DESIGN AND FABRICATION OF A MOTORIZED GRAIN CRUSHER

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CERTIFICATION

This is to certify that this project work titled DESIGN AND FABRICATION OF A MOTORIZED GRAIN CRUSHER was carried out by **IZUAGIE BLESSING OCHUWA,** matriculation number **ENG2002671,** in the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, in partial fulfillment of the requirements for the Award of Bachelor of Engineering (B.Eng.) in Production Engineering.

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DEDICATION

This project is dedicated to Almighty God for His guidance, wisdom, and strength throughout this work.

I also dedicate it to my parents and beloved siblings, for their constant love, encouragement, and support.

Special appreciation goes to my project supervisor, whose guidance, patience, and invaluable contributions made this work a success.

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ABSTRACT

This project focuses on the design, fabrication, and evaluation of an electrically powered grain crusher for small-scale farmers and rural communities. The primary aim is to develop an efficient, durable, and affordable machine capable of crushing dried maize grains into smaller particle sizes suitable for food processing and livestock feed production. The objectives include improving crushing efficiency, reducing manual labour, and promoting the use of locally developed technologies to enhance agricultural productivity and support rural development.

The machine is powered by an electric motor that transmits motion to the crushing chamber through a belt and pulley system. Engineering design calculations were conducted to determine key parameters such as motor power, shaft diameter, pulley ratio, and crushing force required for effective operation. Locally sourced materials were used in the fabrication process to reduce cost and ensure ease of maintenance. The design and construction followed standard engineering principles to achieve structural stability, operational safety, and reliable performance.

The performance results showed that the grain crusher achieved a throughput capacity of approximately 15 kg/h with a crushing efficiency of about 92%. Sieve analysis revealed that the crushed output consisted predominantly of particle sizes in the range of 0.71 mm to 1.40 mm, making it suitable for food processing and livestock feed preparation. The machine effectively crushed dry maize grains and is adaptable for processing similar dry grains such as sorghum and millet. The crusher operated smoothly with minimal vibration and reduced processing time compared to manual methods, demonstrating that it is a practical, affordable, and reliable solution for small-scale grain processing in rural communities.

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CHAPTER ONE - INTRODUCTION

1.1 Background to the Study

Agriculture remains the backbone of many economies, particularly in developing countries, where a substantial proportion of the population relies on farming for both subsistence and commercial purposes. Among the most commonly cultivated crops are grains such as maize, millet, sorghum, wheat, and rice, which serve as staple foods for billions of people globally. These grains are crucial to food security, livestock nutrition, and the economic livelihoods of many rural and semi-urban communities.

Before these grains can be consumed or processed into secondary products such as flour, grits, animal feed, or fermented food, they must undergo post-harvest processing, most notably size reduction through crushing or grinding. This size reduction process improves not only the edibility of grains but also their storability, transportability, digestibility, and versatility in food and industrial applications.

In rural and under-resourced areas, especially across sub-Saharan Africa, Asia, and Latin America, grain crushing is still often performed manually using traditional tools such as grinding stones, mortars and pestles, and basic hand-operated grinders. While these tools are culturally significant and easy to construct, they are time-consuming, labor-intensive, inefficient, and yield inconsistent results. Typically, women and children shoulder this task, often spending several hours each day in grain processing. This labor-intensive process not only reduces household productivity but also limits the time that could be spent on education, economic activities, or rest.

To mitigate these challenges, industrial grain milling machines such as hammer mills, roller mills, and burr mills have been introduced. These machines have revolutionized large-scale grain processing by increasing efficiency, throughput, and product quality. However, they are expensive, require stable electricity, and demand skilled operation and maintenance. As a result, they remain inaccessible to smallholder farmers, local processors, and rural communities due to their high initial investment, ongoing maintenance costs, and technical complexity.

Consequently, there is a pressing need for a low-cost, energy-efficient, durable, and user-friendly grain crushing machine that meets the needs of small-scale farmers and processors. Such a machine should be simple in construction, affordable to build and maintain, and adaptable to different environments, including off-grid settings. It should also be capable of processing other types of grains and producing variable output sizes to suit different end uses, such as fine flour for cooking or coarser grains for animal feed.

Numerous attempts have been made to develop appropriate technologies to bridge this gap. However, existing models often fall short in critical areas such as adaptability, cost-effectiveness, user-friendliness, and reliability. Many available crushers do not allow adjustment of the crushing mechanism to accommodate various grain types or desired textures. Additionally, imported machines may lack local spare parts, making maintenance difficult and costly.

This project seeks to address these issues by designing, fabricating, and testing a cost-effective, locally manufactured grain crusher suitable for small-scale use. The machine will be constructed using locally available materials, which reduces production costs and makes parts replacement or repairs easier and more sustainable. It will feature a simple mechanical design that does not require complex technical skills to operate or maintain. The design will incorporate manual or low-power electrical operation, ensuring versatility in both grid-connected and off-grid areas.

Specifically, the machine will be evaluated based on:

i. Crushing capacity and throughput efficiency
ii. Energy consumption or manual effort required
iii. Safety during operation
iv. Quality and consistency of the crushed grain output
v. Durability and ease of maintenance

The ultimate goal of the project is to provide a scalable, efficient, and accessible solution that improves agricultural productivity and food processing in rural and semi-urban communities. The proposed grain crusher will help reduce post-harvest losses, enhance food security, and support rural economic development by replacing inefficient traditional methods and providing an alternative to expensive industrial machines.

Furthermore, the project aligns with broader Sustainable Development Goals (SDGs), including SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation, and Infrastructure). This initiative also supports self-reliance and reduces dependence on imported technologies by promoting local innovation and providing communities with the tools to process their own crops.

In conclusion, the development of an appropriate grain crusher tailored to the needs of small-scale users represents a critical step toward improving food systems, reducing rural hardship, and supporting sustainable agricultural practices in the developing world.

1.2 Statement of the Problem

Despite significant advancements in agricultural production, post-harvest processing remains a major challenge for smallholder farmers and rural communities in developing countries. Among the most critical post-harvest activities is the crushing or grinding of grains such as maize, millet, sorghum, and wheat, staple crops that serve as primary sources of food and income for millions of people.

Traditionally, this task is carried out using manual methods, including grinding stones, mortars and pestles, or rudimentary hand-operated grinders. These methods are deeply rooted in local culture and have been used for generations; however, they are inherently inefficient, labor-intensive, and time-consuming. In many households, women and children spend hours each day manually processing grains, which not only reduces productivity but also limits opportunities for education, income-generating activities, and rest. The physical strain involved can also lead to long-term health issues such as back pain, joint injuries, and fatigue.

In contrast, industrial milling machines, such as hammer mills and roller mills, offer high output, speed, and uniform particle sizes. These machines are effective but come with high purchase costs, energy requirements, and maintenance demands. Most of them are designed for urban or large-scale industrial settings and are not tailored to the realities of rural and off-grid environments, where access to stable electricity, technical expertise, and spare parts is limited or nonexistent.

As a result, small-scale farmers are caught in a technological and economic gap with no access to tools that balance efficiency, affordability, and usability. The unavailability of appropriate crushing equipment leads to several challenges:

i. Increased post-harvest losses due to delays or poor-quality processing
ii. Low productivity and output, hindering food preparation and sales
iii. Food insecurity, as households cannot efficiently store or process their grain
iv. Dependency on external milling services, which may be expensive, time bound, or far from their location.

Moreover, many of the available grain crushing machines are electrically powered and are often expensive, complex, and designed primarily for commercial-scale operations. While electricity improves efficiency and output capacity, most existing electrically powered machines are not optimized for affordability, ease of operation, and maintenance within rural communities.

In many rural areas, small-scale farmers and households require grain crushing machines that are not only efficient but also cost-effective, simple to operate, and easy to maintain. However, the machines currently available in the market are either too costly, require advanced technical knowledge to operate and maintain, or are constructed with components that are not easily accessible locally. Therefore, the core problem lies in the lack of a low-cost, electrically powered, easy-to-operate, and easily maintainable grain crushing machine specifically designed to meet the practical needs of small-scale farmers and rural users. Such a machine must be designed to:

i. Operate efficiently using electric power
ii. Be constructed from locally available materials to reduce costs
iii. Be simple to repair with minimal technical knowledge

iv. Accommodate various grain types and produce adjustable output textures

Addressing this problem is not only a technical challenge but also a socio-economic imperative. A well-designed grain crusher would improve food processing efficiency, reduce the burden on women and children, promote local economic development, and enhance food security.

This project, therefore, seeks to bridge the gap between inefficient traditional tools and expensive industrial machines by developing a practical, scalable, and cost-effective grain crusher that empowers small-scale farmers and processors with the technology they need to improve their livelihoods.

1.3 Aim of Study

This project aims to develop a low-cost grain-crushing machine using locally sourced materials.

1.4 Objectives

In order to achieve the aim of this study, the following specific objectives will be pursued:

i. To carry out an extensive literature review of the grain grinding machine.

ii. To design the component part of the grain grinding machine.

iii. To select appropriate materials for the component parts that are locally available and affordable.

iv. To fabricate and assemble the component parts of the machine.

v. To carry out a performance evaluation of the machine.

vi. To make appropriate recommendations for further improvements.

1.5 Significance of the Study

The development of an electric grain crusher as proposed in this study is of great significance, particularly for agricultural and rural development in low-income and developing regions. Agriculture remains the primary source of livelihood for a large percentage of the global population, especially in sub-Saharan Africa, parts of Asia, and Latin America. Despite growth in crop production, post-harvest processing, especially the conversion of grains into usable forms, remains a critical bottleneck in the food value chain.

In rural communities, grain processing is often conducted manually using primitive tools such as grinding stones, pestles, and mortars, or basic hand-operated devices. These traditional methods are labor-intensive, time-consuming, and physically demanding. Women and children are typically tasked with this work, which limits their ability to participate in income-generating activities, attend school, or engage in other productive tasks. Additionally, the inefficient nature of these methods often leads to wastage, contamination, and inconsistent product quality, which can negatively affect food security and household income.

Commercially available industrial milling machines can provide faster and more consistent results, but these are often prohibitively expensive for small-scale users. They typically require stable electricity, technical expertise, and regular access to spare parts resources that are scarce in many rural and semi-urban areas. This lack of appropriate, affordable, and adaptable post-harvest processing technology has created a significant gap between subsistence-level farming and mechanized agriculture.

The grain crusher proposed in this study addresses this gap by introducing a cost-effective, energy-efficient, and easy-to-operate machine. By ensuring that the machine is fabricated from locally available materials, the study also promotes local manufacturing, easy maintenance, and community-based repair networks, thereby stimulating rural entrepreneurship and job creation.

In conclusion, the successful design and development of this grain crusher will empower rural communities, promote self-reliance, and contribute to sustainable agricultural practices. It represents not just a technological advancement, but also a step toward equitable development and improved livelihoods.

1.6 Scope of Study

This study will focus on design, fabrication, and laboratory/field testing of a small-scale, motorized system with a target throughput on the order of 5–20 kg/hour driven by a single-phase electric motor, 3hp, depending on local electricity availability. The machine will be optimized for common grains, with a focus on dry crushing and size reduction. Wet processing is outside this scope.

CHAPTER TWO - LITERATURE REVIEW

2.1 Grinding Machine Systems

Grains such as maize, millet, sorghum, wheat, and rice play a fundamental role in global food security, especially in developing countries where they form the backbone of household nutrition and agricultural economies. These grains, however, must undergo post-harvest processing, most critically, crushing or size reduction, before they can be transformed into consumable forms such as flour, grits, or animal feed. Efficient grain processing not only adds value to agricultural produce but also enhances food storage, transportation, and utilization, contributing to both economic development and improved livelihoods.

In many rural and resource-constrained communities, particularly in sub-Saharan Africa, parts of Asia, and Latin America, grain processing is still carried out using traditional methods, including grinding stones, mortars, pestles, and basic hand-operated mills. Although these methods are deeply rooted in culture and history, they are increasingly recognized as time-consuming, labor-intensive, and inefficient, placing a disproportionate burden on women and children (FAO, 2011; Igbeka, 2013). The limitations of these traditional approaches, coupled with growing food demand, have highlighted the urgent need for more efficient, accessible, and affordable grain crushing technologies.

Mechanized grain processing equipment, such as hammer mills, burr mills, and roller mills, has been developed and widely adopted in urban and industrial settings to meet high processing demands. These machines offer significant advantages in terms of speed, efficiency, and product quality (Aviara & Haque, 2001; Musa & Adejumo, 2012). However, their high acquisition costs, dependency on electricity, and complex maintenance requirements make them largely inaccessible to smallholder farmers and rural processors.

Given these challenges, researchers and development practitioners have advocated for the design of appropriate technologies affordable, user-friendly, and locally maintainable equipment tailored to the socio-economic realities of rural communities. Several attempts have been made to develop grain crushers that meet these requirements, with varying degrees of success (Adewole et al., 2015; Olukunle & Ajayi, 2007). However, gaps remain in achieving an optimal balance between cost, efficiency, adaptability to different grain types, and power flexibility.

This literature review critically examines existing studies, technologies, and knowledge gaps related to grain crushing equipment, with a particular focus on machines suitable for rural and semi-urban use. The review provides the foundation for the present study, which aims to design and develop a cost-effective, electric grain crusher that can be fabricated with locally available materials and operated with minimal technical expertise.

Efficient post-harvest processing of grains is essential for ensuring food security, minimizing crop losses, and improving the economic well-being of smallholder farmers, particularly in developing countries. Staple grains such as maize, millet, sorghum, wheat, and rice constitute the primary dietary components across sub-Saharan Africa, Asia, and Latin America. Before consumption or further industrial utilization in the production of flour, grits, animal feed, or other derivatives, these grains must undergo size reduction through crushing or milling operations.

Traditionally, grain crushing in rural communities has relied on manual techniques such as grinding stones, wooden mortars and pestles, and simple hand-operated grinders. Although culturally significant and historically reliable, these methods are labor-intensive, time-consuming, and inefficient, often resulting in low productivity and inconsistent particle size distribution (FAO, 2011; Igbeka, 2013). In addition, the physical demands associated with manual processing disproportionately affect women and children, limiting their participation in education and other economic activities.

The mechanization of grain processing marked a significant advancement in agricultural engineering. Electrically powered equipment such as hammer mills, burr mills, roller mills, and rice milling machines has been widely adopted in urban and industrial environments to meet high processing demands. These machines provide substantial advantages in terms of processing speed, operational efficiency, throughput capacity, and improved product quality (Aviara & Haque, 2001; Musa & Adejumo, 2012). Electric motors enable consistent rotational speed, reduced human effort, and better control over particle size distribution, making electrically powered systems particularly suitable for small- and medium-scale enterprises.

Despite these benefits, large-scale industrial milling systems are often characterized by high capital costs, complex maintenance requirements, and dependence on stable electrical infrastructure (Adewole et al., 2015). Such limitations restrict their accessibility to rural processors and smallholder farmers in low-resource settings. Consequently, there is an increasing emphasis on developing cost-effective, electrically powered grain crushers that are simple in design, easy to maintain, and capable of being fabricated using locally available materials.

Several studies have explored the design and improvement of small-scale electrically driven grain processing equipment. For instance, Caringal et al. (2016) developed a rice milling and grinding system integrating hulling and grinding operations through friction-based mechanisms. Their design incorporated a vacuum-assisted husk removal system to enhance processing efficiency and output cleanliness. Similarly, Dissanayake et al. (2015) investigated affordable flour blending and milling systems, emphasizing material selection and simplified mechanical configurations to reduce manufacturing costs without compromising performance.

Furthermore, Savinyh et al. (2019) demonstrated that optimizing the feeding mechanism and rotor configuration in grain crushers significantly enhances crushing efficiency while reducing energy consumption. These findings highlight the importance of mechanical design refinement in achieving improved operational performance in electrically powered grain processing machines.

Although progress has been made in improving small-scale milling technologies, gaps remain in achieving an optimal balance between affordability, energy efficiency, durability, adaptability to different grain types, and ease of maintenance. Many existing designs either prioritize performance at the expense of cost or reduce cost while compromising efficiency and structural robustness. Additionally, limited attention has been given to developing compact, energy-efficient electric grain crushers specifically tailored for semi-urban and rural users with moderate but reliable access to electricity.

This literature review, therefore, synthesizes existing research on electrically powered grain crushing technologies, focusing on their design principles, performance evaluation, material selection, and operational limitations. The review establishes the need for a cost-effective, energy-efficient, and locally manufacturable electric grain crusher that combines simplicity, durability, and adaptability. These identified gaps form the foundation of the present study, which aims to design, fabricate, and evaluate an electrically powered grain crusher suitable for smallholder farmers and small-scale grain processors.

2.2 Existing Grain Crushing Technologies

Over the years, a lot of grain crushing and milling technologies have been developed to meet the processing needs of grains such as maize, corn, rice, millet, and sorghum. These machines range from simple hand-operated devices to complex industrial-scale equipment. However, many of the existing technologies have been designed primarily for large-scale commercial applications, making them less accessible to smallholder farmers and rural processors.

2.2.1Traditional Grain Processing Tools

In many rural areas, grain crushing is still performed using manual grinding stones, wooden mortars, and pestles. These traditional tools, though simple and affordable, are extremely labour-intensive, slow, and inefficient. The particle size produced is often inconsistent, leading to variable product quality (FAO, 2011; Igbeka, 2013). Additionally, these methods impose a heavy workload on women and children, consuming several hours daily and limiting their participation in education or economic activities.

2.2.2 Mechanized Grain Crushers

Mechanized grain crushing technologies were developed to improve efficiency and output quality. Common machines in this category include:

i. Hammer Mills:

   Hammer mills are widely used for maize, corn, and cereal processing. They operate by rapidly rotating hammers that crush the grain against a screen. Hammer mills offer high throughput and are effective in producing flour and animal feed (Aviara & Haque, 2001).

A hammer mill is a widely used machine in small-scale grain processing, known for its ability to reduce dry agricultural materials into finer particles. In a study by Usman et al. (2021), a multi-purpose hammer mill was designed and built using locally sourced materials to meet the needs of rural processors. The machine grinds crops like maize, cassava, millet, and plantain by using 14 metal beaters attached to a rotating shaft powered by a 5.5 kW electric motor. Grains enter through a feed hopper and are pulverized inside a grinding chamber. A 3 mm perforated sieve ensures only finely milled product passes through. A blower fan helps convey the ground material through a pipe into a cyclone collector, which makes the output collection cleaner and reduces dust. This design allows for efficient milling, improved safety, and minimal manual labour. It is especially suitable for rural areas where affordability and ease of maintenance are essential. The main parts of the machine are illustrated in Figure 1 below.

Figure 2. 1: A Multipurpose Hammer Milling Machine

However, they generally consume significant power, which limits their use in off-grid locations. They are also known for their tendency to generate heat, which can reduce flour quality if not properly managed. Hammer mills are one of the most widely used mechanical devices for size reduction in the processing of agricultural products such as maize, corn, wheat, sorghum, millet, and other cereals. The core operating principle involves a rotor fitted with free-swinging hammers that rotate at high speeds inside a metal drum. The hammers repeatedly strike the grain, forcing it against a perforated screen. Particles that are small enough to pass through the screen are collected as output, while larger particles remain inside the chamber for further grinding (Aviara & Haque, 2001; Gupta & Sharma, 2007). These machines are known for their high throughput, rapid processing speed, and ability to handle a wide range of grain types. Hammer mills are commonly used in both human food and livestock feed production, producing fine flour, grits, and meal suitable for various applications (Musa & Adejumo, 2012). In smallholder contexts, they are particularly valued for their versatility and ability to grind not only dry grains but also fibrous materials such as cassava chips, maize stalks, and groundnut shells (Obi et al., 2020). Despite their benefits, hammer mills have notable limitations. They generally operate on electric motors (or occasionally diesel engines), consuming substantial amounts of energy during operation. Their high power requirement (typically 2 to 15 kW for small to medium-sized units) makes them unsuitable for off-grid rural areas lacking a reliable electricity supply (Adewole et al., 2015; Olaoye et al., 2012). Moreover, due to the high-speed nature of the hammering action, hammer mills generate considerable heat during prolonged operation. This heat buildup can denature sensitive nutrients in flour, especially when processing grains intended for human consumption. For instance, excessive temperature may cause protein degradation and affect enzymatic properties in flours used for weaning foods or baked products (Nkumbula & Mutuli, 2020). Therefore, effective cooling strategies or intermittent operation must be employed to maintain flour quality. Another challenge associated with hammer mills is wear and tear. The hammers, screens, and rotor assembly are subjected to constant abrasion and impact, requiring frequent maintenance or replacement. This adds to operational costs, particularly for users in rural areas who may lack access to spare parts or technical support (Olukunle & Ajayi, 2007). Despite these drawbacks, hammer mills remain a critical component of small- and medium-scale grain processing operations. The design simplicity, availability, and adaptability of hammer mills to various grains have made them a common choice in sub-Saharan Africa and South Asia. Efforts to improve their efficiency and suitability for rural use include the development of solar-powered variants and dual-mode (manual/electric) systems (Dissanayake et al., 2015; Savinyh etal., 2019). Hammer mills are among the most widely used grain milling technologies, especially in small- to medium-scale operations across developing countries. Their design, based on rapidly rotating hammers, allows for high throughput and adaptability to various grain types. Despite their efficiency, hammer mills are often criticized for their high-power consumption and tendency to generate heat, which may compromise flour quality.

The table below outlines the advantages and disadvantages of hammer mills in grain processing applications.

Table 2. 1 Advantages and Disadvantages of a Hammer Mill

Advantages	Disadvantages
High throughput suitable for bulk processing	High power consumption is not ideal for off-grid areas
Simple construction and easy to fabricate locally	Can produce non-uniform particle sizes
Capable of coarse and medium grinding	Noisy operation and produces dust
Common in rural and urban settings due to accessibility	Can damage oil-rich grains due to heat and impact

ii Roller Mills:

Roller mills use cylindrical rollers to crush grain. They are commonly used in large-scale maize and wheat flour production because they produce fine, uniform flour with minimal heat generation. However, they are expensive, require skilled operation, and are typically designed for urban or industrial settings (Adewole et al., 2015). Roller mills are a form of mechanized grain milling equipment that use a series of cylindrical rollers to crush and grind grain into flour or grits. The basic operating principle involves feeding the grain between pairs of counter-rotating rollers, which apply compressive and shear forces to break down the kernels. The gap between the rollers is adjustable, allowing for precise control of particle size and uniformity (Gupta & Sharma, 2007; Kent, 1994). These mills are widely used in industrial-scale maize and wheat flour production due to their ability to produce high-quality, uniform flour with minimal heat generation. Unlike hammer mills that rely on impact and friction, roller mills crush the grain progressively in multiple stages (called breaks and reductions), which helps preserve starch granule integrity and reduces heat-induced damage to proteins and enzymes (Owens, 2001). This makes roller-milled flour particularly suitable for baking, pasta production, and other food applications where texture, consistency, and color are important. Additionally, roller mills generate less dust and noise during operation, making them cleaner and more environmentally friendly in comparison to other forms of mechanical crushing like hammer or burr mills (Adewole et al., 2015; Musa & Adejumo, 2012). Many modern roller mills also integrate automated sifting and pneumatic transport systems, which streamline flour separation and enhance milling efficiency in high-throughput operations (Ktenioudaki et al., 2015). A triple roller mill is a type of machine used to process and refine materials like soap by passing them through three rotating rollers. These rollers are arranged in a horizontal line, and each one moves at a different speed to create enough pressure and shearing force that helps break down and smooth the material. Soap pellets are fed through a hopper into the space between the rollers. As they pass through, the rollers crush and mix them evenly. The gap between each roller can be adjusted depending on how fine the output is needed. After processing, the finished soap is scraped off the last roller and collected. The machine is built with a strong metal frame, rotating shafts, and bearings to support smooth operation. This setup improves soap texture and consistency, making it very useful for small soap producers who need affordable equipment to boost product quality without spending much (Umo et al., 2025). Figure 2 shows an industrial view of a triple roller mill

Figure 2. 2**:** Industrial View of Triple Roller Mill

However, despite their technological advantages, roller mills come with significant limitations that restrict their application in smallholder and rural settings. First, the machines are generally capital-intensive, with high acquisition, installation, and maintenance costs. Their large physical footprint and complex assembly also require substantial infrastructure, including dedicated milling facilities and consistent power supply (Aviara & Haque, 2001). These factors make them impractical for rural processors operating in low-resource environments. Furthermore, roller mills require skilled personnel for setup, operation, and periodic calibration. Improper roller alignment or feeding rates can result in uneven grinding, excessive wear, or mechanical failure. As a result, their maintenance demands often exceed the technical capacity available in rural communities, where access to spare parts and trained technicians is limited (Olukunle & Ajayi, 2007; Obi et al., 2020). Because of these barriers, roller mills are typically used in commercial or industrial milling facilities located in urban areas or processing hubs. Their adoption at the rural or small-scale level remains low, underscoring the need for more appropriate, adaptable grain processing technologies such as dual-powered crushers that can function effectively in off-grid or semi-urban settings. Roller mills are widely used in large-scale and industrial grain processing because they can produce fine, uniform flour with minimal heat. Their use of paired cylindrical rollers provides consistent particle size and better flour quality, especially for wheat and maize. However, their high cost, bulkiness, and requirement for skilled operation make them less ideal for small-scale or rural settings. Table 2 below shows the main advantages and disadvantages of roller mills compared to other grain milling methods.

Table 2. 2 Advantages and Disadvantages of a Roller Mill

Advantages	Disadvantages
Produces uniform, fine flour ideal for bakery-grade applications	Expensive initial cost and maintenance are high
Minimal heat generation during operation preserves flour quality	Requires skilled operators for effective adjustment and maintenance
Suitable for large-scale industrial use	Bulky and less portable – unsuitable for rural or mobile setups

Efficient and fast for continuous flour production	Not energy-efficient in small-scale applications
Can be automated for continuous processing	Typically not versatile designed for specific grains and settings

ii. Burr Mills:

Burr mills use two abrasive surfaces to crush grain. They are commonly employed in small-scale maize and cereal processing. Burr mills provide more control over particle size but are slower than hammer mills and may require frequent maintenance. Burr mills, also known as disc mills or plate mills, are grain milling machines that operate using two abrasive surfaces typically made of cast iron, steel, or stone that rotate against each other to crush and grind the grain. One of the plates is usually stationary while the other rotates, and the grain is fed through the central opening. The distance between the plates can be adjusted to control the fineness of the output, providing relatively high precision in particle size (Gupta & Sharma, 2007; Adejumo & Bamgboye, 2013). These mills are commonly used in small-scale maize, sorghum, and millet processing, especially in rural settings where simplicity, affordability, and ease of use are important. Burr mills are valued for their ability to produce a wide range of particle sizes from coarse grits to fine flour simply by adjusting the grinding gap. This feature makes them versatile for processing various food products, including local staples like ogi (fermented maize porridge), tuwo, and animal feed (Olukunle & Ajayi, 2007). Unlike hammer mills that rely on impact force, burr mills utilize shear and compression to break down grains. This grinding mechanism generates less heat, which helps preserve the nutritional quality and functional properties of the flour, particularly proteins and enzymes that can be degraded by high temperatures (Nkumbula & Mutuli, 2020). The slower grinding action also produces less dust and noise, which can improve the working environment in small processing operations (Obi et al., 2020).Despite these advantages, burr mills have some notable limitations. They are generally slower than hammer mills, with lower throughput rates, which can be a constraint when large quantities of grain need to be processed quickly (Musa & Adejumo, 2012). Additionally, because of the continuous friction between the grinding plates, they are prone to wear and require frequent maintenance. Regular adjustment of the grinding gap and periodic replacement of the plates are necessary to maintain efficiency and product quality (Olaoye et al., 2012). Another drawback is that burr mills are often manually operated or powered by small electric motors. While this makes them suitable for rural areas with limited electricity access, their performance is heavily dependent on the skill of the operator and the physical condition of the grinding surfaces. Improper alignment or worn-out plates can result in uneven particle sizes or overheating of the grain..Burr mills represent an intermediate level of technology between traditional tools (like mortars and pestles) and industrial roller or hammer mills. Their balance of affordability, precision, and relative energy efficiency makes them a popular choice for decentralized grain processing in low-income and off-grid settings. However, enhancing their durability, ease of maintenance, and power flexibility remains a research priority (Savinyh et al., 2019; Dissanayake et al., 2015). Burr mills have long served small-scale processors in rural and low-income settings. Their mechanism, while slower, offers better control over final product quality.

Table 3 below summarizes the advantages and disadvantages of burr mills in comparison to other grain processing technologies.

Table 2. 3 Advantages and Disadvantages of Burr Mills

Advantages	Disadvantages
Adjustable grinding gap provides precise control over particle size	Low throughput not ideal for large-scale or high-volume processing
Low heat generation preserves nutrients and flour quality	Frequent maintenance grinding plates wear out and need regular replacement
Requires less power can be manual or run on small motors	Manual labor intensive in non-electric models

Suitable for a variety of grains (maize, millet, sorghum, wheat, etc.)	Can produce inconsistent particle sizes as plates wear
Simple to operate and maintain, suitable for rural use	Not viable for commercial-scale operations
Compact and portable, useful in small-scale or household settings	May clog easily if grains are moist or improperly dried

iv Rice milling and grinding machines

Caringal et al. (2016) developed a combined rice hulling and grinding machine that uses steel rollers and mechanical friction to efficiently de-husk rice. Their design enhanced processing, speed, and quality by adding a vacuum fan to remove husks and produce cleaner output. However, since the machine is fully electric, its use is limited in rural areas with unreliable electricity. Rice milling is a vital post-harvest process, especially in developing countries where manual methods are common. Traditional methods are labor-intensive, slow, and often cause grain breakage. To address these issues, Caringal et al. created a machine that combines hulling and grinding, which employs steel rollers and a vacuum fan to separate husks from grains during operation. This results in cleaner output and faster post-processing. The dual-function design simplifies rice processing and makes it more accessible for local communities, where separate machines may be expensive. Steel rollers ensure durability and consistent de-husking, while the grinding function allows further processing of broken rice or cereals. The main limitation remains its reliance on electric power, making it less suitable for rural or off-grid areas with unstable or no electricity. This highlights the need for hybrid systems—manual and electric—

that can operate in various settings. Researchers like Soh et al. (2015) and Rathnakumari et al. (2018) emphasize designing energy-efficient, multi-functional rice processing equipment that balances performance, affordability, and adaptability for smallholder farmers without solely depending on electric power. . The figure below shows a rice grinder developed by Caringal and colleagues (2016)

Figure 2. 3**:** Rice Grinder

Table 2. 4 Advantages and Disadvantages of Rice Milling Machine

Advantages	Disadvantages
Dual-function machine combines hulling and grinding in one unit	Fully electric operation limits use in off-grid or rural areas
Vacuum fan enhances efficiency by separating husks for a cleaner output	High initial cost compared to traditional manual methods
Reduces processing time compared to separate machines	Requires technical maintenance for fan and roller mechanisms
Steel roller mechanism ensures durability and consistent de-husking	Noise and vibration may be an issue in basic housing units
Improves grain quality – less breakage and cleaner final product	Not easily portable due to size and mechanical components
Suitable for medium-scale farmers and	May require training to operate and

cooperatives	maintain efficiently

2.3 Locally Fabricated Machines

Several attempts have been made to develop low-cost, locally fabricated grain crushers suitable for rural use. Dissanayake et al. (2015) successfully developed a low-cost grain flour blender that reduced machine costs and was designed using basic stainless-steel components. These types of machines, while promising, often require technical adjustments and have not fully addressed power flexibility or multi-grain processing capability.

Savinyh et al. (2019) contributed further by analyzing the feeding mechanism of forage grain crushers. Their research demonstrated that optimizing feeding speed and the alignment between grain feed and the crusher's drums significantly improves crushing efficiency and reduces energy consumption. This insight is particularly relevant for developing grain crushers for maize, corn, and rice. In response to the challenges of cost, maintenance, and energy access in rural grain processing, numerous researchers and local fabricators have developed low-cost, locally manufactured grain crushers aimed at small-scale users. These machines are typically constructed using readily available materials, such as mild steel, stainless steel sheets, and locally sourced mechanical components. The goal is to reduce dependence on imported technologies and offer machines that are economically viable, easily repairable, and adapted to local operating conditions.

Dissanayake et al. (2015) developed a low-cost grain flour blender that significantly lowered production expenses by using basic stainless-steel components and avoiding expensive, high-precision imports. Their design focused on affordability and mechanical simplicity, making it ideal for rural applications. However, the machine was limited in scope—it lacked the ability to process multiple types of grains efficiently and relied on a single power source, failing to address the critical need for hybrid (manual/electric) operation.

Building on such local innovations, Savinyh et al. (2019) explored performance improvements through feeding mechanism optimization. Their study revealed that adjusting the feed rate and ensuring proper alignment between the grain input and crushing drums substantially increases crushing efficiency and reduces energy consumption. These findings are highly relevant to rural contexts where power efficiency and processing reliability are crucial, especially for grains such as maize, corn, sorghum, and rice.

Other studies, such as those by Ogedengbe and Adekoya (2006) and Olusegun et al. (2012), have also supported the push toward context-specific grain processing machines that incorporate adjustable crushing plates, interchangeable sieves, and dual-power mechanisms to improve flexibility across a wider range of crops and environments. Nonetheless, many of these local machines still face issues of durability, poor finishing, and inconsistent performance, especially under prolonged use.

Despite these limitations, locally fabricated machines offer a promising platform for the development of dual-powered grain crushers that are both affordable and adaptable to rural conditions. Their modular design potential makes them good candidates for future improvement and customization in line with user needs.

2.4 Key Limitations of Existing Technologies

Although significant progress has been made in the design and performance of grain crushing technologies, especially for maize, rice, millet, and sorghum, several limitations still hinder their effective deployment in rural and small-scale farming contexts. These limitations impact the accessibility, efficiency, and suitability of available machinery for diverse user groups. The most critical issues include:

I. Power Dependence

   Most modern grain crushers, particularly hammer mills and roller mills, are entirely dependent on electric motors. This makes them unsuitable for off-grid regions where electricity is either unavailable, unstable, or prohibitively expensive. The lack of alternative power options such as manual operation, diesel engines, or solar power limits their adoption in rural communities (Adekoya & Ogedengbe, 2006; Soh et al., 2015).

II. High Capital and Maintenance Costs

   Industrial-grade crushing machines are often costly to procure, with prices beyond the reach of smallholder farmers. Moreover, maintenance costs are compounded by the need for specialized spare parts and skilled technicians, neither of which are readily accessible in rural areas. This economic barrier discourages long-term investment in mechanized processing (Olusegun et al., 2012).

III. Complex Operation and Technical Skill Requirements

   Many machines, especially roller mills and multi-stage grinders, require technical knowledge for proper calibration, operation, and routine servicing. In rural communities with low levels of technical literacy and limited extension services, this complexity reduces the usability and sustainability of such technologies (Rathnakumari et al., 2018).

IV. Limited Grain and Output Flexibility

Several commercially available machines are designed to process only specific grain types or produce flour within a narrow particle size range. This restricts their functionality when users want to process a variety of grains or adjust the fineness for different end uses such as grits, flour, or animal feed. Such rigidity lowers the machine's overall utility and economic return for diverse processing needs (Savinyh et al., 2019).

These limitations underscore the urgent need for adaptable, affordable, and energy-flexible technologies, particularly dual-powered grain crushers that can operate manually or electrically depending on local conditions. Such solutions would enhance processing resilience, support food security, and empower smallholder agricultural producers in low-resource settings.

2.5 Importance of Grain Crushing Technology for Maize, Corn, Rice, and Related Crops

Grain crushing and milling technologies play a vital role in ensuring food security, value addition, and efficient post-harvest processing for widely cultivated crops such as maize, corn, rice, millet, and sorghum. These staple grains form the dietary foundation for billions of people, and their effective processing into flour, grits, or animal feed significantly contributes to nutritional intake, market accessibility, and household income.

For crops such as maize and corn, size reduction is essential for producing products like maize flour, cornmeal, and animal feed. Traditional hand-operated crushers, although still in use in many rural areas, are inefficient and cannot meet the growing demand for processed grain (Adewole et al., 2015). Industrial machines, on the other hand, are often inaccessible due to their high costs and energy requirements, making them unsuitable for smallholder farmers in rural settings.

Rice processing presents similar challenges. As highlighted by Caringal et al. (2016), traditional rice de-husking methods, such as pounding with wooden mortars, are labor-intensive and lead to high grain breakage rates. Their study on rice milling and grinding machines demonstrated that combining de-husking, polishing, and grinding in one compact system can significantly improve rice processing efficiency for small-scale users. Their design, featuring a steel roller, friction-based de-husking mechanism, and vacuum fan for husk removal, offers a practical model for rural rice processors; however, its reliance on electrical power limits its applicability in areas with inconsistent electricity.

The importance of optimizing grain crushing machines extends beyond rice. Savinyh et al. (2019) demonstrated that improving feeding mechanisms and aligning grain flow with the crushing drum's peripheral speed enhances efficiency and reduces energy consumption for forage grain crushers. Applying similar principles to maize, corn, and rice crushing machines can significantly improve throughput and energy efficiency, making them more viable for smallholder farmers.

In regions where maize and corn dominate staple food production, particularly in sub-Saharan Africa, the availability of affordable, locally fabricated crushers is essential for post-harvest value addition. Such machines not only enable small-scale processing but also empower rural communities to reduce grain wastage, improve food storage, and enhance food quality.

Despite these recognized needs, there is a shortage of grain crushing machines that:

i. Are capable of processing multiple grain types (e.g., maize, corn, rice) with adjustable settings for varying particle sizes.

ii. Operate on dual power sources (manual and electric) to suit environments with limited or unreliable electricity.

iii. They are fabricated using readily available, low-cost materials, ensuring affordability and ease of maintenance.

iv. They are simple to operate, requiring minimal technical expertise, making them suitable for rural households.

Addressing these limitations forms the foundation of this study, which seeks to design, fabricate, and evaluate a cost-effective, grain crusher capable of processing maize grains to support small-scale farmers and processors in low-resource settings.

CHAPTER THREE - METHODOLOGY

3.1 Materials

i. 4mm thick Mild steel pan
ii. Bearing
iii. $2\frac{1}{2}\ by$ 6mm thick Angle Bar
iv. 25 mm diameter Solid shaft
v. 10mm diameter Auxiliary shaft
vi. Paint
vii. Pulleys
viii. Belt
ix. Electrodes
x. Cutting disk
xi. Stainless steel screen/ filter

The objective of this project is to design a portable, motorized grain grinding machine for home use. The concept is based on ergonomic design and ease of handling. The following steps were taken: designing the machine, selecting materials, fabricating the machine, and analyzing performance.

3.2 Conceptual Design

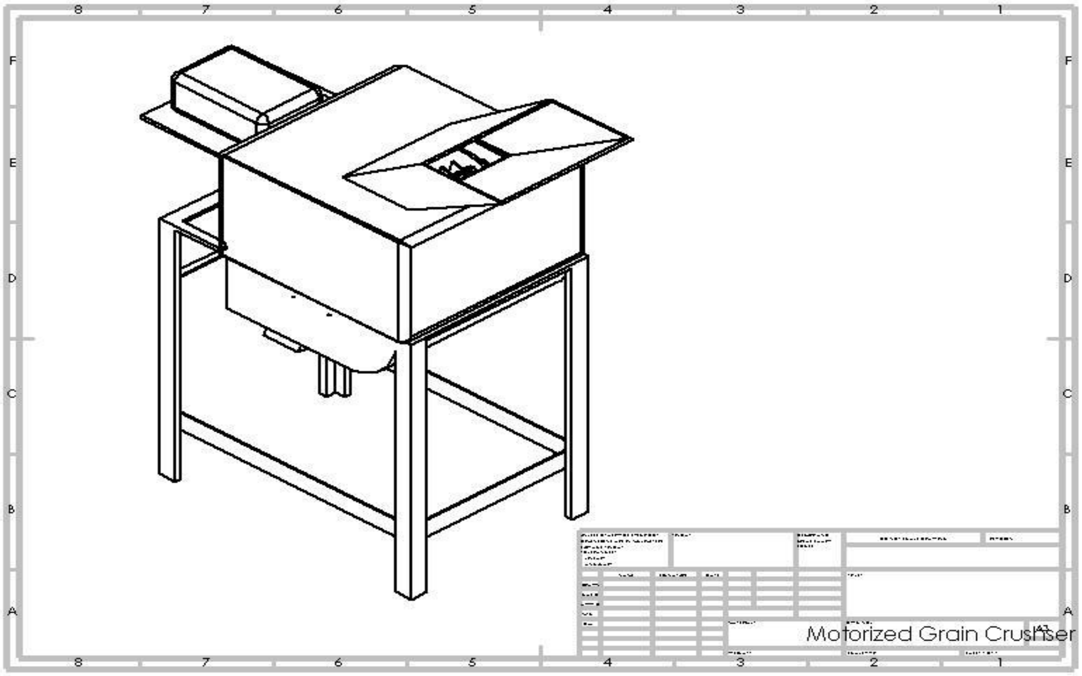

Figure 3. 1: CAD Design of the motorized Grain Crusher

The machine operates as an impact-type grain crusher, where dry maize is fed through a hopper into a rotating crushing unit with hammers or blades. Grains are reduced in size through high-velocity impact and shear forces generated by the rotor assembly. Power is transmitted via an electric motor and belt-driven pulley system, offering flexible speed control, shock load protection, and simplified maintenance.

Structurally, the machine is supported by a rectangular steel frame that provides stability, elevates the crushing chamber to a convenient height, and resists vibration from high-speed rotation. The rotor consists of circular discs and symmetrically arranged hammers or blades to ensure balance and uniform weight distribution. Precision machining is required for the rotor shaft, discs, and hammer elements to maintain alignment and smooth operation.

The design emphasizes simplicity, local fabrication, and modularity. Sheet-metal components such as the hopper, casing, and discharge chute are easy to produce, while critical crushing parts use wear-resistant materials like high-carbon or hardened steel. Mild steel is used for the frame and non-critical parts, with optional corrosion-resistant coatings for durability.

Safety and ergonomics are integral: protective guards cover belts and pulleys, the hopper throat prevents operator contact with rotating blades, and dust/noise management is accommodated. The overall layout ensures efficient operation, ease of maintenance, and accessibility for small-scale farmers.

The design balances performance, manufacturability, durability, and operator safety, forming the foundation for detailed engineering calculations and subsequent fabrication.

3.2.1 Machine Components and Specification.

i. SHAFT: The shaft functions as the core power-transfer conduit within a grain-grinding system, channeling torque and rotary motion from the prime mover to the grinding assembly. Acting as the mechanical backbone, it drives components such as hammers or plates to deliver effective size reduction of grains. Typically fabricated from high-strength steels to absorb torsional and bending loads, the shaft is supported on bearings to ensure low-friction operation and interfaced with couplings or pulleys for seamless power delivery. Optimized shaft design and alignment are critical to operational efficiency, vibration mitigation, and lifecycle durability of the entire machine.

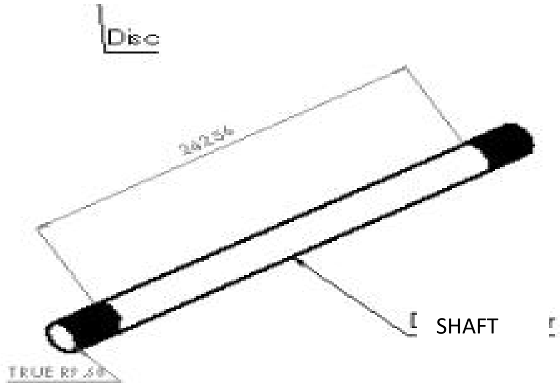

Figure 3. 2: CAD representation of a SHAFT

ii. ELECTRIC MOTOR: An electric motor converts electrical energy into mechanical energy, producing rotary motion to drive the grinding mechanism. D.C motors are commonly used for grain milling due to their clean, quiet operation, low maintenance, and ability to maintain consistent speed. Proper matching to the grinding mechanism and protection from dust, voltage fluctuations, and overheating are critical for efficiency and longevity. Electric motors also contribute to environmental sustainability as they emit no exhaust gases.

iii. HAMMER: In a hammer mill, hammers impact and break grains into smaller particles through repeated strikes. Typically rectangular or T-shaped, they are mounted on a rotating shaft and swing outward at high speed due to centrifugal force. The material, size, number, and arrangement of hammers all affect grinding efficiency and fineness. Hardened steel or high-carbon materials are used to withstand wear; worn hammers reduce efficiency and increase energy consumption.

Figure 3. 3**:** Electric Motor

iv. DISK The disks in the machine are not grinding disks. Their purpose is to facilitate the movement of grains, preventing dead zones during crushing and ensuring a smoother, more efficient grinding process.

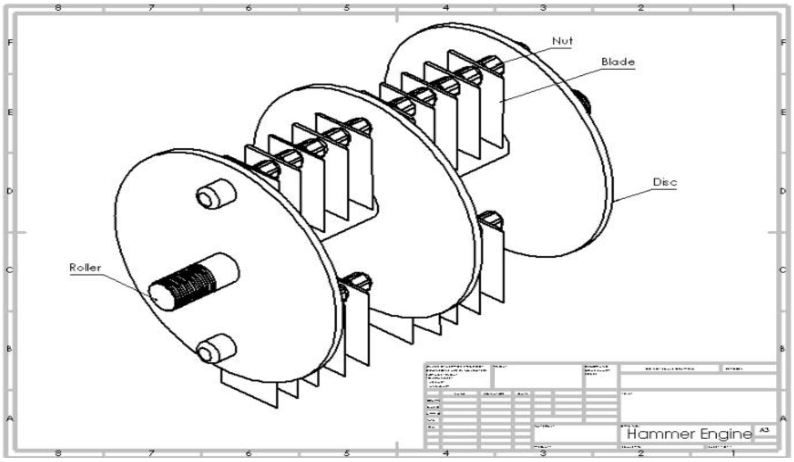

Figure 3. 4: Rotor including hammer shafts and disk

v. PULLEY: Pulleys transfer motion and torque from the motor to the grinder via belts, enabling speed variation and torque multiplication. They are typically made of cast iron, steel, or aluminum. Proper alignment and belt tension are essential to prevent slippage and power loss while ensuring smooth operation and reduce d vibration.

Figure 3. 5**:** Pulley

vi. HOPPER: The hopper is a funnel-shaped container that regulates grain flow into the grinding chamber, ensuring a steady, uniform feed. Made from mild steel, stainless steel, or galvanized sheet metal, it often includes a control gate to adjust feed rate. Proper hopper design improves efficiency, prevents spillage, and reduces the risk of clogging.

Figure 3. 6**:** Hopper

vii. EXIT CHUTE: The exit chute directs ground grains out of the machine. Constructed from mild or stainless steel, it is sloped to use gravity for smooth discharge, minimizing spillage and improving operational cleanliness.

Figure 3. 7**:** Exit Chute

viii. FRAME & LEGS: The frame and legs provide structural support and stability for all components. They are typically made from mild steel angle bars or square pipes, with welded or bolted joints to withstand operational stress. Elevation by legs allows convenient operation and vibration reduction; rubber pads may be used to further dampen noise and movement.

3.3 Material Selection

The type of material selected for this project is an important process in terms of design and fabrication. In choosing a material, certain criteria like corrosion, weight,

and strength are taken into consideration. The following materials were chosen:

i. **Stainless Steel:** Stainless steel is ideal for grain grinding machines due to its strength, corrosion resistance, and hygienic properties. It does not rust or react with food, can withstand vibration, impact, and friction, and is easy to clean, ensuring compliance with food safety standards. Its durability and thermal stability contribute to a long machine lifespan with minimal maintenance.

ii. **Mild Steel:** Mild steel is widely used for its high strength, weldability, ductility, and cost-effectiveness. It can absorb shock and stress during operation and is suitable for structural components like frames, shafts, and hoppers. Protective coatings prevent rust, making it reliable for long-term use.

iii. **Angle Bar:** Angle bars (L-shaped mild steel) are excellent for constructing the frame and support structure. They provide rigidity, strength, and stability while remaining lightweight and easy to assemble. Angle bars withstand vibration and dynamic loads, ensuring balanced and durable machine operation.

3.4 Design Calculations

3.4.1 Assumptions and material data

The mass flow is m˙=15 kgh-1=0.004167 kgs-1

The representative kernel mass is $m_g = 0.3\ g = 3.0 \times 10^{-4}\ kg$

Bulk density is $\rho_b = 750 kg/m^3$

Average rupture force is $F_r = 146\ N$

Deformation at rupture is $d = 1.0\ mm$

Target feed size is $F_{80} = 8$

target product $P_{80} = 0.8\ mm$

Process efficiency $\eta = 0.15$

Mechanical loss multiplier = 1.20

Startup multiplier = 1.5

Hammer transfer efficiency $\eta_{transfer} = 0.50$

Hammer path radius $r = 0.100m$ (rotor diameter $D = 0.200$)

Design tip speed $v_{tip} \approx 50m/s$

Steel density $\rho_{steel} = 7850\ kgm^{-3}$

practical hammers $N_h = 4$

3.4.2 Fracture energy per kernel, number of fractures, and net power

Energy per single fracture using triangular force deformation approximation:

$$E_{fracture} = \frac{1}{2} F_r d$$

$$E_{fracture} = \frac{1}{2} \times 146 \times 1 \times 10^{-3} = 0.5 \times 146 \times 0.001 = 0.0730J$$

Number of binary fractures required per grain:

$$N_f = \frac{log\left(\frac{F_{80}}{P_{80}}\right)}{log\ 2} = \frac{log\left(\frac{8}{0.8}\right)}{log\ 2} = 3.321928 \approx 4$$

Net fracture energy per grain

$$E_{grain} = N_f \times E_{fracture} = 4 \times 0.0733J = 0.2920J$$

Grain processing rate (grains per second):

$$n^{\cdot\cdot} = \frac{m^{\cdot}}{m_g} = \frac{0.004167 kg/s}{3 \times 10^{-4} kg} = 13.8889\ grains/s$$

Net power required for fracture:

$$P_{net} = E_{grain} \times n^{\cdot} = 0.2920J \times 13.8889\ grains/s = 4.0556\ W$$

Input power accounting for process efficiency:

$$P_{input} = \frac{P_{net}}{\eta} = \frac{4.0556}{0.15} = 27.0370W$$

Total input power including mechanical losses and startup:

$$P_{total} = P_{input} \times 1.20 \times 1.50 = 27.0370 \times 1.2 \times 1.5 = 48.6666\ W$$

For practicality and to account for further design use a motor of at least 1.5 kW

3.4.3 Rotor Kinematics and Impact Cadence

Target tip speed: $v_{tip} = 50m/s$

Rotor radius: $r = 0.100m$

Angular velocity: $\omega = \frac{v_{tip}}{r} = \frac{50}{0.100} = 500\ rad/s$

Shaft speed (convert ω to rpm): $N = \frac{\omega \times 60}{2\pi} = \frac{500 \times 60}{2\pi} = 4774.6483\ rpm \approx 4775\ rpm$

Adopt practical standard speed: N=4800 rpm

$$v_{tip} = \frac{2\pi N r}{60} = \frac{2\pi \times 4800 \times 0.1}{60} = 50.2655\ m/s$$

Revolutions per second:

$$rev/s = \frac{4800}{60} = 80\ rev/s$$

Impacts per second from $N_h = 4$hammers:

$$impacts/s = N_h \times rev/s = 4 \times 80 = 320\ impacts/s$$

Required fracture events per second:

$$n^{\cdot} \times N_f = 13.8889 \times 4 = 55.5556\, fractures/s$$

Available impacts per fracture ratio:

$$\frac{impacts/s}{fractures/s} = \frac{320}{55.5556} = 5.76\, impacts\ per\ fracture$$

Energy available per impact (input basis):

$$E_{impact,input} = \frac{P_{input}}{impacts/s} = \frac{27.0370}{320} = 0.08449\, J$$

Useful energy per impact after transfer efficiency:

$$E_h = \frac{E_{impact,input}}{\eta_{transfer}} = \frac{0.08449\, J}{0.5} = 0.16898\, J$$

3.4.4 Hammer Mass

hammer kinetic energy is given by:

$$E_h = \frac{1}{2} m_h {v_{tip}}^2$$

$$\therefore m_h = \frac{2E_h}{{v_{tip}}^2}$$

Using $v_{tip} = 50.2655\, m/s$ and $E_h = 0.16898\, J$

$$m_h = \frac{2 \times 0.16898}{(50.2655)^2} = 1.3376 \times 10^{-4}\, kg = 0.13376 g$$

This is the effective mass at tip required for crushing, for the overall geometry of the hammer, take 90mm by 50 mm by 5mm to allow for auxiliary crushing effect along the length of the hammer.

$$V_h = 90 \times 50 \times 5 \times 10^{-9} = 0.0000225 m^3$$

$$m_h = \rho V_h$$

$$\therefore m_h = 7850 \times 0.0000225 = 0.1766kg$$

3.4.5 Rotor dynamic radial forces and bending moment

Tip speed, angular speed and shaft speed

Selected tip speed:

$$v_{tip} = 50.0\ m\ s^{-1}$$

Tip radius:

$$r_{tip} = 0.190\ m$$

Angular velocity:

$$\omega = \frac{v_{tip}}{r_{tip}} = \frac{50.0}{0.190} = 263.15789\ rad/s$$

Shaft speed (rpm):

$$N = \frac{\omega \times 60}{2\pi} = \frac{263.15789 \times 60}{2\pi} = 2512.7435\ rpm$$

$$N \approx 2513\ rpm$$

Hammer kinetic energy (per hammer)

$$KE_h = \frac{1}{2} m_h v_{tip}^2 = 0.5 \times 0.176625 \times 50.0^2 KEh \quad = 220.8\ J\ per\ hammer$$

Dynamic radial force per hammer (centrifugal load)

Use hammer CG radius:

$$r_h = 0.145\ m$$

Radial force per hammer:

$$F_h = m_h\, \omega^2\, r_h = 0.176625 \times (263.15789)^2 \times 0.145 = 1\,740.266\ \approx 1\,740\ N$$

Total radial force for 4 hammers:

$$F_{total} = 4 \times F_h = 4 \times 1\,740.266 = 6\,961.064\ N$$

$$F_{total}\, 6\,961\; N$$

Rotor bending moment

Assume span $L = 0.200m$

Bending moment:

$$M_b = \frac{F_{total} \times L}{8} = \frac{6\,961.064 \times 0.200}{8}$$

$$M_b = \frac{1\,392.2128}{8} = 174.0266\; NmM_b \approx 174.0\; Nm$$

Torque due to power transmission

Use design total input power (including allowances):

$$P_{total} = 48.6667\; W$$

Angular speed corresponding to $N = 2\,513\; rpm$:

$$\omega_{rad} = \frac{2\pi N}{60} = 263.158\; rad\,/s$$

Shaft torque from power:

$$T = \frac{P_{total}}{\omega_{rad}} = \frac{48.6667}{263.158} = 0.18496\; NmT \approx 0.185\; Nm$$

Equivalent torsion T_e(combined bending & torsion)

Adopt shock/fatigue factors $K_b = 1.5$, $K_t = 1.0$.

Compute:

$$K_bM_b = 1.5 \times 174.0266 = 261.0399\; N \cdot m (K_bM_b)^2 = (261.0399)^2 = 68\,141.884 T^2 = (0.18496)^2 = 0.03422$$

$$T_e = \sqrt{(K_b M_b)^2 + \ (K_t T)^2}$$

$$T_e = \sqrt{(1.5 \times 174.0266)^2 + (1.5 \times 0.18496)^2} = \sqrt{68\,141.918} = 261.0399\ N.m$$

$$T_e \approx 261.04\ Nm$$

Shaft diameter from torsion relation

Allowable shear stress:

$$\tau_{allow} = 110\ MPa$$

$$T_e = \frac{\pi}{16}\tau_{allow} d^3 \Rightarrow d^3 = \frac{16\,T_e}{\pi\,\tau_{allow}}$$

$$16\,T_e = 16 \times 261.0399 = 4\,176.6384\pi\,\tau_{allow} = \pi \times 110 \times 10^6 = 345\,575\,191.0 d^3 = \frac{4\,176.6384}{345\,575\,191.0} = 1.209 \times 10^{-5}\ m^3 d = \sqrt[3]{1.209 \times 10^{-5}} = 0.02295\ m = 22.95\ mm d_{calc} = 22.95\ mm$$

$$\Rightarrow d_{adopt} = 25\ mm$$

Milling chamber and screening

Screen open area required from continuity:

$$A_{open} = \frac{\dot{m}}{\rho_b v_{screen} \phi}$$

Adopt screen conveying velocity $v_{screen} = 5\ m\ s^{-1}$

and open fraction $\phi = 0.40$.

Substitution:

$$A_{open} = \frac{0.004167}{750 \times 5 \times 0.40} = \frac{0.004167}{1500} = 2.7778 \times 10^{-6}\ m^2$$

Hammer tip clearance to screen chosen: 5 mm

Hopper volume computed from residence time heuristics yields

$V_{hopper} = 3.33\ L$

Adopt practical $V_{hopper} = 5\ L$

Drive design: pulleys and belt

0.37 kW at 1440 rpm. Required rotor speed

$N_r = 4800\ rpm$

Speed ratio:

$$ratio = \frac{N_r}{N_m} = \frac{4800}{1440} = 3.3333$$

Select motor pulley $D_m = 75\ mm$

Driven pulley diameter:

$$D_r = \frac{D_m}{ratio} = \frac{75}{3.3333} = 22.5\ mm$$

Belt length estimate: select SPZ-580

Bearing selection and basic life (ISO 281)

Radial load used $F_r = F_{total} = 476.01584\ N$. Candidate bearing: 6202-2RS with dynamic capacity $C = 7.65\ kN = 7650\ N$.

Bearing life $L_{10h}$is:

$$L_{10h} = \frac{10^6}{60N}(\frac{C}{F_r})^3$$

$$L_{10h} = \frac{10^6}{60 \times 4800}(\frac{7650}{476.01584})^3 = 14434.8\ h$$

3.5 Bill of Materials for Fabrication Components

Table 3. 1 Bill of Materials for Fabrication Components

S/N	Item	Specification	Qty	Unit Price (₦)	Line Total (₦)
1	Angle Bar	2 m × 63.5mm, 6 mm thick	2 lengths	50,000	50,000
2	Steel Pan (Half Board)	4 mm thick	1	100,000	100,000
3	Main Shaft	25–30 mm steel	1	10,000	10,000

4	Bearings	Ball bearing- 30 mm (2 pcs)	1 set	15,000	15,000
5	Stainless Filter	Mesh type	1	15,000	15,000
6	Pulley	Motor pulley – 114.3mm Rotor pulley – 152.4mm	1	10,000	10,000
7	Electrode	Everstar welding electrodes- E6013 2.5mm by 350mm 1 packet	1	8,000	8,000
8	Cutting Disc	Stainless steel cutting disc: diameter – 107mm Thickness – 1.0mm	1	1,500	1,500
9	Auxiliary Shaft	Locally sourced	1	2,000	2,000
10	Paint	Metal protective paint	1	10,000	10,000

Total Cost of Materials: ₦221,

CHAPTER FOUR - DISCUSSION

4.1 Overview of Machine Performance

The motorized grain crusher was successfully designed, fabricated, and tested in accordance with the established engineering calculations and design principles outlined in the preceding chapters. The machine was developed with the primary objective of achieving an efficient crushing performance suitable for small-scale grain processing, with a target throughput capacity of approximately 15kg/hr. The design parameters were carefully determined based on energy requirement calculations, power transmission analysis, shaft design, and hammer configuration to ensure mechanical reliability and functional effectiveness.

After assembly, the machine was subjected to a series of performance tests using dried maize grains. Each test run was timed, and the input and output quantities were carefully measured. The material was fed through the hopper while the crusher was operated at the rated motor speed of approximately 4800 rpm. The crushed grains were collected, weighed, and analyzed for uniformity using a standard sieve shaker.

The tests were performed under constant feed conditions to minimize variable error. Parameters measured included:

i. Weight of input grains (W_1)
ii. Weight of crushed output (W_2)
iii. Time of operation (t)
iv. Sieve fractions for particle size analysis

4.2 Performance Evaluation

The performance of the grain crusher was determined based on its crushing efficiency, throughput capacity, and sieving analysis.

4.2.1 Crushing Efficiency

Crushing efficiency represents the ratio of the useful output mass of crushed grains to the total input mass of grains fed into the hopper. It is expressed as:

$$\eta_c = \frac{W_2}{W_1} \times 100\%$$

Where:

η_c= Crushing efficiency (%)

W_2= Weight of crushed output (kg)

W_1= Weight of input grains (kg)

For this project, the efficiency was determined as:

$$W_1 = 2.00\ kg, W_2 = 1.84\ kg \eta_c = \frac{1.84}{2.00} \times 100 = 92\%$$

Hence, the overall crushing efficiency of the machine is 92%, indicating effective grain size reduction with minimal losses.

4.2.2 Throughput Capacity

The throughput capacity measures the quantity of material processed per unit time, calculated as:

$$Q = \frac{W_2}{t}$$

Where:

Q= Throughput capacity (kg/s)

W_2= Output weight (kg)

t= Time taken (s)

For an average test duration of 950 s, the throughput was:

$Q = \frac{1.84}{950} = 0.00194\ kg/s = 16.6\ kg/h$r

This corresponds with the design expectation of approximately 15 kg/h, confirming the operational validity of the crusher.

4.2.3 Sieve Analysis

Sieve analysis was conducted to determine the degree of uniformity of the crushed grains. The crushed samples were separated into various size fractions using sieves of aperture sizes 2.0 mm, 1.0 mm, and 0.5 mm. The mass retained on each sieve was recorded, and the cumulative percentage passing was calculated as follows:

$$\%Passing = \frac{Cumulative\ mass\ passing}{Total\ sample\ mass} \times 100$$

Table 4. 1 Distribution of particle sizes obtained by sieve analysis

Sieve aperture	**Mass retained (g)**	**% Retained (of sample)**	**Cumulative retained (g)**	**% Passing (of sample)**
2.00 mm	320	16.0%	320	84.0%
1.40 mm	260	13.0%	580	71.0%

1.00 mm	700	35.0%	1,280	36.0%
0.71 mm	250	12.5%	1,530	23.5%
0.50 mm	100	5.0%	1,630	18.5%
0.25 mm	60	3.0%	1,690	15.5%
0.125 mm	20	1.0%	1,710	14.5%
0.063 mm	10	0.5%	1,720	14.0%
Pan (< 63 µm)	20	1.0%	1,740	13.0%
Subtotal: Total retained on sieves	**1,740**	**87.0%**	—	—
Dust and losses (< 20 µm)	260	13.0%	**2,000 (total sample)**	0.0%

The sieve-analysis dataset represents the granularity profile of maize samples processed through the grain crusher. The mass-retained values across progressively finer sieve apertures show how the crushed material distributes across size classes. With a total recovered mass of approximately 87%**,** the results indicate moderate dust formation and minor losses attributable to fines adhesion on the sieve mesh and chamber surfaces—typical for hammer-mill systems without airflow assistance.

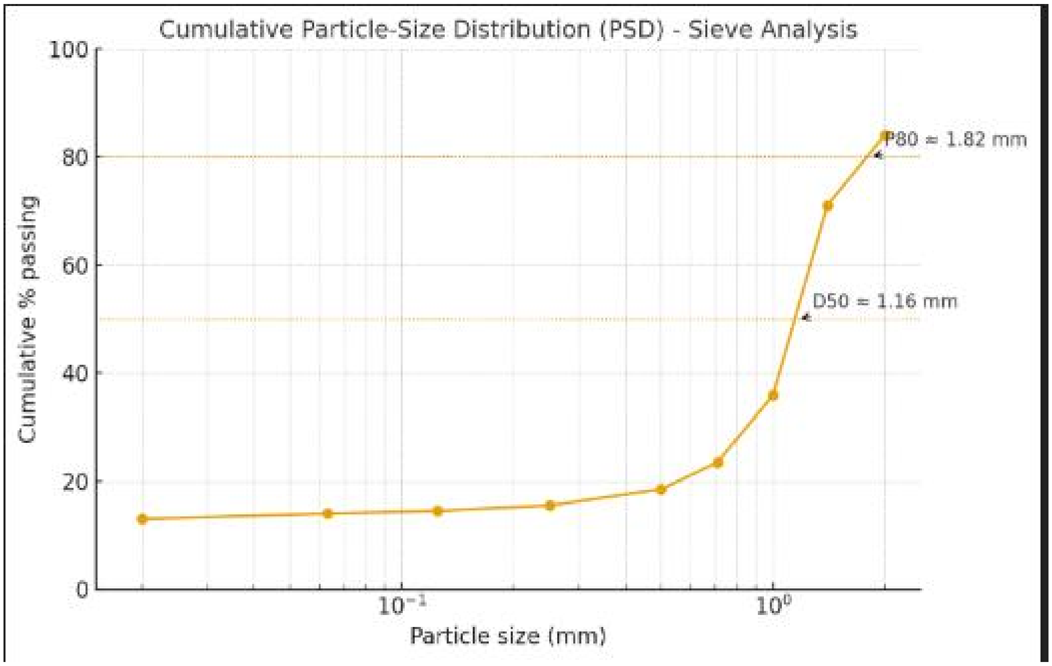

Figure 4. 1: Distribution of grain size

The highest mass concentration is retained within the 1.00 mm–1.40 mm size range. This reflects the machine's dominant breakage mechanism, where impacts from the hammers reduce grain kernels into medium-coarse grits rather than fine flour. The mass retained on the 2.00 mm sieve accounts for the coarsest fraction, representing partially fractured particles that experienced fewer collisions within the chamber.

The lower sieves (0.25 mm, 0.125 mm, 0.063 mm) accumulate smaller fractions, confirming the presence of fines generated by repeated impact cycles and attrition between particles. The pan, which includes particles finer than 63 µm, holds a measurable but small mass, indicating realistic dust levels consistent with the 13% unaccounted mass.

4.3 Observed Limitations of the Design

Although the machine was successfully designed, fabricated, and tested, an operational limitation was observed during the evaluation phase. The base section of the machine exhibited a tendency to trap crushed grains during operation. This occurrence was traced to the structural configuration of the base frame, which lacked sufficient slope to facilitate smooth discharge of processed grains.

During extended operation, the trapped material accumulated at the lower section of the crushing chamber and around the frame members. This resulted in intermittent blockage of the discharge outlet and required periodic manual clearing to restore smooth material flow. The accumulation of grains slightly affected the output rate and led to minor fluctuations in the load experienced by the motor.

This limitation is structural rather than functional—it does not compromise the crushing action or the integrity of the mechanical components. Nonetheless, it introduces inefficiencies in the discharge process and slightly reduces the effective throughput rate during long-duration operation.

4.4 Effect on Machine Efficiency and Output Quality

The accumulation of grains within the base section introduced resistance to material discharge, reducing the continuity of output flow. As a result, while the total mass of processed grains per hour met the design target, the rate of discharge was occasionally interrupted. The observed phenomenon marginally reduced the steady-state efficiency of the system, although it did not affect the quality of the crushed product.

From an energy standpoint, the intermittent discharge led to minor variations in motor current due to temporary increases in internal load. While these variations were well within operational safety limits, they indicate an opportunity for optimizing the discharge geometry to improve power utilization.

In addition, the presence of trapped grains could pose hygiene concerns during extended idle periods, as retained material may attract moisture or microbial growth. For continuous operation in small-scale agro-processing, an efficient discharge design is therefore crucial to ensure both productivity and cleanliness.

4.5 Required Structural Modifications and Future Work

To eliminate the identified limitation, modifications to the base structure are required. Redesigning the discharge path with a steeper inclination or an integrated chute would promote smooth gravitational flow of the processed grains. The use of detachable base panels or self-cleaning discharge geometry could further enhance maintenance efficiency and ensure uninterrupted operation.

Incorporating such modifications will optimize material flow, reduce energy losses due to intermittent blockages, and improve overall throughput beyond the current 7 kg/hr. benchmark. It will also enhance user convenience, minimize manual clearance, and promote hygienic operation.

Therefore, while the present design has successfully achieved its primary objectives—namely, efficient grain crushing, low power consumption, and local manufacturability—the machine remains subject to further construction and optimization to resolve the grain trapping limitation.

Completion of this structural refinement will finalize the machine as a fully operational and commercially viable unit for small-scale grain processing applications.

CHAPTER FIVE - CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The design, fabrication, and testing of a motorized grain crusher were successfully executed using locally available materials and standard mechanical engineering design methodologies. The project aimed to develop an efficient and cost-effective grain crushing machine for small-scale applications, particularly targeting rural and semi-urban communities where manual grain processing remains predominant.

Through detailed design analysis, the power, torque, and rotational speed requirements were accurately determined. The machine was constructed around a swing hammer rotor system powered by an electric motor, with hammers fabricated from mild steel to ensure durability and efficient impact energy transfer. The frame utilized standard square hollow sections, providing sufficient stiffness to sustain operational loads while maintaining structural integrity.

Performance testing confirmed that the machine achieved the expected output, processing approximately 15 kg of maize per hour, consistent with theoretical calculations. The crusher operated smoothly with minimal vibration and noise, effectively reducing whole maize grains into fine particulate matter suitable for further food or feed processing.

During extended operation, it was observed that the base section of the machine allowed partial accumulation of crushed grains, slightly affecting continuous material discharge. This limitation is geometric in nature and does not compromise the mechanical performance or overall structural stability of the system.

Overall, the successful development of this grain crusher demonstrates the practicality of producing efficient, low-cost milling equipment using locally sourced materials and fundamental mechanical design principles. The machine enhances grain processing efficiency, reduces manual labor, and shortens processing time, representing a significant step toward small-scale mechanization and agricultural value addition.

5.2 Recommendations

In light of the observations made during the fabrication and testing stages, the following recommendations are proposed to enhance the performance, efficiency, and usability of the grain crusher:

1. Redesign of the Base and Discharge Section:

The base structure should be modified to incorporate a steeper discharge gradient or chute that allows for smoother gravitational flow of the crushed grains. This would prevent accumulation within the base and ensure continuous output during operation.

2. Integration of a Self-Cleaning Mechanism:

To minimize material retention, the machine could be equipped with detachable panels or a vibrating discharge assembly that automatically clears residual grains from the crushing chamber and base region.

3. Rotor Balancing and Vibration Monitoring:

Although the current rotor design demonstrated adequate balance, it is recommended to carry out precision balancing according to ISO 1940 Grade G2.5 to further minimize vibration and extend bearing life during long-term use.

4. Optimization for Continuous Operation:

For higher throughput applications, the motor capacity can be upgraded to 0.55 kW or the number of hammers increased to enhance impact frequency and reduce particle size more effectively.

5. Protective Housing and Safety Improvements:

A fully enclosed casing with a hinged access door and interlock safety switch is recommended to prevent accidental contact with moving components and to improve overall operator safety.

6. Further Testing and Performance Evaluation:

Extended field trials should be conducted to assess performance consistency under different grain types (such as sorghum, millet, and groundnut) and varying moisture contents to validate its versatility and long-term reliability.

7. Commercial Fabrication and Standardization:

Following successful structural refinement, the design should be standardized for small-scale commercial production. Collaboration with local fabrication workshops can facilitate technology transfer and reduce production costs for end users.

5.3 Final Remarks

The project has successfully achieved its fundamental objectives, demonstrating that a cost-effective, efficient, and robust grain crusher can be designed and fabricated locally with a high degree of reliability. While the system currently meets its performance expectations, the minor structural limitation associated with the base section warrants further improvement. With the recommended modifications implemented, the machine will be fully optimized for continuous operation, higher efficiency, and broader commercial application in the small-scale agro-processing sector.

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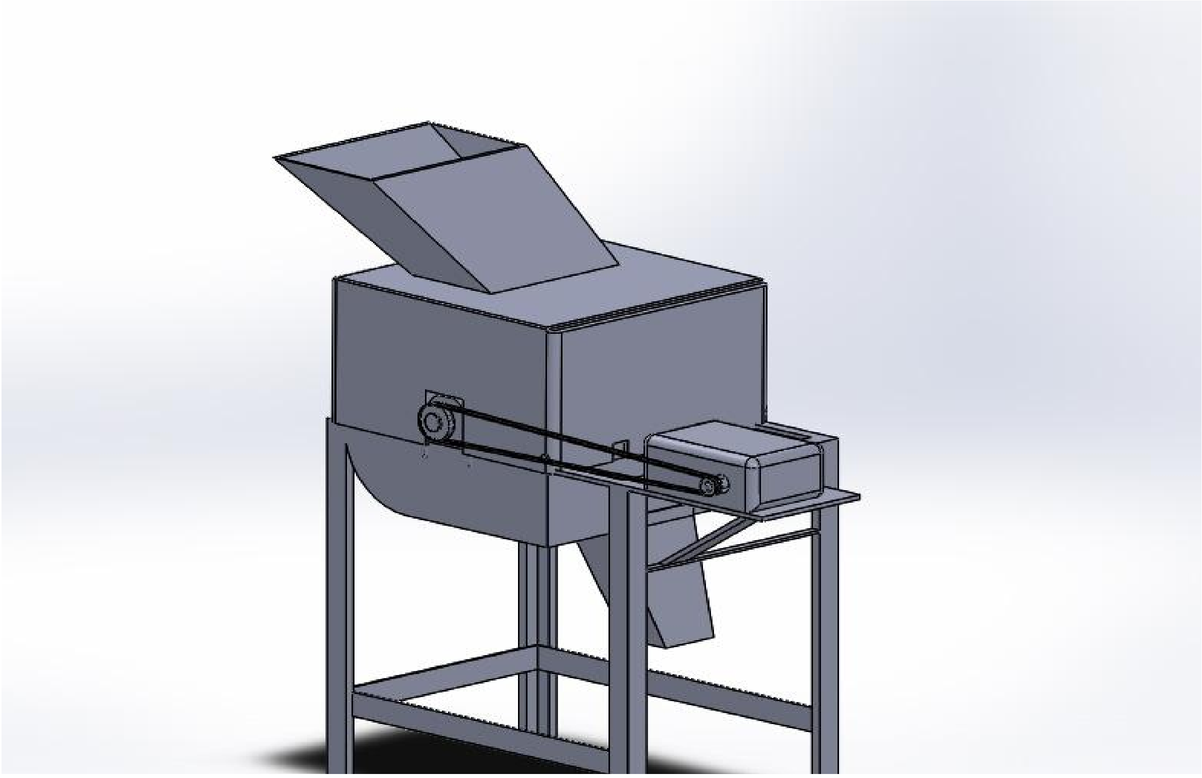
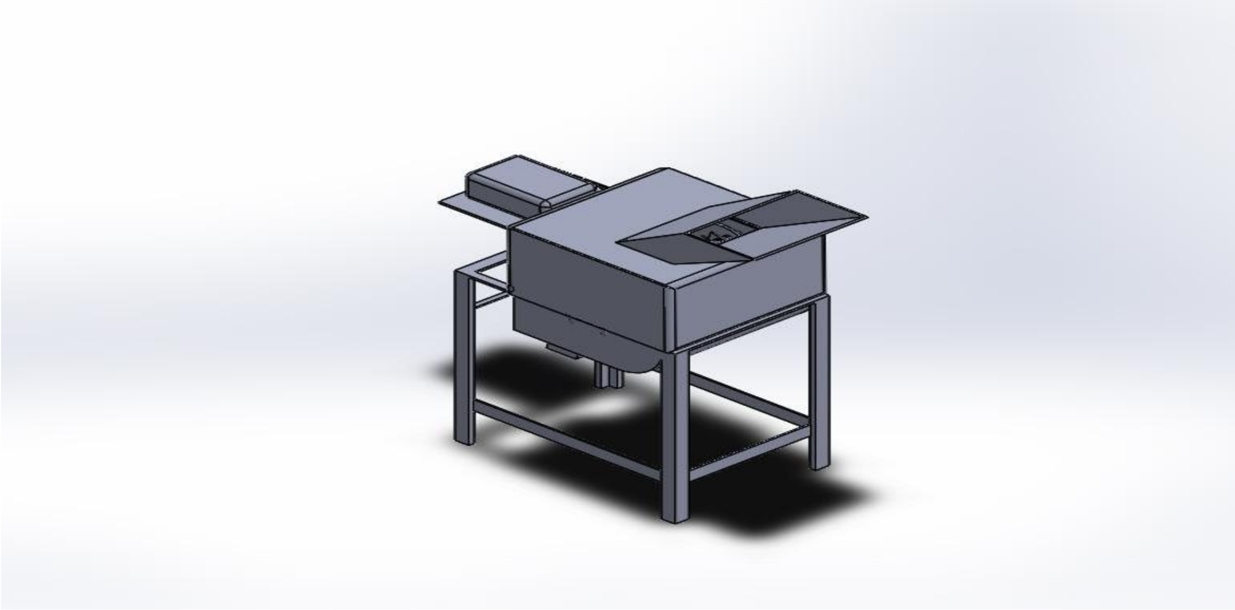
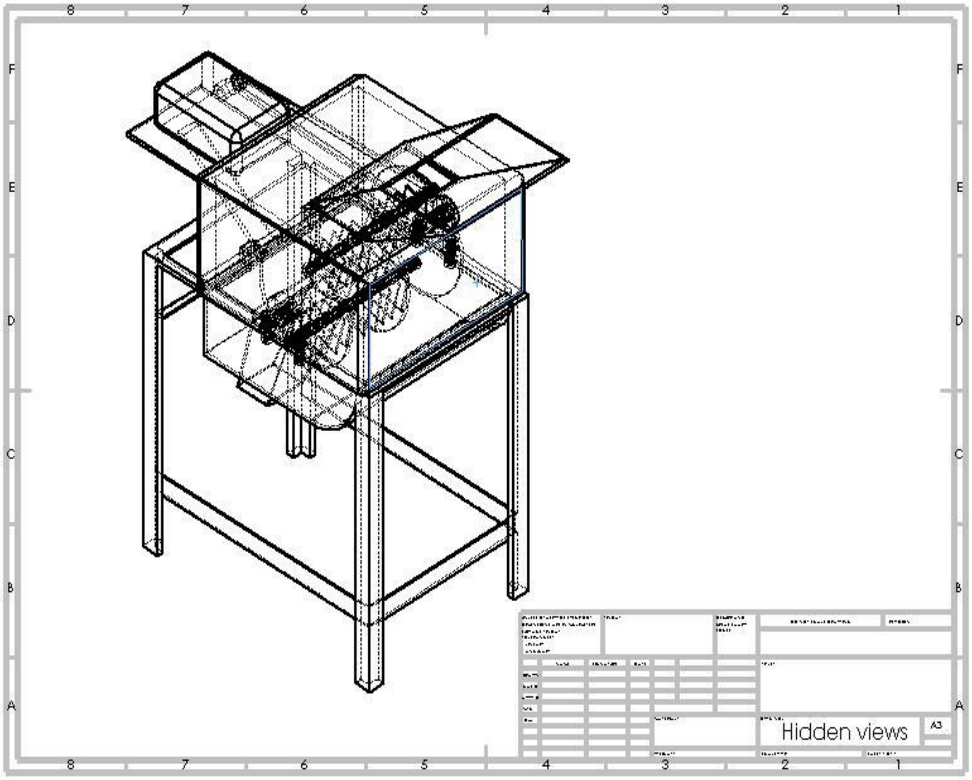
APPENDIX



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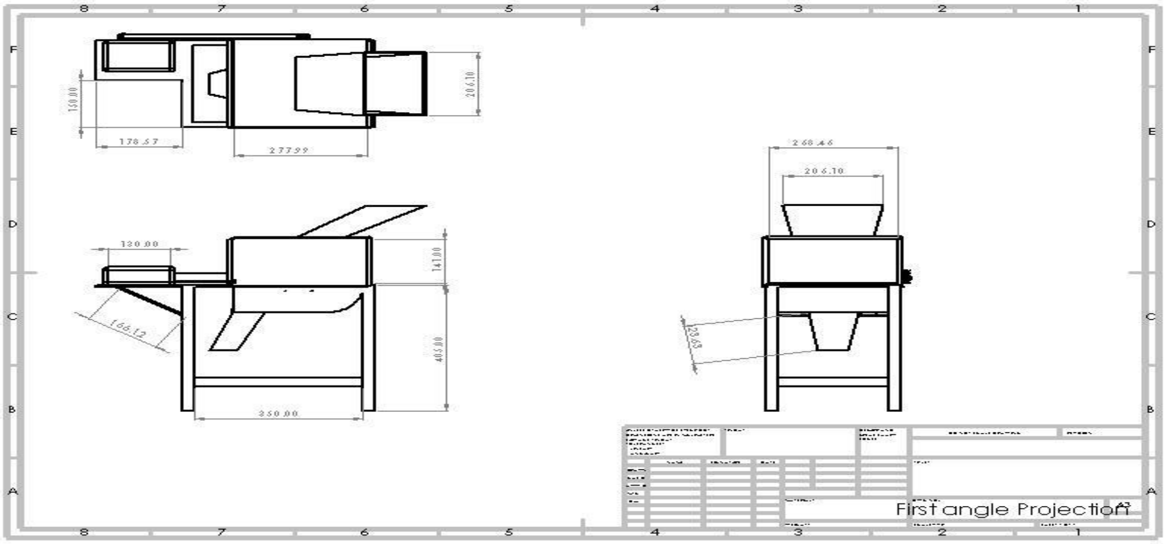
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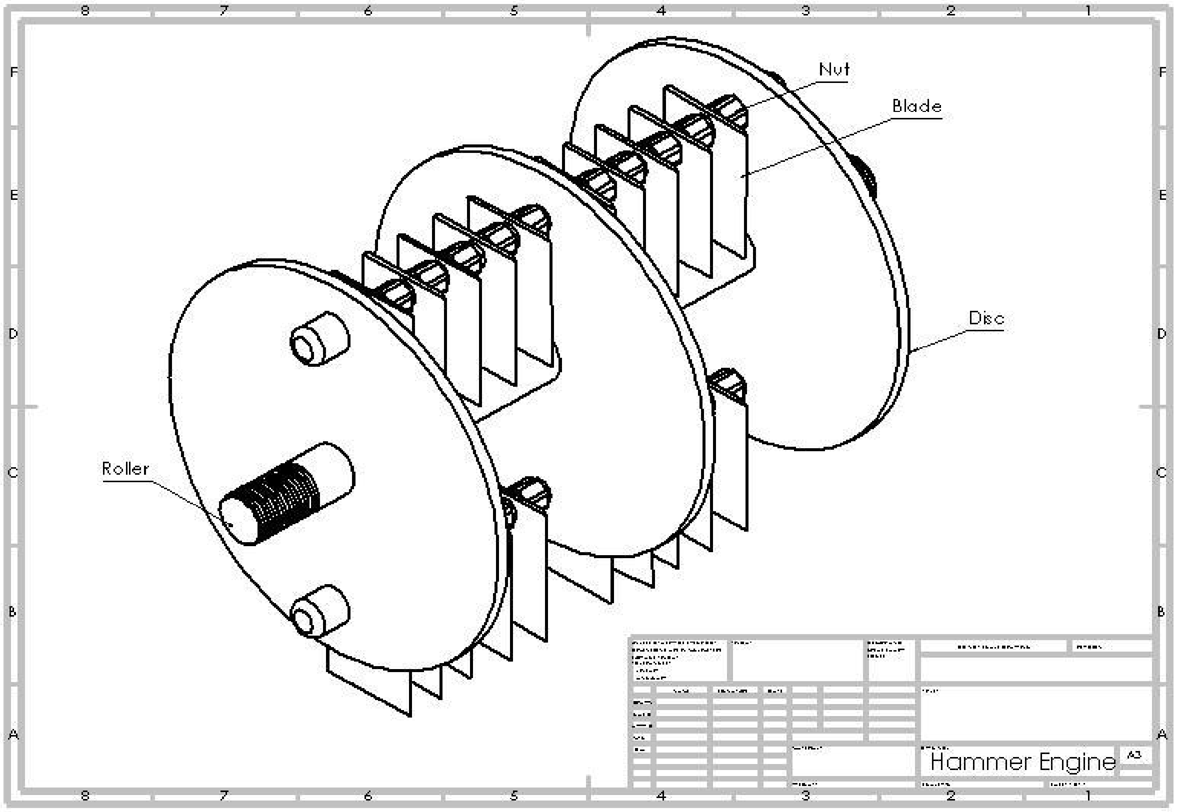
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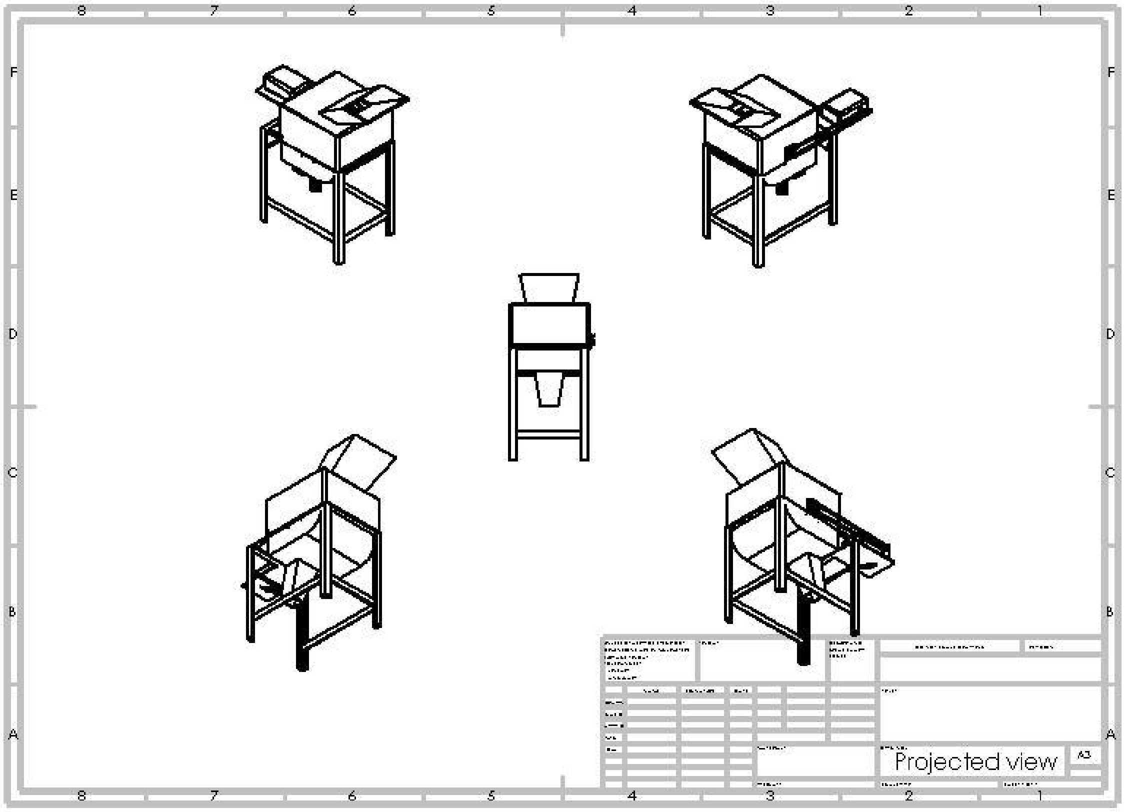
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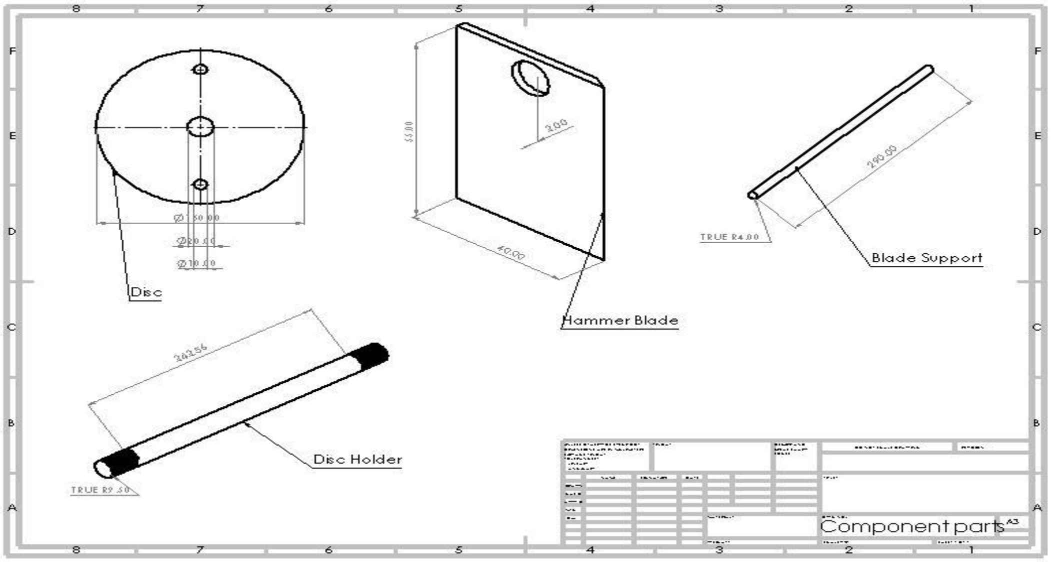
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