



OPTIMIZATION OF PERFORMANCE PARAMETERS FOR A MAIZE SHELLING MACHINE

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Abstract

Many farmers in developing countries could not afford the cost of acquiring some of the imported shelling machines making them resorted to the manual methods of maize shelling. These had resulted in low efficiency and high wastage. This research work focused on optimizing the performance parameters for a maize shelling machine. The machine was evaluated using four moisture content levels, feed rates and air velocities. According to the results, the threshing efficiency of the machine ranges from 81.65% to 99.6% with minimal grain damage of 2.56%. The cleaning efficiency of the machine ranges from 52.75% to 96.6% while the threshing capacity ranges from 9 kg/h to 51.46 kg/h. The machine operates smoothly and efficiently when in operation at the different machine speeds. The shelled grains flow freely through the grain outlet, the chaffs were blown off in opposite direction by the blower while the cobs were discharged easily through the cob outlet.

Keywords: Feeding rate, moisture content, threshing efficiency, cleaning efficiency, threshing capacity

Introduction

Maize (*Zea mays*) is one of the most important cereal crops in the world agricultural. Maize is a cereal crop that is grown widely throughout the world in a range of agro-ecological environments. About 50 species exist and consist of different colours, textures and grain shapes and sizes (Bako and Bature, 2017). The white and yellow varieties are preferred by most people depending on the region (Susan, 2004). Maize was introduced into Africa in the 1500s and has since become one of Africa's dominant food crops. Like many other regions, maize is consumed as a vegetable although it is a grain crop. The grains are rich in vitamins A, C and E, carbohydrates, and essential minerals, and contain 9% protein (Gibson and Benson, 2002). Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled which play an important role in filling the huge gap after dry season. In rural communities, the dwellers use maize in production of porridge (*fura*) and *tuwo* (Gibson and Benson, 2002).

Shelling is the process of removing seed or grain from their respective cobs for both human and industrial use (Nwakaire *et al.*, 2011). This separation, done by hand or machine, is obtained by threshing, by friction or by shaking the products. The difficulty of the process depends on the varieties grown, and on the moisture content as well as the degree of maturity of the grain.

Maize shelling operation can be carried out in the field or at the storage environment (Mali *et al.*, 2015).

Maize shelling a post-harvest operation is the removal of maize seeds from the cob. This operation can be carried out in the field or at the storage environment. Maize shelling therefore is an important step towards the processing of maize to its various finished products like flour (Azeez *et al.*, 2017). The different methods of maize shelling can be categorized based on various mechanization technology used. These includes: hand-tool technology, and engine power technology. Maize production in Nigeria is of great importance with the increase in population and use of maize grain, the market demand for maize grain also increased. However, maize shelling in developing and under-developed nations has been and remains a serious problem to its processing as it is tedious and often require considerable labour hours (Ali *et al.*, 1996; Aremu *et al.*, 2015). According to Okure and Ssekanyo (2017), the traditional method of maize dehusking was done manually with hand and shelling was by beating the dehusked cob of maize with sticks.

Engine powered technology is the most adopted method of shelling. This method can be powered using electric motor, petrol engine or tractor driven. The use of motorized shellers or sheller operated by tractor

power has become very common for threshing of maize (Akor *et al.*, 2004). In describing operations of threshing or shelling with motorized equipment, the principal reference will be to motorized threshing-machines. Although they are gradually being replaced by combine harvesters, these machines still have an important place in the post-harvest production process, especially for their convertibility (Al Sharifi *et al.*, 2019). Shelled maize grains are important because they are consumed worldwide and are used for different purposes in different industries that's why its shelling is considered to be crucial (Sedara *et al.*, 2020). When maize seeds are removed from cob this is referred to as shelling and it's a postharvest process. It's performed on the farm or processing facilities (Nwakaire *et al.*, 2011). Equipped with a rotating threshing-drum (with beaters or teeth) and a stationary counter-thresher, these machines often have devices to shake out the straw and to clean and bag the grain (Bako and Bature, 2017; Ugwu and Omoruyi 2016). Whether self-propelled or tractor-drawn, these threshers are often mounted on rubber tyre wheels for easy movement to the field. The use of motorized threshers may require two or three workers. Yields depend on the type of machine, the nature and maturity of the grain, the skill of the workers and organization of the work, and they can vary from 100 to 5 000 kg/h (Hassan *et al.*, 2009). Ojomo and Alemu, (2012) reported that most of locally fabricated maize sheller/thresher have low efficiency due to limited knowledge on how to optimize parameters for improve performance. Different designs for maize shelling still the operational conditions still need to be optimized. Nsubuga *et al.* (2020) worked on optimizing the maize shelling operation of a multipurpose maize threshing machine. It was reported that the optimum performance of the machine was achieved at the maize moisture content of 13% and machine speed 896 rpm.

Materials and Methods

The speed of the machine (the motor and the driven pulley) was measured using a digital tachometer, stopwatch was used to measure time taken to run the machine during performance test and digital weighing balance was used to measure mass of maize. Moisture content was determined using gravimetric method, samples at all levels of moisture contents were randomly assigned to the sequence of test runs. Each test at a particular moisture content was replicated four times. The four different levels are; speed (400, 600, 800, and 1000 rpm), moisture content (10, 14, 16 and 18 %), air velocity (3, 4, 5 and 6 m/s) and the feed rate (300, 400, 500 and 600 g/s).

Description of the Sheller

The components of the shelling machine include the machine frame, engine seat (vibration damper), hopper, shelling drum housing, shelling shaft pulley, fan shaft pulley, shelling shaft, beater, blower, sieve (bottom concave), bearing, cob outlet and maize

outlet. The machine frame holds every other components of the machine together and the hopper serves as medium of passage of the maize to the shelling drum as designed by Soyoye and Tehinse, (2020).

The machine developed by Soyoye and Tehinse, (2020) (Figure 1) was operated by powering the prime mover (Electric motor). Motion of the electric motor provides an angular velocity that is translated to the driving pulley. The power from the driving pulley is transmitted to the driven pulley that is fixed on the primary shaft which is supported by pillow bearing on both ends. Hence the resultant velocity of the driven shaft generates the required power at the shelling drum. This power provides rotary motion of the beater which pulls and shells the maize cobs by friction and shearing action against the confining walls. This secondary shaft transmits rotary motion to the fan blades. The fan blades blow away the impurities. The empty cobs pass out through the cob's outlet opening and are thrown out by the force of rotation of the beater, and clean grains pass through the screen to the grain outlet.



Figure 1: The fabricated maize sheller (Soyoye and Tehinse, 2020)

Performance Evaluation of Maize Shelling Machine

The evaluation of the machine was carried out by determining the effect of the machine speed, air velocity, feed rate and moisture content levels on the

shelling capacity, shelling efficiency and cleaning efficiency. A known quantity (5, 19, 15 and 20 kg) of maize is pour into the maize thresher, the threshing time, the output quantity and quality are noted and recorded at four moisture content levels, feed rates and air velocities. The threshing and cleaning efficiencies and the threshing capacity were calculated using Equations 1, 2 and 3 (Hassan *et al.*, 2009). The results obtained were analyzed using Design Expert and Analysis of Variance (ANOVA).

$$\text{Shelling Capacity} = \frac{\text{Mass of shelled grains(kg)}}{\text{Time taken (h)}} \quad (1)$$

$$\text{Shelling Efficiency} = \frac{\text{Mass of shelled grains(kg)}}{\text{Total mass of grains (shelled + unshelled)}} \times 100\% \quad (2)$$

$$\text{Cleaning Efficiency} = \frac{T_{m-out} - R_{m-out}}{T_{m-out}} \times 100\% \quad (3)$$

where; T_{m-out} is the total grain received at the main outlet (kg) and R_{m-out} is the refraction at the main outlet (kg) (Hassan *et al.*, 2009).

Results and Discussion

Threshing Efficiency

Figures 2 and 3 show the graphical representation (contour and 3d Surface plot) of threshing efficiency of the developed maize thresher at different machine speed, air velocity, feed rate and moisture content. According to the Figures, the threshing efficiency of the machine ranges from 81.65 % to 99.6 %. It was revealed that the following parameters affect the threshing efficiency; the feed rate, moisture content, machine speed and air velocity. The feed rate can increase or decrease threshing efficiency because a unit increase in the feed rate resulted in an average increase in the throughput of the maize thresher by 0.0002 %. Also moisture content affects threshing efficiency, a unit increase in the moisture content resulted in an average increase in the threshing efficiency of the maize thresher by 0.0083 %. When the material is too dry it increases breakage which decreases the efficiency but when the material is a bit wet the breakage was reduced since the tensile stress of a maize increases when moisture is added, meanwhile when the water is too much it lead to grain breakage therefore moisture content for threshing maize should be at an acceptable percentage. Also, the machine speed affects the threshing efficiency, the speed is expected to

increase efficiency if the impact force does not exceed the design limit or the breaking point of the material and this improves the performance and production. Meanwhile, when the speed is too much it leads to breaking of the materials which leads to an average decrease in the threshing efficiency of the maize thresher by 0.0055%. The air velocity affects the efficiency of the machine, a unit increase in the air velocity resulted in 1.0333 % decrease in threshing efficiency, the air velocity affects mainly the Cleaning efficiency. This is because the air velocity must not be more than the terminal velocity of the threshed grains.

The mathematical relationship between the threshing efficiency and the input parameters (machine speed, air velocity, feed rate and moisture content) is shown in Equation 4 with a coefficient of determination (R^2) 0.5413 and this shows that the equation can significantly ($P < 0.05$) predict about 54.13% change in the threshing efficiency as a function of machine speed, air velocity, feed rate and moisture content

$$TE = 104.6734 - 0.0055S - 1.0333V + 0.0002F + 0.0083Mc \quad (4)$$

where; TE is the threshing efficiency, S is machine speed (rpm), V is air velocity (m/s), F is feed rate (g/s) and Mc is moisture content (%).

This result has a similar trend with that reported by Hassan *et al.* (2009); Soyoye and Tehinse (2020) when they evaluated the performance of maize shelling machine and reported that the efficiency of the machine reduces at increased machine speed. The machine speed when increased about a certain point leads to reduced performance as the maize either breaks or forced out of the threshing chamber without efficient chaff removal. The threshing efficiency of their machine was 89.3% which is relatively closer to the recorded 81.65 % to 99.6 %. The optimum threshing efficiency was achieved at machine speed of 300 rpm and the efficiency reduces at any machine speed above or below the optimum speed (Figure 2). Table 1 shows the result of the analysis of variance (ANOVA) of the threshing efficiency. Based on the table, the combination of machine speed, air velocity, feed rate and moisture content cannot significantly explain the variation in the threshing efficiency at 95% probability level. However, the change in the threshing efficiency significantly ($P < 0.05$) depends on the machine speed followed by the machine speed (Table 1), by air velocity, moisture content and feed rate has the least significant effect on the threshing efficiency of the maize thresher.

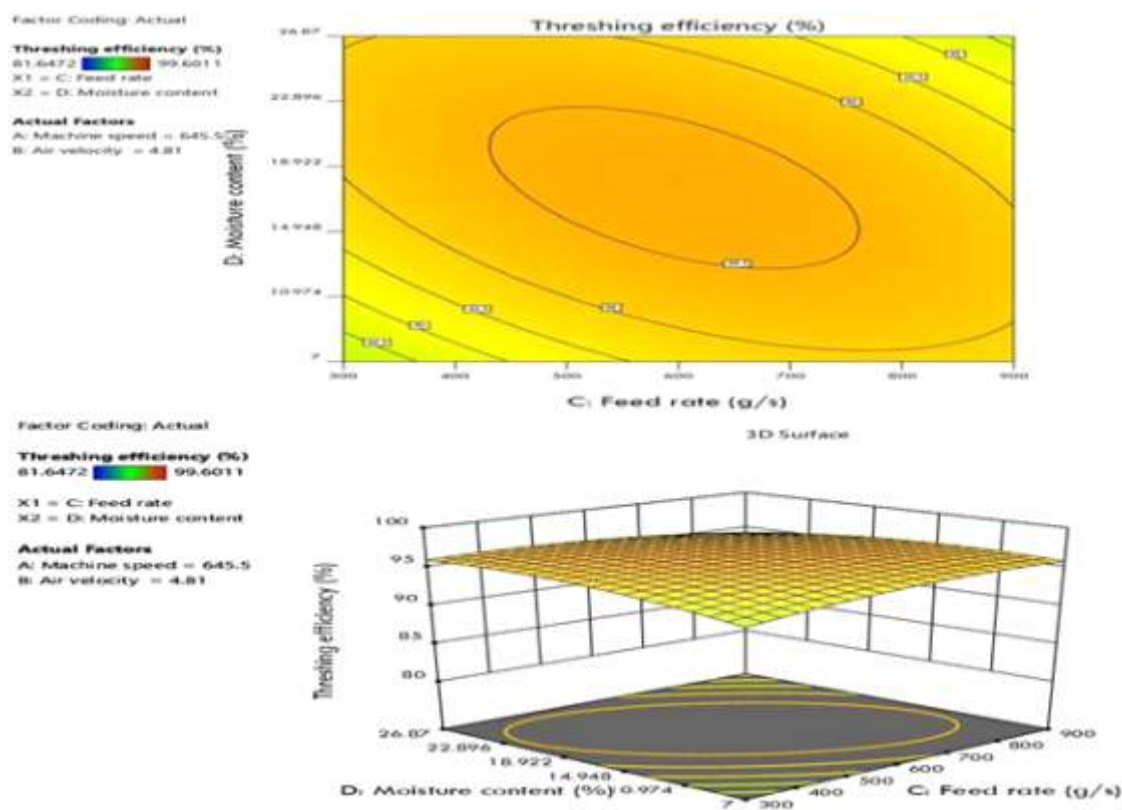


Figure 2: Effect machine speed and air velocity on the threshing efficiency

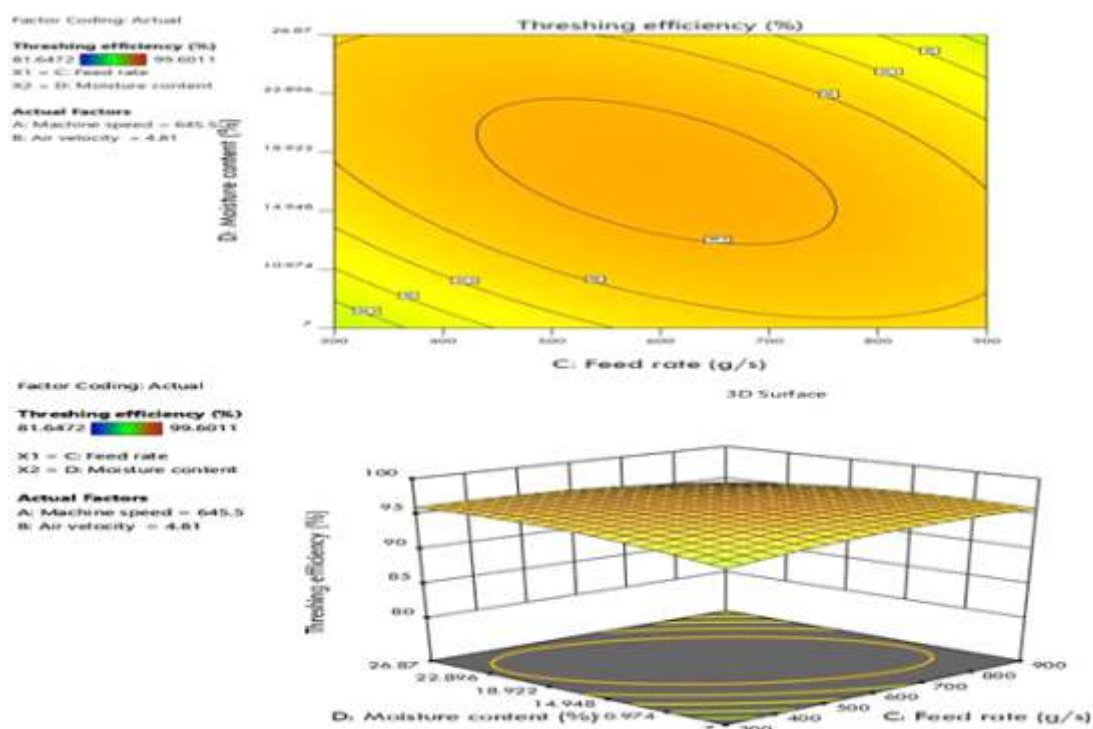


Figure 3: Effect moisture content and feed rate on the threshing efficiency

Table 1: Analysis of Variance (ANOVA) for the Threshing Efficiency of the Maize Sheller

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob > F)	Remark
Model	178.784	14	12.770	1.012	0.498	Not Significant
A-Machine speed	53.685	1	53.685	4.252	0.062	
B-Air velocity	30.591	1	30.591	2.423	0.146	
C-Feed rate	0.027	1	0.027	0.002	0.964	
D-Moisture content	0.232	1	0.232	0.018	0.895	
AB	19.400	1	19.400	1.537	0.239	
AC	5.042	1	5.042	0.399	0.539	
AD	18.848	1	18.848	1.493	0.245	
BC	0.001	1	0.001	0.000	0.994	
BD	30.948	1	30.948	2.451	0.143	
CD	11.472	1	11.472	0.909	0.359	
..	0.035	1	0.035	0.003	0.959	
BÂ²	3.598	1	3.598	0.285	0.603	
CÂ²	1.388	1	1.388	0.110	0.746	
DÂ²	1.946	1	1.946	0.154	0.702	
Residual	151.494	12	12.625			Significant
Lack of Fit	150.395	10	15.040	27.370	0.036	
Pure Error	1.099	2	0.549			
Cor Total	330.278	26				

Cleaning Efficiency

Figures 4 and 5 show the graphical representation (contour and 3d Surface plot) of cleaning efficiency of the maize thresher at different machine speed, air velocity, feed rate and moisture content. According to the figures, the cleaning efficiency of the machine ranges from 52.75% to 96.6%.

The feed rate, machine speed, moisture content do not have much effect on the cleaning efficiency, it is mainly affected by the air velocity. If the air velocity is too high [greater than terminal velocity of maize (13.29%)], instead of blowing away the chaff from the grain it will blow both the grain and the chaff, this reduces the cleaning efficiency. When the air velocity is reduced, it might take a slower movement before it could pack the chaff which makes chaff drooping with the threshed grain, such a situation will reduce the cleaning efficiency by 1.5192 %. Same is applicable with moisture content, when the moisture content is high the chaff and the grains can be sticky, therefore at high moisture content, due to the stickiness it will reduce the cleaning efficiency by 0.4594 %. A unit increase in the feed rate resulted in an average increase in the cleaning efficiency of the maize thresher by 0.0085 %, whereas a unit increase in the machine speed, air velocity resulted in an average decrease in the cleaning efficiency of the maize thresher by 0.0039 %.

The mathematical relationship between the cleaning efficiency and the input parameters (machine speed, air velocity, feed rate and moisture content) is shown in Equation 5 with a coefficient of determination (R^2)

0.5413 and this shows that the equation can significantly ($P < 0.05$) predict about 54.13% change in the cleaning efficiency as a function of machine speed, air velocity, feed rate and moisture content.

$$CE = 84.7491 - 0.0039S - 1.5192V + 0.0085F + 0.4594Mc \quad (5)$$

where; CE is the cleaning efficiency, S is machine speed (rpm), V is air velocity (m/s), F is feed rate (g/s) and Mc is moisture content (%).

This result has a similar trend with that reported by Bako and Bature, (2017); Sedara *et al.* (2020) when they evaluated the performance of the maize shelling machine where they also reported that the cleaning efficiency of the machine reduces at increased air velocity. The threshing efficiency of the machine ranges from 52.75 % to 96.6 %. The machine speed for this research was 300 rpm at which the optimum threshing efficiency was achieved and furthermore above this speed, the efficiency reduces (Figure 4).

Table 2 shows the result of the analysis of variance (ANOVA) of the cleaning efficiency. Based on the table, the combination of machine speed, air velocity, feed rate and moisture content cannot significantly explain the variation in the cleaning efficiency at 95% probability level. However, the change in the cleaning efficiency significantly ($P < 0.05$) depends on the machine speed followed by air velocity. Moisture content and feed rate has the least significant effect on the cleaning efficiency of the maize thresher.

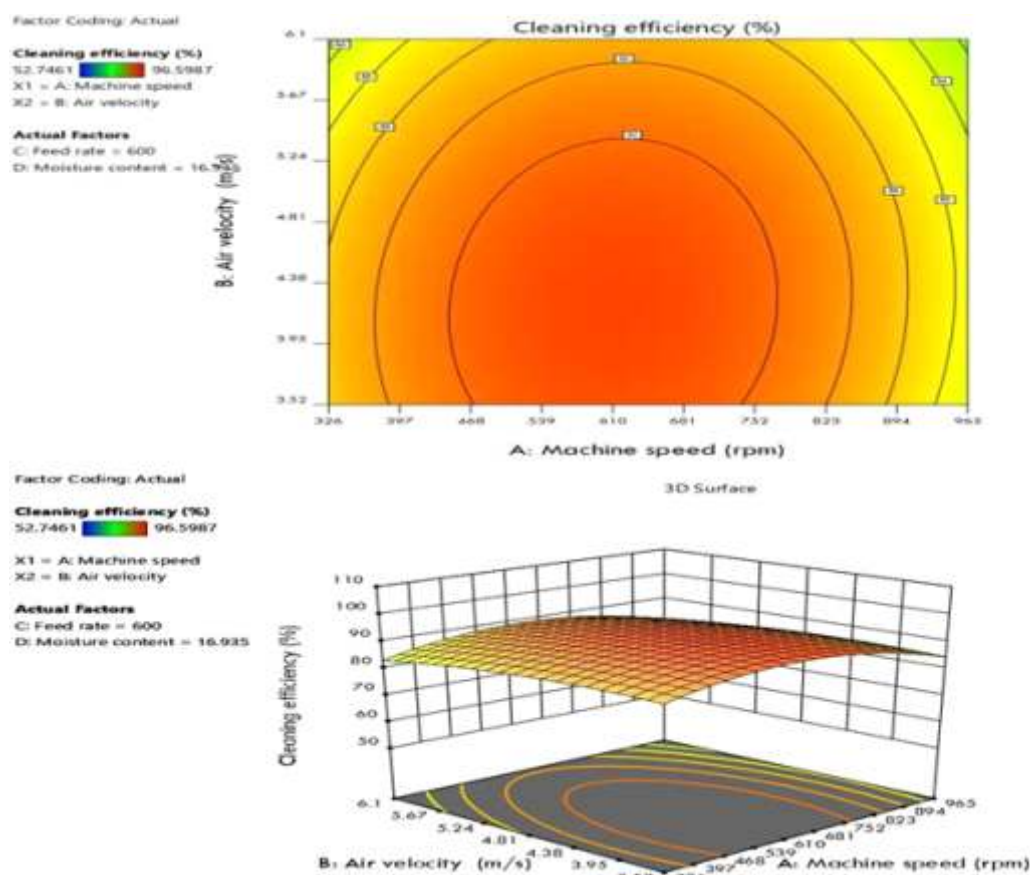


Figure 4: Effect machine speed and air velocity on the cleaning efficiency

Table 2: Analysis of Variance (ANOVA) for the Cleaning Efficiency of the Maize sheller

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob >F)	Remark
Model	1383.239	14	98.803	1.397	0.284	Not Significant
A-Machine speed	29.374	1	29.374	0.415	0.531	
B-Air velocity	66.955	1	66.955	0.947	0.350	
C-Feed rate	115.836	1	115.836	1.638	0.225	
D-Moisture content	430.401	1	430.401	6.085	0.030	
AB	3.506	1	3.506	0.050	0.828	
AC	4.402	1	4.402	0.062	0.807	
AD	48.004	1	48.004	0.679	0.426	
BC	326.666	1	326.666	4.619	0.053	
BD	34.744	1	34.744	0.491	0.497	
CD	0.018	1	0.018	0.000	0.987	significant
Residual	120.367	1	120.367	1.702	0.217	
B ²	11.640	1	11.640	0.165	0.692	
C ²	0.004	1	0.004	0.000	0.994	
D ²	1.189	1	1.189	0.017	0.899	
Lack of Fit	848.748	12	70.729			
Pure Error	842.664	10	84.266	27.702	0.035	
Cor Total	6.084	2	3.042			
	2231.987	26				

Threshing Capacity

Figures 6 and 7 show the graphical representation (contour and 3d Surface plot) of threshing capacity of the developed maize thresher at different machine speed, air velocity, feed rate and moisture content. According to the figures, the threshing capacity ranges from 9 kg/h to 51.46 kg/h. The moisture content, air velocity, machine speed affect the threshing capacity, but the feed rate is a key factor that affects the threshing capacity. When the rate at which input increases (so far the limit of the machine is not exceeded), more products will be obtained so therefore the capacity will be improved by 1.0238 %. A unit increase in the machine speed, air velocity and moisture content resulted in an average increase in the threshing capacity of the maize thresher by 0.0137 %, 0.0138 %, 0.0941 %, respectively.

The mathematical relationship between the threshing capacity and the input parameters is shown in Equation 6 with a coefficient of determination (R^2) 0.7548 and this shows that the equation can significantly ($P < 0.05$) predict about 75.48% change in the threshing capacity as a function of machine speed, air velocity, feed rate and moisture content.

$$TC = 8.5574 + 0.0137S + 1.0238V + 0.0138F + 0.0941Mc \quad (5)$$

where; TC is the threshing capacity, S is machine speed (rpm), V is air velocity (m/s), F is feed rate (g/s) and Mc is moisture content (%).

This result has a similar trend with that reported by Bako and Bature, (2017); Soyoye and Tehinse, (2020) when they evaluated the performance of the maize shelling machine where they also reported that the threshing capacity of the machine reduces at increased feed rate. The feed rate when increased about a certain point leads to reduced performance as the capacity exceeds the designed capacity. The threshing capacity of the machine ranges from 9 kg/h to 51.46 kg/h. The machine speed for this research was 300 rpm, the optimum threshing efficiency was achieved and furthermore above this speed, the efficiency reduces (Figure 6).

Table 3 shows the result of the analysis of variance (ANOVA) of the threshing capacity. Based on the table, the combination of machine speed, air velocity, feed rate and moisture content can significantly explain the variation in the threshing capacity at 95% probability level. However, the change in the threshing capacity significantly ($P < 0.05$) depends on the machine speed followed by the machine speed and then by feed rate, air velocity and moisture content has the least significant effect on the threshing capacity of the maize thresher.

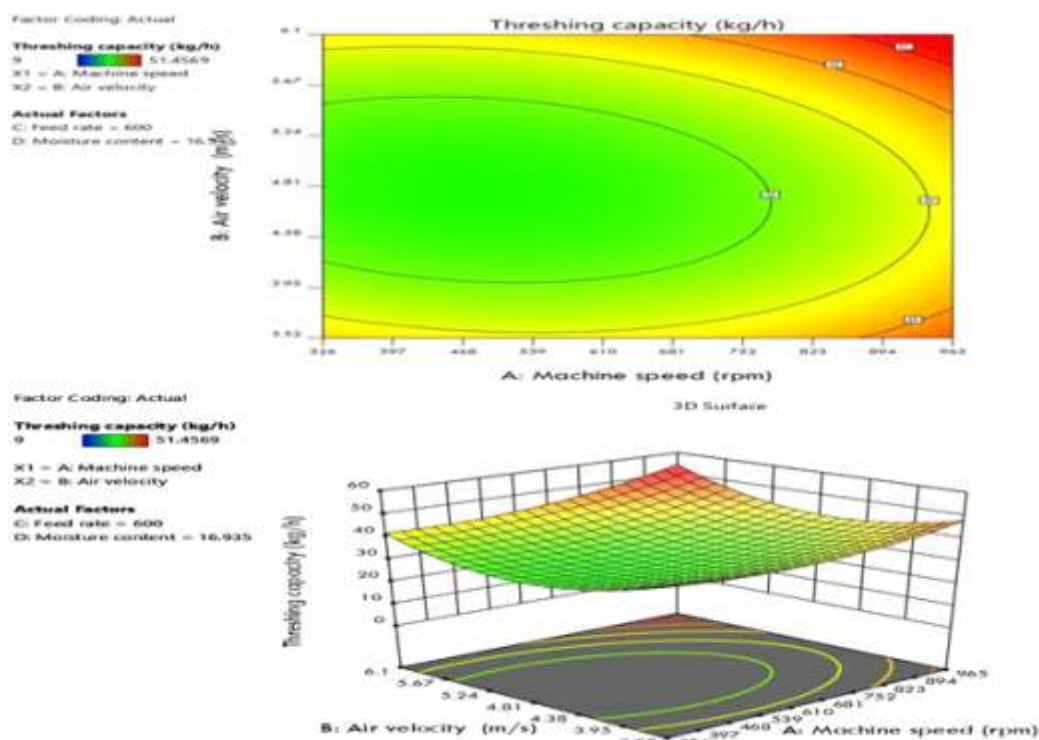


Figure 6: Effect machine speed and air velocity on the threshing capacity

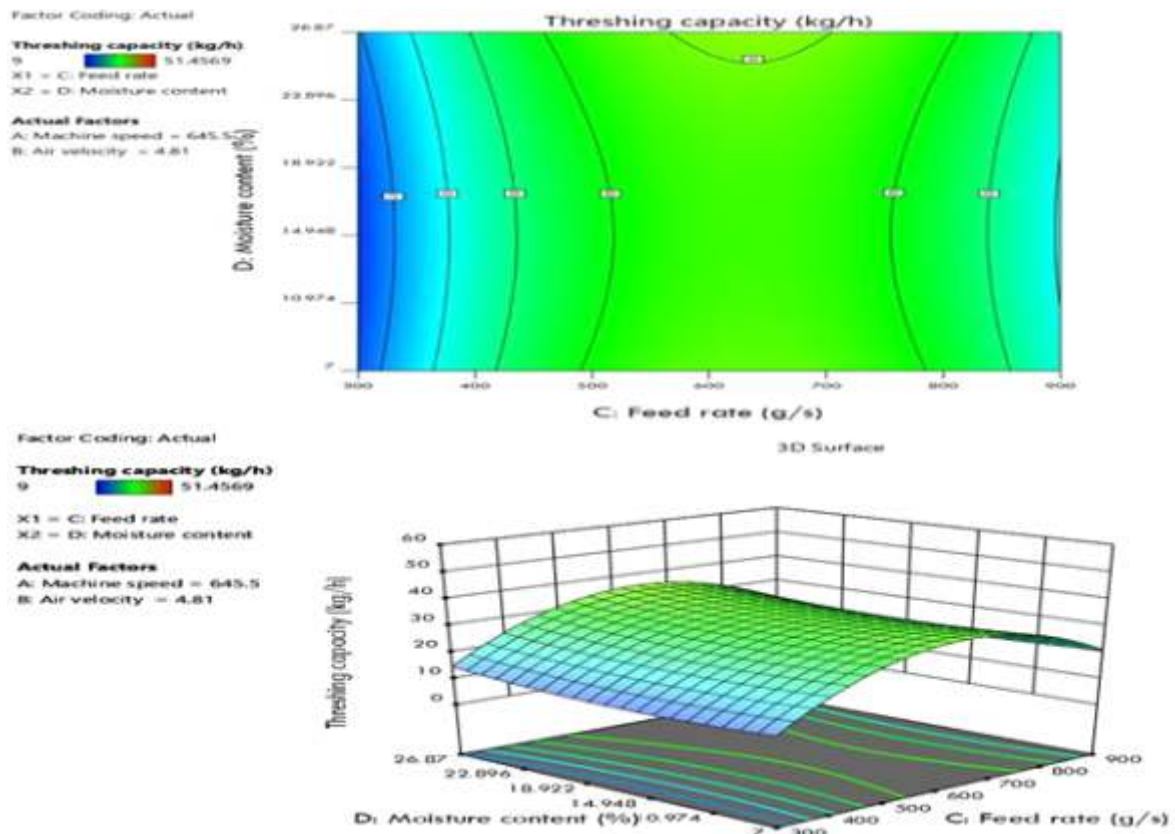


Figure 7: Effect moisture content and feed rate on the threshing capacity

Table 3: Analysis of variance (ANOVA) for the Threshing Capacity of the White Maize

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob >F)	Remark
Model	1800.408	14	128.601	2.638	0.050	Significant
A-Machine speed	352.562	1	352.562	7.233	0.020	
B-Air velocity	33.936	1	33.936	0.696	0.420	
C-Feed rate	308.844	1	308.844	6.336	0.027	
D-Moisture content	14.985	1	14.985	0.307	0.589	
AB	54.903	1	54.903	1.126	0.309	
AC	0.533	1	0.533	0.011	0.918	
AD	118.555	1	118.555	2.432	0.145	
BC	0.005	1	0.005	0.000	0.992	
BD	102.747	1	102.747	2.108	0.172	
CD	0.168	1	0.168	0.003	0.954	
..	46.770	1	46.770	0.960	0.347	
B ²	255.623	1	255.623	5.244	0.041	
C ²	741.859	1	741.859	15.220	0.002	
D ²	12.432	1	12.432	0.255	0.623	
Residual	584.900	12	48.742			Significant
Lack of Fit	582.889	10	58.289	57.968	0.017	
Pure Error	2.011	2	1.006			
Cor Total	2385.308	26				

Conclusion

A simple, efficient, less tedious machine for shelling maize has been evaluated. The efficiency of the maize shelling machine was evaluated as a function of the following parameters at four different levels; speed (400, 600, 800, and 1000 rpm), moisture content (10, 14, 16 and 18 %), air velocity (3, 4, 5 and 6 m/s) and the feed rate (300, 400, 500 and 600 g/s). According to the results, the threshing efficiency of the machine ranges from 81.65 % to 99.6 % with a minimal grain damage of 2.56%. It was also concluded that, the cleaning efficiency of the maize thresher ranges from 52.75 % to 96.6 %. The threshing capacity of the machine ranges from 9 kg/h to 51.46 kg/h.

The machine operates smoothly and efficiently when in operation. The shelled grains flow freely through the grain outlet, the chaffs were blown off in opposite direction by the blower while the cobs were discharged easily through the cob outlet. The threshing machine is less bulky and the user friendly considerations in the design would allow for its comfortable use in a standing posture of the operator.

The machine can help to significantly reduce the human labour and stress involved in shelling maize at an affordable cost and also reduces the time used for shelling operation. There is no doubt that the machine will ease the long-term problem of maize shelling especially for the rural farmers.

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