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ORIGINAL RESEARCH ARTICLE

TECHNICAL APPRAISAL OF SOME MAIZE SHELLERS IN OYO AND KWARA STATES OF NIGERIA

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ABSTRACT

This study assessed the performance of some maize shellers in use in grain markets in Oyo and Kwara States, Nigeria. A preliminary survey conducted identified shellers in use as basic maize sheller (BMS) without blower, maize sheller with blower attachment (MSB) and the multi-purpose sheller (MPS). The shelling/cleaning performance of the shellers were assessed using yellow maize (SWAN I variety) and some key equipment parameters, which impact performance were measured. The air velocity for MSB and MPS ranged between 0.4 and 2.4 m/s which was not sufficient for efficient cleaning of chaff from shelled grains. Shaft speed for BMS, MSB and MPS were 845, 920 and 820 rpm, respectively. Average throughput for BMS, MSB and MPS was 1,714, 600 and 840 kg/hr, respectively with mean shelling efficiencies of 92.9, 82.7 and 97.9%, respectively. Mean cleaning efficiencies were 54.0 and 57.7% for MSB and MPS, respectively. The percentage grain loss for BMS, MSB and MPS were 17, 7.1 and 1.9%, respectively. It was observed that many fabricators do not consult agricultural engineers when producing machines, relying more on previous experience. Additionally, there was a lack of consideration for operator safety with the exposure of moving parts of the equipment in all the designs evaluated. A key recommendation from this study is that sheller designs should be standardized to ensure the provision of quality and highly efficient machinery for processors.

1.0 Introduction

The production of grains such as maize, millet and sorghum is on the rise in many African countries with maize being the largest in production. Maize is the most important cereal crop in the world after wheat and rice, providing the nutrient requirements of humans and animals including raw materials to produce essential commodities including oils, alcoholic beverages, starch and even, fuel (Isa *et al.*, 2019). According to FAOSTAT (2020), the global production of maize` in 2018 was estimated to be 1.1 billion tons over a harvested area of about 194 million ha, while production in Africa accounted for about 78.9 million tons from a harvested area estimated at 38.7 million ha.

Ekpa *et al.* (2018) stated that the demand for maize in Sub-Saharan Africa will triple by the year 2050 as a result of the ever-rising population growth. A larger percentage of the cereal harvested in developed countries are used for livestock feed whereas in developing countries, it is used primarily for human consumption (Oliveira et al., 2014). In Nigeria, during the 2015 – 2016 period, 3.8 million ha of maize were cultivated resulting in 7 million metric tons of maize produced; the projected production for the 2016 – 2017 period was 7.2 million metric tons (USDA-FAS, 2017). Approximately 95% of all feed produced in Nigeria is poultry feed, and in the 2013 – 2014 period, feed production was 1.8 million tons (USDA-FAS, 2017).

Post-harvest losses (PHL) can either be direct or indirect. PHL remain a major challenge in food production in many developing countries (Omobowale *et al.*, 2016; Suleiman *et al.*, 2019). Direct losses refer to physical disappearance of the food products, while indirect losses refer to the lowering of quality which can lead to complete rejection of the food especially at the export market (Kader, 2005; Arisukwu *et al.*, 2019).

Processing activities have been identified as a contributor to the losses experienced along the food pipeline (Mijinyawa, 2012). Threshing of grains is a major processing activity which must be carried out to add value as well as to present grains in edible or useable form. It is an important processing activity which must be conducted to add value and make grains edible and useable (Williams and Rosentrater, 2007). Maize shelling operation is the first process involved in post-harvest processing of maize, which separates whole kernels of starch-rich grains from the cob. It occurs either on the field simultaneously during harvesting using a combine harvester, or is done as a separate process at the barn manually or by using mechanical means. Losses which can occur during these activities include spillage (loss of whole kernels), kernel breakage and chipping, and excessive broken cobs and thrash mixed with whole and broken kernels. The threshing method used in grain processing also affects storability of the grains because broken kernels lead to increase in insect infestation and subsequently, reduction in grain storage period (storability) and loss in grain quality (Igbeka, 2013; Oyewole *et al.*, 2019). Loss in quality also has financial implications on the producer as well as health hazards which the consumer might be exposed to because the food has become unsafe or contaminated (Pristavkova *et al.,* 2016).

To facilitate speedy shelling of maize in order to reduce postharvest deterioration, mechanical maize shellers are recommended because hand-shelling methods cannot support large scale production (Adewole *et al*., 2015). In the design of shellers for agricultural processing, the properties of the crop must be fully considered. Physical and mechanical properties need to be determined in order to design shellers which would effectively and efficiently handle the intended crops (Kroupa, 2003; Ilori *et al*., 2013). Sheller designs vary based on the crop to be handled. For maize, a factor that affects its threshability in a mechanized system is the mean girth of the maize cob. For maize, the girth ranges from 50–85 mm depending on the variety (Nwakairea *et al*., 2011).

There are different types of commercially available grain shellers featuring different designs of the shelling unit, however most of them are primarily based on the threshing principles of impact, rubbing, combing, and grinding (Fu *et al.,* 2018). The performance of the threshing equipment can be influenced by some properties of the maize such as type of variety, degree of crop maturity, and the moisture content (Alsharifi *et al.,* 2019a). The variety of the grain in this case would be characterized by the physical properties of the unthreshed grain - size, shape and uniformity of the bulk to be threshed.

Oriaku *et al.* (2014) designed a ''corn de–cobbing and separating'' machine which was able to remove the grains from the cobs at a rate of 123 kg/hr with a threshing and separation efficiency of 78% and 56% respectively. This machine was therefore suitable as a replacement for human labour on a small/ household scale. Aremu *et al.* (2015) designed a motorised maize shelling machine with a shelling efficiency of 87% and output capacity of 624 kg/hr with a shelling speed of 886 rpm. It was recommended that the best moisture content for maize shelling is at 13% dry basis and that the addition of wheels will enhance the mobility of the shellers. They also concluded that there is the need to develop a maize sheller with higher efficiency, better product quality and powered by a smaller engine.

Pavasiya *et al.* (2018) carried out a performance evaluation test on a maize shelling machine at 13% moisture content (maize) and 886 rpm shelling speed, and showed that some parameters such as cleaning efficiency, grain recovery efficiency, shelling efficiency, sheller performance index, total grain losses decreased while output capacity increase. In a study on maize sheller evaluation carried out by Ghatrehsamani *et al.* (2018), it was concluded that the interaction between maize varieties and moisture content was significant on separation efficiency and total kernel loss while variable interaction of maize variety and speed affected only the total kernels lost.

Alsharifi *et al*. (2019b) also reported that increasing rotational speed of the corn sheller resulted in an increase in percent grain damage, while reducing the rotational speed actually reduced the frequency of the blow impacts, thereby decreasing the percent grain damage. Mogaji (2016) identified some problems with existing maize shellers which include bulky design leading to less mobility, significant spillage of grains during operation, high degree of impurities (thrash and cobs) and low product quality, and thereafter presented an improved maize shelling machine which was portable and had 96% shelling efficiency.

This study was initiated as a result of the difficulty encountered in renting a maize sheller fitted with a blower for use in winnowing a large volume of maize (30 tons), which needed to be cleaned prior to storage. The newly fabricated maize shellers that were borrowed for use turned out to be quite unreliable and prone to break-down. The subject of machine reliability and performance with regards to maize shellers available in Oyo and Kwara States became a topic of interest for investigation. There is also lack of reliable data on maize shellers in use across Oyo and Kwara States, Nigeria. This study therefore investigated the design and performance of maize shellers found in grain markets in these two states, with the goal of determining machine performance, threshing efficiency, cleaning efficiency, throughput and maize kernel loss during threshing. This information can then be used for design improvements in maize sheller production. The mode and ease of operation of each sheller, power train type and capacity were also evaluated while also documenting the cost of fabrication and operation of each machine, quality of fabrication and availability of shellers in the two focal states were documented.

2. Materials and Method

2.1 Preliminary Survey

In order to determine the types of maize shellers available for processors in four grain markets located in Oyo and Kwara states, a survey was conducted by field inquiry to determine the location of maize shelling services at the market, and equipment types used.

2.2 Equipment Performance Testing Procedure

During equipment performance testing, two maize shellers were tested for each sheller category. During operation, maize shellers were placed on tarps to capture maize being shelled. Each outlet from the machine (cob, clean grain and chaff outlets) were partially covered with plastic or jute sheeting to effectively direct and collect these streams. Each machine test was replicated three times and each replication was run for an average of 3 minutes. In order to determine whether the maize was sufficiently dry prior to shelling, moisture content of the maize was determined using the gravimetric moisture loss upon drying with 15 g of maize dried in an air-oven at 103^{o}C for 72 h according to ASAE Standards, (2010).

The quantity of unshelled maize on cob used in each trial was recorded. The grain-cob ratio of the maize variety was estimated following the procedure outlined in NIS 319:1997 standard. A digital hot-wire anemometer (TPI 565C1, Test Products International, Oregon, USA) was used in measuring the speed of the moving air generated by the blower section of the shellers with a blower. It was important to determine the air velocity so as to compare with known terminal velocities of maize kernels. A combination contact/laser photo tachometer (Extech RPM40, Extech Instruments, New Hampshire, USA) was used in measuring engine speed, shaft speed (at the drive shaft) and blower shaft speed. The engine speed, drive shaft speed and blower shaft speed were measured on no load (idling) and during operation on full load.

For every replicate per equipment type, three parameters were measured, namely, cob feeding time, maize cob mass at inlet and maize kernel mass at outlet. From these data, the equipment throughput, shelling efficiency and cleaning efficiency were determined using the following equations:

Throughput, which is the weight of material the machine can process over a specific operating period and was measured using:

$$Tp = \frac{Wt}{Tt} \quad \text{(1)}$$

Where Tp is the throughput in kg/hr; Wt is the total weight of material handled in kg; and Tt is the total time taken in handling the materials in hr (Nwakairea et al., 2011)

Shelling efficiency (η) was calculated with the following equation:

$$\eta = \frac{Wa}{Wt} \times 100 \quad \text{(2)}$$

Where η is the percentage shelling efficiency; Wa is the total weight of grain kernels actually processed, or the output in kg and Wt is the total weight of grain kernels, should all the kernels be shelled off the cob, or the input in kg (Nwakairea et al, 2011)

Cleaning efficiency (Ec) was calculated usng:

$$Ec = \frac{Xd}{(Xb+Xd)} \times 100 \quad \text{(3)}$$

Where Ec is the percentage cleaning efficiency; Xb is the total weight of chaff (materials other than grain kernels) received at the grain outlet (g) and Xd is the weight of chaff (g) received at chaff outlet (Negrini *et. al.,* 1994; Ajav and Ojediran, 2006).

Data analysis was done using SAS 9.4 statistical software while Sigma Plot® 13 was used to plot the bar charts.

3. Results and Discussion

3.1 General Observations

Based on the preliminary survey, three different types of sheller designs were identified; *viz*, the Basic Maize Sheller (BMS), Maize Sheller with blower attachment (MSB) and the Multi-purpose Sheller (MPS). These are fabricated locally and readily available to farmers and small-scale processors. Local fabricators constructed a number of these shellers by reverse engineering of imported shellers, which they have worked with in the past. It was also discovered that expert opinion of agricultural engineers was lacking in the design and fabrication of many existing shellers used in the locations surveyed.

3.1.1 The Basic Maize Sheller

This was designed to remove the kernels from the maize cobs by impact force on the cobs within a concave enclosure, while the loose kernels simply fall through the concave screen and are collected from an outlet positioned below the concave while the cobs are collected at the cob outlet typically positioned at the end of the concave. Figure 1 shows a picture of the BMS equipment indicating the various parts. The BMS has no blower attachment for cleaning light materials, and the beaters on the shaft of most the BMS examined were dulled to help reduce kernel damage (Figure 2).

Figure 1. The basic maize sheller typically found in Nigerian markets

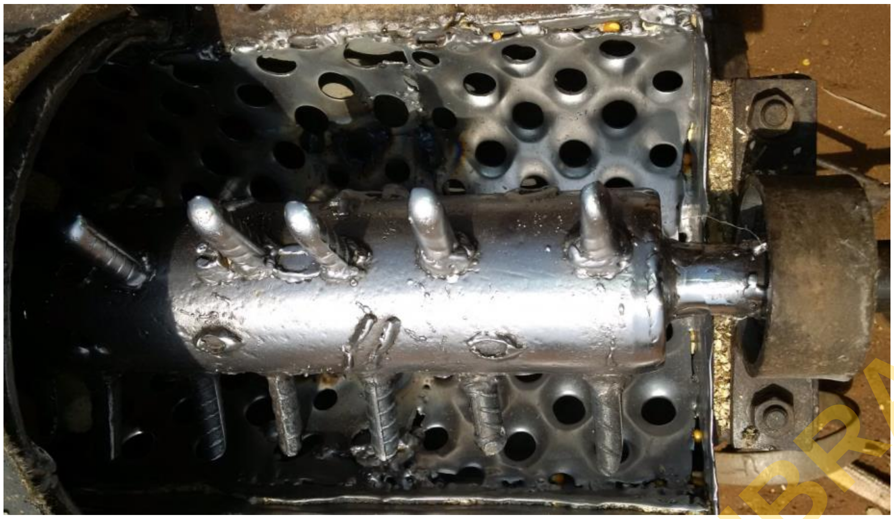

Figure 2. Dulled threshing drum spikes and bottom concave holes.

The basic maize sheller is made up of the machine frame, hopper, concave (which houses the main shaft) and a sieve. The average dimensions of the hopper inlet were 410 by 310 mm at the top and 260 mm^2 where it tappers. The length of the concave was found to be between 720 and 914 mm and average diameter was 230±17 mm. The beaters had a height ranging between 30-50mm and were spaced at 60-100mm intervals along the shaft and at the end of the shaft, just before the cob outlet, flaps were installed to help push out the cobs.

The BMS, which was found to be the major machine used to shell maize at Eleekara and Sabo markets in Oyo has no blower attachment. It is indeed the most widespread sheller design. All the BMS machines in use at the grain markets were locally fabricated and fabricators employed trial-and-error method in the selection of both the materials of construction and the design of the major components such as the main shaft and the type and spacing of spikes or beaters on the shaft. These parameters however, ought to be selected after proper consultation with agricultural engineers or other experts, but it was observed that this was not done. The frame was made from angle iron and then covered using mild steel sheet metal. Efficiency of production depended solely on the skill of the fabricator many of whom never attended technical schools but learnt on the job as apprentices. The welds and joining on the BMS was properly done. However, there were no safety guards to cover moving parts of the machine and this was common with all the types of this machine tested.

The engine used locally is a GX 270 6.5hp petrol engine and the average engine speed was 5450 rpm while shaft speed was lower and ranged between 741 between 950 rpm depending on load. A major working component of the BMS is the shelling drum, shown in Figure 7. Its design is critical to the performance of the sheller. Generally, the spacing of the beaters was 50mm on average and concave clearance of 30-35mm. An attachment near the cobs exit, which helps to push cobs out. The MSB shares a similar design with respect to this threshing drum type. Even though variations in spacing and position as well as size of flat bars was observed in different shellers, the general design principle remains the same.

Users reported that the cost of operation within the first year or two do not involve a lot of expenses on repair work. Therefore, operating cost is limited to fuel and oil expenses and labour expenses. The basic maize sheller requires an operator, two persons to feed the machine and one person at the clean outlet and cobs outlet. Therefore, four (4) persons are required to run this machine effectively. After the shelling operation is completed, the grains require cleaning and the unshelled cobs are shelled manually. At the grain markets, there are women who carry out this extra cleaning work and they are paid. For those who operate the shelling machine at Eleekara Market, the cost of shelling a bag of maize was ₦1,500 ($5).

3.1.2 The Maize Sheller with Blower (MSB)

The MSB is designed to carry out the two operations of shelling, screening of cobs and winnowing of the grains by passing a stream of air before being collected at the grain outlet as shown in Figure 3. It features a separate fan compartment, through which the grains fall before reaching the outlet, ensuring a cleaner product. However, in most designs available fan speed is not regulated and drop height for the kernels is not sufficient thereby, allowing some kernels to be blown off and larger unwanted particles to pass through without being cleaned. In the case of the MSB and MPS, both of which have a blower attachment, the blower shaft is also powered via the same engine. The direction of rotation of both the spike shaft and the blower shaft can be either clockwise or anti-clockwise.

Figure 3. Maize sheller with blower

It was observed that this machine was not widely used in the grain markets visited. The units tested were located at a feed mill in Ibadan, Oyo State. The machine requires 3 persons for effective operation, consisting of an operator, a labourer to feed the machine, and one person each at the clean and cob outlets.

3.1.3 The Multipurpose Sheller: The Multi-purpose Sheller (MPS) was designed to handle various grains such as cowpea, sorghum and maize with little modifications required. It is generally larger in size than the BMS and MSB. It has a separate blower attachment, screen with the diameter selected based on the seeds or kernels to be processed and a vibrating mechanism to agitate the screen. Generally, depending on the particular grains to be threshed, the vibrating screens could be switched, for instance in the handling of maize kernels, the sieve openings to be used will be larger than that for sorghum seeds. The screen can be easily unscrewed and replaced with another one of appropriate diameter depending on the crop to be shelled.

The machine is powered by a prime mover, in this case a diesel engine (ALCO R-175A Model). Motion and torque are transmitted via the pulleys to the shaft, blower and cleaning unit. Both the threshing spikes and blower impeller rotate in a clockwise direction. The units tested were located at the National Center for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria (Figure 4).

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Figure 4. A multipurpose sheller

The multipurpose shellers tested had a bottom concave designed as shown in Figure 5. This concave design enables various fibrous materials to be handled. It is made up of 8 mm diameter rods placed at 5 mm intervals from each other and welded on semi-circular flat bars of 3mm thickness. The spacing is adjusted based on the grain sizes of the material to be threshed.

Figure 5. Bottom concave for the MPS

It was observed that clogging occurs in the machine due to improper rod spacing. It was also observed during the course of the tests that a number of factors could influence the delivery rate of the grains at the clean outlet. One of those factors identified was the slant angle of the outlet chute which was less than the angle of repose of maize and resulted in grains being stuck as shown in Figure 6. It was also observed that a lot of grains were spilled from the cobs outlet and this could result in considerable loses if not covered.

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Figure 6: Heaping of grains at cleaning outlet

The MPS requires an operator, one or two people to feed the machine depending on its capacity and one person at the cob outlet and another monitoring the clean grain outlet. Therefore, 3 to 4 workers are required to effectively handle this machine when used.

3.2 Comparative Analysis

All the shellers tested were powered by internal combustion engines which the fabricators selected, not necessarily based on design calculations, but typical practice handed down by earlier fabricators who trained them. Choice of prime mover is also influenced by the availability of specific models in the market. The average engine speed of the BMS was 5,450 rpm while the shaft speed ranged between 741–950 rpm when fully loaded and when running empty. This drop in speed can be attributed to the load on the beaters on the shaft, and partly due to belt transmission and frictional losses in moving parts of the machine. The MSB had an average shaft speed of 1,200 and 920 rpm for the blower and main shafts respectively. For the MPS, the blower shaft speed averaged 1,100 rpm, while the main shaft speed was 750 rpm on average.

The initial cost of a BMS ranged from ₦95,000 to ₦105,000 ($312-$346) depending on the fabricator and market location. MSB cost price ranged from ₦150,000 to ₦180,000 ($492–$590). The MPS fabricated locally was sold at a price of ₦450,000 to ₦600,000 ($1475-$1967) depending on the capacity, number of crops that can be handled as well as the engine type attached. The finding is consistent with what was reported by Williams and Rosentrater (2007).

3.2.1 Throughput

The basic maize sheller (BMS) recorded the highest mean throughput value of 1714.5 kg/hr (Fig. 7). This can be attributed to the design which allows minimum retention time of grains in the threshing drum. The MPS and MSB had mean throughput value of 839 and 512 kg/hr respectively. An analysis of variance (ANOVA) on the throughput across the shellers showed that there is significant difference ($P < 0.05$) in the throughput of the sheller designs. Clogging was experienced while testing the MSB and this was due to insufficient cob ejection at the cob outlet. Both the MSB and MPS had more functional components, which required more power and the increased retention time for the grains was evident due to the flow

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of materials from the hopper to the shelling drum, and through the cleaning unit. The result was consistent with what has been reported in previous literature by Adewole *et al.* (2015) and Aremu *et al.* (2015).

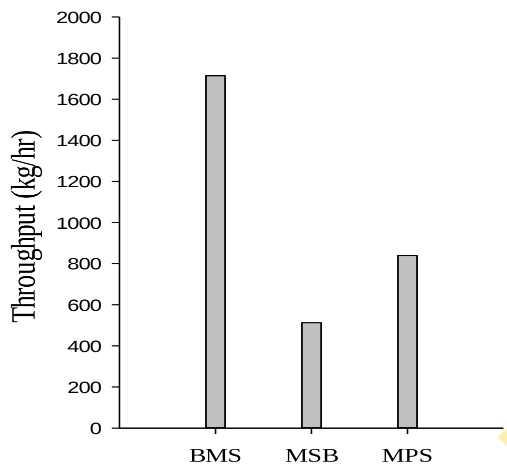

Figure 7. Variations in the throughput of the different shellers tested

3.2.2 Shelling Efficiency

The MPS had the highest threshing efficiency of 97.2%, while BMS and MSB had 92.9% and 82.7%, respectively (Fig. 8). These results are consistent with what is reported in other literature (Nwakaire *et al.*, 2011; Alsharifi *et al.*, 2019). Analysis of variance (ANOVA) on the shelling efficiency showed that there was significant difference in the shelling efficiencies ($P < 0.05$) and this was attributed to threshing mechanism design across the three machine types. The MPS had raspbar design (raspbars on the threshing drum) while the BMS and MSB had spikes on the threshing drum. Similar observations were made with threshing mechanism design for combine harvesters by Fu *et al.* (2018) and Abbas (2019).

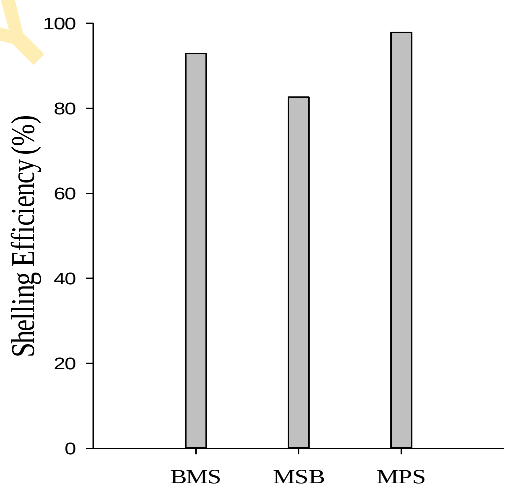

Figure 8. Shelling efficiencies of the three sheller types

3.2.3 Cleaning Efficiency

The mean cleaning efficiency for the three shellers was found to be generally low at 54% and 57.7% for the MSB and MPS respectively (Fig. 9) when compared to other studies in the literature (Ahmed *et al.*, 2019). The blower shaft speed was 1,200 rpm on average for the MSB and 840 rpm for MPS, while the air velocity for both machines ranged from 0.4 – 2.4 m/s. This was lower than the minimum separation velocity

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of 5.5 – 6.4 m/s required for maize chaff (Misener and Lee, 1973; Nsubuga *et al.*, 2020). This shows that the blower was unable to provide the minimum required air velocity for cleaning and this accounts for the low cleaning efficiencies. There is no statistically significant difference across the shellers ($P < 0.05$).

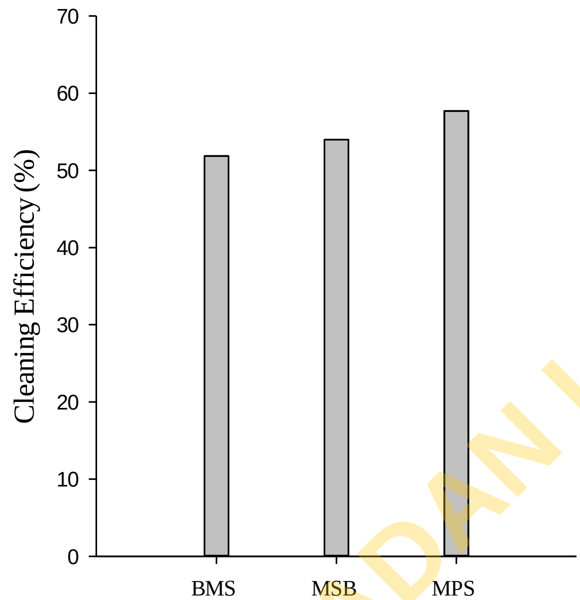

Figure 9. Cleaning efficiencies of the different sheller types

3.2.4 Total loss (%)

Losses as spills, blown off grain kernels and unshelled cobs were highest for the MSB at 17%, followed by the BMS with mean loss value of 7.2%, while the least kernel loss was for MPS at 1.9%. (Fig. 10). An analysis of variance (ANOVA) on the total loss across the shellers showed that there was significant difference in the shelling efficiencies ($P < 0.05$). The total losses were most likely influenced by the cylinder speed and concave clearance.

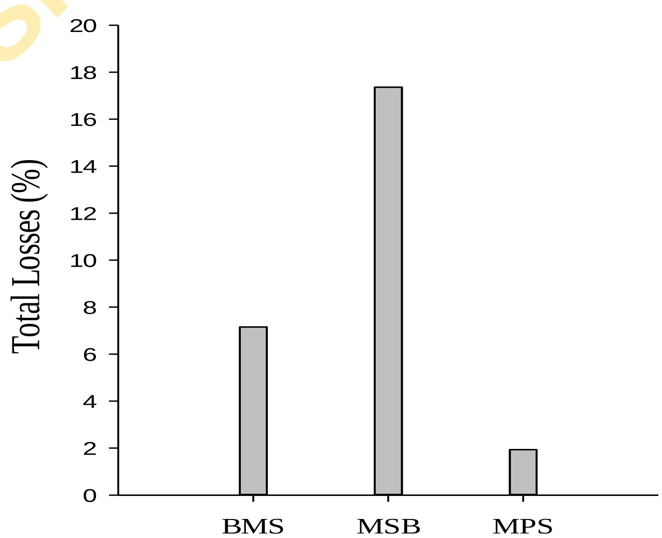

Figure 10. Total losses across the sheller types

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4. Conclusion

The maize shellers which were evaluated had a number of design and production flaws which had a negative impact on their efficiencies and this requires the attention of qualified agricultural engineers. Moreover, engineering properties of biomaterials are not necessarily considered during fabrication. This is evidenced by their choice of materials, specifications of screens and concave clearance which were not standardized. Most of the shellers were designed without safety guards over moving parts and many operators do not make use of personal protective equipment (PPE) such as nose masks, safety goggles, and covered boots.

For the MSB and MPS, blower speed was grossly inadequate and could not be regulated. The blower was unable to provide the minimum required air velocity for cleaning, thereby allowing larger unwanted particles to pass through alongside grain kernels without proper cleaning. It was observed that MSB and MPS equipment were not widely used in the grain markets visited. Most small-scale processors however prefer the basic maize sheller due to its increased output, ease of operation and cheaper cost.

It is therefore recommended that future designs of maize shellers in Nigeria should have a blower unit independent of the shaft. This will make it possible to attain air velocities required for efficient cleaning of shelled grains. Moreover, the grain processing equipment should be standardized in order to ensure good quality equipment are made available to farmers and processors, and quality grains are produced for both domestic consumption and export. Agricultural engineers and fabricators should be in close communication so as to put theory and practice into the best possible use.

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References

Abbas, A. 2019. The effect of combine harvester speed, threshing cylinder speed and concave clearance on threshing losses of rice crop. Journal of Engineering and Applied Sciences. 14: 9959-9965.

Adewole, CA., Babajide, TM., Oke, AM., Babajide, NA., Aremu, DO. and Ogunlade, CA. 2015. Critical evaluation of locally fabricated maize shelling machine. International Journal of Engineering Science and Innovative Technology, 4(2): 67-73.

Ajav, EA. and Ojediran, JO. 2006. Some physical and aerodynamics properties of three Nigerian cereal crops as related to their cleaning. ASABE Meeting Presentation Paper Number. 066006 2006.

Ahmed, JM., Isiaka, M., Saeed, HA. and Idoko, SO. 2019. Performance evaluation of cleaning and grading machine using maize as test grains. In 40th Annual Conference and 20th International Conference of the Nigerian Institution of Agricultural Engineers - Omu-Aran, p. 269–275.

Alsharifi, SKA., Aljibouri, MA. and Taher, MA. 2019a. Effect of sheller rotational speed on some maize cultivars quality. Agricultural Engineering International. CIGR Journal, 21(2): 196 – 203.

Alsharifi, SKA., Aljibouri, MA., Taher MA. 2019b. Effect of threshing machines, rotational speed and grain moisture on corn shelling. Bulgarian Journal of Agricultural Science, 25(2): 243 – 255.

Aremu, DO., Adewumi, IO. and Ijadunola, JA. 2015. Design, fabrication and performance evaluation of a motorized maize shelling machine, Journal of Biology, Agriculture and Healthcare. 5(5): 154-165.

Arisukwu, O., Igbolekwu, CO., Mibzar, SEP., Asamu, F. and Bamidele, R. 2019. Post–harvest preservation methods of beans and rural consumers in ganye, Adamawa state, Nigeria. In 40th Annual Conference and 20th International Conference of the Nigerian Institution of Agricultural Engineers - Omu-Aran, p. 435–442.

ASAE, 2000. ASAE Standards, moisture measurement - Unground grain and seeds. St. Joseph, Mich. ASAE; 43rd ed. S352.1

Ekpa, O., Palacios-Rojas, N., Kruseman, G., Fogliano, V. and Linnemann, AR. 2018. Sub-Saharan African maize-based foods: technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. Global Food Security 17: 48–56.

FAOSTAT, 2020. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/QC/ . Date Accessed: 12 October 2020.

Fu, J., Chen, Z., Han, L. and Ren, L. 2018. Review of grain threshing theory and technology. International Journal of Agricultural and Biological Engineering. 11: 12-20. 10.25165/j.ijabe.20181103.3432.

Ghatrehsamani, S., Ampatzidis, Y., Sadeghi, B. and Ghatrehsamani, S. 2018. Design, fabrication and evaluation of corn sheller. An ASABE Meeting Presentation. DOI. https://doi.org/10.13031/aim.201800159. Paper number. 1800159.

Hell, K., Fandohan, P., Bandyopadhyay, R., Kiewnick, S., Sikora, R. and Cotty, PJ. 2008. Pre- and postharvest management of aflatoxin in maize: An African perspective. Chapter 19 in Mycotoxins: detection methods, management, public health and agricultural trade: Cambridge Publishers, Wallingford, UK, p. 219-229.

Igbeka, JC. 2013. Agricultural Processing and Storage Engineering. Ibadan University Press. Pp. 39.

Ilori, TA., Raji, AO. and Kilanko, O. 2013. Modelling some ergonomic parameters with machine parameter using hand powered maize sheller. Journal of Engineering and Technology Research, 5(3): 51-57.

Isa, J., Jimoh, KA. and Fasuyi, O. 2019. Modeling of the drying characteristics of maize gruel residue. 40th Annual Conference and 20th International Conference of the Nigerian Institution of Agricultural Engineers - Omu-Aran, p. 404–414.

Kader, AA. 2005. Increasing food availability by reducing postharvest losses of fresh produce. Acta Horticulturae, 682.2169-2175.

Kroupa, P. 2003. The outer quality loss during grain post-harvest treatment and handling. Research in Agricultural Engineering, 49(3): 91–102.

Misener, GC. and Lee, JHA. 1973. Aerodynamic separation of grain from straw and chaff in a dispersed stream. Canadian Agricultural Engineering, 15(2): 62-65.

Mogaji, PB. 2016. Design and fabrication of an improved maize shelling machine. African Journal of Science, Technology, Innovation and Development, 83: 275-280.

Negrini, O., Spillman, CK., Wang, YS., Chung, DS., Steel, J. and Posner, JS. 1994. Evaluation of laboratory grain cleaners and separating equipment – Part II. Transactions of the American Society of Agricultural Engineers, 37(6): 1913–1818.

Nwakaire, JN., Ugwuishiwu, BO. and Ohagwu, CJ. 2011. Design, construction and performance analysis of a maize thresher for rural dweller. Nigerian Journal of Technology, 30(2): 49-54

NIS, 1997. Nigerian Industrial Standard (NIS). Test Code for Maize Shellers. NIS 319. 1997. Standards Organisation of Nigeria, SON.

Mijinyawa, Y. 2012. The Design of Farm Structures. First Edition. Ibadan University Press, Publishing House, University of Ibadan, Ibadan, pp. 168

Nsubuga, D., Kabenge, I., Zziwa, A., Kiggundu, N., Wanyama, J. and Banadda N. 2020. Performance evaluation and optimization of the maize shelling operation of the multi-purpose farm vehicle. Agricultural Engineering International. CIGR Journal, 22(4): 174-183.

Oliveira, PM., Zannini, E. and Arendt, EK. 2014. Cereal fungal infection, mycotoxins, and lactic acid bacteria mediated bioprotection. From crop farming to cereal products. Food Microbiology, 37: 78–95.

Omobowale, MO., Armstrong, PR., Mijinyawa, Y., Igbeka, JC. and Maghirang, EB. 2016. Maize storage in termite mound clay, concrete, and steel silos in the humid tropics. Comparison and effect on bacterial and fungal counts. Transactions of the ASABE. 59(3): 1039-1048. 2016.

Oriaku, EC., Agulanna, CN., Nwannewuihe, HU., Onwukwe, MC. and Adiele, ID. 2014. Design and performance evaluation of a corn de-cobbing and separating machine. American Journal of Engineering Research, 3(6): 127-136.

Oyewole, SN., Gbabe, EK., Olayanju, A., Adebiyi, AO., Ogunbiyi OA., Adarabierin, IG., Ogundare, MO., Abel, GI., Olayemi, FF. and Okunola, AA. 2019. Commercial utilization of inert atmosphere silo for maize storage. In 40th Annual Conference And 20th International Conference tf the Nigerian Institution of Agricultural Engineers - Omu-Aran. p. 1176–1182.

Pavasiya, UN., Patel, K., Sumant, MM. and Sutariya, HR. 2018. Design and fabrication of a motorized maize shelling machine. Journal of Materials Science and Mechanics Engineering, 5(1): 5–12.

Pristavkova, M., Zitnak, M. and Lendelova, J. 2016. Hazard analysis in operating of the post-harvest lines. Research in Agricultural Engineering, 62. S53–S60.

Suleiman, AI., Atanda, EO., Ajayi, AS. and Chanchangi, YN. 2019. Advancing post-harvest food loss reduction in sub-saharan africa using solar-powered vacuum cooling storage system as a palliative. In 40th Annual Conference and 20th International Conference of The Nigerian Institution of Agricultural Engineers - Omu-Aran, pp. 214–220.

USDA, 2014. Foreign Agricultural Service, GAIN Report. Global Agriculture Information Network, Nigeria. Grain and Feed Annual Report.

USDA-FAS, 2017. World agricultural production circular series WAP 05-17, May 2017. Foreign Agricultural Service/USDA Office of Global Analysis.

Williams, G. and Rosentrater, K. 2007. Design Considerations for the Construction and Operation of Flour Milling Facilities. Part I. Planning, Structural, and Life Safety Considerations. ASABE Annual International Meeting; Paper Number: 074116, p. 1-23.