ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 11, Issue 1, pp: (30-38), Month: April 2024 – September 2024, Available at: www.paperpublications.org

DESIGN AND EFFICIENCY ANALYSIS OF A MOTORIZED CORN SHELLING MACHINE FOR ENHANCED AGRICULTURAL PRODUCTIVITY

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DOI: https://doi.org/10.5281/zenodo.13234804

Published Date: 06-August-2024

Abstract: **The increasing global demand for maize necessitates advancements in agricultural technology, particularly in post-harvest processing. This study focuses on the design and fabrication of a modern electric corn shelling machine to enhance efficiency and productivity in maize cultivation. The machine addresses significant challenges faced by small-scale farmers, including high post-harvest losses and the inaccessibility of affordable mechanized solutions. Experimental evaluations demonstrated that the machine achieves a shelling efficiency of up to 97% and a shelling capacity ranging between 50 to 85 kg per hour. Additionally, the machine's design prioritizes ease of use, maintenance, and safety, making it an ideal solution for small to medium-scale farming. Cost analysis revealed that while the initial investment is considerable, the long-term benefits in terms of reduced labour costs and improved productivity are substantial. From leveraging locally available materials and focusing on sustainability, this electric corn shelling machine offers a viable solution to improve food security, economic stability, and sustainable agricultural practices in maize-producing regions.**

Keywords: **Agriculture, Corn Shelling design, Electric corn shelling, Maize shelling, Shellers, Shelling machine.**

I. INTRODUCTION

In the 20th century Earth's population experienced a staggering doubling rate from 2.5 billion to 5 billion humans. This population explosion resulted in a demand for food crops such as maize grain all around the world. Till this day, maize production has assumed significant importance. Although the cereal grains prevalent worldwide include other crops (such as wheat, barley, sorghu and rice), corn also known as maize, stands as a key commodity extensively cultivated in West Africa and every continent of the world. Maize boasts essential nutrients, comprising 10% protein, 4% oil, and 70% carbohydrates. Also, its cereal grain houses vital vitamins like Vitamin A, nicotinic acid, riboflavin, and vitamin E, alongside 2.3% crude fibre, 10.4% albuminoides, and 1.4% ash [1]. Originating from Mexico, the plant with the botanical name Zea-mays, is a highly multipurpose seed crop globally. It optimal growth occurs between latitudes 58°N and 40°S of the equator, where favorable conditions include high rainfall, intense light, and suitable temperatures [2]. The agro produce stands as a crucial commodity in the market place [3]. It acts as a fundamental source of carbohydrates, protein, iron, vitamin B, and minerals, serving as a dietary staple for approximately half of the population in Sub-Saharan Africa [4]. In regions with lower income, maize primarily serves as a dietary element, while in more industrialized nations, its primary uses are as livestock feed and as a raw material for various industrial products. Across Africa, maize is consumed as edible food ranging from porridges and pastes to parched, baked, roasted, or boiled green maize on the cob. Apart from its application as a food product, it can also be used as raw material for several industries. Some key industrial products derived from maize include corn starch, corn oil, corn syrup, and corn sugar. Corn starch which finds use in the manufacturing of asbestos, ceramics, dykes, plastics, oilcloth, and linoleum. Corn syrup is widely employed in the production of shoe polish, glassine paper, and rayon, particularly in the tobacco industry. Corn sugar finds applications in chemicals, leather preparation, dykes, and the production of explosives. When subjected to acidic conditions, cooked maize cobs produce furfural, a compound used in the production of adiponitrile (nylon) and in the reconditioning of diesel and lubricating oils. Notably, maize stalks and leaves are occasionally utilized in the production of paper, paperboard, and wallboard. Pulverized maize cobs are extensively employed for removing carbon from airplane motors [2].

In line with the sustainable development goals for technological advancement in agriculture, the aim of this paper is to contribute to efficiency of existing agricultural production as increasing demand for processed food from the global population continues to grow. The design and fabrication of a modern electric corn shelling machine represent a technological leap in post-harvest processing, contributing to increased efficiency and productivity in maize cultivation [5]. Also, post-harvest losses, especially in regions like Northern and Southern Nigeria, where traditional maize shelling methods prevail, pose a significant challenge. The study on a corn shelling machine directly addresses this issue by providing an alternative that minimizes losses. Reducing post-harvest losses is crucial for food security, economic stability, and sustainable agricultural practices [2,6]. Additionally, small-scale farmers often face challenges in accessing and affording modern agricultural machinery. The proposed study focuses on designing a cost-effective electric corn shelling machine, specifically tailored for small-scale agriculture. Through provision of an accessible solution, this research aims to empower local farmers, enhancing their economic viability and contributing to poverty alleviation [6,7]. Lastly, the machine emphasizes the use of locally available, electromechanical, and non-degradable materials. This approach aligns with the principles of sustainability by minimizing environmental impact and promoting the use of materials that are readily available in the local context.

The contributions of this paper are to design an electric corn shelling machine with a simple and efficient mechanism, considering factors such as ease of use, maintenance, and adaptability to different corn sizes. Also, we seek to experimentally evaluate the designed corn shelling machine's performance in terms of shelling capacity, efficiency, and loss reduction, and compare it to manual methods. Hereafter, we will review the results obtained and based on result assessments provide recommendations for further research and development to enhance the efficiency, durability, and safety of the corn shelling machine.

II. LITERATURE REVIEW

The cultivation of maize, a grass-family plant, holds paramount importance globally [8]. Its significance extends beyond human nutrition, usage in animal feed and as a raw material for other industrial products [8,9]. Maize derivatives, such as maltodextrins, corn starch, corn syrup, corn oil, and outputs from fermentation and distillation industries, showcases the wide range of usefulness that maize has. Notably, maize has recently gained prominence as a biofuel source [9,10]. Introduced to Africa in the 16th century, maize rapidly proliferated across the continent, going above millet and sorghum to emerge as a vital cereal [8]. By the 19th century, it solidified its status as a staple food in several African countries [9]. The surge in maize demand is attributable to its diverse applications in society and the economy. Maize serves both human and animal consumption in its natural state, but its processing into flour, beverages, fuel, and oil contributes to an expanded maize.

Evolution of Corn Shelling Machines: A Historical Overview

In historical and rural contexts, traditional methods like beating with a stick, crushing with mortar and pestle, and manual hand shelling were prevalent, demanding substantial human effort and time. Throughout history, numerous research endeavors have delved into unraveling and assessing the diverse models, sizes, and operational mechanisms of previously devised corn shelling machines. Metwalli et al. embarked on crafting a compact, locally-sourced corn shelling machine tailored to meet the needs of Egyptian farmers. After completion of the machine, a comparative performance test was conducted to compare the machine against a small French shelling machine. The evaluation involved unshelled grain, grain damage, and the economical operational cost. The performance evaluation, was influenced significantly by the drum speed and concave clearance ratio, especially under varying moisture conditions during corn ear shelling [11]. The developed corn sheller was designed for adaptability with minimal adjustments across different grain crops, with an objective for the machine to boast superior shelling efficiency and minimized grain damage. In relation to the study by Metwalli et al, Mady emphasized the correlation between increased drum speed and elevated metrics such as damaged kernels, lost kernels, and overall machine productivity. Interestingly, the study revealed that within a specific range of drum speed, there was a decrease in undamaged kernels and machine efficiency. Optimal outcomes, with minimal damage (1.5%) and maximum undamaged kernels (98.5%), were achieved at a moisture content of 13.3% [12]. Furthermore, the study by Abd EL Maksoud, contributed insights into factors influencing the performance of a newly established small corn sheller. The study explored three moisture content levels of kernels across four corn varieties. The highest range of shelling efficiency, at 97.5%, occurred at a kernel moisture content of 18% (w.b.) and a speed ranging from 280 to 320 rpm across all varieties. Notably, the study identified that the least total losses (6-10%) were observed within a speed range of 280 to 600 rpm, maintaining consistent kernel moisture content across most corn varieties [13]. In recent studies, Dr. C. C. Handa et al. introduced an environmentally friendly corn shelling machine with a simple yet effective design. This machine incorporates essential features such as a shelling system and an automation separating system. Threshing force is applied, and the design enhances knowledge in areas of designing, mechanism, and forces. The project's objective was met in creating a machine that facilitates corn shelling, in the process enabling farmers to maximize profits by selling corn directly in the market [14]. Additionally, Sunil Kadam et al. in 2016 presented a machine designed to make farmers self- reliant, eliminating the need for manual labour in the removal of corn covers and deseeding. The corn shelling and threshing machine is efficiently operated by a single person, reducing the time required for weeding compared to manual processes. Controlled feed rate and directional operation contribute showed in the machine to have enhanced productivity. This portable machine includes a collecting system and can be driven automatically [5]. Also, Pradip Kadam et al. outlined a project aimed at developing a machine that reduces human effort and cost-effective, particularly suitable for small-scale farming. The construction of this machine is simple yet effective, featuring a compact size that efficiently peels corn shells and removes corn seeds in a short timeframe. The comprehensive design presented by Pradip Kadam et al. for a corn peeling and shelling machine, highlighted superior efficiency compared to hand or pedal-operated counterparts. At the end of the study, the machine shelling efficiency ranged between 90% to 97%, averaging at an impressive 94%. The operation delicately detached kernels from cobs without causing any damage, showcasing its effectiveness [5].

III. DESIGN MATERIALS AND METHODOLOGY

A. Capacity of the Corn Shelling Machine

To determine the machine's capacity, the intended level of operation that the device will undertake was considered. Based on a detailed market survey, it was observed that the average size of maize shellers ranges between 30 kg per hour to 60 kg per hourly output when manually operated. However, to meet the requirements of a small-to-medium scale production setting while ensuring a reliable output, we have determined that the corn shelling machine's optimal hourly output will be between 50 kg per hour to 85 kg per hour as the machine will be operated electrically. Also, this hourly output matches both small and medium scale maize production requirements as it is neither too high nor too low. The shelling capacity of the machine was resolved with the formular:

$$\text{Shelling Capacity} = \frac{\text{average mass of shelled products (kg)}}{\text{average time taken (s)}} \tag{1}$$

B. Conceptualization of the Design

The machine designed consists of a hopper for loading maize and a shelling unit with rotating shelling blades that will remove the maize kernels from the cob. The shelling unit will be powered by an electric motor. The machine will have a separate container for collecting the shelled maize. Our design focuses on delivering an efficient, reliable, and user-friendly machine that is easy to operate, maintain, and affordable and reliable shelling machine that meets the needs of small and medium scale maize producers. We have conceptualized a machine that is made up of only a few components, ensuring that the machine's fabrication costs are minimal, and the assembly process is straightforward. Here are the key elements of the conceptualized design:

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1. Volume of Hopper

The design features a hopper that allows the operator to load the maize cobs. The hopper will have a capacity limit of about 40 kilograms of maize per charge, which is the required output hourly. We consider the hopper size requirement essential since it determines the number of cobs that can be loaded into the machine at once and ultimately affects the machine's efficiency. The design for the Hopper is based on a common criterion for it to function. The criterion is called the "Angle of repose". Angle of repose is the maximum slope at which a heap of any loose or fragmented bulk material will stand without sliding. It can also be called the angle of friction of rest [15]. This type of hopper is a gravity discharge one and the recommended angle of inclination of hopper for agricultural materials is 80 or more, higher than the angle of repose [2]. The angle of repose of maize is 270. This hopper has a shape of a truncated prism.

2. Shelling Unit

The shelling unit is composed of rotating blades that will remove the maize kernels from the cob. The disk's diameter is optimized to ensure maximum efficiency in shelling the maize cobs. The design of the shelling unit features sharp and durable teeth for effective shelling performance and durability. Also, the disk's thickness is made of high-grade, corrosion-resistant material, ensuring that it can withstand the harsh maize husking environment.

3. Power Source

The con shelling machine is powered by an electric motor for optimal performance and efficiency. We have chosen an electric motor that is adequately powered to meet the machine's requirements while utilizing just enough energy to keep the machine operating optimally and thus minimizing power consumption. The electric motor's power rating will be determined by the machine's operational requirements.

4. Container for Collecting Shelled Maize

The machine is designed to have a separate container for collecting the shelled maize. This design feature aims to provide a convenient and hygienic way of collecting the shelled maize. The container will be detachable, allowing operators to clean it quickly and put it back in place for the next shelling operation.

C. Design analysis

In this research, all values and dimensions are actual measurements of the materials used. According to Khurmi R. S, the knowledge of materials used and their properties is of great significance. The machine components are made of materials with suitable properties for operating conditions. The design was carried with immense consideration on the safety of the machine operator [16].

Table 1. Results of calculations

Calculation	Equation	Parameters	Value	Unit
Number of spikes	(Sn) Sn = Ls/St	Ls = 895mm St = 42mm	43	
Shelling speed (N_2)	$N_2 = (D_1 \times N_1/D_2)$	D_1= 0.14m D_2=0.22m	1330	rpm
Length of belts (L)	$L= 2C + (\pi/2)(D_1 + D_2) + (D1\text{-}D2/4C)^2$	C=490mm D_1=140mm D_2=220mm	1297.301	mm
Belt contact angel (β)	$\beta=\sin^{-1}(R\text{-}r/C)$	R=55mm r=38mm C=490mm	1.84	degree
Angles of wrap (α1) (α2)	α1=180 + 2β α=180-2β	$\beta=1.84^o$	168.24	degree
Angles of wrap (α1) (α2)	α1=180 + 2β α=180-2β	$\beta=1.84^o$	168.24 156.05	Degree
Mass per unit length of the belt (m)	m=btp	b=0.008m t=0.013m p=1140kg/m3	0.1186	kg/m

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Velocity (V)	$\pi DN/60$	D=140mm N=1330rpm	9.03	m/s
Belt tension (T_1) (T_2)	$(T_1/T_2) = e\mu\theta$ $T_c = (T_1/3)$ $T_c = mv2$	m=0.1186kg/m v=9.03m/s	29.01 15.2	N
Power (P)	$(T_1 + T_2)$ V	V=9.03m/s T_1=29.01N T_2=9.03	399.2	W
Threshing force	P/V	P=399.2W V=9.03m/s	44.2	N

The Developed Machine

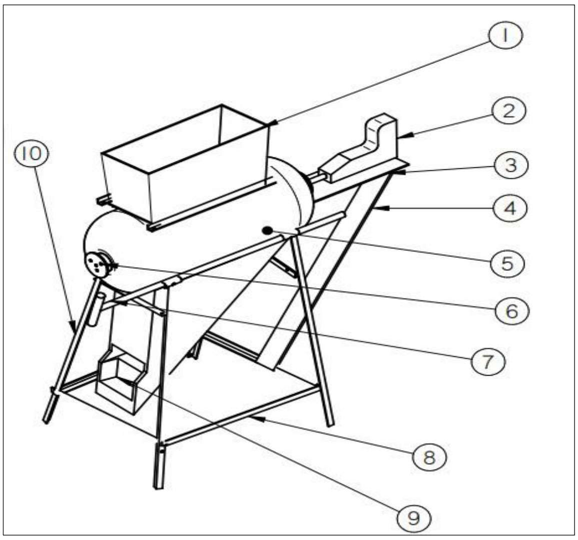

Fig. 1. The Fabricated Corn Shelling Machine and its 3D modelling design representation

Table 2. Corn Shelling Machine Parts

SN	PART NAME	QTY
1	Hopper	1
2	Electric motor	1
3	Bracing sheet	1
4	Sheet metal	1
5	Cylinder	1
6	Cylinder cover	2
7	Short angular rod	4
8	Long angular rod	2
9	Channel	1
10	Stand	1

IV. RESULT AND DISCUSSION

A. Testing protocols and methodologies

This section contains the implementation of methodology, testing, performance evaluation and analysis of results obtained. It includes tables, graphs, and discussions on the experiments carried out to determine the functionality of the maize shelling machine. Extreme physical conditions such as dust, high humidity levels, low humidity, significant temperature variations affect the development and testing of the corn shelling machine. Thus, it is important to monitor the physical environment where the machine is installed and operated while conducting the required test [17]. Standard industrial procedures as well as test materials and maize dimensions are also key in the actualization of robust results [18]. For accuracy in test results, a good understanding of the instrumentation and the possible errors involved during operation and testing must be accounted for [19].

ISSN 2393-8471

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B. Performance Analysis

To test for performance metrics, the products were grouped into four different samples, each weighed before and after shelling with the aid of a chemical beam balance. The time taken for each of these samples to be shelled was also taken into consideration and recorded alongside the weight of each sample. This is a principal means of determining the operational efficiency and possible faults in the operation process. With a gross weight of 75kg, the fabricated machine can be easily transported to various sites. Table 3 shows the weight of different samples before and after shelling while the time taken for the shelling operation is also recorded.

Table 3. Test results of grouped corn (maize)

Sample no	Mass of maize before shelling (kg)	Mass of maize after shelling (kg)	Time (sec) to shell the maize
1	0.20	0.14	8
2	0.30	0.26	14
3	0.40	0.37	19
4	0.50	0.47	24
Average	0.35	0.31	16.25

- The average mass of the maize before shelling ---- 0.35kg
- The average mass of the maize after shelling ----- 0.31kg
- The average time taken to shell ----- 16.25sec

The Capacity of the Machine

Having calculated for the various average results, the shelling capacity can be calculated using the equation 2:

$$Shelling\ capacity = \frac{average\ mass\ of\ shelled\ products\ (kg)}{average\ time\ taken\ (s)} \quad (2)$$

$$Average\ mass\ of\ the\ shelled\ corn\ (kg) = \frac{1.24}{4}$$

= 0.31kg

If a corn (maize) of 0.31kg is shelled for 16.25 sec

The rate of shelling is:

$$Unknown\ value\ (Xkg) = \frac{0.31\ x\ 60}{16.25}$$

= 1.145kg/min

Therefore, the rate of shelling for 1min is 1.145kg/min

In one hour, the capacity of the fabricated shelling machine is

$$(Xkg) = \frac{1.145kg/min\ x\ 60min}{1}$$

= 68.7kg/hr

In 24hrs, the capacity of the fabricated shelling machine will be

X_2kg = 68.7 x (24) hrs =1649kg/day

Thus,

1 tone = 1000kg; It implies 1.648 tons per day can be shelled.

Performance Efficiency (E) of the Fabricated Shelling Machine

Weight of shelled corn = 0.31kg = 321kg

Weight of unshelled corn = 0.35kg = 350kg

$$Efficiency = \frac{output}{input} x\ 100 \qquad (3)$$

Therefore;

$$Shelling\ Efficiency = \frac{weight\ of\ shelled\ corn}{eight\ of\ unshelled\ corn} x\ 100 \qquad (4)$$

$$= \frac{0.31}{0.35} x\ 100$$

= 88.6%

The efficiency of the fabricated shelling machine was calculated to be 88.6%

Determination of Losses (Grain Breakage)

$$Losses = \frac{W_b - W_a}{M_b} \qquad (5)$$

Where:

W_b = weight of maize before shelling

W_a = weight of maize after shelling

$$Losses = \frac{0.35 - 0.31}{0.35} = 0.0857\ or\ 8.57\%$$

C. Discussion

Table 3 gives the result of the measured and shelled maize which was grouped and weighed. Figures 2 show a graphical representation of the results. Table 4 shows the shelling efficiency against time and Figure 3a/4b explains graphically how efficiency increased with respect to time.

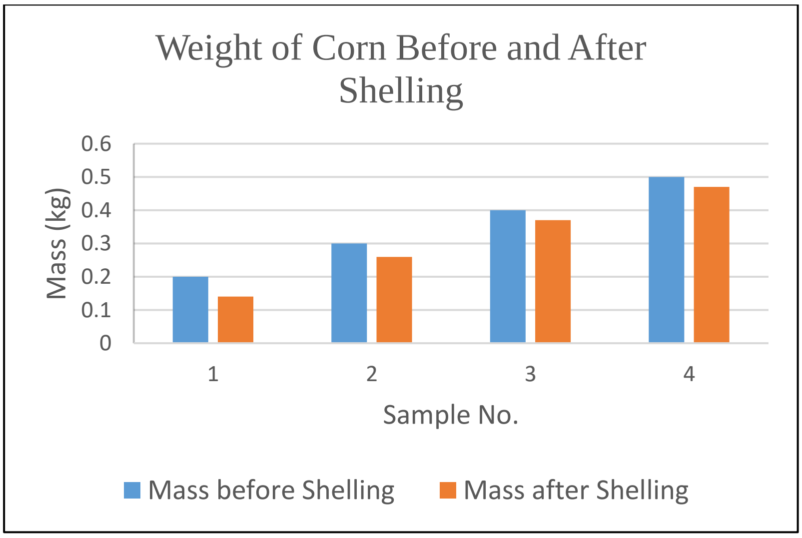

Fig. 2. Graph representation of Weight of maize before and after shelling

Table 4. Showing time and Efficiency

Sample no	Time (sec) to shell the maize	Efficiency (%)
1	8	70
2	14	82
3	19	92.5
4	24	94

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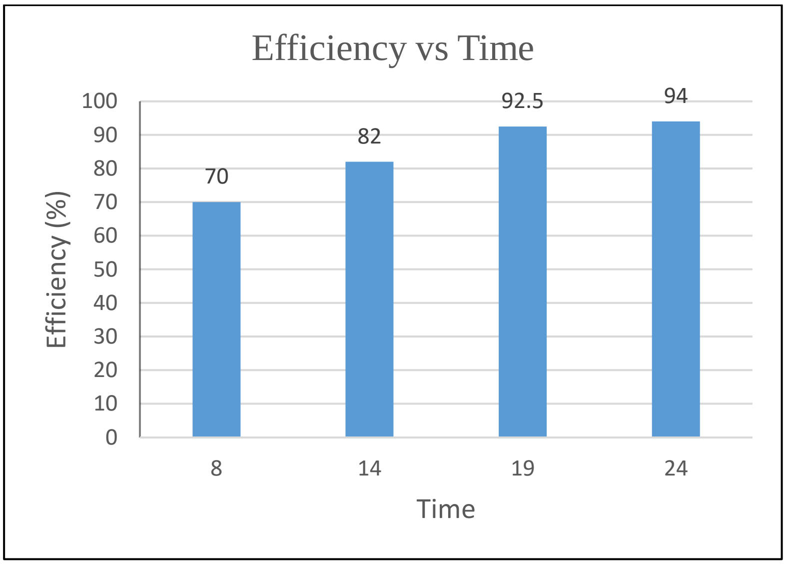

Fig. 3a. Graph of Efficiency (%) against Time (sec)

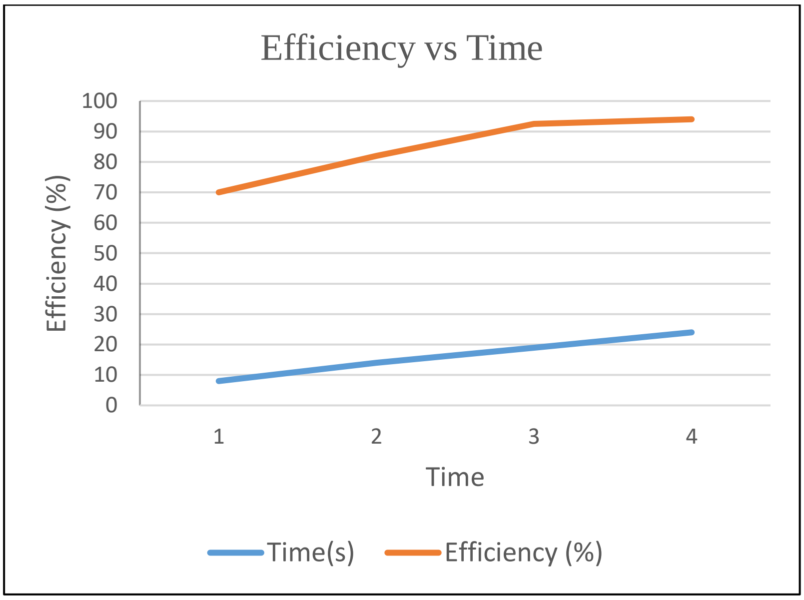

Fig. 3b. Graph view of Efficiency (%) and Time (sec)

V. CONCLUSION

The time and energy expended in shelling corn manually have necessitated the detailed design and fabrication of a modern electric corn shelling machine. The major problems associated with the manual corn shelling machine were the high level of fatigue of the operator and low shelling capacity, leading to reduced productivity. These problems motivated the fabrication of a corn shelling machine with a simple design, that employs a swift mechanism and pulley drive, is simple to use and maintain and results in improved efficiency.

Results obtained show that the electric corn shelling machine developed in this project is cost effective and has a shelling efficiency of 88.6%, whereas the manual corn sheller was shown to have an efficiency of 45% or less. Therefore, if the electric corn shelling machine were used, especially in rural settings, it could optimize the time and energy currently taken to shell corn manually on a large scale. Moreover, form the results of the experiments carried out, the average shelling capacity of the designed machine was found to be 1.145kg/min with a shelling capacity of 68.7kg/hr. The total amount of loss recorded was 0.0857 or 8.57%. The fabricated corn shelling machine proved to solve our stated problems, with simplicity being the key. The machine is better in terms of structural design, it has fewer moving parts for easy mobilization. The only manual process involved is feeding of the corn with the important factor being that the machine can accommodate any corn size.

ISSN 2393-8471

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REFERENCES

[1] D. Naveenkumar, "Modification and evaluation of power operated maize sheller.","," *Dep. Agric. Engg., Univ. Agric. Sci. Bangalore*, 2011.

[2] D. O. Aremu, I. O. Adewumi, and J. A. Ijadunola, "Design, fabrication and performance evaluation of a motorized maize shelling machine," *J. Biol. Agric. Healthc.*, vol. 5, no. 5, pp. 154–164, 2015, [Online]. Available: https://www.researchgate.net/profile/Engr-Idowu-Adewumi/publication/281274006_Design_Fabrication_and_Performance_Evaluation_of_a_Motorized_Maize_Shelling_Machine/links/55ddf75408aeaa26af0f1f87/Design-Fabrication-and-Performance-Evaluation-of-a-Motorized-M

[3] A. O. Yusuf, A. J. ABDULLAHI, and L. I. ATIKU, "DEVELOPMENT OF A MAIZE SHELLING MACHINE: A REWIEW," *Int. J. Eng. Process. Saf. Res. Publ. by Cambridge Res. Publ.*, vol. 24, 2022, [Online]. Available: https://www.cambridgenigeriapub.com/wp-content/uploads/2022/05/CJEPSR_Vol24_No5_March_2022-15.pdf

[4] E. Ugoamadi, C, & Igboayaka, "DESIGN AND DEVELOPMENT OF A MOTORIZED CORN SHELLING AND THRESHING MACHINE," *UMUDIKE J. Eng. Technol.*, pp. 1–9, Feb. 2020, doi: 10.33922/j.ujet_v5i2_1.

[5] K. Patil, S. Pandit, G. Pol, S. Kadam, and A. Jadhav, "Design and fabrication of corn shelling and threshing machine," *Int. J. Innov. Res. Sci. Technol.*, vol. 5, no. 7, pp. 13981–13986, 2016.

[6] H. H. Pande, N. Raj, and J. J. Raut, "Design And Manufacturing Of Corn Shelling Machine," *Int. J. Innov. Eng. Res. Technol.*, pp. 1–4, 2018.

[7] P. B. Mogaji, "Design and fabrication of an improved maize shelling machine," *African J. Sci. Technol. Innov. Dev.*, vol. 8, no. 3, pp. 275–280, Jun. 2016, doi: 10.1080/20421338.2016.1163473.

[8] A. B. Olaniyan, "Maize: Panacea for hunger in Nigeria," *African J. Plant Sci.*, vol. 9, no. 3, pp. 155–174, 2015.

[9] E. C. Oriaku, C. N. Agulanna, H. U. Nwannewuihe, M. C. Onwukwe, and I. D. Adiele, "Design and performance evaluation of a corn de-cobbing and separating machine," *Am. J. Eng. Res.*, vol. 3, no. 6, pp. 127–136, 2014.

[10] M. Takawira-Nyakuchena and T. Mushiri, "Design of an automated maize de-husking machine for the case of Zimbabwe," *Procedia Manuf.*, vol. 43, pp. 127–134, 2020, doi: 10.1016/j.promfg.2020.02.126.

[11] M. M. Metwalli, M. A. Helmy, S. M. Gomaa, and M. E. Badawy, "Evaluation of some parameters affecting corn sheller performance," *Misr J. Ag. Eng*, vol. 12, no. 2, pp. 439–455, 1995.

[12] M. A. A. Mady, "MANUFACTURED AND EVALUATION OF CORN SHELLER SUITABLE FOR EGYPTIAN FARMER," *Misr J. Agric. Eng.*, vol. 33, no. 2, pp. 319–334, Apr. 2016, doi: 10.21608/mjae.2016.97799.

[13] M. A. Abd EL-Maksoud, "Establishing and testing a racked Vertical disk corn Sheller," *Misr J. Ag. Eng*, vol. 13, no. 1, pp. 101–121, 1996.

[14] A. G. Darudkar, C. C. Handa, A. G. Darudkar, and C. C. Handa, "Literature review of corn sheller machine," *Int. J.*, vol. 2, pp. 238–240, 2015.

[15] P. C. Rousé, "Comparison of Methods for the Measurement of the Angle of Repose of Granular Materials," *Geotech. Test. J.*, vol. 37, no. 1, p. 20120144, Jan. 2014, doi: 10.1520/GTJ20120144.

[16] J. K. G. R.S.KHURMI, *Theory of Machines. 1st edition*. New Delhi: Eurasia Publishing House Pvt Ltd, 2010.

[17] S. Nemat-Nasser, "Brittle Materials: Compressive Strength," in *Encyclopedia of Materials: Science and Technology*, Elsevier, 2001, pp. 806–811. doi: 10.1016/B0-08-043152-6/00154-6.

[18] D. Nsubuga, I. Kabenge, A. Zziwa, N. Kiggundu, J. Wanyama, and N. Banadda, "Improving Maize Shelling Operation Using Motorized Mobile Shellers: A Step towards Reducing Postharvest Losses in Low Developing Countries," in *Maize Genetic Resources - Breeding Strategies and Recent Advances*, IntechOpen, 2022. doi: 10.5772/intechopen.101039.

[19] B. O. Ezurike, J. O. Osazuwa, and C. A. Okoronkwo, "Performance evaluation of an electric corn shelling machine for small scale indigenous industries in Nigeria," *African J. Sci. Technol. Innov. Dev.*, vol. 12, no. 4, pp. 355–364, Jun. 2020, doi: 10.1080/20421338.2019.1651480.