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Development and Performance Evaluation of A Grain Grading Machine for Small and Medium Scale Farmers

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

Abstract: *Grading remains an unlikely operation to many small and medium farm holders who account for about 99 percent of grains produced in Nigeria, despite its importance. Grain quality is generally assessed virtually, it is influenced by the end-use and the price is determined more by locals rather than a national factor. Grain grading provides for a wider acceptability of grains, selection of good seeds, improvement of standards and market value. A grain grading machine was developed to grade maize grains according to size only. The machine was designed to be within the reach of small and medium scale farmers. Three independent variables (crank amplitude, feed rate and screen tilt angle) were varied during the performance evaluation to determine the grading efficiency and percentage scatter loss of the machine. The best grading efficiencies of 96.83, 95.32, and 92.93 % were obtained for grades; A, B, and C, at crank amplitude of 25 mm, feed rate of 500 kg/hr., and screen tilt angle of* 12^0*. The percentage scatter lossof grains around the machine ranged between 0.3370 and 0.4074 %.*

Keywords: *Grading efficiency, Scatter loss, Grains, Maize, Screen.*

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I. Introduction

Grading is an agricultural processing operation that is undertaken to separate good, broken, immature, shrieked or weed seeds and other materials that are unsuitable for consumption, storage or planting from a grain stock.Variation in uptake of inputsandnaturehave made it impossible to grow and harvest pure and uniformly sizegrainswithout variable physical characteristics. Therefore, grading is used to categorizegrains into different grades based on the desired quality parameters for storage, seed preparation, commercialization or further processing (EAC, 2014). The main objectives of grading are to attract more market value for grains and the selection of good viable seeds, as large seeds have been reported to germinate with higher survival rates, better than small and medium seeds(Saeed and Shaukat, 2000; Taley and Bansod, 2012). Grading machines exploits the differences in the engineering and physical properties of grain materials to achieve the separation into different grades. Grain grading depends on setting different crop and machine parameters in the separation process, these parameters include screen tilt angle, screen oscillation, oscillation frequency, length of stroke, frequency of vibration, feed rate, crank amplitude, crank speed, scatter loss, throughput capacity, screen size, screen type, blower setting or blower suction and moisture content of the grain (Sahay and Singh, 2008; Salwa *et al*., 2010;Taley and Bansod, 2012; Muhammad *et al*., 2013; Yayock, 2016).

Grains are important sources of carbohydrates, dietary protein, vitamin B complex, vitamin E, iron and trace minerals. They also have excellent storage stability and nutritional values making them the most desired foods for holding in reserves. Maize is a grain that dominates the diets in Nigeria and the entire Sub-Saharan Africa. It is the third most important cereal in the world, next to wheat and rice (Sobukola *et al.*, 2013). The Food and Agricultural Organization Statistics (FAOSTAT, 2014) reported that the annual production figure for maize in Nigeria was in excess of 9 million metric tonnes. Based on the report, maize is the top most grown cereal in Nigeria followed by other cereals like rice, sorghum and millet. Maize grains are used for three main purposes: as a staple food, as feed for livestock and poultry, and as a raw material for many industrial products. Unripe cobs are consumed as vegetable or green maize, boiled or roasted (EAC, 2014).

The quality of the food grains we consume is important.Clean graded grains have potentials both at local and International markets for wider acceptability, improving standards and market value (Rohabach, 2004). The presence of variable grain sizes lower grain's value and market prices.Dahimiwal *et al.*, (2017) reported that there are possibilities of food grains adulteration by the traders butin this day and age, people arebecoming more educated and increasing in the demand for quality grains.Grain quality may have different meanings to different people and may depend onthe grain type and its end use. Since the requirements of seed processors, farmers, traders, millers and consumers are not necessarily compatible,quality standards are established to even the playing field. Most countries andregions have developed national/regional standards for their main grain crops. These have evolved to facilitate the movement of grain, providing both sellers and purchasers with guidelines to support financial transactions, and ensuring that quality meets up with end-use requirements (EAC, 2005). In the United State, maize is divided into three classes based on colour (Yellow corn, White corn, and Mixed corn), and each class is divided into five U.S. numerical grades and U.S. Sample Grade (USDA, 2013), while in the East African Community classification, maize is divided into three standard specifications, which are; Grade 1, Grade 2 or Grade 3 (EAC, 2014).

In most Nigerian towns and villages where maize is mostly grown by small and medium farmers who account for about 99 percent of the grains produced(Mgbenka *et al.*, 2015),grading still remains an unlikely operation. These farmers take their grains to the market in poorgrades and low quality standards.Grading standards are rarely employed in the markets and quality is assessed visually. Grain quality is influenced by the end-use and the price is determined more by locals rather than a national factor. The use of a grain grading machine would be important to the small and medium grain producers and small scale seed processors, as it will add value to their products and increase the market prices. The This research aimed at developing a grain grading machine and obtaining the optimum parameters suitable for good qualitygrades at appreciable throughput and less grain losses or wastes.Thiswork focuses on grain grades asabase for ensuringgrain standards.

II. Materials And Method

2.1 Construction of Grain Grading Machine

Theknowledge of grainsphysical propertiesis paramount in the design and construction of grading machines. Physical properties are important in the selection of suitable screens for grain grading operations. A grain grading machine was developed and tested in the metal and fabricating workshop of the Department of Agricultural and Bio-Environmental Engineering Technology, Nuhu Bamalli Polytechnic, Zaria, Kaduna State, Nigeria, based on detailed engineering design as expressed in Figure 1 and the determined physical properties of the grain.Figures 2(a. and b.) showsthe isometric sketches of the machine andFigures 3 depicts the photographic plates of the constructed machine.The materials used in constructing the major parts of the machine are described in Table 1. The main components of the machine consist of the frame, hopper, shaft, connecting rod, pulley, V-belt,screens, screencompartment, prime mover, and prime mover seat.

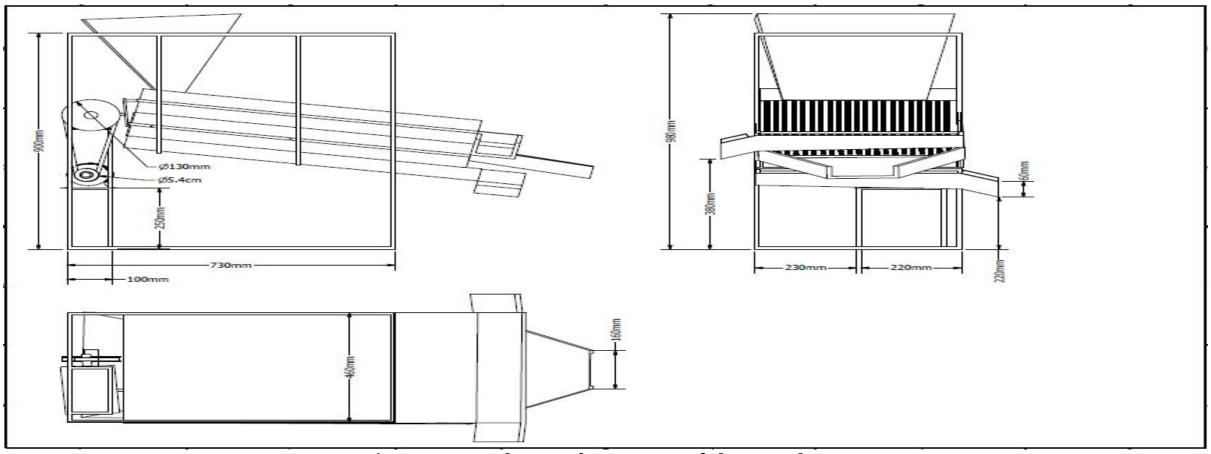


Figure 1: Orthographic View of the Machine

The machine components were designed as highlighted below.

i. **Frame:** The frame serves as the skeletal support and means of coupling or holding other component parts together. It was constructed using 25 × 25 × 3 mm angular bars. The frame dimensions are; 980 × 1000 × 460 mm for height, length and width, respectively.

ii. **Hopper:** The hopper is more of a frustum with the base bent at an angle of 30^0 to discharge and distribute the grains evenly over the first screen. It is designed to give continuous feeding of the grain mixture to the screen units.

iii. **Shaft diameter:**Shaft material of 25 mm diameter was selected from mild steel, based on bending and torsion moment analysis. The shaft diameter was determined using equation (1) as given by Khurmi and Guptar, (2007).

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

where:

d = Shaft diameter,

S_s = Allowable shear stress,
ρ = Density of mild steel,
M_b = Maximum bending moment,
M_t = Torsional moments, and
K_b and K_t = Combine shock and fatigue factors.

iv. Pulley diameter: Pulley of Ø130mm, mild steel was determined, using equation (2) as given by Khurmi and Gupta (2007).

$$\frac{d_1}{d_2} = \frac{N_2}{N_1} \quad \text{--} \quad (2)$$

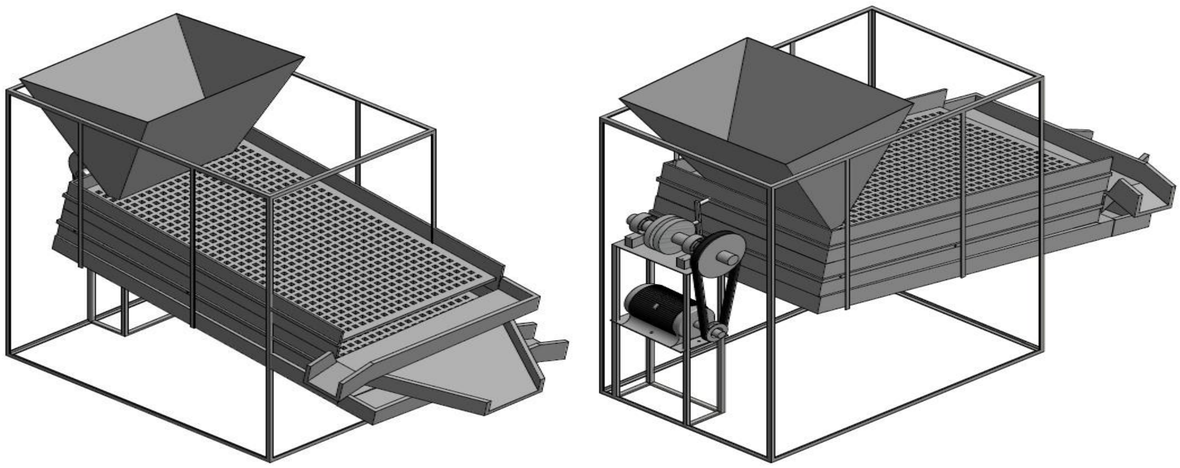
where:
N_1 = speed of driving pulley (rpm),
N_2 = speed of driven pulley (rpm),
d_1 = diameter of driving pulley (mm), and
d_2 = diameter of driven pulley (mm)

v. Length of belt: V-belt was used to transmit power from the power source to the drive mechanism. V-belt was selected based on design calculations and used. The length (L) of the belt used was obtained using equation (3) as given by Khurmi and Gupta (2007).

$$L = \frac{\pi}{2}(D + d) + 2c\,\frac{(D-d)^2}{4C} \quad \text{---} \quad (3)$$

where:
L = Length of belt,
C = Distance between the driving and driven pulleys,
D = Diameter of driven pulley,
d = diameter of driving pulley.

vi. Drive mechanism: A crank of 20mm was allowed by misaligning the main shaft, to facilitate the oscillation of the screen compartment.
vii. The selection of screens: Two round hole screens were selected from the market, based on the determined physical properties of the grains.



(a.) (b)

Figure 2(a. and b.): Isometric Views of the Grading Machine

Figure 3: Photographic views of machine after testing and validation

2.2 Physical properties of the sample grain

SAMAS 14 which is a dominant local variety of maize was sourced locally and used to test the performance of the machine in grading. The Principal dimensions of SAMAZ 14 (maize) were determined at 9.83% moisture content (db) with regards to selectingappropriate screens for the grading machine. The length, width, thickness and geometric mean diameter were obtained within the ranges of; 7.32 to 9.59, 5.64 to 8.19, 3.75 to 4.20, and 6.16 to 6.83 mm, respectively. Two round hole screens (8 and 6 mm), were selected and used as the first and second screens, respectively.

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	1	M.S
5	Pulley (130 diameter)		M.S
6	V-Belt	1	Leather
7	Screen compartment (3mm)	1	M.S – Sheet (Gauge 18)
8	Screens (2.0, 4.5 & 6.0 mm hole diameter)	3	M.S – Sheet (Gauge 18)
9	Wire strip (0.5 mm)	4	M.S – Sheet (Gauge 18)
10	Outlets	3	M.S – Sheet (Gauge 18)
11	Prime mover seat (25 × 25 × 5mm -Angle iron)	1	M.S - Angle iron
12	Prime mover (2.24 kW)	1	
Scale - 1:5			
All dimensions in mm			

2.3 Operation of the Machine

A batch of the grain is fed at a time into the hopper, to flow by gravity into the screen compartment of the machine. The grains flow down through the hopper outlet onto the upper screen and the oscillating motion of the screen chamber causessmall grains to pass through the screenwhile the oversized grains roll-over it, to an outlet chute. The two screens are pitched with the same orientation. The grains that passed through the upperscreen are controlled back to the top of the second screen via an inclined plane placed between the screens.The second screen further separates the grains by allowing smaller sized grains to pass through it,to the base (pan) of the compartment where they are collected through an outlet chute.Grains larger than the screen holes of the second screen, rolls over itand are collected at an outlet toward the lower end of the screen.Two wire strips,2mm, were place at intervals over each of the screens to obstruct the free flow of the grains over the screens and create room for the grains to spread over the screen holes for a better separation.The screencompartment is linked to a connecting rod which rotates via a crank provided on the main shaft.The rotary motion of the connecting rod around the crank, provides the horizontal oscillation of the compartment.

2.4 Design of Experiment

An experiment was conducted to determine the effects of some independent variables on the performance parameters of the machine. A three factor and four level experiment was designed in a layout and replicated three times to give 192 treatments. The factors consideredarethe Crank amplitude, feed rate and screen tilt angle and the four levels include;C_1 = 17mm, C_2 = 19mm,C_3 = 22mm and C_4 = 25mm, for the crank amplitude; F_1 = 400kg/hr., F_2 = 500kg/hr., F_3 = 600kg/hr. and F_4 = 700kg/hr., for feed rate; and $T_1 = 8^0$, $T_2 = 12^0$

T_3 = 15^0 and T_4= 18^0, for screen tilt angle. Two parameters, grading efficiency and grains scatter loss, were considered in evaluating the machine.The data wasanalyzed at 5% level of significance using the Statistical Analysis Software (SAS).

2.5 Test Procedure

i. Grading efficiency: The grading efficiency was obtained by manual re-sieving of the grains retained over the screen surfaces and the pan,using the same screen sizes. The efficiency was obtained using equation (4) as used by Yayock (2019).

$$\eta_g = \frac{G_o}{G_o + G_{cg}} 100 \text{ -- (4)}$$

where:

η_g =grading efficiency, %;

G_o = weight of grains retained over screen by manual sieving with same screen size (kg), and

G_{cg} = weight of grains that passed through screenby sieving manually (kg)

ii. Percentage of scatter loss: This refers to all the grains that got scattered around the machine during operation. The scatter loss was determined using equation (5) as given by Ndirika (1994).

$$S_c = \frac{Q_l}{Q_t} \text{ -- (5)}$$

Where:

S_c = percentage of scatter loss (%),

Q_l = quantity of grains scattered around the machine (kg), and

Q_t = quantity of grains fed into the machine (kg).

III. Result And Discussion

3.1 Effects of the Crank amplitude on Grading Efficiency

The effects of crank amplitude on grading efficiency of the machine is shown in Figures 4. The result showed that there is a significant differencein grading efficiency as a result of the variedcrank amplitudes. Grades A and B, which are the grains retained over the first and second screens, respectively, and grade C (grains collected at the base/pan) all displayed a positive linear correlation between grading efficiency and crank amplitude. The grading efficiency of grade A grains improved significantly from 91.41 to 96.83 % (5.93% increase) as crank amplitudewas varied between 17 and 25 mm. The efficiency of grade B grains, followed a similar pattern to that of grade A, as the crank amplitude was varied. The efficiency of grade B increased from 89.95 to 95.32 % (5.97 % increase). The grading efficiency for grade C grains also increased with increase in the crank amplitude. The coefficient of determination (R^2) for the relationship are; 0.9908, 0.8871, and 0.8822, for grades A, B, and C, respectively.The grading efficiencies of the three grades all increased with increase in the stroke lengths of oscillation. Salwa *et al.*, (2010), reported a similar trend. They reported that the separation efficiency of a grading machinewill improve significantly, eitherinnvertical and lateral motion and at all screen slopes,whenthe stroke length of oscillation is increased.The result in Figure 4, showed that the best grading efficiency was produced by the 25mm crank amplitudefor all grades.

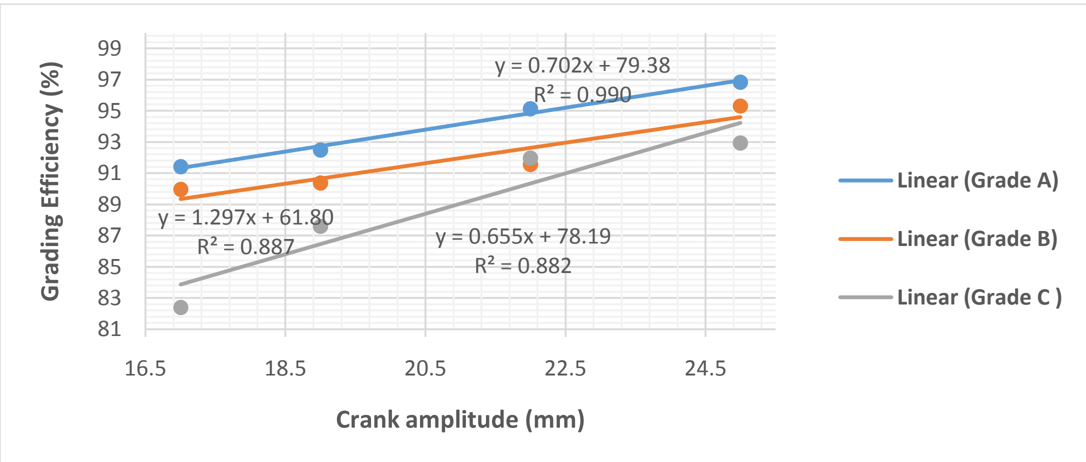


Figure 4: Effects of the crank amplitude on grading efficiency

The purpose of screen motion is to; spread the material over the surface of the screen, cause the fine particles to settle at the sub-surface, and discharge the over-sized particles. Fast shaking, however, can cause the grains to turn, tumble and not properly sieved. Also, at low crank amplitude levels, lower sieve tilt angle and higher feed values, more clogging occurs over the screen holes permitting a greater fractions of immature, broken and poor seeds to go through with the main grains/ seeds without passing through the sieve perforations.

3.2 Effects of Feed Rate on Grading Efficiency

Figures 5.0 shows the effects of feed rate on the grading performance of the machine. The grading efficiencies of grades A and B showed a little improvement from the initial feed value of 400 kg/hr. to a peak value at 500 kg/hr. but decreased afterward with increase in feed rate. The grading efficiency of grade C however, decreased with increasing feed rates from the initial value to the highest test rate of 700kg/hr. The characteristic decrease in grading efficiency with increasing feed rates may be due to increasing load intensity on the screen.Salwa *et al.*, (2010) reported that high feed rates create a thick layer of the material on the screen, which causes a considerable deterioration of the conditions requiredto penetrate through the sieve perforations. Simonyan *et al.* (2006), Salwa*et al.*, (2010), Muhammad *et al.* (2013) and Yayock (2016) all reported that efficiency decreases with increasing feed rates. Therefore, at higher feed rates the grading performance of grading machines often results to poor graded grains. The best efficiency was however, observed at500 kg/hr. feed rate,forboth A and B grades.

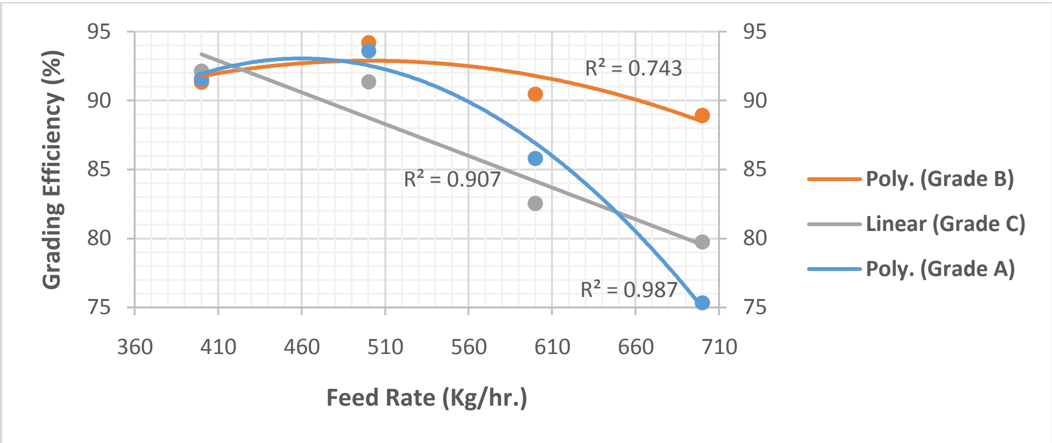


Figure 5: Effects of Feed Rate on Grading Efficiency

The relationship between the feed rate and grading efficiency produced a polynomial relationship for grades A and B grains, and a negative linear relationship with grade C. The equations and coefficients of determination (R^2) for relationships are; $y = -0.0004x^2 + 0.3529x + 7.3405$ and 0.9871, for grade A; $y = -0.0001x^2 + 0.1106x + 65.181$ and 0.7431, for grade B; and $y = -0.046x + 111.73$ and 0.9072, for grade C.

3.3 Effects of Screen Tilt Angle on Grading Efficiency

The relationship between screen tilt angle and grains grading efficiency is expressed in Figure 6. The behavior of grade A grains with screen tilt anglefollowed a polynomial pattern. A similar trend is shown by grade C grains, where the grading efficiency increased from the lowest tilt angle of 8^0 to a peak value at 12^0 before decreasing with further increase in screen tilt angle. The relationships took a negative linear form with grade C.The coefficient of determination (R^2) for the three grades, A, B, and C are 0.7807, 0.7026, and 0.9050, respectively.

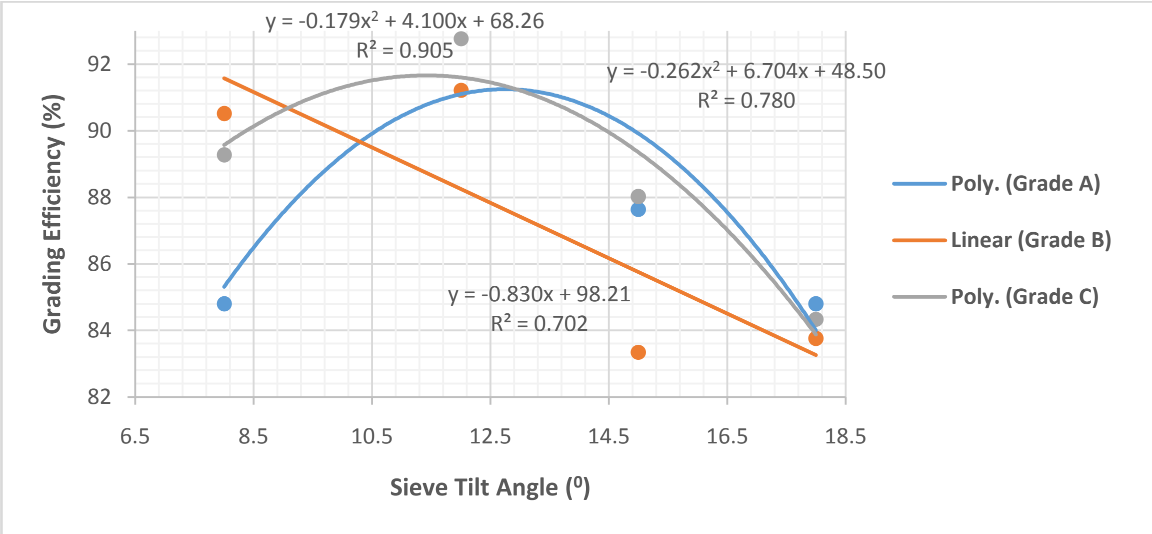


Figure 6: Effects of screen tilt angle on grading efficiency

Hanna *et al.* (2010) stated that the optimum slope of an inclined vibration screen is that which handles the greatest volume of oversize and still remove the available undersize required by the standards of particular operation. High capacity grain separators may have a greater adjustable pitch to move grains rapidly over the screen, but in precision seed graders and cleaners, 4-12^0 pitch gives adequate cleaning and grading capacity (Sahay and Singh, 2008). The best grading efficiency was obtained at 12^{0}screen tilt angle, for the grades.

3.4 Scatter Loss

The effect of the independent variables on the machines scatter loss is expressed in Figure 7.0. The result shows that grain scattered around the machine increased with increase in the value of the independent variable (crank amplitude, feed rate, and screen tilt angle). The variables all showed a positive linear relationship with the machine scatter loss.

Ebaid (2005) reported that total losses increased with increase inscreen tilt angle and oscillation for cleaning and grading operations. Muhammad *et al.* (2013), reported a polynomial relationship between machine scatter loss and feed rate in cleaning three crops (sorghum, soybeans and millet).

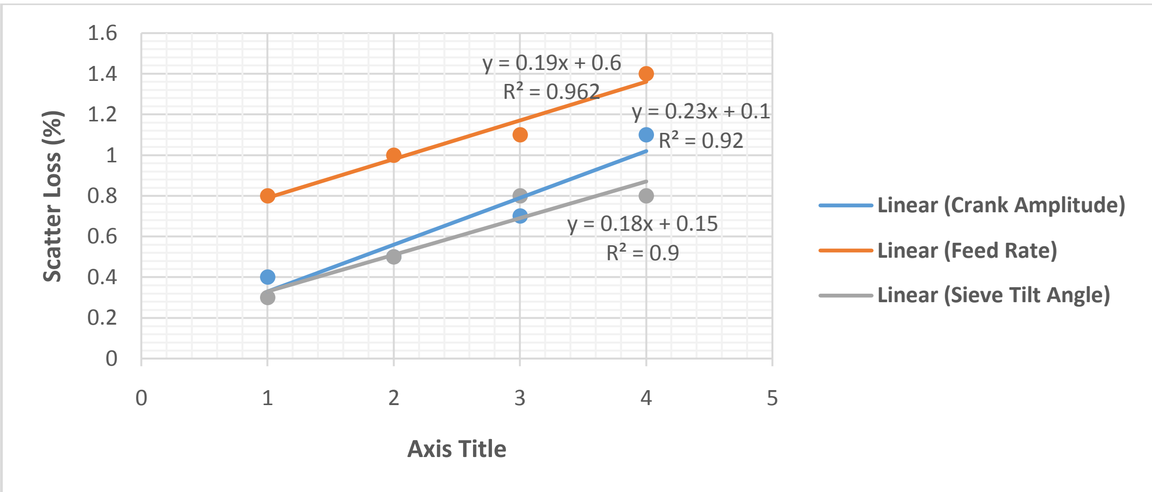


Table 7.0: Effect of crank amplitude, feed rate, andscreen tilt angle on Machine Scatter Loss

IV. Conclusion

A prototype grain grading machine was constructed and evaluated. The machine was successfully used to grade maize (SAMAZ 14) grains into threedifferent grades (grades A, B and C). It can alsobe used to grade other grains of different sizes and shapes by replacing the screens with suitable ones. The best grading efficiencies of 96.83, 95.32, and 92.93 % were obtained for grade A, grade B, and grade C,at crank amplitudeof

25 mm,feed rate of 500 kg/hr., and screen tilt angle of 12^0. The percentage of grain scattering around the machine ranged between 0.3370 and 0.4074 %.

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