International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 9 Issue 8 Series I || August 2020 || PP 35-42

Development of a Grain Cleaning Machine for Sorghum and Millet

Yayock E. S., J. Shebayan and B. J. Bature
Agricultural and Bio-Environmental Engineering Technology Department, School of Agricultural Technology, Nuhu Bamalli Polytechnic, Zaria, Kaduna State, Nigeria.

ABSTRACT:
It is impossible to grow and harvest cereal grains without getting undesirable intermixtures despite proper care and tending of the crops. The cleanliness of small sized grains such as sorghum and millet, is usually challenging after threshing operations. A grain cleaning machine was developed using locally available materials and based on detailed engineering design. The machine was used to clean sorghum and millet. It was evaluated using output capacity, cleaning efficiency, and percentage grain scatter loss as the performance parameters, while feed rate, air speed and crank amplitudes were used as the experimental factors. Results from the machine evaluation, indicates that the output capacity ranged between 620.83 to 1088.5 kg/hr. and 620.50 to 1097.83 kg/hr. for sorghum and millet, respectively while the cleaning efficiency ranged between 98.04 to 98.66 % and 97.30 to 98.05 % for sorghum and millet, respectively. The scatter loss was obtained within ranges of 0.83 - 1.27 % and 1.31 - 2.12 % for millet and sorghum, respectively. The best performance of the machine was obtained at air speed and crank amplitude of 4.5 m/s and 25 mm, respectively for both crops, and feed rates of 1400 kg/hr. for sorghum and 1200 kg/hr. for millet. The research however, achieved the best cleaning efficiencies of 98.64 and 98.05 %, for sorghum and millet, respectively.

KEYWORDS: *Grain cleaning, fabrication, cleaning efficiency, output capacity, grain scatter loss*

Date of Submission: 15-08-2020 Date of Acceptance: 01-09-2020

I. INTRODUCTION

Grain cleaning is a post-harvest operation undertaken to remove foreign and undesirable materials from threshed seeds/grains thereby leaving the produce clean for storage, planting or further processing. It is a material separation process. Cereal and leguminous crops need to be threshed and detached from their cops, panicles or pods before the process of cleaning. Grain cleaning is done to: reduce requirement for drying and cost; remove materials that could cause deterioration during storage; remove materials that could damage the conveying and milling machinery; remove materials that cause a reduction in the grade (thus reducing the value of the grain); and reduce storage requirements. There are a number of factors that affects the cleanliness and loss of grains during cleaning operations. According to Simonyan (2006), the physical parameters that affect grain cleaning processes are broadly grouped into; crop characteristics and machine parameters. The crop factors are; crop variety, maturity stage, grain moisture content, straw moisture content, bulk density of grain, bulk density of straw, stalk length, and equivalent grain diameter, while the machine factors are; velocity of air, air stream pressure, air density, angle of air direction and terminal velocity of particles (both grain and other materials). Other scholars and researchers have also reported on factors such as feed rate, amount of wind or air velocity, shaker frequency, sieve tilt angle, dimension of sieve opening, crop variety and moisture content (Awady *et al*., 2003; Ebaid, 2005; Sahay and Singh, 2008; Salwa *et al*., 2010, Muhammad *et al*., 2013).

In Northern Nigeria, cleaning or winnowing is usually done by women in an open space when there is free flow of natural wind using a woven circular tray of average diameter of 500 mm made from the back of sorghum stalk or the stalk of certain grass species. Muhammad *et al*. (2013) reported that it takes between seven to twelve minutes to clean a batch of 1 kilogram of uncleaned grains, depending on the winnower's skill, the required cleanliness, grain/non-grain ratio, amount and stability of the natural air current and other environmental factors. The traditional or manual method is arduous, time and labour consuming operations on the persons performing the operations. The natural wind condition may not also be favourable for the operation and may therefore, result to increased time of operation and drudgery. The long hours associated with the traditional method results in fatigue, loss of concentration and consequently, reduction in separation quality.

The average farmer finds it more economical to thresh crops manually but requires extremely high labour and time to clean the grains using the manual method (Muhammad *et al*., 2013). The farmers oftentimes become exhausted to continue with cleaning operations after threshing and as a result keeps the grain-foreign material mixture over long or short periods before cleaning. These practices usually result to mold and insect infestation and possibly damage and destruction to the grains. The presence of foreign matter in grains also increases the weight and bulk volume and resulting increase in the cost of handling, transportation and storage. Over the years, little or no effort has been applied in developing units of cleaning machines with high cleaning efficiencies, most of them are produced as integral parts of threshers, shellers, de-huskers, decorticator or combines. The output of some of these machines like the thresher, are low due to the presence of the threshing units whose threshing capacities are not significantly higher than manual threshing using sticks. Muhammad *et al*. (2013) reported that the threshing units also convey long straw onto the shaker which results in increase grain loss. The high cost of thresher–cleaner machine is due to the additional cost of the threshing component which is not needed by an average farmer. Therefore, it is imperative to develop a grain cleaner capable of relieving farmers and processors of the hard spent energy, time, labour, and resources in manual cleaning operations.

Sorghum and millet are cereal crops that are grown in large quantities in Nigeria as staple food. They have excellent storage stability and nutritional values, making them the most desired foods for holding in reserves. Sorghum, (*Sorghum bicolor (L) Moench*) is the fifth most important cereal after rice, wheat, maize, and barley (FSD, 1999). It constitutes the main food grain for over 750 million people who live in the semi-arid tropics of Africa, Asia, and Latin America. The largest group of producers are small-scale subsistence farmers with minimal access to production inputs. It is also a major source of raw material to many agro-based industries. Sorghum is grown mostly in the Guinea and Sudan savannah zones, in Nigeria. Millet (*Pennisetum glaucum*) is however, a security crop that can be grown where other cereals like maize or wheat would not survive. It is the sixth most important cereal after Sorghum, cultivated annually as rain fed crop in arid and semi-arid areas of Africa and the Indian sub-continent (Kajuna, 2001). In Nigeria, the annual yield of sorghum is reported to be in excess of 7 million tons, while millet is estimated at about 5 million tons (FAOSTAT, 2014). The FAO estimates in 2003 put the annual production of millet at over 18 million tons in Sub-Saharan Africa. Sorghum and Millet are important sources of dietary protein, carbohydrates, the B complex of vitamins, vitamin E, iron and trace minerals. There has been an increasing demand of the crops for use in the production of food; feed products; alcoholic and non-alcoholic beverages. However, the traditional consumption of the crops still utilizes 98 % of the annual production.

This research aims to develop a prototype cleaning machine for major cereal crops that can clean at-least one ton of the grains in an hour, thereby reducing the drudgery in post-harvest processing. The development of the prototype machine would be of importance to cereal and seed producers, as it will improve the cleanliness of their products and increase the market value.

II. MATERIALS AND METHODS

Construction of Grain Cleaning Machine

A prototype grain cleaning machine was designed and constructed in the metal and fabricating workshop of the Department of Agricultural and Bio-Environmental Engineering Technology, Nuhu Bamalli Polytechnic, Zaria, Kaduna State. The major components of the prototype machine are shown in the drawing (Fig. 1) and Table 1 gives a description of the machine. Figure 2(a and b) present the pictorial views of the machine. The main parts of the cleaner consist of the frame which serves as the skeletal support and means of coupling and holding other component parts together. The hopper is trapezoidal shape with the base inclined at an angle of 30^0 for discharge and even distribution of grains over the first screen. The shaft diameter was determined using Equation 1, as expressed by Khurmi and Gupta (2007), while the size of the driven pulley was determined using Equation 2, as given by Hannah and Stephen (1984). The blower has three blades enclosed in the casing to deliver air current over the reciprocating screens. The sieve compartment consists of the casing, two outlets, and three round screens (6.0, 4.5 and 2.0 mm) made with mild steel, selected based on determined physical properties of the grains. All screens are replaceable and adjustable between 0 and 12^0. The screen compartment oscillates with the aid of a connecting rod attached to the main shaft and an adjustable crank which helps to achieve various levels reciprocating amplitude.

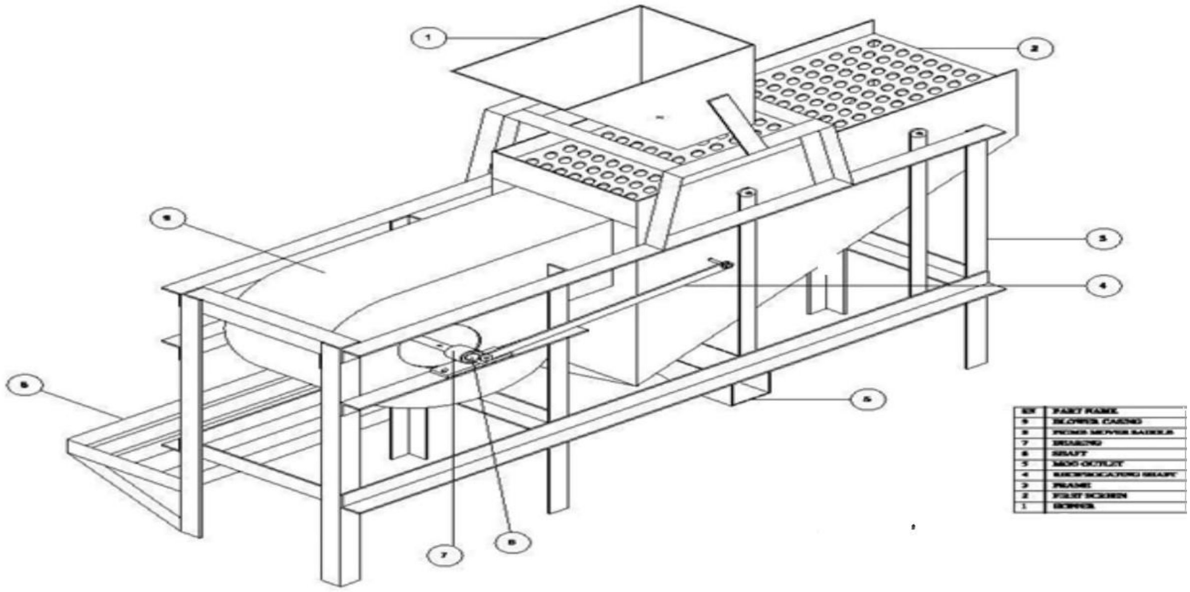

Fig. 1. Isometric view of the machine showing the major component

$d^3 = \frac{16}{\rho Ss}\sqrt{(K_b M_b)^2 (K_t M_t)^2}$ .... (1)

where:
d=Shaft diameter (mm),
K_b = Combine shock and fatigue factors for bending moment,
K_t = Combine shock and fatigue factors for torsional moment,
M_b = Maximum bending moment (Nm),
M_t = Torsional moments (Nm),
S_s = Maximum allowable shear stress (N/m^2)

$N_1 D_1 = N_2 D_2$ .... (2)

where:
N_1 = speed of driving pulley (rpm).
D_1 = diameter of driving pulley (m), and
D_2 = diameter of driven pulley (m)
N_2 speed of driven pulley (rpm)

Table 1. Description of Construction Materials

S/No	Material Description	Quantity	Material
1	Frame (25 × 25 × 5mm - Angle iron)	1	M.S - Angle iron
2	Hopper (1.5mm)	1	M.S – Sheet (Gauge 18)
3	Shaft (Ø 25mm)	1	M.S - Rod
4	Connecting rod (Ø 16 mm)	1	M.S - Rod
5	Pulley (150 diameter)		M.S
6	V-Belt	1	Leather
7	Sieve compartment (3mm)	1	M.S – Sheet (Gauge 18)
8	Sieves (2.0, 4.5 & 6.0 mm hole diameter)	3	M.S – Sheet (Gauge 18)
9	Flexible support for sieve compartment (5mm)	4	M.S – Flat bar
10	Fan housing (1.5mm)	1	M.S – Sheet (Gauge 18)
11	Fan blades (5 mm)	3	M.S – Sheet (Gauge 18)
12	Outlets	2	M.S – Sheet (Gauge 18)
13	Pillow Bearing	2	
14	Prime mover (Petrol Engine - 3.5hp)	1	
Scale - 1:5			
All dimensions in mm			

Operation of Prototype Machine

A batch of unclean threshed grains is fed through the hopper to flow by gravity over the first screen which is inclined at an angle of 6^0. The second screen is inclined at 9^0 in the same orientation as the first while the third sieve is inclined at 12^0 at the reverse direction. The first screen initiates the separation by size when the sieve chamber oscillates. As the grains and chaff mixture flow between the screens, it passes across an air stream from the blower which performs the separation based on the aerodynamic properties of the mixture. The cleaned grains roll over the third screen and are collected at one of the outlets, while broken grains, stalk and other smaller particles passes through the screen are collected at the other outlet. The machine is powered by a small 3.5 hp petrol engine.

(a). Side view of the machine

(b). Front view of machine

Fig. 2(a and b). Different views of the constructed machine

Machine Evaluation

SAMSORG 43 variety of sorghum and EX BORNO variety of pearl millet were sourced and used for the experiment. Feed rate, Air speed and Crank amplitude were used as the independent variables in evaluating the performance of the machine. Four levels of feed-rate (F_1 = 800Kg/hr., F_2 = 1000Kg/hr., F_3 = 1200Kg/hr. and F_4 = 1400Kg/hr.), four levels of air speed (S_1 = 2.5 m/s, S_2 = 4.5 m/s, S_3 = 6.0 m/s, and S_3 = 8.0 m/s) and three levels of crank amplitude (C_1 = 10 mm, C_2 = 25 mm and C_3 = 40 mm), were used for the experiment. Machine output capacity, cleaning efficiency and percentage grain loss were determined as the performance indices of the machine. The expression in Equation 3 was used as given by Simonyan *et al* (2006) to determine the cleaning efficiency of the grains while the grain scatter loss was obtained using Equation 4 as given by Ndirika (1994). The combination of experimental factors in three replications produced a total of 144 treatments. Grain samples of both grains were analyzed manually before the experiment and the result showed that the Millet sample consist of 84 % pure grains and 16 % impurities (chaff, straw, dust, small immature seeds), while the Sorghum sample on the other hand consist 87 % pure grains and 13 % impurities.

$$\eta = \frac{G_o}{G_o + G_{cg}} \times 100 \qquad (3)$$

where:

η =cleaning efficiency, %

G_o = weight of pure grain at the outlet, kg

C_{cg}= weight of foreign materials in pure grains, kg

$$S_c = \frac{Q_l}{Q_t} \qquad (4)$$

Where:

S_c = percentage of scatter loss, %

Q_l = quantity of grains scattered around the machine, kg

Q_t = summation of grains trapped within the machine and those scattered around, kg

III. RESULTS AND DISCUSSIONS

Effect Feed Rate on Machine Performance

The effect of feed rate on cleaning efficiency of the machine in cleaning sorghum and millet is expressed in Figures 3.The regression analysis shows a polynomial relationship of feed rate with cleaning efficiency for millet and a high negative linear correlation of feed rate with cleaning efficiency for sorghum. The coefficient of determination for the effect feed rate on the cleaning efficiency for sorghum and millet is 0.9182 and 0.7174, respectively. Simonyan *et al.* (2006), Salwa *et al.* (2010), Muhammed *et al.* (2013) and Afolabi (2015) have reported similar trends of decreasing cleaning efficiency with increasing feed rates. The effect of decreasing cleaning efficiency with increasing feed rates may be attributed to the increasing load intensity on the sieve and multiple particles acting as obstructions to the air flow. As the feed rate is increased the material flowing across the air current forms a thicker blanket making it increasingly more difficult for air current to penetrate and flush out the unwanted materials.

The effect of feed rate on grain scatter loss is expressed in Figure 4. The regression analysis showed a positive linear correlation between feed rate and scatter loss for sorghum and a polynomial relationship for millet. Grain scatter loss increased with corresponding increase in feed rate. Muhammad *et al.* (2013) reported a polynomial relationship between scatter loss and feed rate for sorghum and millet grains. The coefficients of determination for the relationship is 0.9996 and 0.9566 for sorghum and millet, respectively. The increase in grain scattering with feed rate could be explained due to the fact that as the feed rate increase gradually, the material that flow across the air current allows air to flush out some of the grains alongside the unwanted material. Figure 5 express the effect of feed rate on output (throughput) capacity of the machine. The output capacity for both grains increased with increase in the feed rate.

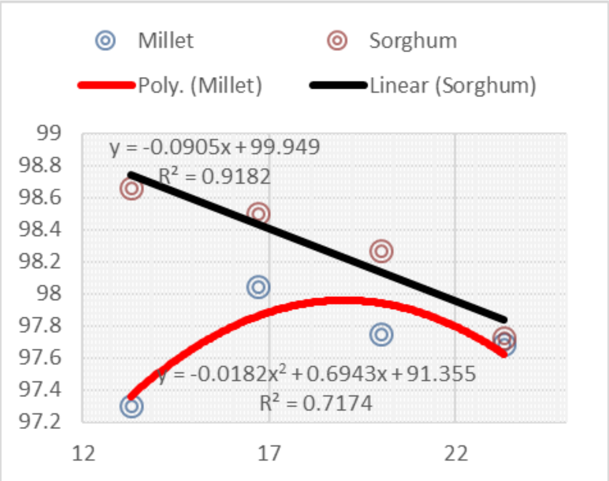

Figure 3.Effect of feed rates (Kg/min)on cleaning efficiency (%) of the machine

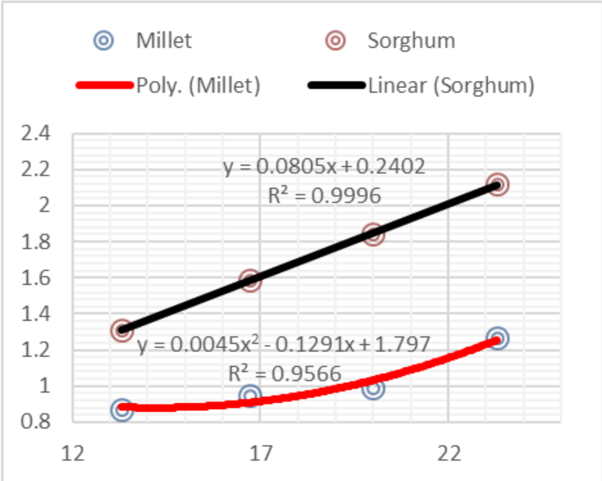

Figure 4. feed rates (Kg/min) onscatter losses (%)

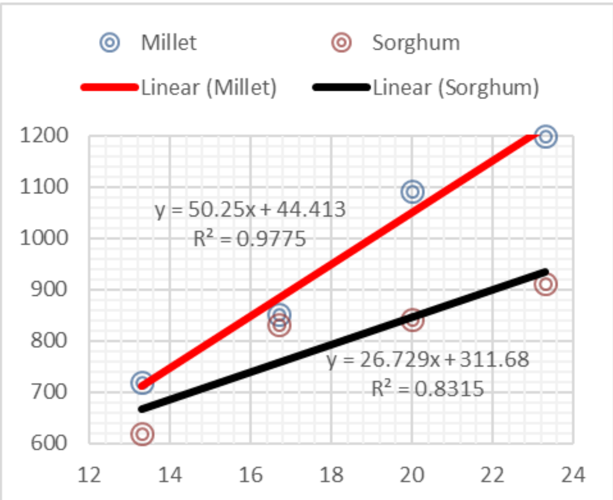

Figure 5. Effect of feed rates (Kg/min) on output capacity (throughput) (Kg/hr)

Effect of Air Speed on Machine Performance

The effect of air speed on the cleaning efficiency of the machine is expressed in Figure 6. The regression analysis shows a polynomial relationship between air speed and cleaning efficiency for both grains. The cleaning efficiency increased from the air speed of 2.5m/s to a peak value at 4.5m/s and decreases afterward. The coefficient of determination for the relationship is 0.9347 for sorghum and 0.6984 for millet. Simonyan *et al.* (2006) reported a decrease cleaning efficiency with increase in air speed for sorghum. These phenomena may be attributed to the reduction in the resident time of flight of materials to be cleaned within the air stream. When the resident time is longer, it positively affects the efficiency of separation, as there is greater likelihood for lighter particles being displaced in the air stream (Simonyan *et al.*,2006).

The effect of air speed on scatter loss for millet and sorghum is expressed in Figure 7. Grain scatter loss shows a positive linear correlation with air speed, for both grains. More grain losses were recorded as the air speed progressively increase from 2.5, 4.6, 6.0 to 8,0m/s. The behaviour may be attributed to a state where the increasing air speed overcomes the terminal velocity of the grains and some particles get then blown off together with the chaff. Mohammad *et al.*(2013) reported a polynomial relationship between fan speed and grain scatter loss for both sorghum and millet. They reported that the grain scatter loss for both grains increased with further decrease or increase in fan speed.

The effect of air speed on output (throughput) capacity is shown in Figure 8. The output capacity of the two grains increases with increase in air speed. 0.9963 and 0.7939 are the coefficients of determination for millet and sorghum, respectively, as machine output increased with increase in air speed. Increasing the feed rate increases the effect of the blanket formed across the air stream and a substantial quantity of the grains is collected at the outlet. A reduction in the air strength that would initiate the separation process may cause more grains roll over the sieve, to be collected together with the chaff. An increase in the load intensity across the air stream causes turbulence while a decrease lowers the free stream turbulence intensity which causes the drag coefficient to decrease.

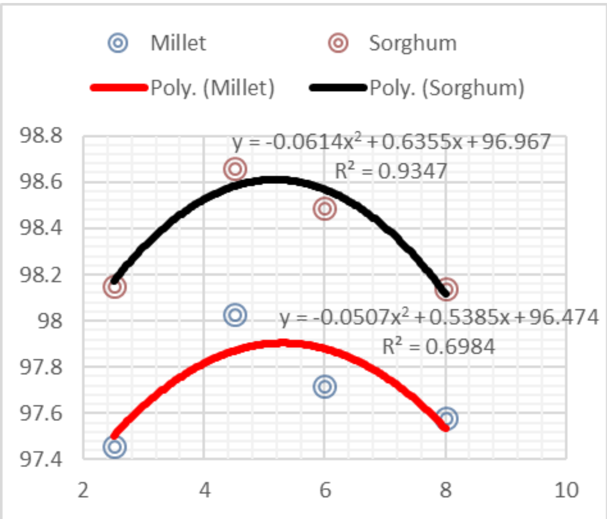

Figure 6. Effect of air speed (m/s) on cleaning efficiency (%) of the machine

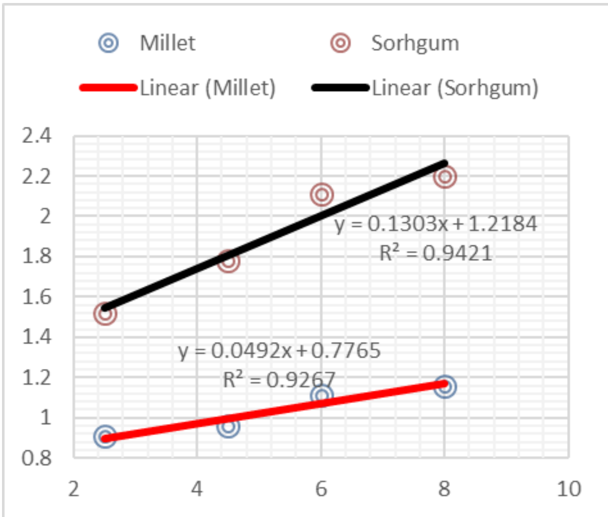

Figure 7. Effect of air speed (m/s) on scatter loss (%)

s

Figure 8. Effect of Air speed (m/s) on output capacity(Kg/hr) of machine

Effect of Crank Amplitude on Machine Performance

The effect of crank amplitude on the cleaning efficiency of the machine for the millet and sorghum is expressed in Figure 9. Both grains exhibited a polynomial relationship with regards to the effect of crank amplitude on cleaning efficiency. The percentage cleaning efficiency for the two grains increases or decreases withfurther increase in the crank amplitude. The transport of particles along an oscillating sieve is a function of the oscillation frequency. Increasing agitation is to allow more materials to pass through the sieve holes. It affects the frequency of the process and affects the metering of particulate substances along the sieve. These trend of increase or decrease in the cleaning efficiency with further increase in sieve oscillation may be due to less resident time of the materials to be separated on the sieve. The increasing load intensity of materials may also be the reason for the decrease in cleaning efficiency. The results obtained for the effect of crank amplitude on cleaning efficiency is similar to the findings of Salwa *et al.* (2010), who reported that the cleaning efficiency obtained in cleaning fennel seed increased from 15 to 20 mm amplitude and later decreased from 20 to 30 mm amplitude.

The effects of crank amplitude on grain scatter loss is expressed in Figure 10. The regression analysis showed a high positive correlation of crank amplitude with grain scatter loss for sorghum and millet. Scatter loss for both millet and sorghum increases with increase in crank amplitude. The coefficient of determination for sorghum and millet are 0.8596 and 0.9735, respectively. Simonyan *et al.* (2006) reported that frequency of oscillation has a greater effect the passage of particles through the sieves.

The relationship between the crank amplitude and output capacity of the machine in cleaning millet and sorghum is represented in Figure 11. The relationship followed a polynomial pattern for both grains. The output increases within crease in crank amplitude to a peak amplitude and decreases afterward. The coefficient of determination (R^2) for the two grains is 1.

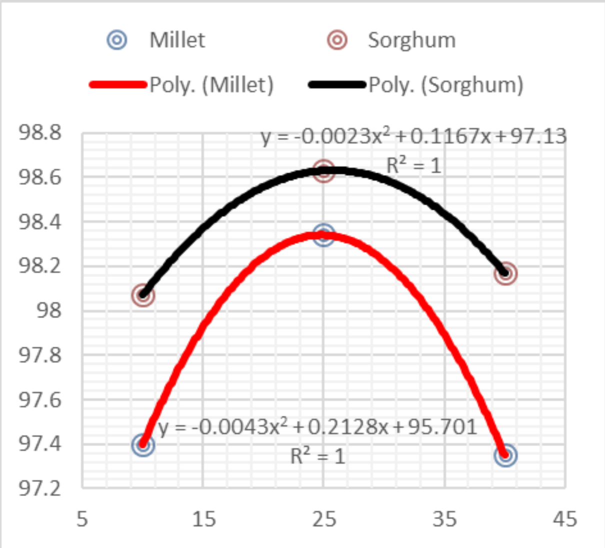

Figure 9. Effect of crank amplitude (mm) on cleaning efficiency (%)

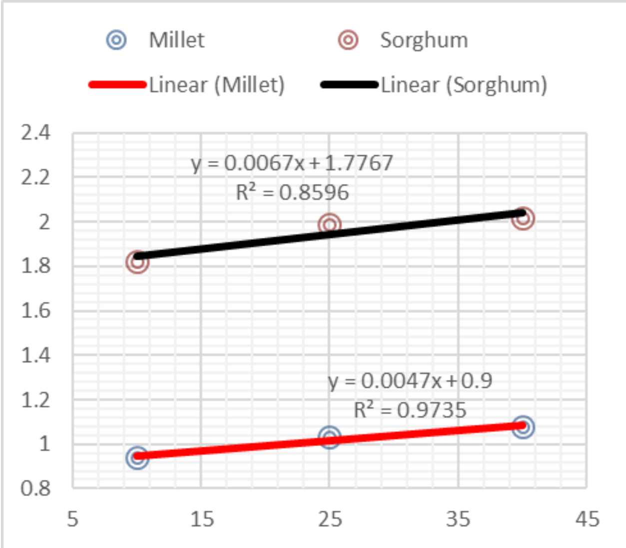

Figure 10. Effect of crank amplitude (mm) on grain scatter losses (%)

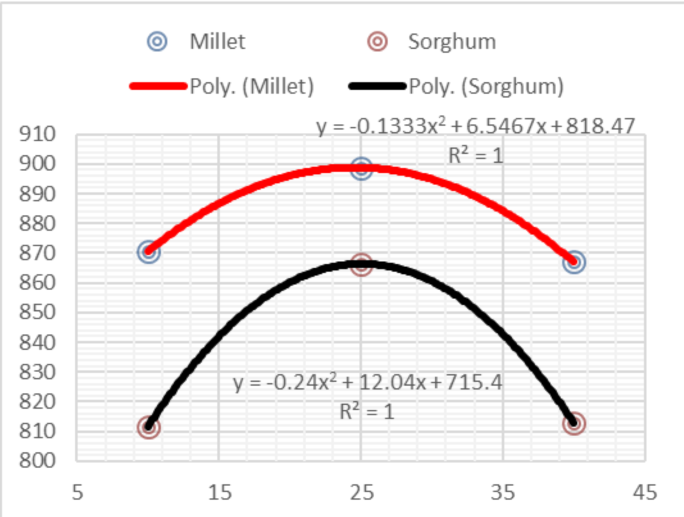

Figure 11. Effect of crank amplitude (mm) on output of machine (Kg/hr)

IV. CONCLUSION

A multi-crop cleaning machine was developed based detailed design and it was found to be very efficient in the separation process of grains from the associated foreign matter. Samples of sorghum

(SAMSORG 43) and millet (Ex BORNO) at moisture levels suitable for storage were sourced locally and used as the test crops. The machine was tested and the output capacity ranged between 620.83 to 1088.5 kg/hr and 620.50 to 1097.83 kg/hr for sorghum and millet, respectively, while 98.04 to 98.66 % and 97.30 to 98.05 % are the respective ranges for cleaning efficiency of sorghum and millet. The scatter loss was obtained within ranges of 0.83 - 1.27 % and 1.31 - 2.12 % for millet and sorghum, respectively. Cleaning efficiency of 98.05% at 0.89%grain loss was obtained as the best in cleaning millet, while the corresponding value for sorghum is 98.64% at 1.59%.The optimum cleaning efficiencies were obtained at air speed of 4.5m/s, crank amplitude of 25mm, and feed rates of 1400kg/hr and 1200kg/hr for sorghum and millet, respectively.

REFERENCES

[1]. Afolabi A. (2015). Design, construction and performance evaluation of an axial - flow millet thresher. *Unpublished M.Sc Thesis.* Ahmadu Bello University, Zaria.

[2]. Awady M. N., I. Yehia, M. T. Epaid, and E. M. Arif. (2003). Development and theory of rice cleaner for reduce impurities and losses. *Misr. j. Ag. Eng*., 20(4): 53-68.

[3]. Ebaid M. T., (2005). Effect of physical properties of wheat on cleaner performance. *Misr. j. Ag. Eng*. 22(1): 127-144.

[4]. Food and Agricultural Organization (FAO), 2003. *Statistical Database*. United Nations.

[5]. http//www.apps.fao.org.

[6]. Food and Agriculture Organization Statistics (FAOSTAT), 2014. *Population data and standard food composition*. Population and Food Balance Sheets. All crop data: FAO Statistics Division 2014. Updated: 04 August 2014, Accessed on 09 October 2014 from http://faostat.fao.org/site/567/Desktopdefault.aspx?pageID=567#ancor.

[7]. Food Security Department (FSD), (1999). SORGHUM: Post-harvest Operation. *Post-harvest Compendium*. AGSI/FAO. National Resource Institute (NRI).

[8]. Hannah J. and R. C. Stephen, (1984). *Mechanics of machine*. 2nd edition. Edward Arnold Publishers Ltd. London. pg. 10-26.

[9]. Kajuna S. T. A. R. (2001). MILLET: Post-harvest Operation. *Post-harvest Compendium*. AGSI/FAO. Sokone University of Agriculture (SUA).

[10]. Khurmi R. S. and J. K. Gupta, (2007). *A textbook of machine design.* 14th edition. Eruasian Ltd. Ran. New Delhi, India. pg 314-330.

[11]. Muhammad U.S., L.G. Abubakar, M. Isiaka and R.M. Davies, (2013). Design and evaluation of a cleaning machine. *Applied Science Reports*1 (3), 2013: 62-66. www.pscipub.com/ASR.

[12]. Ndirika, V. I. O. (1994). Development and performance evaluation of a millet thresher. *Journal of Agricultural Engineering and Technology*. *vol. 2*. pg. 80-89.

[13]. Sahay K. M. and K. K. Singh, (2008). *Unit operation of Agricultural processing*. 2nd revised ed. VIKAS Publishing House, New Delhi. India. Pg. 1-12.

[14]. Salwa S. H., S. M. Ahmed, and N. M. El_Ashmawy. (2010). Selection of the main factors affecting cleaning and grading fennel seeds at inclined sieve oscillation. *Misr. j. Ag. Eng.*, 27(2): 628-643.

[15]. Simonyan K. J. (2006). Mathematical modeling of grain cleaning process in a stationary Sorghum thresher. *Unpublished Ph.D. dissertation*. Ahmadu Bello University, Zaria.

[16]. Simonyan K. J., Y. Yiljep, and O. J. Mudiare, (2006). Modeling the cleaning process of a stationary sorghum thresher. *Agricultural Engineering International: CIGR Ejournal.* Manuscript PM 06 012 vol. viii.

Yayock E. S, et. al. "Development of a Grain Cleaning Machine for Sorghum and Millet." *International Journal of Engineering Science Invention (IJESI)*, Vol. 09(07), 2020, PP 35-42. Journal DOI- 10.35629/6734