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Development of an Integrated Mobile Corn-Starch Processing Machine

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***Abstract**: This study presents development of an integrated mobile corn-starch processing machine. Sieving and dehydrating operation in corn-starch production are mostly carried out locally thereby introducing drawbacks such as time-consuming, tedious, and inefficient. The existing machines for corn-starch processing, are primarily designed for industrial use, limiting accessibility for rural communities. This necessitate the development of an integrated corn-starch machine aims to improve the efficiency and effectiveness of the corn-starch production process. The machine involved the streamlining the overall corn-starch process, thereby eliminating the need for multiple pieces of equipment. The performance of the machine was evaluated based on extraction efficiency, throughput rate, and mass of chaff separated. The evaluation was conducted through three processing test runs using the fabricated prototype and the results revealed an average extraction efficiency of 70.58% for the sieving process, with a throughput rate of 57.59 kg/hr and a mass of chaff separated amounting to 1.73 kg. Also, the grinding operation exhibited an average extraction rate of 80% for soaked grain, with a throughput rate of 25.16 kg/hr. The results show that the machine has the potential to improve the efficiency of corn-starch processing and contribute to the sustainable production of value-added products from corn. However, further modification of the machine's design and operating conditions are necessary to address its limitations and improve its sustainability and versatility.*

Keywords: Corn-starch, machine, grinding, sieving, dehydrating.

1. INTRODUCTION

Corn has been a staple food for many cultures for thousands of years and is consumed directly by humans when boiled or fried, use as animal feed and processed products like corn-starch. Corn-starch is given special prominence because is a widely used ingredient in the food industry for its thickening and stabilizing properties [1, 2]. Corn-starch is typically processed manually, starting with soaking of the corn, followed by wet-milling of the fermented product to soften it. The softened product is then sifted to separate the nutrient from the chaff, with the nutrient collected through decantation. The quality of the final product is greatly influenced by the grinding and sifting processes, which impacts the nutritional content of the product for human consumption [3].

The manual method, as elucidated by [4], has been characterized as a labour-intensive, tedious, and unsanitary process. Studies have unveiled that a substantial quantity of nutrients is lost during the processing, and the arduous technique contributes to reduction in its taste profile [5]. However, grinding and sieving of dry products have evolved from traditional mechanical techniques to advanced approaches, there is a noticeable dearth of attention directed towards mechanizing sieving wet agricultural food products on a modest scale for home use considering its high demand [6].

Most of extraction machines for processing corn-starch were designed for industrial use without consideration of rural dwellers who do not have access to industrial machines [7]. Despite the availability of corn-starch machines, many small and medium scale productions in developing economies still use the traditional method due to economic reasons.

In Nigeria corn-starch has played a vital role in ensuring meal sufficiency for human population, average Nigerians take pap on a daily basis, unlike rice. Corn-starch is considered a highly nutritious food that is rich in vitamins, lipids, oils, protein, and carbohydrates [8]. Proper processing enhances its nutritional value, making it a valuable and well-regarded food that does not require refrigeration during storage and distribution due to its fermentation. Despite process common misconceptions, it is not a typical food, but rather a nutritious product derived from cereals and the fermentation process, offering numerous health benefits [8].

The processing of corn-starch ("Ogi") involves various unit operations after harvesting, such as cleaning the corn by winnowing and floatation, soaking the corn in water for two to three days to allow for fermentation (which is accelerated by increasing the ambient temperature), wet-milling the soaked grains to form a paste, and separating the starch content from the chaff through sieving. The complete process takes around 60 to 120 hours (3 to 5 days). After the separation of the starch content from the chaff through sieving, it is left to settle for some time before undergoing the final stages, dehydration and drying. Traditionally, corn-starch is wet-milled into paste using grinding stones or pestle and mortar, while sieving is performed manually by hand stirring the grain paste on a chiffon cloth (sieving bag) tied firmly over a big bowl with water being added at intervals to wash the starch content into the bowl, leaving the chaff on the surface of the chiffon cloth [9]. Dehydration is a crucial step in the production of lump-form filtered food with a low moisture content and process takes place right after sedimentation or decantation, and is just as indispensable process to sedimentation as sieving is to milling.

A multi-functional machine was developed by [10-12] for sieving both dry agricultural products and soil sample. There have been several machines designed for the process of corn-starch but relatively little work has been done on developing a machine that combines the batch tasks and complete them all at once [13]. According to [6], the current method of grain production results in low productivity and the majority of available wet sieving machines are complex and designed for large-scale businesses, posing difficulties for small-scale processors. To address this issue, a reciprocating mechanism-based motorized starch extraction machine was developed and the results of the study indicated that when the concentration decreased, the machine's performance coefficients and sieving capacity increased. [13] also developed an automated grain beverage processing machine that is capable to complete a batch tasks (blending of soaked grains, mixing the slurry, extracting the aqueous liquid, and discharging the paste from the machine). The absence of a backup power source and high-power consumption, preclude it from being utilized in rural locations. A batch grain beverage processing machine that blends soaked grains, mixes the slurry, and extracts the aqueous liquid at a go was developed by [8]. The machine major drawback is absence of automation. Also, [4] designed a suction-based sieving machine for corn slurry using vacuum pressure, but it had several shortcomings such as low sieving rate, insufficient suction pressure, and suction line interfering with the filtrate flow stream at the exit. To address these issues, [14] developed an improved prototype of food slurry processing machine using vibration. However, the efficiency of the machine extraction heavily relies on the particle size of the fine paste from wet-milling, and thus, its performance was unsatisfactory. [15] evaluated suction and vibration-based sieving machines and proposed an integrated grinding and sieving system for slurry food processing. The primary aim was to provide a sieving system whose paste extraction efficiency will be less reliant on the milling process, which led to designing a single flow process machine capable of milling and sieving slurry products by [16]. This machine is a modification on [17] cassava starch extractor. [9] modified [13] machine and was able to eliminate the limitations.

Literature revealed the gaps of the existing designs for corn-starch processing, including issues with low sieving rates, the absence of an automated dehydration process, inadequate measures for contamination control and environmental pollution, and rural communities' who are major consumers of corn-starch inaccessibility to processing machines. This research aims to design and develop a streamlined mobile corn-starch processing machine capable to bridge the gap of the aforementioned shortcomings. To address the identified limitations, the project incorporates a dehydration unit with an automated hydraulic press. This unit is integrated with other processes to produce a unified and efficient machine. Also, the existing sieving operation is substituted with a stirring mechanism, chosen for its high sieving output. These enhancements aim to improve overall efficiency and performance in terms of sieving, dehydration, contamination control, and accessibility for rural communities.

2. MATERIALS AND METHODS

2.1 Materials

Selecting the right material is crucial in engineering. It involves selecting materials that are best suited to meet the design requirements and functional needs. Material selection plays a significant role in determining the functionality, feasibility, environmental impact and cost-effectiveness of a design, while also ensuring that the design goals are met [18]. The various materials selected for the various parts are based on its functionality. The materials used in this study are stainless steel, mild steel, and plastic.

1) *Stainless steels:* They are characterized primarily by their resistance to corrosion, high strength and ductility, and high chromium content [18]. Stainless steel's unique properties make it suitable for food and pharmaceutical applications and make it an ideal choice for use in milling, sieving, and dehydrating chambers.

2) *Mild steel:* Also known as low carbon steel, is a type of steel that contains a low percentage of carbon, typically up to 0.3 %. It is not responsive to heat treatment and this makes it easy to machine when compared to harder steels. Mild steel is less expensive, easy to weld, machine, and is considered the most versatile form of steel with properties that are suitable for general engineering applications. Due to its ductility and toughness, mild steel

was chosen for the construction of the frame and waste container.

3) Plastic: Plastic is a synthetic material employed in manufacturing a vast array of products, ranging from packaging materials and consumer goods to industrial components and medical devices. The composition of plastic varies, allowing for a diverse range of properties such as flexibility, strength, transparency, and resistance to heat or chemicals. As a result of these properties plastic was selected for the valves and discharge pipes.

2.2 Methods

1) Design analysis of the machine: The designs were on the milling capacity, milling shaft selection, sieving capacity, sieving power requirement, stirrers, mesh, dehydrating capacity, and shaft selection.

a. Milling capacity

The milling capacity is the throughput of processed corn-starch, and the efficiency of the milling operation is determined by the hopper capacity, feed rate and milling shaft. The hopper capacity was calculated using Equation (1).

$$V = \frac{1}{3}\pi h(R^2 + r^2 + Rr) = 0.008 \text{ m}^3 \quad (1)$$

Where V, π, h, R, r are the milling capacity (m^3), 3.142, height of the milling chamber (0.375 m), top radius (0.115 m), and bottom radius (0.044 m) respectively.

b. Milling shaft selection

The milling shaft is designed to endure the stresses involved in the milling operation. As a result, a solid shaft made of stainless steel was chosen for this purpose. The shaft diameter was calculated using Equation (2).

$$D = \sqrt[3]{\frac{16T}{\pi\sigma}} \quad (2)$$

Where D, P, σ, T are the shaft diameter (mm), power required (2 hp = 1.5 KW), design stress, torque (or twisting moment) acting on the shaft, respectively.

$$T = \frac{P}{\omega} \quad (3)$$

When N=1500 rpm, ω = 157.1 rad/sec

Torque, $T = \frac{1.5}{157.1}$ = 9.5 Nm

Stainless steel strength = 241 MPa and factor of safety = 10

Permissible shear stress strength $\tau = \sigma = \frac{241}{10}$ = 24.1 MPa

D = 0.0126 m = 12.6 mm.

c. Sieving capacity

The capacity of the sieving chamber was determined using Equation (4).

$$\mathbf{V} = \boldsymbol{\pi}\mathbf{r}^2\mathbf{h} = 0.0147 \text{ m}^3 \quad (4)$$

Where V, r, h are sieving capacity (m^3), radius of sieving chamber (0.25 m), and height of sieving chamber (0.3 m) respectively.

d. Mesh design

Mesh capacity

The capacity of mesh was obtained using Equation (4).

$V = \pi r^2 h$ = 0.0086 m^3

Where V, r, h is mesh capacity (m^3), mesh radius (0.1 m), and mesh height (0.275 m).

Mesh thickness

The thickness of mesh was determined as expressed by [19].

$$t = \frac{P_i \, x \, d}{2\Delta t} \quad (5)$$

$$P_i = P + P_w \quad (6)$$

Where t d, P_i, P, P_w are the wall thickness of the mesh, internal diameter of mesh, intensity of internal pressure, mesh pressure and mixture pressure respectively.

$$P = \frac{F_c}{A_c} \quad (7)$$

$$F_c = mr\omega^2 \quad (8)$$

The mass is given as:

$$m = \rho \times V = 5.375 \text{ kg} \quad (9)$$

Where F_c, m, ρ are the centrifugal force of stirring, mass of mixture, and bulk density of wet corn-starch (625 kg/m^3) respectively. The force acting in the mesh is given as:

$$F = m \times g = 52.73 \text{ N} \quad (10)$$

Where g is the acceleration due to gravity (9.81 m/s^2).

$$\omega = \frac{2\pi N}{60} \quad (11)$$

N=300 rpm, ω = 31.42 rad/sec, F_c = 530.63 N

Area on which Fc act, A_c = 2πrh = 0.173 m^2 (12)

P = 1839.4 N/m^2

$$P_w = \rho g h = 3070.6 \text{ N/m}^2 \quad (13)$$

$\Delta t \leq 5$ MPa

P_i = 3070.6 + 1839.4 = 4909.998 N/m^2

10 mm thick mesh was used.

e. Stirrer

The stirrer diameter was calculated using the following mathematical approach.

$$T = \frac{P}{\omega} \quad (14)$$

$T = \frac{373}{31.42}$ = 11.87 Nm

$$\tau = \frac{16T}{\pi d^3} \quad (15)$$

Where τ, T, d is the torsional stress, shaft required torque and shaft diameter respectively.

The design stress, σ and the torsional stress, τ are connected by the relation below;

$$\sigma \geq \tau \quad (16)$$

Substituting Equation (14) into Equation (15), the relations below were obtained

$$\sigma \geq \frac{16T}{\pi d^3} \quad (17)$$

$$d \geq \sqrt[3]{\frac{16T}{\pi\sigma}} \quad (18)$$

$$\sigma = \frac{\sigma_y}{F_s} \quad (19)$$

where σ_y, F_s are the yield strength for stainless steel and factor of safety respectively.

σ_y= 241 MPa and F_s = 4 [20].

$\sigma = \frac{241 \text{ x } 10^6}{4}$ = 60.25 MPa

$$d \geq \sqrt[3]{\frac{16 \times 11.87}{60.25 \times 10^6 \times 3.142}} = 0.01 \text{ m}$$

f. Sieving power requirement

$$P = T \times \frac{2\pi N}{60} \quad (20)$$

Required speed, N = 300 rpm

Required torque,

$$T = Fr \quad (21)$$

Radius of the shaft, r = 0.025 m, T = 1.32 Nm, and P = 41.47 W (0.1 hp)

0.5 hp is taken.

g. Dehydrating capacity

The capacity of dehydration unit was obtained using Equation (4).

$$V = \pi r^2 h = 0.0083 \text{ m}^3.$$

Where V, r, h are the dehydrating capacity (m^3), dehydrating radius (0.115 m) and dehydrating unit height (0.2 m) respectively.

2)Machine performance test: The performance of the machine was evaluated based on the sieving and dewatering efficiency of the machine and is defined as:

$$\eta_e = \frac{M_s}{M_s + M_c} \times 100 \quad (22)$$

Where η_e, M_s, M_c are the sieving efficiency (%), mass of slurry grain (kg), and mass of chaff (kg) respectively.

Milling efficiency was evaluated based on the grinding ability of the machine and was determined using Equation (23).

$$\eta_m = \frac{M_s}{M_g} \times 100 \quad (23)$$

Where η_m, M_g, M_s are the milling efficiency (%), mass of milled grain (kg) and mass of soaked grain (kg) respectively.

The capacity of the machine was evaluated based on the sieving throughput of the machine and is defined using Equation (24).

$$C_p = \frac{M_s}{t_p} \quad (24)$$

Where C_p, M_s, t_p are the throughput (kg/hr), mass of slurry grain or soaked grain (kg), and processing time (hr) respectively.

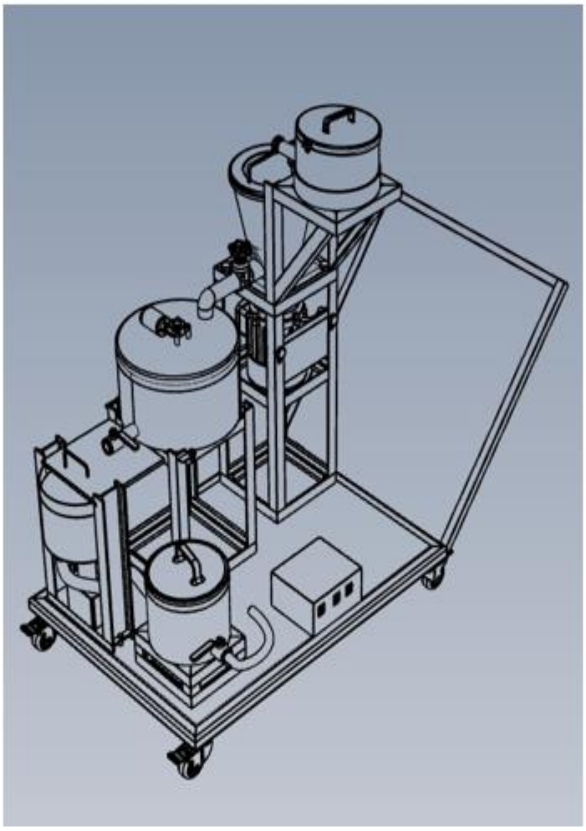


Figure 1: Isometric view of the corn-starch processing machine

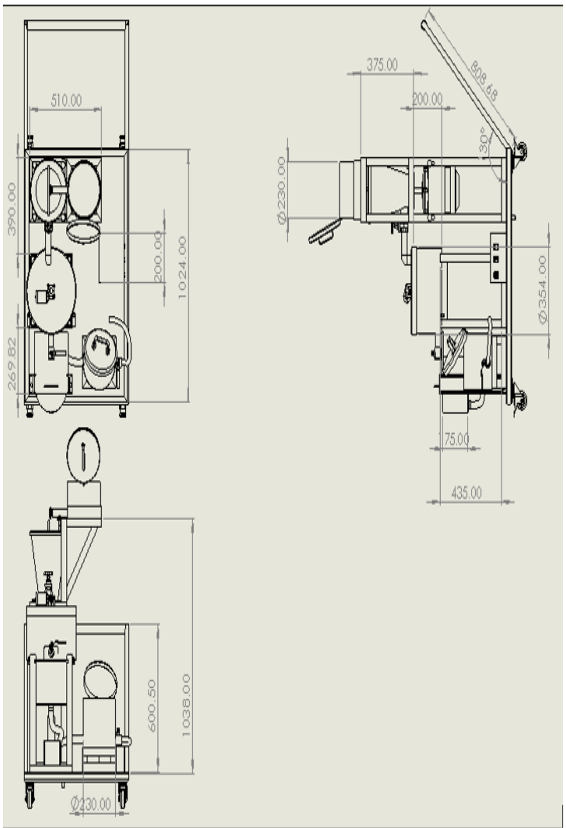
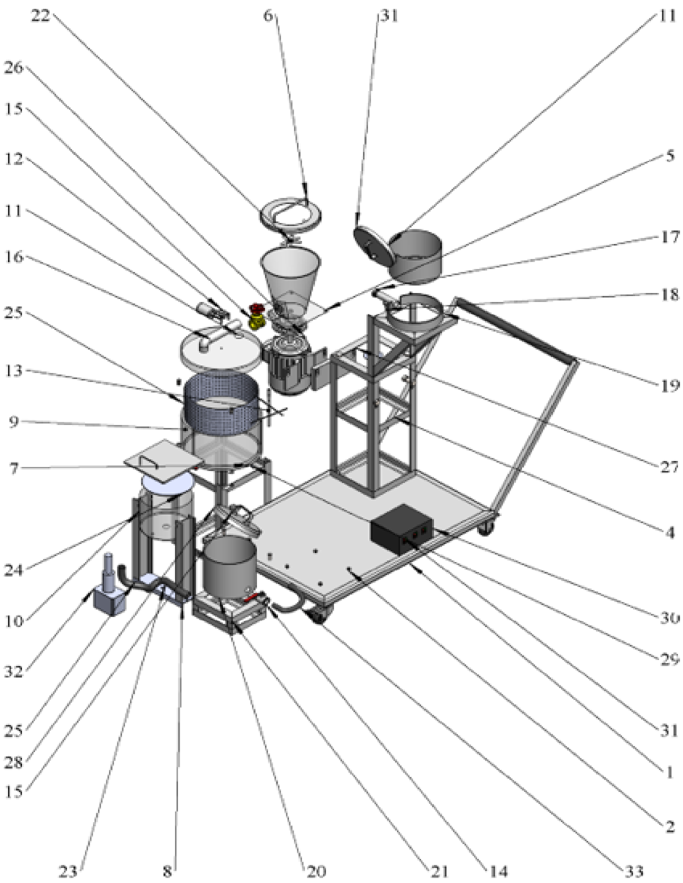


Figure 2: The orthographic view of the corn-starch processing machine



PART LIST		
ITEM	QTY	PART NAME
33	1	Discharge hose
32	1	Electric jack
31	3	Switch
30	1	Connector
29	1	Control box
28	1	Container cover
27	1	Electric motor support
26	1	Electric motor
25	1	Mesh
24	1	Dehydrating plate
23	1	Dehydrating base
22	1	Blade
21	1	Container frame
20	1	Waste container
19	1	Water reservoir support
18	1	Hose
17	1	Knob
16	1	Discharge pipe
15	1	Pipe valve
14	2	Ball valve
13	1	Stirrer
12	1	Gear motor
11	1	Water reservoir support
10	1	Dehydrating chamber

PART LIST		
ITEM	QTY	PART NAME
9	1	Sieving chamber
8	1	Dehydrating frame
7	1	Sieving frame
6	1	Grinding unit cover
5	1	Grinding unit
4	1	Grinding unit frame
3	4	Swivel plate
2	1	Trolley base
1	1	Trolley

Figure 3: The exploded view of the corn-starch processing machine

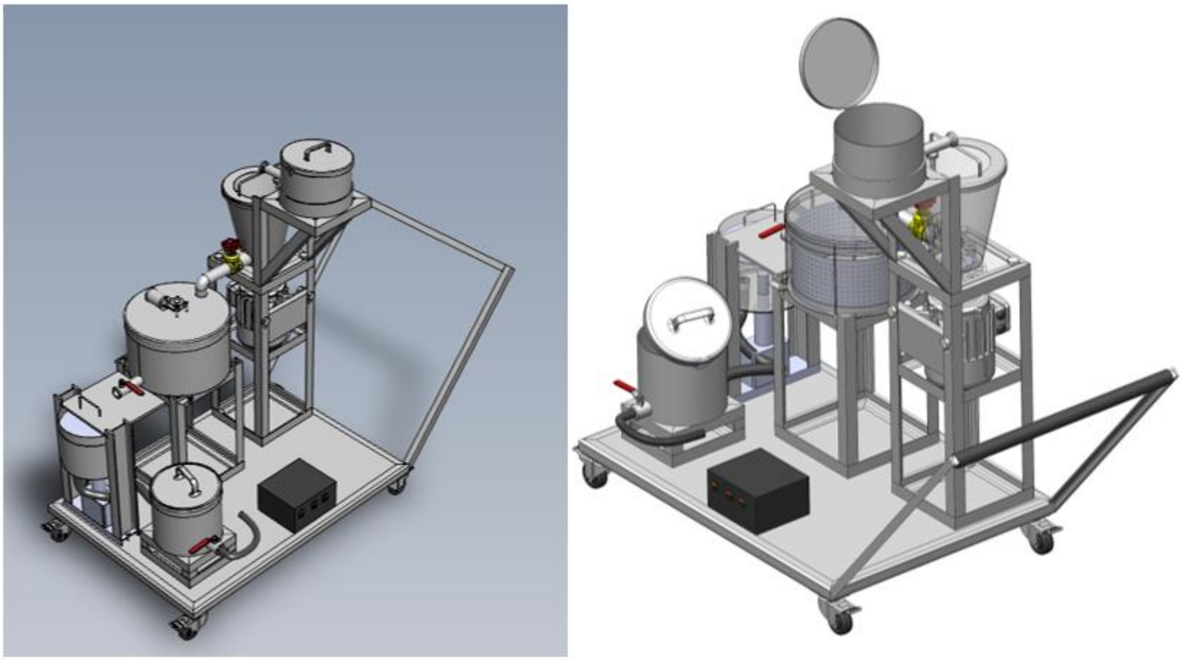


Figure 4: The model of the corn-starch processing machine

3. RESULTS AND DISCUSSION

Figure 5 presents the corn-starch processing machine fabricated and assembled according to the design specifications (see Figures 1 - 4). The major parts of the machine include the frame, milling unit, sieving chamber, mesh (perforated sieve drum), shaft, and dehydrating chamber

.

Figure 5: Corn-starch processing machine developed

Tables 1 and 2 show the performance of the corn-starch milling and sieving operations of the machine respectively based on three different processing tests. The tables include the mass of the slurry grain or mass of soaked grain (M_s) being processed, water capacity (C_w), mass of milled grain M_g), processing time (t_p), mass of chaff (M_c), milling efficiency (η_m), sieving efficiency (η_e), and throughput (C_p).

From Table 1, the average mass of processed soaked grain totalled 4.67 kg, resulting in 5.81 kg of milled grain. The average processing time was 0.20 hours, yielding an average throughput of 25.16 kg/hr and average milling efficiency of 80%, closely aligning with findings from a similar study [9] (80.34%).

Table 2 presents the average mass of slurry grain, water capacity, average processing time, and average mass of chaff separated. The average sieving efficiency in this current study is 70.58%, indicating that the machine was able to sieve a significant amount of corn-starch from the slurry. The average throughput of the machine was 57.59 kg/hr, which is similar to sieving rate reported by [15], but higher than previously reported study by [17].

Table 1: Performance of the milling unit

S/No	M_s (Kg)	M_g (Kg)	t_p (hr)	η_m (%)	C_p (Kg/hr)
1	3.12	4.20	0.10	0.74	30.00
2	4.90	5.80	0.20	0.84	25.00
3	6.00	7.42	0.29	0.81	20.48
Average	4.67	5.81	0.20	0.80	25.16

Table 2: Performance of the sieving unit

S/N	M_s (Kg)	C_w (L)	t_p (hr)	M_c (Kg)	η_e (%)	C_p (Kg/hr)
1	5.40	3.00	0.08	1.83	74.69	67.50
2	3.13	3.00	0.09	2.10	59.85	34.78
3	4.23	3.00	0.06	1.25	77.19	70.50
Average	4.25	3.00	0.08	1.73	70.58	57.59

4. CONCLUSIONS AND RECOMMENDATIONS

The integrated corn-starch processing machine was successfully designed and developed. The grinding operation ground an average of 80% of soaked grain with a soaked grain with a throughput rate of 25.16 kg/hr and was able to sieve an average of 70.58% of corn-starch during the sieving operation with a high throughput rate of 57.59 kg/hr and. The machine passed the test of workability. These test results show that the machine had the maximum sieving rate while sifting maize that had been properly blended while a high grinding efficiency was obtained when the grain is well soaked. Thus, this integrated machine save energy, water, time and also improved hygiene.

However, further study is necessary to improve its efficiency and reduce the amount of chaff separated during processing. Here are some recommendations to help address this, which involve making modifications to the machine's design and operating conditions:

i. The machine should be fully automated to increase the performance efficiency.
ii. The performance of the machine should be evaluated under different conditions, including different slurry grain types, moisture contents, and processing rates, to determine the generalizability of the results presented.
iii. That further research be conducted to explore the potential applications of corn-starch and other agricultural waste products as a source of sustainable, value-added products in various industries.
iv. The machine should be modified for processing other types of agricultural waste products or slurry grains, which limits its generalizability to other applications.

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