23763	19683	24300	67746
Σd²	134	8	18	160
$\sigma^2 = \frac{\Sigma d^2}{n-1}$	67	4	9	

ANOVA table for sieving efficiency of sieve 1

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F_{cal}
Between Treatments	146	2	73	2.74
Residual	160	6	26.7	
Total	306	8		

From statistical tables (Obi, 2002; Fisher and Yates, 1963), F_{tab} = 5.14. Since the tabulated value is greater than the calculated F value, it means that there is no significant difference between the means of the sieving efficiencies obtained using sieve 1 for the three crops.

Appendix 2

ANOVA of sieving efficiency using sieve 2

Replicate/Item	Maize	Millet	Sorghum	Row Totals
1	72	94	78	244
2	81	86	89	256
3	78	90	81	249
ΣX	231	270	248	749
n	3	3	3	
$\overline{X}$	77	90	82.7	
ΣX²	17829	24332	20566	62727
$\frac{(\Sigma X)^2}{n}$	17787	24300	20501.33	62588.33
Σd²	42	32	64.67	138.67
$\sigma^2 = \frac{\Sigma d^2}{n-1}$	21	16	32.34	

ANOVA table for sieving efficiency of sieve 2

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F_{cal}
Between Treatments	254.89	2	127.45	5.52
Residual	138.67	6	23.11	
Total	393.56	8		

From Statistical tables, F_{tab} = 5.14. Since the tabulated value is lower than the calculated F value, it means that there is a significant difference between the means of the sieving efficiencies obtained using sieve 2 for the three crops.

Appendix 3

ANOVA of sieving efficiency using sieve 3

Replicate/Item	Maize	Millet	Sorghum	Row Totals
1	67	99	64	230
2	79	89	76	244
3	71	94	74	239
ΣX	217	282	214	713

n	3	3	3	
$\overline{X}$	72.33	94.00	71.33	
ΣX^2	15771	26558	15348	57677
$\frac{(\Sigma X)^2}{n}$	15696.33	26508	15265.33	57469.66
Σd^2	74.6667	50	82.6667	207.3334
$\sigma^2 = \frac{\Sigma d^2}{n-1}$	37.33	25	41.33	

ANOVA table for sieving efficiency of sieve 3

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F_{cal}
Between Treatments	984.22	2	492.11	14.24
Residual	207.34	6	34.56	
Total	1191.56	8		

From Statistical tables, F_{tab} = 5.14. Since the tabulated value is lower than the calculated F value, it means that there is a significant difference between the means of the sieving efficiencies obtained using sieve 3 for the three crops.