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INCORPORATING GRAIN DETECTION AND SPEED CONTROL MECHANISMS IN HAMMER MILL OPERATIONS

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Abstract

The traditional way of achieving different grain particle sizes in hammer mills is by manually changing the screen to the desired size. This manual process is a production procedure that is time-consuming, demanding, and resource-draining. This study incorporated a grain identification and speed control mechanism into a hammer mill machine. The grain detection mechanism is a system that recognizes a grain type through an RGB (Red, Green, Blue) colour sensor. The system has been programmed and trained to vary the speed of a 2hp electric motor with a maximum speed of 2800rpm based on the colour-matching result obtained when the grain is scanned on the colour sensor. The machine was evaluated using performance parameters such as power consumption and grain sieve analysis of milled grains using three crops (yellow corn, white corn, and cowpea). The Three crops were programmed for milling at three motor speeds (2800rpm, 2200rpm, and 1800rpm), and the result is presented. This paper showed that fine, medium and coarse aggregates were obtained for all three-grain types by varying motor speeds, eliminating the need to manually change the screen. The system was responsive to grain identification and speed selection as programmed.

Keywords: Hammer mill, Motor speeds, Colour sensor, Particle size.

1.0 INTRODUCTION

Due to its ease of use, low maintenance requirements, and simplicity, the hammer mill is almost exclusively used to prepare animal feeds [1]. Grinding of grains for feed production requires different particle sizes to fit in for different livestock; for example, the particle size requirement for the preparation of feed for day old chick is different from the particle size requirement for feed production for layers. Some of the established reasons why animal feeds undergo size reduction include expedited feed consumption, improved nutrient absorption, reduction in material handling and labor costs [2, 3]. One of the ways to control the particle size due to differences in mechanical properties of biomaterials is to regulate the speed of the electric motor to suit either the grain type or the purpose of grinding. One of the factors that affect the efficiency of the Hammer mill is also the speed of rotation of the hammers, which is directly proportional to the speed of the motor shaft [4, 5].

With the advent of agriculture 3.0 and 4.0, academics are increasingly focusing on creating novel manufacturing processes through automating agricultural production processes, aiming for efficient and sustainable resource utilization. Automated feed mills operations can reduce operating costs, allow for better control over grinding rate, loss factor, and mill functionality, and increase production throughput. Agricultural automation and robotics have the potential to help society meet its future food production needs. These technologies have already reduced production costs, reduced intensive manual labour, improved farm product quality, and improved environmental control. The use of automation to complete tasks consistently eliminates the need for human intervention. Physically performing repetitive tasks is no longer required, allowing workers to focus on more complex and critical duties. Automation can be used to both remove workers from hazardous areas and install dependable safety controls.

A thorough understanding of the raw material grinding process through the hammer mill is required before automating one. The traditional method of obtaining variable particle sizes for feed manufacturing is changing the screen to match the desired micrometre size, making changing the screen a crucial manual job in hammer mill operation. The operator must also disassemble the complete machine to retrieve the screen. This repetitious procedure is time-consuming, exhausting, and resource-draining. When grinding grain, the operator will first identify the grain and select a screen size that best fits the desired grain size, as is a common procedure.

The hammer mill principally consists of two major parts which are the grinding and the sieving components [6]. This research aims to automate the process of obtaining different grain sizes by introducing a grain recognition mechanism and eliminating the need to change the screen manually through the electric motor speed variation. The primary focus of this system is to reduce the amount of manual labour required by the operator in grain sorting and changing the screen. The objective of this study is to develop a mechanism for a hammer mill machine to produce different grain sizes during grinding operation without the need to change the screens as obtainable in conventional hammer mills. The Automation method developed in this study saves time, labour and money.

Hammer mills have wide applicability in biomaterial size reduction because of their simple design, ruggedness, and versatility. Hammer mills have achieved merit because of their ability to finely grind a greater variety of materials than any other machine [7]. Some of the factors that influence hammer mill performance include; tip speed, grinding rate, screen size, and clearance [8, 9]. One of the crucial steps in making feed is grinding the raw materials. It's a noisy, dirty operation that often requires a lot of electricity [10]. The hammer mill is the most common machine used for this purpose. The basic principle behind hammer mills is that most materials will crush, shatter, or pulverize when struck [10, 11]. For the hammer mill to function, it relies on a simple four-step process discussed below; 1) Material is usually fed into the mill by gravity. 2) The material is repeatedly struck by flailing ganged hammers inside the grinding chamber, which are connected to a shaft that rotates at a predetermined speed, a combination of hammer blows, collisions with the grinding chamber walls, and particle-on-particle impacts crush the material. 3) Mill discharge openings are covered with perforated metal screens or bar grates, retaining coarse material for further processing while permitting the passage of sizeable material. 4) Gravity allows hard, heavy materials such as stone, glass, or metal to exit the mill. For effective discharge of lighter or low-density materials like wood and paper, pneumatic suction may be required [10].

The principle behind grain detection in this work is the attribution of sample grain types to their specific colour range. A colour sensor was used to determine and store the primary colour of a sample grain by assigning a range of values in red, blue and green.

Quite a number of shortcomings of conventional hammer mills have been identified and suggestions put forward by some researchers [12, 13]. A further review of research carried out in the field of grain grinding, which investigates the performance of the hammer mill in relation to particle size and power consumption, is discussed. The particle size of the grounded output from a hammer mill is an important factor when determining the end user of the feed to be produced. Martins [14] stated that using large particle sizes for the grain component of the diet is attractive because of the substantial reduction of energy for grinding if the grain could be less finely ground without adverse effects. He added that ingredients with widely varying particle sizes are more difficult to mix properly, and large particles tend to segregate from smaller ones during subsequent handling after mixing. The speed of rotation of the revolving hammer speed affects the general grinding outcome and it has previously been established that the speed and the number of hammers have direct effects on both the fuel consumption and the overall efficiency of the machine. It has likewise been proven that increasing hammer revolving speeds from 1000 to 2500rpm (16.6 to 41.5m/s) will cause a corresponding increase in machine productivity [15, 16].

In relation to energy and power consumption, [17] indicated that the power requirements for grinding biomass are related to biomass selection, initial and final particle sizes (geometric mean diameter), moisture content, and feed rate of the material. Hassan [18] discovered that increasing the drum speed from 1460 to 2930 and 3910rpm reduced grinding energy by 59.1 and 67.9%, respectively, he observed that the grinding energy increased by 20.1 and 49% as grain moisture content increased from 5.4 to 8.1 and 11.4% respectively. He concluded that the fine grinding percentage was obtained at a lower grain moisture content and a faster drum speed. Furthermore, an opposite trend was observed when the fineness degree of grinding (medium and coarse) was compared to fine grinding [18].

2.0 MATERIALS AND METHODS

2.1 Methodology Overview

Grinding grains for feed requires different particle sizes to accommodate different livestock. For example, the particle size requirement for day-old chick feed preparation differs from that for layer feed production. To control particle size due to differences in mechanical properties of biomaterials, one method is to adjust the speed of the electric motor to suit either the grain type or the purpose of grinding. One of the factors influencing hammer mill efficiency is the speed of rotation of the hammers [19] which is directly proportional to the speed of the motor shaft. The principle underlying grain detection in this work is the attribution of sample grain types to their specific colour range. The primary colour of a sample grain was determined and stored by assigning a range of values in red, blue, and green to a colour sensor.

Figure 1 is the overall block diagram which gives an overview of the interaction between the key components of the developed system. Figure 2 shows a circuit controlling the speed based on the material's colour to be ground. It uses a TCS34725 RGB sensor, which can detect and represent colours in terms of the primary colours; red, green, and blue. Atmega 328 microcontroller converts analogue reference voltage (5v) into 10-bit number from 0 to 1023 [20]. When the sensor detects a colour, it sends the corresponding colour values to the C++-programmed microcontroller (Atmega328p). The circuit has been designed to be trainable. A specific colour is detected through training, and a motor speed is assigned to it through programming using the push buttons shown in the circuit diagram in Figure 2.

The motor is primarily powered by a high current (41A) thyristor (BTA41600B), and the circuit configuration of R1, RV1, and C1 all work together to control the motor speed. RV1 is a variable resistor that changes the phase angle of the thyristor's gate trigger voltage. The circuit diagram shows that the variable resistor's spindle has been assigned to the servo motor (speed-controlling servo). The servo motor can be set to turn in extremely small angular ranges, enabling it to turn the variable resistor to any angle that has been programmed into it.

The circuit also incorporates a 20 x 4 alphanumeric LCD. This display provides the interface between the user and the Device. It displays the speed and the detected colours by default. In this circuit, the motor runs on a 220V alternating current (AC) mains system while the low voltage electronics run on a 5V direct current (DC) system. An AC to DC converter module has been used to step down the regular 220V AC from the public mains to 5V DC required by the low voltage control circuit.

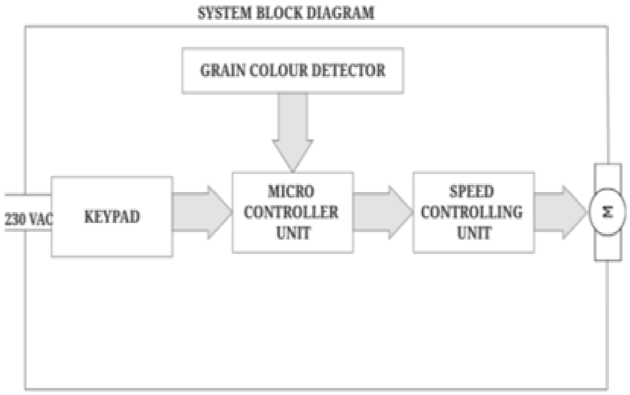

Figure 1: Block Diagram for Colour-Based Speed Controller

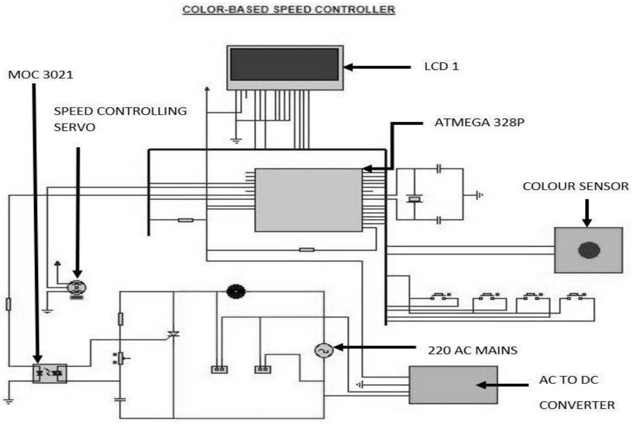

Figure 2: Circuit Diagram for Colour-Based Speed Controller

2.2 Material Overview

2.2.1 Microcontroller ATmega328

ATmega328 is an 8-bit AVR microcontroller with 28 pins. It is an 8-bit AVR microcontroller with low power consumption and good performance. It has 14 digital I/O pins. It operates on a 5V DC voltage. It is the system's control centre.

2.2.2 Voltage regulator dimmer/motor speed controller module

This 4000W Thyristor SCR Voltage Regulator Temperature Dimmer for Speed (AC 220V) can be used to regulate 220V Appliances. It can control up to 4000W of power. The onboard potentiometer knob controls and sets the 220V Device's needed power output.

2.2.3 TCS34725 RGB sensor module

The RGB TCS34725 Color Sensor Module is one of the greatest modules for displaying various breathtaking colours. This module has a range of 3800000:1. The TCS34725 RGB Color Sensor Module returns digital values for sensing Red, Green, Blue (RGB), and clear light. The TCS34725 RGB Color Sensor Module's high sensitivity, wide dynamic range, and IR blocking filter make it an ideal colour sensor for various lighting settings and attenuating materials. This data is transmitted to the host through I2C.

2.2.4 LCD display

This provides a user interface for information display. A rotary encoder is utilized to navigate and select menu items on display. It is a 20-character-by-4-line LCD panel with a blue backlight and white characters. Each character is represented by a 5 × 8 dot matrix to ensure accurate character representation.

2.2.5 DC cooling fan

A 12V DC cooling fan was attached to the speed controller module to cool it as it releases a significant quantity of heat when in operation.

2.3 Experimental Testing of the Grain Detection and Speed Selection Module

The grain detection and speed selection module was connected to an suction hammer mill as shown in Figure 3. Performance evaluation of the hammer mill was carried out to determine the geometric mean diameter, the uniformity index of the particle size, and the flour produced. Power consumption.

Whole yellow dent corn, White corn and cowpea (Brown) was used in this experiment. The colour disparity in the chosen grains is important because we are making use of a RGB colour sensor to identify each grain, once the colour of a particular grain is captured and stored by the microcontroller, a desired grinding speed threshold is assigned. The grains were kept at a constant moisture content of 10%. The grain identification and speed selection module was trained to identify each crop and programmed to grind at 3 different speeds of the electric motor. The hammer mill was turned on and 500g of each sample grain was milled at three different speeds (2800rpm, 2200rpm and 1800rpm). Each milled grain sample was collected in a porous sack and poured in a container. The milled samples were collated and taken for grain sieve analysis. The power consumption during the experimental procedure for the milling at three different speeds was also recorded with a wattmeter.

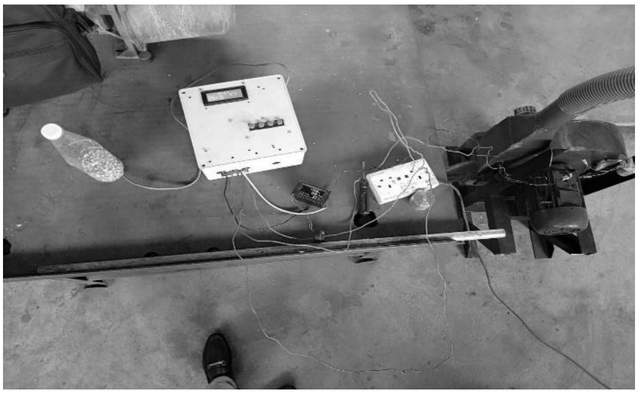

Figure 3: Grain Detection and speed control apparatus

2.3 Performance Evaluation

The performance evaluation of the hammer mill grinding operation was done using the following performance indicators.

2.3.1 Geometric mean diameter (d_{gw})

The Geometric mean diameter (d_{gw}) parameter was used to evaluate performance. The geometric mean diameter measures the central tendency of substrate materials' particle size composition that is sometimes used as an index of spawning gravel quality. When data is highly skewed, as in most particle size distributions, geometric means are the best choice. The Geometric mean diameter (d_{gw}) of the particle size distribution of the ground corn at the hammer rotor maximum speed of 2800rpm and the particle size distribution of the ground corn at two other different levels of hammer/rotor speed is to be determined according to (ASABE,1999) Standard.

$$d_{gw} = \log^{-1}\left(\frac{\sum_{i=1}^{n}(W_i \log d_i)}{\sum_{i=1}^{n} W_i}\right)$$

where, d_{gw} = The geometric mean diameter (mm), W_i = The mass on the i_{th} sieve (g), n = The number of sieves, d_i = The Nominal sieve aperture size of the i_{th} sieve (mm).

At the end of the evaluation, a graph was used to illustrate the effect of hammer speed at a constant feeding rate and on the geometric mean diameter of the grain.

2.3.2 Geometric standard deviation (S_{gw})

The mean standard deviation is a measurement of the particle size variation around the geometric mean diameter d_{gw}. It calculates the particle size range to represent 68% of the particle in a sample. 68% of the particles are determined by finding the difference between the upper and lower limits using the S_{gw}.

$$S_{gw} = \text{Log}^{-1}\left[\frac{\sum W_i\left(\text{Log}\, d_i - \text{Log}\, d_{gw}\right)^2}{\sum W_i}\right]^{1/2}$$

S_{gw} = is the standard deviation of d_{gw},

$\frac{d_{gw}}{S_{gw}}$ = Lower limit, $d_{gw} \times S_{gw}$ = Upper limit

3.0 RESULT AND DISCUSSION

It was discovered that the RGB sensor was capable of detecting grains with high precision during the test. A hammer mill machine was incorporated with the grain detection mechanism that enables the hammer mill machine to match each grain colour to a specific speed as requested by the operator. The grain detection mechanism is controlled by Atmega328p microcontroller. When grain is recorded by the RGB sensor, the hammer mill has the capability of assigning a certain rotor speed to a given type of grain. Samples of each treatment were collected and stored in vacuum-sealed bags to minimize moisture loss and later analyzed for particle size. The particle size distribution of the sample was then determined using the sieving method by employing sieve vibrator equipment. Eight available sieve sizes (4760µm, 2380µm,1190µm, 595µm, 297µm, 149µm, 74µm, and 53µm) were mounted on the sieve vibrator in decreasing order with a pan collector directly placed beneath the sieve 53 µm.

The sample was placed on the top sieve of a set of sieves. The sieve vibrator was operated for 10 minutes, and the results are presented below. The amount of material on each sieve was used to calculate the geometric mean diameter (d_{gw}) and geometric standard deviation (S_{gw}).

3.1 Geometric Mean Diameter and Standard Deviation

The grain sieve analysis showed a geometric mean diameter of 149, 954, and 1995 microns for milled yellow corn, 150, 954, and 1993 microns for milled white corn, and 103, 480, 891 microns for milled cowpea each at 2800 rpm, 2200 rpm, and 1800 rpm. The graphical representation of the results obtained is shown Tables 1 and 2.

Table 1: Geometric mean diameter at different motor speed

Test Sample	**Geometric mean diameter**		
	2800 rpm	**2200 rpm**	**1800 rpm**
Milled White maize	149	954	1995
Milled Yellow maize	150	955	1795
Cowpea	103	480	891

Table 2: Geometric standard deviation at different motor speed

Test Sample	**Geometric standard deviation**		
	2800 rpm	**2200 rpm**	**1800 rpm**
Milled White maize	2.89	2.259	2.89
Milled Yellow maize	2.9	2.27	2.85
Cowpea	2.6	2.202	2.62

3.2 Power Consumed During Testing

The power consumption during the experimental procedure for the milling at three different speeds was recorded from the wattmeter, and the result is shown in Table 3. The graphical representation of the results obtained is shown in Figure 5.

Table 3: Power Consumption at a speed of 1800rpm, 2200rpm, 2800rpm

Rotor Speed (RPM)	1800	2400	2800
Power Consumed (WATT)	625	845	1260

Figure 4 shows how the geometric mean diameter of milled yellow corn, white corn, and cowpea increased steeply as the electric motor speed changed at 2800, 2200, and 1800rpm. This increase demonstrates an inverse proportionate relationship between the geometric mean diameter and the speed of the electric motor. This result bolstered and supported the claim that increasing drum speed results in an opposite trend in grain fineness [8].

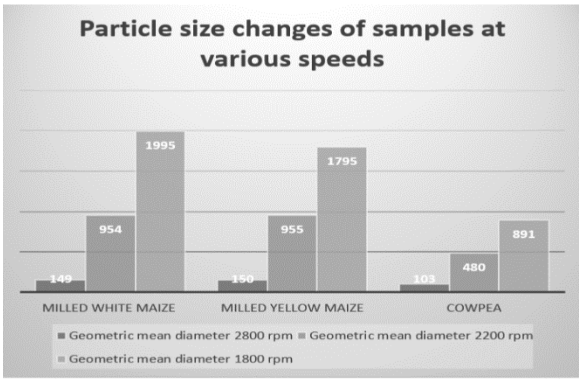

Figure 4: Sieve analysis graph depicting the geometric mean diameter of each grain while milling at different rotor speeds.

According to the sieve analysis performed at a milling speed of 2800rpm, 68% of the yellow milled corn particles range in size from 112 to 897 microns, with a mean diameter of 317 microns. At a milling speed of 2200rpm, 68% of the white milled corn particles are between 370 and 5176 microns in diameter, with a mean diameter of 1384 microns, while at a milling speed of 1800rpm, 68% of the milled bean particles are between 481 and 4989 microns in diameter, with a mean diameter of 1517 microns.

Figure 5 shows that the geometric standard deviation was at its peak for grains milled at 2800 rpm and 1800 rpm, representing the electric motor's highest and lowest speed levels, respectively. However, the geometric standard deviation dropped for all grains when milled at an average speed of 2200 rpm. This geometric standard deviation calculates the 68th percentile of a given sample's grain geometric diameter.

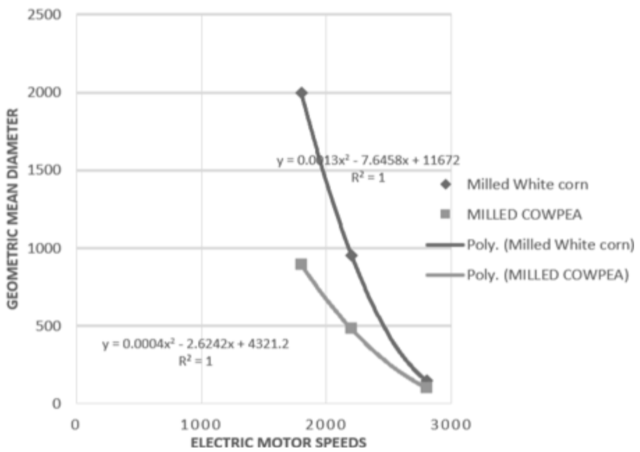

Figure 5: Geometric mean diameter versus electric motor speed

The results of the sieve examination for the milled white corn showed that at a speed of 2800rpm, 68% of the particles were between 52 and 421 microns in size. When milling at 2200rpm, 68% of the particles are between 422 and 2156 microns in size, while when milling at 1800rpm, 68% of the particles are between 702 and 5666 microns in size. According to the sieve analysis performed on the milled yellow maize, 68% of the particles are between 52 and 435 microns in size at a milling speed of 2800rpm. While 68% of the particles are 420-2167 microns in size while milling at 2200rpm, this number increases to 81% at 1800 rpm. It was determined by sieve analysis that at 2800 rpm, 68% of the particles in the cowpea are between 40 and 268 microns in size. Milling at 2200 rpm produces particles between 420 and 1067 microns in size, while milling at 1800 rpm produces particles between 340 and 2334 microns.

The study of hammer mill machine speed is important to let the operator program the machine to a particular speed that guarantees optimization. The plot of power utilized against the motor speed, as shown in Figure 6, indicates that the power consumption during the milling process is directly proportional to the electric motor speed. This can affect the overall process efficiency of the machine as more power consumption will mean more energy usage, leading to an increase in machine operating costs [21]. The highest power consumed was noticed at the operating speed of 2800 rpm. The power consumption was at its lowest when the machine was at its lowest speed. The machine performed more optimally with an electric motor of 1.75kw, resulting in a crushing capacity of 150 ± 2.4 kg/hr when compared with a similar machine developed with an electric motor of 3.7kw but with a lower crushing capacity of 100kg/hr [22].

The relationship between the geometric mean diameter to electric motor speeds of the machine for maize milling is given by;

$$y = 0.0013x^2 - 7.6458x + 11672$$
$$R^2 = 1$$

While the relationship of geometric mean diameter to electric motor speeds of the machine for cowpea milling is given by;

$$y = 0.004x^2 - 2.6242x + 4321.2$$
$$R^2 = 1$$

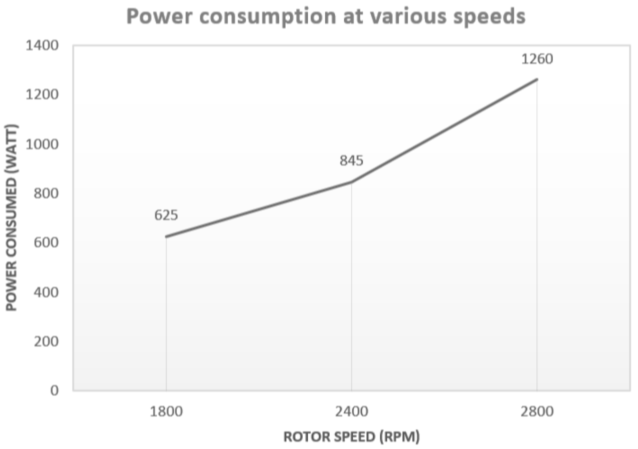

Figure 6: Sieve analysis graph depicting the power consumption against different milling speed

4.0 CONCLUSION

This design incorporates a grain detection mechanism that allows the hammer mill machine to match each grain colour to a specific speed specified by the operator. The Atmega328p Microcontroller controls the grain detection mechanism. When the RGB sensor detects grain, the hammer mill can assign a specific rotor speed to each type of grain. Small-scale feed mills and poultry farmers who want to create a compound feed on their farms using small-scale feed equipment will be able to automate the production process by programming the control part of the machine to operate at a specific speed for a specific grain to achieve a desired grain particle size using this new technique.

This design also eliminates the need to constantly change hammer mill screens, which is typical of traditional hammer mills. The grain particle size can be changed simply by programming the required speed to create the desired grain size. The results established that decreasing the machine's electric motor speed yields a larger geometric mean diameter in a milling process. It was also discovered that decreasing the electric motor speed results in lower power consumption or energy requirement of the machine. The relationship between motor speed and productivity and electricity consumption per ton has been shown. It was observed that the increase in the motor speed caused an increase in the fineness degree of the milled corn, and the decrease in the motor speed increased the coarseness of the milled cowpea. The results obtained established that decreasing the electric motor speed of the machine yields a higher geometric mean diameter in a milling process. It was also established that by decreasing the electric motor speed, a lower power consumption or energy requirement of the machine is obtained.

The findings of this study may provide useful guidance for low-scale farmers in selecting an appropriate hammer mill machine to greatly reduce feed production costs to optimize hammer mill performance by automating the production process to save time and reduce the cost of man labour.

REFERENCES

[1] Dhanashri, U. B., Ramdas, V. K., Avinash, A. H., and Sawant, S. S. “Half Sieve Hammer Mill Machine”, *International Journal of Advanced Engineering Research and Science (IJAERS)*, vol. 10, no. 5, pp.28-31, 2023. https://dx.doi.org/10.22161/ijaers.105.3

[2] Mugabi, R., Byaruhanga, Y. B., Eskridge, K. M., and Weller, C. L. “Performance evaluation of a hammer mill during grinding of maize grains”, *Agricultural Engineering International: CIGR Journal*, vol. 21, no. 2, pp.170-179, 2019. http://www.cigrjournal.org

[3] Basiouny, M. A. and El-Yamani, A. E. “Performance Evaluation Of Two Different Hammer Mills For Grinding Corn Cobs”, *Journal of Soil Sciences and Agricultural Engineering*, vol. 7, no. 1, pp.77- 87, 2016.

[4] Mariam A. A., El-Sayed A., Ali, E., and Victor, M. D. “Modified and improved performance of local hammermill for mushroom residues chopping”, *Bulletin of the National Research Centre*, Vol. 46, no. 228, pp.1-9, 2022. https://doi.org/10.1186/s42269-022-00920-y

[5] Joseph, B. B., Isaac, F. O., and Joshua, A. O. “A Comparative Technique for Performance Evaluation of Hammer Mill and Disk Mill in Yam Flour Processing”, *World Journal of Engineering and Technology*, vol. 10, pp.613-625, 2022. https://doi.org/10.4236/wjet.2022.103040

[6] Ojomo, A. O., and Fawohunre, A. J. “Development of a Hammer Mill with Double Sieving Screens”, *EJERS, European Journal of Engineering Research and Science*, vol. 5, no. 5, pp.617-621, 2020. http://dx.doi.org/10.24018/ejers.2020.5.5.1763

[7] Scholten, R., and McEllhiney, R. “The effects of prebreaking in hammer mill particle size reduction”, *American Society of Agricultural Engineers*, pp. 85-3542, 1985.

[8] Hall, C., and Davis, D. “Processing Equipment for Agricultural Products”, *The AVI Publishing Company, Inc*., 1979.

[9] Lopo, P. “The right grinding solution for you: roll, horizontal or vertical. Feed Management”, *American Journal of Food science and Technology*, pp. 53(3):23-26., 2002.

[10] Buffalo, S. “Introduction to size reduction,” 2002. [Online]. Available: www.hammermill.com. [Accessed 17 January 2023].

[11] Ezurike, B. O., Osazuwa, O. J., Okoronkwo, C. A., and Okoji, K. I. “Design, construction and performance evaluation of a flat screen hammer mill machine” African Journal of Science, Technology, Innovation and Development, vol. 10, no. 6, pp.683-690, 2018. https://doi.org/10.1080/20421338.2018.1491675

[12] Oluwole, F. A., Gujja, A., and Abubakar, A. K. “Effect of Number of Beaters on the Performance of Household Hammer Mill. Arid Zone”, *Journal of Engineering, Technology & Environment*, Vol. 15, no. 3, pp.619-627, 2019. www.azojete.com.ng

[13] Justine, O. B., Mustapha, M., and Mukhtar, D. H. “Design, Fabrication and Testing of a Direct

Drive Electric Powered Hammer Mill Machine", *FUOYE Journal of Engineering and Technology*, Vol. 7, no. 2, pp.200-204, 2022. http://doi.org/10.46792/fuoyejet.v7i2.794

[14] Martin, S. "The effect of particle size on mixing and pelleting quality", *Proceedings of The First International Symp. on Particle Size Reduction in the feed*, Manhattan, U.S.A, 1983.

[15] Hegazy, K. E. S, Mosa, M., El-Ashhab, A., Magda, M., and Hemeda, B. "Preparation and conversion of eggshell as hatchery by-product wastes to produce untraditional poultry", *Misr Journal of Agricultural Engineering*, Vol. 19, no. 2, pp.958- 972, 2002.

[16] Alhaji, G., Bawu, B. M., Grema, L. U., Ndriza, Y. M., and Bunu, M. "Design, Modification and Performance Evaluation of Household Hammer Mill", *International Journal of Information, Engineering and Technology*, Vol. 2, no. 5, pp.95-103, 2021.

[17] Mani, S., Tabil, L., and Sokhansanj, S. "Grinding Performance and Physical Properties of Selected Biomass", *St. Joseph: American Society of Agricultural Engineers*, Vol. 27, no. 4, pp.339-352, 2004.

[18] Hassan, M. "Modifying and evaluation of a small locally made mixmilling unit suitable for egyptain poultry farms", *Misr Journal of Agriculture*, Vol. 11, no. 2, pp. 569 -584, 1994.

[19] Desta, M. A., and Oumer, A. "Design and Performance Evaluation of Grain Feed Grinding Machine", *Turkish Journal of Agricultural Engineering Research*, vol. 3, no. 2, pp.231-244, 2022. https://doi.org/10.46592/tu rkager.1144063

[20] Oyelami, A. T. and Shoge, S. A. "Low-Cost Automated Poultry Feeding System Using Atmega328 Microcontroller", *International Journal of Basic Science and Technology*, Vol. 8, no. 3, pp.251-257, 2022. https://doi.org/10.5555/RFPY5777

[21] Opadotun, O. O, Oladipo, N. O, Okoro, O. N and Oriola, K. O. "Effects of Operating Speed and Screen Diameters on the Efficiency of a Hammer Mill", *Journal of Agricultural Engineering and Technology (JAET)*, Vol. 23, no. 2, pp.9-18, 2017.

[22] Workalemahu, M., Beruk, H., and Ashokkumar, T. "Redesign and Fabrication of Hammer Milling Machine for Making Pasta", *International Journal of ChemTech Research*, vol. 12, no. 3, pp.202-218, 2019. http://dx.doi.org/10.20902/IJCTR.2019.120327