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DESIGN AND EFFICACY WITH RESPECT TO MOISTURE CONTENT OF A MAIZE-SHELLING MACHINE

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ABSTRACT

The manual shelling of seed grains from maize cobs is a tedious and time-consuming task. Thus, this study was aimed at developing a cost-effective, easy-to-use maze-shelling machine that also separates the cob from the grains after shelling. The design of the maize sheller was aided by AutoCAD and CAM model software, and construction was done at the Federal Ministry of Labour, Onireke Ibadan.The experiment set-up was a Completely Randomized Design (CRD). Data collected were subjected to descriptive statistics and analysis of variance. The least significant difference (LSD) was used for the posthoc test. Performance test of the machine was achievedfor maize moisture content (MC %db) g/m^3 at the Crop Production Technology Department, Federal College of Forestry, Jericho,Ibadan. The performance evaluation of the maize huller showed that the mass of wholly shelled maize grains (W5) (0.190 ± 0.016 g) wasgreater than the damaged grains (0.0063 ± 0.004 g), while the machine shelling capacity and efficiency at 10, 15, and 20% MC_{db} are 315, 298 and 264 kg/hr and 99.02, 94.50 and 88.20%respectively. In addition, the grain breakage percentages were calculated to be 1.77, 3.64, and 5.02 % for 10, 15, and 20% MC_{db}. Machine efficiency and capacity were significantly different at the moisture content (Fpr = 0.05) and performed best at 10% MC_{db}. It was therefore concluded that; the moisture contents of maize samples influenced the efficacy of the maize shelling machine. Thus, the machine is best suitable for maize dried to 10% MC_{db}.

Keywords: *Zea-mays*, shelled grains, shelling machine, moisture content, shelling capacity

Introduction

The word Cereal is derived from the Latin word 'cerealis' meaning 'grain'which is botanically a type of crop referred to as caryopsis, consisting of the endosperm, bran, and germ (Sarwar*et al*., 2013).The grains are annually common grass cereal, including the Poaceae(a monocot family Poaceae, also known as Gramineae), which usually possess a lengthy, thin stem, namely wheat, maize, rice, millet, barley, sorghum and rye, of which the starchy grains are used as food and are harvested for the consumption of animal and personage (Babatunde and Emeka-Oha 2015). Grain crops are plants grown for their high edible starch and protein content. They are-regarded as the most important agricultural products stored by farmers in both tropical and sub-tropical fields (FAO, 1992). Maize (*Zea mays* L.) is among mostly grown seed crops worldwide. It isconsumed directly or indirectly by millions around the globe; however,maize is consumed as a very important staple food mostly by Nigerians and residents of West Africa (Smith, 1997).

Maize cultivars usually determine the period between the planting and harvesting, however, the crop matures physiologically between 7 to 8 weeks after flowering.At this period, the kernels hold 35- 45% of water and have the highest placidity of dry matter (Danilo, 1991).Noteworthy, harvesting, de-husking, drying, shelling, and storing are the crucialtreads involved in maize processing. Maize shelling involves the separation or separation of maize seeds from the cobs by abrasive impression. The operation follows the harvesting stage; the hard part of maize shelling operation usually builds upon the moisture content, varieties of maize cultivated, and level of maturity of grain crop (FAO, 2005).Traditionally, the shelling of maize often involves the pressing of thumbs on the maize seeds or rubbing together two maize cobs. Evidently, labour requirement for these methods is high, and one worker can only shell 15 – 40kg/hr (FAO, 2005). Additionally, Akubuo, (2002) noted that shelling of maize manually is tedious and time-consuming, and not many existing mechanized sheller machines are imported and/or affordable and accessible to peasant farmers who are characterized by impoverishment and own small farms.

Ogunlade*et al*., (2014) in their research wrote that most existing maize shellers are normally large and heavy, requiring high power input to operate and producing low product quality in terms of percentage seed breakage and purity. The high moisture content of the maize seeds lead to an increased breakage percentage resulting ina decrease in the total efficiency of the machine, as the high moisture content of the maize seeds affected the rotational speed of thethreshing cylinder of the machine (Alwan*et al*., 2016).

A study explained that there was a significant effect on husking (shelling) efficiency on amaize shelling machine due to the high moisture content of the maize grain and concluded that high moisture content of the maize resulted in a decrease in theshelling efficiency of the maize shellerused in the experiment (Al Sharifi *et al*., 2018).

This researchaimedat studying thedesign and efficacy of a maize-shelling machine with respect to moisture content and the determination of optimal moisture content percentage dry basis(%MC_{db}) of the maize to be shelled. Also, to fabricate a cost-effective maize shelling machine to assist maize farmers with the maize shelling process.

Materials and Method

The maize shelling machine construction was carried out at the Federal Ministry of Labour and Productivity/Skills Acquisition/Upgrading Training center and Trade testing office, Onireke Ibadan, while the performance evaluation was conducted at Crop Production Technology Department, Federal College of Forestry, Jericho, Ibadan located between (latitude 7^{0}23'46" N andlongitude 3^{0}51'47"E), Ibadan, Oyo state Nigeria. Annual rainfall is 1250 mm having dual mode seasons,a wet season of about 8 months, between April and November, and a brief dry spell which starts mostly in the second half of August. The minimum and maximum meandaily temperatures are 21.9^{0}C and 35.5^{0}C respectively.

The characteristics of the machine assessed included the shelling capability and efficiency based on the moisture content %MC_{db} of the maize samples used. As shown in Fig. 1, the designed maize shelling machine partsincludethe hopper– which serves as the inlet for the maize on the cob to be shelled, the shelling chamber –which houses the shelling drum and the outlets - for the shelled grains and the other outlet is for the maize cob. The maize shellingmachine was powered by an electrical motor of 1hp running at 1440 rpm.

Elemental design of machine

The AutoCAD diagram of the machine design is seen in Fig 1. In carrying out the project study, the following components of the machine were considered:

Length of the main shaft, Diameter of the main shaft, Speed of shaft. Belt length and tension, Shelling shaft diameter, Pulley centre distances and Power transmission.

The pivotal shaft of the shelling device is a pivotal component that operates within a chamber or cylindrical casing of the shellingmachine, however, the primary factor that was used to evaluate the shelling performance capacity of the shellingmachine is the shaft diameter, whilst the main performance evaluation was based on shelling operation and shelling efficiency of the machine.

Moisture content determination

The moisture content percentage (%MC_{db})of freshly harvested maize samples was initially at 23.8%as determined in the laboratory using the oven dryInternation Seed Testing Association (ISTA, 1999) method for determining the moisture contentfor seeds. However, for this study,the collected samples with intialmositere content 23.8 %MC_{db}were further oven dried to 10, 15 and 20 %MC_{db}in the laboratory using the ISTA oven dry standard method respectively and the resultant dried samples were lebelled A,B and C for easy identification respectively.. Conversely, the dried maize samples collected were usedto perform the experiment ofdetermining the optimum moisture content for shellingmaize with minimum damage to the maize kernels.

Shelling-machine specifications:

1. Overall machine dimension (b x w x h) 235mm x 850mm x 600mm
2. Length of belt 150mm
3. Shaft of at least 340mm in length and 40mm in diameter
4. Hopper of overall height 520mm inlet allowances of 205mm by 205mm
5. Centre to centre shaft distance not less than 500mm
6. Angle steel of 38mm by 38mm and 2mm thickness

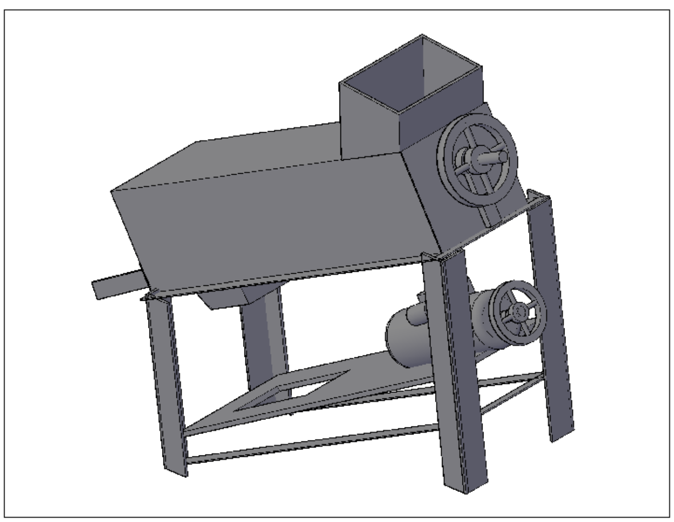
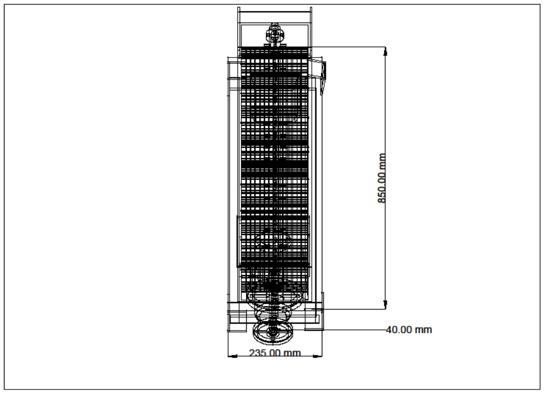


Figure 1: Pictorial View of the Maize-shelling machine



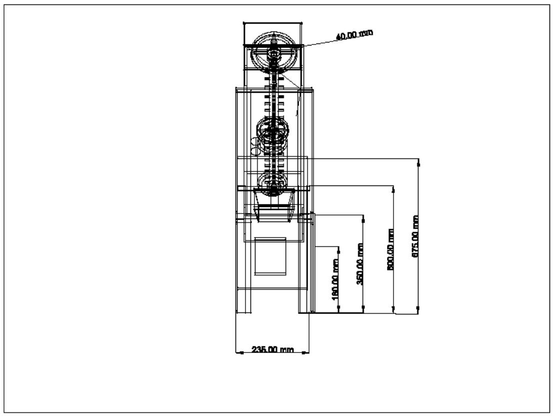


Fig. 2: The plan of the Maize-shelling machine Fig.3: Front view of the Maize-shelling machine

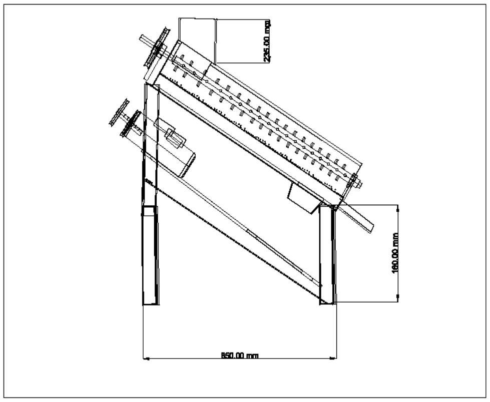
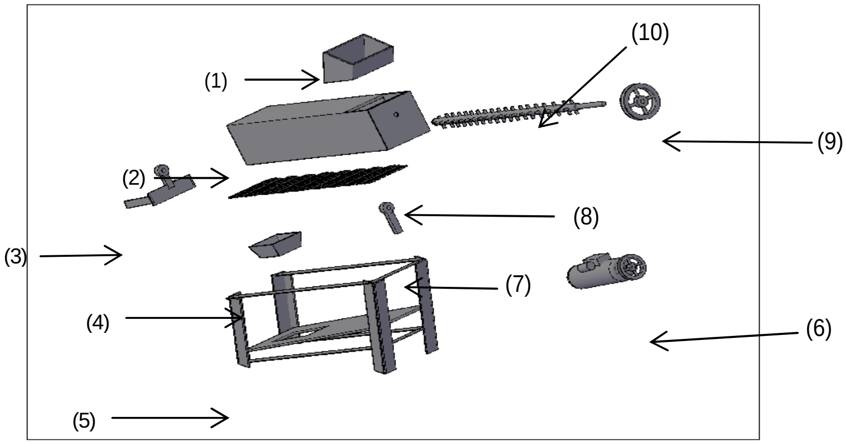


Fig. 4: Side view of the Maize-shelling machine



1- Hopper; 2- shelling chamber; 3- grain outlet; 4- cob outlet; 5- machine frame; 6- electric motor; 7- belt; 8- sieve; 9- pulley; 10- shelling shaft (spikes).

Figure5: Exploded view of Maize-shelling machine

Design Analysis

Shelling shaft design

The shaft design of the maize-shelling machine consisted majorly of the computations of the appropriate diameter and length to guarantee adequate rigidity and robustness whilst the shaft is conveying capacity under various loads and operating conditions. The shaft diameter considered for this work was obtained from the diameter of a pre-existing maize shelling machine. Shafts are usually solid or hollow, however,a solid shaft made up of mild steel 40C8 having a yield strength of 380 Mpa was selected for this maize-shelling machine design. The shaft was coupled to an electric motor with a rotating speed of 1440 rpm. The following demonstration is positioned on shafts of malleable materials and cylindrical cross sections.

Shelling shaft speed

Shaft speed was obtained as indicated below:
V (m/s) = belt velocity at the angle of wrap
Therefore, the angular and linear velocity relationship is given as:
$V = \pi Nd$, (1)

Since V (velocity) is the same on both large and small pulleys:

$V_1,$
$\pi N_1 d_1 - \pi$(2)

Therefore, $\frac{d_1}{d} = \frac{N_1}{N_2}$ (3)

Where:
N_1= small pulley speed (rpm)
N_2 = large pulley speed (rpm)
d_1 = diameter of small pulley (mm)
d_2 = larger pulley diameter (mm)
The speed of rotation reduces in value by 4% due to creep and slip on belts and pulleys.
Shaft Power transmission is given by:
$P = F \times V$ (4)

Where; P = power (Nms^{-1}),
F = threshing force (N), and V = linear velocity (ms^{-1})
Therefore the required force to shell maize isexpressed as;
$F = mw2r$ (5)

Where F is the required force for shelling maize, *m* is the weight of the prime movers, and *w*is the angular velocity of the shaft.
Shaft length (L) = 570mm = 0.57m
Shaft diameter (d) = 20mm = 0.02 m
Radius r is given as; $\frac{d}{2}$ = 0.01m
Shaft density (p) = 640kg/m^3 (Ni-chrome alloy)
Shaft weight (F) = mg (6)

But M= *pv*= $M = pv\pi^2 = p\pi r^2 L$
(7)

Where,
M = shaft weight
r = shaft radius
L = shaft length
Therefore,
$F = ppr^2L \times g$ (8)
F = 8400 × 3.142 × 0.01 × 0.57 × 9.81 = 33.58N
The angular velocity$'w' = \frac{N}{60}$, gotten from equation (2) above
where; N(rpm) = speed of threshing.
Transmission power of shaft = (*Fwr)*
The -total- threshing power is determined as an appropriate speed for threshing that will be delivered the least mechanical -damage, having high -threshing delivery- whichranged between 40 and 100 rpm.

Radius, *r*, of threshing arm

The radius, *r*, of the threshing limb increases together withthe length of the shaft, which reversely decreases as it approaches the other end of the shaft

where:

r = radius of threshing limb, given as;

r_{max} = 0.045m (assumed),
r_{min} = 0.035m (assumed)
Therefore; centripetal force at maximum $(F) = m = 2mr_{max}$
Centripetalforce atr_{min} $(F) = m = 2mr_{min}$

Shelling shaft speed and torque determination

The rigidity, strength, and power of the shaft under operation conveyance at various load conditions depend to a larger extent on shaft diameter. Shafts are usually hollow or solid. For this study, a solid shaft was selected according to equitation (9).

$$d^3 = \frac{16}{\pi\tau_s}[(K_bM_b)^2 + (K_tT_t)^2]^{\frac{1}{2}}, \quad (9)$$

Where:
dis the diameter of the shaft (mm)
τ_s is torsional shear stress (MPa)
M_b is bending moment (Nm)
T_t = torque
K_b = shock and fatigue factors on bending moment
K_t = shock and fatigue factors on the torsional moment.
Torque T is given as:

$$T = Fr \quad (10)$$

Where:

F = available centripetal force;
r = threshing radius

Determination of power delivered by primary shelling machine

Power transmission could be defined as the movement of kinetic energy from a place of generation to a place of application to perform work while, torque is a force to turn ortwist which causes an object to oscillate on its axis after a measure of force is exerted (Abd El-Maksoud *et al*., 2012).

The power transmission of the shaft is calculated by considering the tension both on the lax and tense sides of the belt alongside the belt velocity.
Let T_1 = tension tensed side of the belt
T_2 = tension lax side of the belt
V = belt velocity (m^{-1})
Mechanical power transmission P:
$P = Fv$,
Where; F = Force; $v = \pi ND$(rpm); D = the diameter of pulley, N = (rpm)
This design focuses on the forces pulling in opposite directions to each other; hence, the net power transmission is derived as:

$$P = \pi ND(T_1 - T_2)v \quad (11)$$

$$P = \pi ND(T_1 - T_2) \quad (12)$$

Frictions between the belt and pulley develop different tension in the arrangement. Moreover, the different tensions that develop between the pulley and belt causethe belt to lengthen or shorten generating a relative motion both on the belt and pulley surfaces. The relative motion generated between the pulley and belt surface occurs due as a result of a phenomenon referred to as elastic creep (Robert2006).
Belts generally possess pretension after being installed on pulleys. This pretension occurs throughout the length of the belt even when motionless. However, during the rotational drive, the tension of the tensed side increases above the pretension, whereas, the tension on the lax side decreases below that of the pretension. (FAO 2005)
Furthermore, when the belt fixed over the driving pulley becomes elongated it may results in it leaving the environment of contract, then an average velocity acting on the surface of the driving pulley from the belt becomes slightly decreased than the second pulley speed.
The magnitude of the pretension in the belt is expressed in equation (13).

Tense side elongation

$\alpha(T_1 - T_1)$ (13)

lax side:

$\alpha(T_1 - T_1)$ (14)

where T_i = prime belt tension.

Since belt length remains the same (elongation and same length contraction)

Therefore; $T_i = \frac{T_1 + T_2}{2}$ (15)

Main shaft torque (t) can be calculated considering tension; lax and tense sides of belt T_1, and T_2, and radius of main shaft (R);

$\alpha = T_1 - T_1$ (16)

Evaluation of maize-shelling machine performance

A total of thirty (30) samples of fresh maize cobs (maize ears) were oven-dried to a moisture content of 10, 15, and 20 $\%MC_{db}$, whilst ten(10) samples each were collected for each level of maize moisture content. Thereafter, the machine was subjected to testing by running the samples through the machine to test its shelling performance. The mass of the maize was measured and recorded at the beginning and the back ofthe shelling process. Data obtained were thereafter used to determine the capacity and effectiveness of the machine using eq. (17) and (18). The tests were performed in five (5)replicates.

The following parameters were determined from the data collected using the following equations;

$$\text{Capacity (rate of shelling)} = \frac{\text{mass of shelled grains } (W_5)}{\text{time taken } (s)} \times 3600 kg/hr \quad (17)$$

$$\text{Shelling effiecency} = \frac{\text{mass of shelled grains } (W_5)}{\text{total weight of grains (shelled } W_2 + \text{unshelled } W_4)} \times 100 \quad (18)$$

$$\text{Grain damage} = \frac{\text{the total mass of damaged grains} (W_3)}{\text{total weight of grains (shelled } W_2 + \text{unshelled } W_4)} \times 100 \quad (19)$$

(Azeez *et al.*, 2017)

Where: W_1 = Control (mass of whole maize)

W_2 = mass of incompletely shelled maize cob

W_3 = mass of damaged shelledgrains

W_4 = mass of grains collected from the incompletely shelled maize

W_5 = mass of wholly shelled grains

Data Analysis

The experiment was set up in a completely randomized design, and data collected were assigned to expressive statistics and analysis of variance with respect toFpr = 0.05 using GenStat statistical tool.

$$Y_{ij} = \mu + A_i + E_{ij} \quad (20)$$

Y_{ij}= Observation

μ = Mean

A_i = Effect of factor 'A' (Moisture Content $\%MC_{db}$)

Results

The performance of the shellingmachine tested with respect to moisture content at 10, 15, and 20$\%MC_{db}$ are shown in Table 1. The control(W_1) at 10 $\%MC_{db}$had the highest pool mean mass(0.226±0.049g),while the mass of wholly shelled maize grains (W_5) (0.190±0.016g) from the resultswas higher than the damaged grains (0.0063 ±0.004g) and incompletely shelled maize (0.019 ±0.014g), for all maize samplestested. However, the mean mass of maize at 15 $\%MC_{db}$was 0.247 ±0.084 -a value higher than samples at 10% (0.224 ±0.014) and 20% (0.206 ±0.017). The time utilizedby the machine for the maize shelling operation was found to be between 11s and 12s for the tested samples. In addition, the statistical analysis obtained from the results revealed that the mass of samples tested across the moisture contents $\%MC_{db}$for: W_2, W_4, and W_5 were significantly different, meanwhile, thesedifferences were not significant with respect to time.

Table I: Shelling performance

(MC %)	Sample	W_1(g)	W_2(g)	W_3(g)	W_4(g)	W_5(g)	Time (s)
	1	0.250	0.007	0.005	0.002	0.198	12
	2	0.220	0.002	0.001	0.001	0.200	12
10%	3	0.216	0.006	0.004	0.002	0.210	11
	4	0.220	0.004	0.003	0.001	0.200	12
	5	0.216	0.009	0.005	0.004	0.207	11
Mean		**0.224 ±0.014a**	**0.006 ±0.003a**	**0.004 ±0.002b**	**0.002 ±0.001a**	**0.203 ±0.005b**	**11.60 ±0.55a**
	1	0.397	0.021	0.006	0.015	0.187	11
	2	0.205	0.021	0.008	0.013	0.184	12
15%	3	0.209	0.013	0.001	0.012	0.196	11
	4	0.205	0.010	0.009	0.001	0.195	12
	5	0.219	0.026	0.011	0.015	0.199	12
Mean		**0.247 ±0.084a**	**0.018 ±0.007b**	**0.007 ±0.004a**	**0.011 ±0.06b**	**0.192 ±0.006b**	**11.60 ±0.54a**
	1	0.185	0.03	0.005	0.025	0.155	11
	2	0.193	0.034	0.011	0.023	0.159	11
20%	3	0.223	0.037	0.013	0.024	0.186	12
	4	0.207	0.022	0.001	0.021	0.185	12
	5	0.223	0.049	0.012	0.019	0.192	11
Mean		**0.206 ±0.017a**	**0.034 ±0.009c**	**0.008 ±0.005a**	**0.022 ±0.002c**	**0.175 ±0.017a**	**11.40 ±0.55a**
Pooled Mean		**0.226 ±0.049**	**0.019 ±0.014**	**0.0063 ±0.004**	**0.012 ±0.009**	**0.190 ±0.016**	**11.53 ±0.52**

Mean ± S.D. Means in the same column having the same alphabets are not significantly different from one another other at 5% level of significance.

Where: W_1 = Control (mass of wholemaize), W_2 = mass of incompletely shelledmaize cob, W_3 = mass of damaged shelledgrains, W_4 = mass of grains collected from the incompletely shelled maize, W_5 = mass ofwholly shelled grains

Machine efficiency

The shelling efficiency results of the machine as shown in Table 2 were evaluated from the total mass of shelled grains divided by the total mass of shelled and unshelled grained at 10%, 15%, and 20% MC. The highest significant efficiency (99.02%) was recorded at 10% MC followed by 15% (94.5%) efficiency and 20% (88.20%) respectively.

Table 2: Maize Shelling Machine Efficiency

MC(%)	Mass of shelled grains(kg)	Mass of grains (W_5+W_4)(Kg)	Mass of damaged grains(kg)	Shelling Efficiency (%)	Damaged grains(%)
10	1.015	1.025	0.018	99.02±0.57c	1.77±0.002a
15	0.961	1.017	0.035	94.50±2.84b	3.64±0.004a
20	0.837	0.122	0.042	88.20±1.93a	5.02±0.005a

Machine capacity

Table 3 shows the capacity of the maize shelling machine with respect to moisture contents. It was observed that maize samples with 10%MC_{db} had the significantly highest shelling capacity at 63.17±4.64kg/hr, followed by 15%MC_{db}(59.75±3.30 kg/hr) and then 20 %MC_{db}55.38±4.71kg/hr.

Table 3: Shelling Capacity of Maize Shelling Machine

MC(%)	Total Shellingcapacity (kg/hr)	Mean shelling capacity (kg/hr)
10%	315	63.17±4.64b
15 %	298	59.75±3.30ab
20 %	264	55.38±4.71a

PLATE I: Side viewof fabricated shelling-machine

Discussions

It was observed from the results of theperformance evaluation of the maize shelling machine that the highest mean mass of wholly shelled gains percentage (0.203%)was recorded at 10 %MC_{db} and the lowest mean mass of damaged grain percentage(0.001 %), the mass of incompletely shelled maize cob (0.009 %), and mass of grains collected from the incompletely shelled maize (0.002%) respectively, after shelling operation as shown in Table 1. This implies that lower moisture content percentage significantly influenced the maize shelling efficiency of the machine as indicated in W_2,W_3, W_4, and W_5. As such, higher moisture contents inhibit the performance of the maize shelling machine to adequately shell all grains from a maize cob. Hence, contributing significantly to the highest mass of grains retrieved from the incompletely shelled maize cob (W_4). Also, the significantly lowest mass of damaged shelled grains at 10 %MC_{db}implies that thedryer maize the lesser the grains damaged when operating the shelling machine.Consequently, the machine performed best at the least moisture content (10) %MC_{db}, owing to the significantly highest mass of the wholly shelled grains produced compared to the higher moisture content of other maize during the experiment.

In the same vein, this study affirmed that the efficiency of the shelling machine was influenced by moisture content. Hence, the lesser the moisture content, the higher the machine efficiency and the rate of shelling. Inferentially, the design shelling machine performed satisfactorily. However, moisture was identified as a factor influencing the working performance, capacity, and efficiency of the shelling machine.

Unsurprisingly, Danilo (1991) already reported that maize de-hulling is difficult at a moisture content level greater than 25 %MC_{db}.At this moisture content, grains removal ability becomes very poor using a high operational power which may cause mechanical damage to the grains. He observed that a more accomplished shelling is obtained when seeds have been thoroughly dried to between 12 and 15 %MC_{db}(Danilo, 1991). Concurrently, the machine designed in this study revealed a suitable shelling performance,having 99.02% efficiency for maize at 10%MC_{db}.

Furthermore, the findings of this work were similar to Pavasiya *et al*., (2018) who found an efficiency, Shelling performance index, total grain losses, and output capacity of 95.48%, 91.55%, 2.96%, and 623.99kg/hr respectively at 13 %$MC_{db}$and 886rpm shelling speed for a developed maize shelling machine. Also, Olayide*et al*., (2018), whose maize shelling machine had a 600 kg/hr rate of shelling, and shelling efficiency of 99.5 % at 11 %MC_{db}. It also compares favourably with Azeez *et al*., (2017). Their machine is electrically operated (2.235 kW), speed of 1430 rpm and torque of 14.92 Nm, having a shelling efficiency of 91.29 %. Soyoye *et al*., (2020) also observed similar results from the performance evaluation of the designed maize shelling machine which shelled at an average efficiency of 89.3%,an average capacity of about 109kg/h rotating at 600rpm and a speed of 1,400 rpmat 13 %MC_{db}.

Conclusions

Based on the findings from this study, it was concluded that moisture content %MC_{db} of the maize samples as a factor of evaluation influenced the shelling operation of the machine's performance, capacity, and efficiency. Consequently, the shelling machine performed best at the lowest moisture content.

Recommendations

It is recommended to further study the following:

1. Reductionin the size of the maize shelling machine
2. development of a mobile maize shelling machine

3. effects of lower moisture content of maize on machine shelling efficiency

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