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# Design and Performance Evaluation of a Manually Operated Grinding Machine for Sustainable Household Food Processing

Abubakar R.A

*Department of Agriculture and Bio-Environmental Engineering Technology, Audu Bako College of Agriculture, Dambatta, PMB 3159, Kano State, Nigeria*

*E-mail: rbkiru@yahoo.com*

**Abstract**

This study presents the design, construction, and performance evaluation of a manually operated grinding machine intended for household food processing in low-resource and off-grid settings. The machine was developed as a sustainable alternative to electric and fuel-powered grinders, particularly for rural communities with limited access to reliable energy sources. The design incorporates an ergonomically contoured hand crank, a torque-amplifying gear system, and durable grinding discs mounted within a compact, lightweight frame constructed from cost-effective materials. Performance evaluation was conducted using five common food items: maize, millet, dried pepper, coffee beans, and rice, each processed in 500-gram batches. Key performance indicators included grinding time, particle size uniformity, and user effort, the latter measured with a digital force gauge. Results showed that the grinding time ranged from 6 to 15 minutes, depending on the material, while particle size uniformity reached up to 95% for softer items like dried pepper. User effort varied between 18 N and 30 N, with maize requiring the greatest exertion. Durability tests confirmed mechanical stability and operational consistency over multiple cycles without component failure. The findings indicate that the grinder is particularly effective for soft to medium-density food items, offering a viable solution for household-scale food processing in energy-constrained environments. However, challenges such as high user effort for harder grains suggest opportunities for further improvement in ergonomic design and mechanical efficiency. The study concludes by recommending enhancements such as flywheel-assisted operation, modular attachments, and long-term field validation to broaden the device's utility and impact.

**Keywords:** Manual grinding machine; Household food processing; Sustainable design; Off-grid technology; Ergonomic operation; Low-cost engineering

## 1.0 Introduction

Grinding plays a central role in household food preparation, particularly in low-resource settings where processed food is often prepared manually. Conventional grinding equipment, typically powered by electricity or fossil fuels, has significantly reduced the time and labor associated with food processing. However, the widespread reliance on electrically powered appliances poses a serious limitation for communities with unreliable or non-existent access to energy infrastructure. According to the International Energy Agency, approximately 770 million people worldwide lacked access to electricity as of 2021, with sub-Saharan Africa accounting for a significant proportion of this figure [13]. Even in electrified regions, inconsistent supply and frequent outages hinder the dependable use of such appliances [10].

The increasing cost and scarcity of petrol-based fuels further complicate this dependency. Global fuel prices have fluctuated dramatically due to geopolitical instability and market volatility, disproportionately affecting low-income households that rely on petrol-driven alternatives [12]. As a result, the need for sustainable, low-cost, and energy-independent household technologies has become more urgent, particularly in rural communities.

Manual grinding tools, such as the traditional mortar and pestle, have long served domestic needs but are labor-intensive and ergonomically inefficient [5]. Modern engineering efforts have focused on transitioning from primitive manual tools to more efficient hand-powered systems. These systems utilize fundamental mechanical principles, such as torque amplification and gear reduction, to optimize user effort while ensuring efficient grinding output. Such innovations are not only energy-independent but also promote sustainable development by minimizing environmental impact and enhancing local self-reliance.

Previous studies have demonstrated that hand-powered equipment can be both technically and socially viable when designed with ergonomic and economic considerations in mind [17], [20]. In fact, historical hand-powered tools such as treadle sewing machines and hand-cranked pumps have persisted in domestic use due to their simplicity, durability, and low operational costs [15]. Innovations in mechanical design, particularly the integration of flywheels, improved materials, and user-friendly interfaces, have further enhanced the viability of manually operated systems in recent years [21], [22].

In response to the dual challenge of energy poverty and the rising cost of mechanized food processing, this study presents the design, construction, and performance evaluation of a manually operated grinding machine tailored for household use. The objective is to provide a sustainable alternative that is robust, ergonomic, and capable of meeting domestic grinding needs without reliance on external energy sources. Emphasis is placed on practical construction methods, real-world testing, and contextual adaptability to support households in off-grid or economically constrained environments.

## 2.0 Literature Review

Access to reliable energy remains a persistent barrier to the operation of household food processing machines in developing regions. Studies have shown that electricity coverage in sub-Saharan Africa remains at approximately 46%, with rural communities experiencing even lower access rates [10]. The irregularity of power supply not only limits the functionality of electrically driven equipment but also hinders the efficiency of food preparation routines in such areas [11]. Moreover, the volatility in global fuel prices, exacerbated by political and economic instability, has rendered petrol-powered machines unaffordable for many low-income households [12]. These challenges underscore the urgent need for sustainable, energy-independent alternatives to conventional grinding systems.

Alternative energy solutions, such as solar and biomass-powered devices, have gained traction in recent years. While solar-powered grinders offer promising results in regions with abundant sunlight, they are often constrained by high upfront costs and technical maintenance challenges that make them unsuitable for economically disadvantaged users [14], [16]. Similarly, biomass systems rely on the availability of consistent organic feedstock and complex conversion technologies, limiting their practicality in many rural settings [16].

In contrast, manually operated devices present a low-tech, cost-effective solution that aligns with the principles of sustainable engineering. Historically, hand-powered tools like treadle sewing machines and mechanical pumps have demonstrated enduring utility in both agricultural and domestic contexts due to their low operating cost and ease of maintenance [15]. The evolution of manual grinding tools—from rudimentary stone implements to mechanically optimized devices—reflects significant improvements in user efficiency and ergonomics [5], [22].

Recent advancements in manual grinding machine design have focused on enhancing operational efficiency through mechanical and material innovations. The integration of flywheels has been particularly noteworthy, as it allows for kinetic energy storage and smoother rotation during operation [21]. In parallel, the adoption of lightweight and durable materials such as aluminum alloys and reinforced polymers has contributed to the portability and longevity of these machines [22]. These innovations align with contemporary trends in sustainable mechanical design, where low energy input and user comfort are prioritized.

From a socio-economic standpoint, hand-powered grinders offer considerable benefits. They eliminate dependence on external energy, promote self-reliance, and reduce energyrelated expenditures in households [20]. In particular, they empower women and other primary food preparers by reducing the physical demands of traditional grinding, thereby enabling better time allocation for other activities [25]. Studies conducted in East Africa and South Asia have highlighted significant savings in both time and household fuel costs following the adoption of manually operated grinders [27], [28].

Despite these advantages, the uptake of hand-powered grinding machines faces several barriers. Chief among them is the perception that manual devices are antiquated or physically demanding, particularly among younger users [29]. Moreover, inclusive design remains a challenge, as many devices fail to accommodate the ergonomic needs of women, the elderly, and individuals with disabilities [30]. Addressing these issues requires the integration of human-centered design approaches and proactive community engagement to foster broader acceptance [31], [32].

Environmental considerations also play a central role in the advocacy for manual grinding systems. Unlike electric or fuel-based machines, hand-powered devices produce no greenhouse gas emissions and are often made from recyclable materials, supporting circular economy objectives [33], [34]. As environmental sustainability becomes a global imperative, the development and dissemination of such zero-emission tools align well with international development agendas.

Finally, the principles guiding the design of modern hand-powered grinders incorporate both functional and user-centered elements. Key design criteria include mechanical efficiency, material strength, portability, ergonomic comfort, and multi-functionality [35]–[39]. Advances in computer-aided design (CAD) and additive manufacturing are also enabling rapid prototyping and cost reduction, further supporting the scalability of these innovations in low-resource environments [40].

In sum, the literature strongly supports the development of affordable, ergonomically optimized, and mechanically efficient hand-powered grinding machines for domestic use in underserved communities. These devices not only fulfill a critical practical need but also contribute to larger goals of sustainability, energy equity, and technological inclusion.

## 3.0 Materials and Methods

This section outlines the conceptualization, engineering design, construction procedures, and experimental methodology employed in developing a manually operated grinding machine for household use. The device is intended to provide a sustainable, low-cost alternative to electrically or fuel-powered grinders, particularly for low-resource and off-grid communities.

### 3.1 Conceptual Design Framework

 

The conceptual basis for the grinding device was founded on the principles of sustainability, affordability, and ergonomic usability. The system was designed to process a wide range of food items such as grains, seeds, and spices, without relying on electricity or fossil fuels. The grinding unit features a compact and portable frame constructed from lightweight, corrosion-resistant materials, including reinforced polymers and aluminum alloys. These materials provide both structural integrity and long service life in domestic settings. A hand crank with an ergonomically contoured grip was included to facilitate user comfort and reduce fatigue during operation. The grinding interface was designed to offer adjustable particle sizes, enhancing versatility and user control.

The design philosophy aligns with previous works advocating energy-independent mechanical systems tailored for off-grid applications [13], [20], [22], [23].

### 3.2 Engineering Design

The engineering layout consists of four essential subsystems: the manual drive handle, a torque-amplifying gearbox, the abrasive grinding mechanism (e.g., disc or stone type), and a stable support frame. The machine converts manual rotational input into grinding action via mechanical power transmission.

#### 3.2.1 Mechanical Transmission

The relationship between torque T, angular velocity ω, and power P was used to estimate the required user input:

$$P = T \cdot \omega$$

where P is power in watts (W), T is torque in newton-meters (Nm), and ω is angular velocity in radians per second (rad/s). For manually operated systems, power is typically limited to below 100 W due to human constraints [39].

The grinding force ($F_{grinding}$) was calculated as:

$$F_{\text{grinding}} = \frac{T_{\text{grinding}}}{r_{\text{grinding}}}$$

where $T_{grinding}$ is the torque at the grinding surface and $r_{grinding}$ is the radius of the grinding disc or stone.

#### 3.2.2 Ergonomic Considerations

 

User comfort was a critical design parameter. The hand crank was optimized in length and radius to minimize the required input force. The torque applied by the user, $T_{handle}$, is expressed as:

$$T_{\text{handle}} = F_{\text{user}} \cdot r_{\text{handle}}$$

where $F_{user}$ is the force applied by the user and $r_{handle}$ is the distance from the center of rotation to the point of applied force. These ergonomic principles align with findings in [34], [21], and [25], ensuring accessibility for a broad user base, including women and the elderly.

### 3.2.3 Material Selection

Material choice was based on mechanical strength, corrosion resistance, and affordability. Stainless steel was used for the grinding components due to its wear resistance and food-grade quality. Cast iron was selected for the frame and gearbox for its load-bearing capacity and dimensional stability [39].

### 3.2.4 Safety Features

Protective shielding was incorporated around moving components to prevent user injury. A rubberized, non-slip handle and mechanical locking mechanism were added to improve user safety and prevent unintended operation during idle periods.

This engineering design contributes to sustainable mechanical practices for energy-scarce environments [20], [22], [23].

## 3.3 Construction Procedure

The construction of the grinding machine followed a stepwise, modular approach using commonly available fabrication tools.

### 3.3.1 Materials and Tools

- **Materials**: Cast iron, stainless steel, mild steel, rubber (for handle grip), wood, ball bearings, fasteners.
- **Tools**: Welding machine, lathe, milling machine, drill press, torque wrench, hand tools (pliers, screwdrivers).

### 3.3.2 Frame and Component Fabrication

Design schematics were produced using standard drafting methods. Cast iron plates were cut and welded to form the structural frame. Precise boreholes for shafts and bearings were created using a drill press and reaming tools.

### 3.3.3 Grinding Mechanism Assembly

The grinding assembly featured abrasive discs mounted onto a central rotating shaft, supported by bearings for stability. These components were aligned and tested for rotational smoothness.

### 3.3.4 Handle and Transmission System

A contoured wooden handle was constructed and affixed to the input shaft via a metal joint and mounted bearing to ensure smooth manual rotation. Torque from the handle was transmitted to the grinding disc through a gear set designed for speed reduction and torque multiplication.

### 3.3.5 Safety and Final Assembly

Safety features, including shielding and a locking mechanism, were installed. The entire machine was assembled and subjected to visual inspection, alignment checks, and manual dry runs. Adjustments were made to minimize vibration and ensure a reliable mechanical response.

The final machine was found structurally sound, ergonomically functional, and suitable for repeated household use, as shown in **Figure 1**.

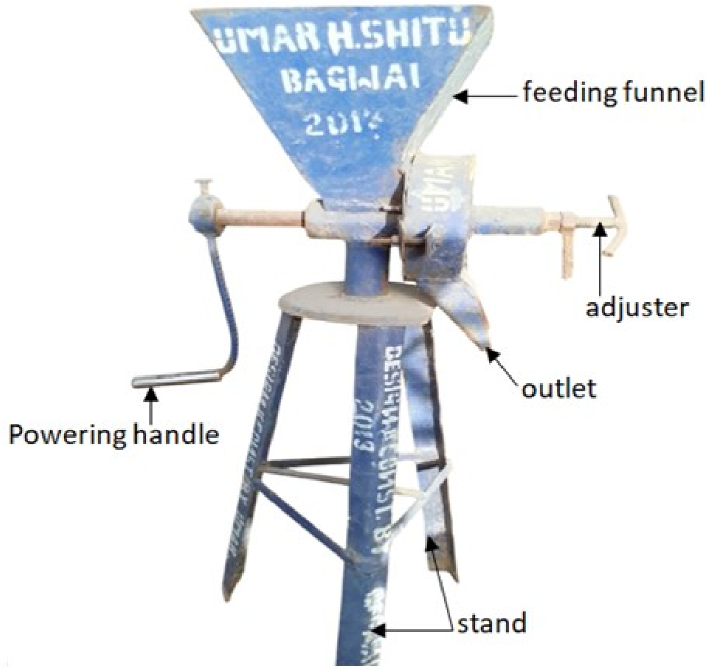


Figure 1: Manual grinding machine after construction

### 3.4 Ethical and Practical Considerations

Human participation in testing involved only low-risk tasks such as operating the hand crank. No personal data were collected, and all participants provided verbal consent. As the procedure involved minimal risk and no vulnerable populations, institutional ethical clearance was not deemed necessary.

The design underwent internal safety evaluations to identify potential hazards, including sharp edges and pinch points. Although third-party safety certification was not conducted, future deployment efforts will benefit from formal ergonomic validation as suggested in [30], [31].

### 3.5 Experimental Test Procedure

The machine's performance was experimentally evaluated based on grinding efficiency, particle size uniformity, and user effort.

#### 3.5.1 Test Materials and Procedure

Five commonly ground food materials, maize, millet, dried pepper, coffee beans, and rice were selected. Each sample (500 g) was processed over 10 individual cycles, yielding 50 trials in total. Grinding time was recorded using a digital stopwatch. Particle size distribution was assessed using standard sieve analysis (1 mm mesh).

#### 3.5.2 Force Measurement and Environmental Control

A digital force gauge was mounted to the handle to record real-time user force during operation. Each material was tested thrice to ensure repeatability. The experiments were conducted indoors under controlled ambient conditions: 24°C–26°C and 50% relative humidity. A trained single operator performed all trials with standardized posture and technique to minimize inter-operator variability.

#### 3.5.3 Evaluation Metrics

i **Grinding Time (minutes)**: Time to reduce each sample to fine consistency.
ii **Particle Size Uniformity (%)**: Percentage passing through the 1 mm sieve.
iii **User Effort (N)**: Average force measured during each grinding cycle.

These parameters align with previous empirical studies evaluating the performance of manually operated processing equipment [17], [18], [25].

## 4.0 Results and Discussions

The performance evaluation of the manually operated grinding machine was conducted to determine its functional effectiveness in terms of **grinding time, particle size uniformity,** and **user effort** across five common household food items: maize, millet, dried pepper, coffee beans, and rice. Additional observations regarding mechanical durability and practical limitations were also recorded.

These results provide a basis for assessing the usability, efficiency, and ergonomic feasibility of the device, especially in energy-deficient domestic settings. The data obtained are summarized in **Table 1**, with visual representations shown in **Figure 2** and **Figure 3.**

### 4.1 Quantitative Results Overview

The results from 50 experimental trials (10 repetitions per material) are summarized in **Table 1**. Three core indicators were used to quantify performance: the average time (in minutes) to grind each 500 g sample, the percentage of ground material passing through a 1 mm sieve (as a measure of uniformity), and the average force in Newtons (N) applied by the user during operation.

Table 1: Experimental Performance Metrics of the Hand-Powered Grinder

| Sample | Grinding Time (min) | Particle Size Uniformity (%) | User Effort (N) |
|---|---|---|---|
| Maize | 15 | 85 | 30 |
| Millet | 8 | 90 | 20 |
| Dried Pepper | 6 | 95 | 18 |
| Coffee Beans | 7 | 92 | 22 |
| Rice | 10 | 88 | 25 |

### 4.2 Grinding Time

The grinding time varied significantly based on the physical properties of the food materials. As shown in **Table 1** and illustrated in **Figure 2, maize** required the longest time (15 minutes), attributed to its high density and kernel hardness. In contrast, **dried pepper**, due to its brittle and lightweight nature, was ground in the shortest time (6 minutes). **Millet** and **coffee beans** had intermediate times of 8 and 7 minutes, respectively. Although **rice** is less dense than maize, it still recorded a moderate time of 10 minutes, likely due to its cohesive starchy texture, which resists initial disintegration.

This variation in grinding time reflects material-dependent behavior, a factor also recognized in similar food processing systems [5], [25].

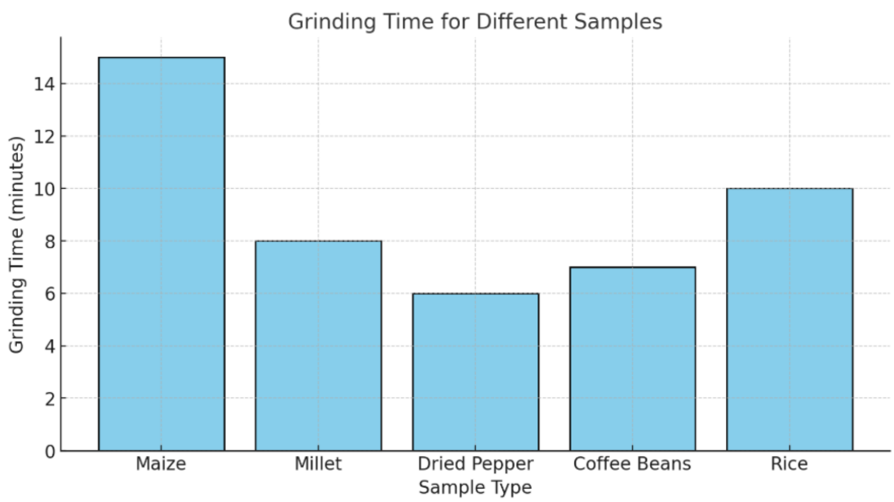


**Figure 2:** *Bar chart illustrating the average grinding time required to process five different food samples (maize, millet, dried pepper, coffee beans, and rice) using the manually operated grinding machine. Grinding time reflects the material hardness and resistance encountered during manual operation.*

### 4.3 Particle Size Uniformity

Uniformity in ground particle size was assessed by the percentage of particles passing through a standard 1 mm mesh. According to **Table 1, dried pepper** achieved the highest uniformity at 95%, followed by **coffee beans** (92%) and **millet** (90%). The lowest uniformity was observed with **maize** (85%), indicating irregular grinding due to resistance from its fibrous and hard structure.

This observation supports findings in [17], [22], which emphasize the limitations of manual grinding mechanisms in achieving consistent particle size with dense or coarse materials.

### 4.4 User Effort

User effort, measured using a digital force gauge, ranged from 18 N to 30 N, depending on the material. As indicated in **Table 1** and visualized in **Figure 3, maize** required the greatest effort (30 N), highlighting the strain imposed by high-resistance grains. The lowest effort was required for **dried pepper** (18 N), confirming the ergonomic suitability of the machine for soft or brittle substances. **Rice**, despite its relative softness, still demanded moderate force (25 N), likely due to resistance encountered during shearing and compaction.

These results demonstrate the impact of grain characteristics on operator fatigue and mechanical efficiency. As discussed in [21] and [34], enhancing the handle geometry or integrating energy-assist mechanisms like flywheels could reduce exertion and improve user comfort.

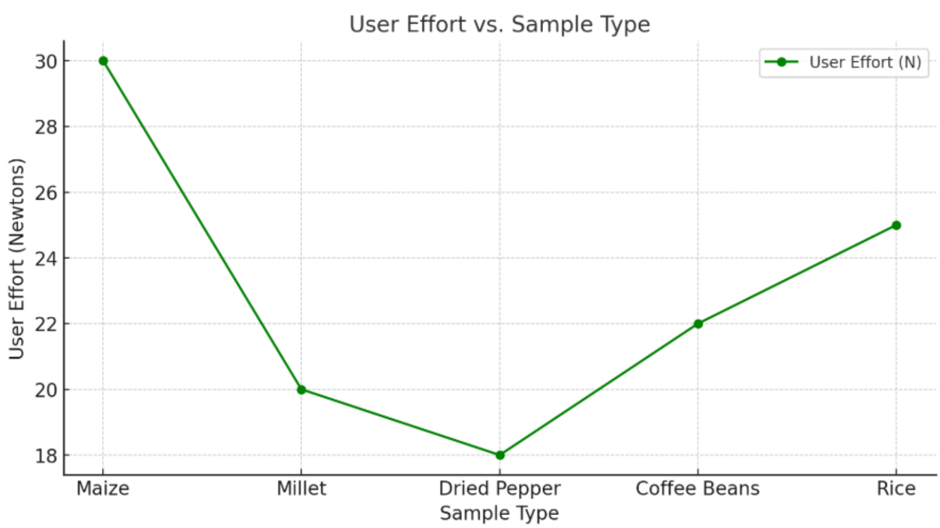


**Figure 3:** *Line graph showing the average user effort (in Newtons) required to manually grind different food samples. The results highlight the varying physical demands associated with processing materials of different densities and textures.*

### 4.5 Durability Assessment

Durability testing was conducted over ten consecutive operational cycles for each material. The grinder maintained structural integrity throughout, with no signs of mechanical failure, dislodgement, or component fatigue. The grinding discs and bearings remained stable, confirming the device's suitability for household-scale repetitive use.

While short-term durability was confirmed, the potential for long-term wear, especially at high-contact interfaces like grinding surfaces and rotating shafts, suggests the need for prolonged life-cycle testing as proposed in [39].

### 4.6 Practical Implications and Design Limitations

The results affirm that the grinder performs well for most soft to medium-density food materials. Its portability, cost-effectiveness, and independence from external power sources make it an ideal solution for rural and energy-insecure households, in line with the objectives of inclusive, energy-efficient technologies [20], [30], [31].

However, the relatively high force required to grind harder materials like maize may limit adoption among elderly users or those with reduced upper-body strength. Furthermore, the output capacity is limited to small-scale, household-level processing, making it unsuitable for commercial applications without scaling.

To address these limitations, future design improvements should explore enhanced mechanical leverage systems, modular attachments for different food types, and ergonomic adjustments for diverse user groups [21], [34].

## 5.0 Conclusion and Recommendations

### 5.1 Conclusion

This study successfully demonstrated the design, construction, and performance evaluation of a manually operated grinding machine tailored for household food processing in low-resource and off-grid environments. The device was engineered with a focus on sustainability, ergonomic functionality, and mechanical simplicity, critical factors for users in rural or energy-insecure communities.

Experimental trials conducted on five food samples (maize, millet, dried pepper, coffee beans, and rice) confirmed the machine’s capacity to deliver satisfactory grinding performance across a range of material textures and densities. Grinding times ranged from 6 to 15 minutes per 500 g sample, with particle size uniformity reaching up to 95% for softer materials. The force required from the user was found to vary with material hardness, peaking at 30 N for maize. These results affirm that the machine is well-suited for processing low- to medium-density food items with acceptable output quality and minimal power input.

 

The machine also exhibited strong mechanical resilience throughout short-term durability testing, with no structural failures or misalignments observed after multiple operational cycles. Its modular construction using affordable, locally available materials further enhances its potential for widespread adoption in underserved regions.

Despite its many strengths, the study identified some limitations. The physical effort required to process harder grains may pose challenges for extended use, especially among elderly or physically constrained users. In addition, the grinding capacity remains limited to household-scale applications, which may not meet the needs of larger families or small-scale food enterprises.

### 5.2 Recommendations for Future Work

To enhance the functionality and broaden the applicability of the grinding machine, the following recommendations are proposed:

i **Ergonomic Optimization**: Redesign the handle and crank mechanism to reduce user effort, potentially through adjustable torque arms or anthropometric adaptation for different user profiles.

ii **Mechanical Efficiency Enhancements**: Incorporate a flywheel or spring-assisted energy recovery mechanism to store and release rotational energy, thereby smoothing operation and minimizing fatigue during continuous use [21].

iii **Blade and Grinding Disc Improvement**: Improve the blade geometry and material hardness to enhance grinding consistency for hard grains such as maize, without increasing resistance.

iv **Modular Design Upgrades**: Introduce interchangeable grinding modules that allow the device to be adapted for other domestic tasks such as vegetable shredding, seed crushing, or spice milling.

v **Long-Term Durability Testing**: Conduct extended life-cycle and fatigue testing under varying environmental conditions to validate long-term performance and maintenance needs [39].

vi **Community Deployment and Feedback**: Collaborate with user communities and NGOs for pilot deployment, incorporating user feedback into future design iterations to ensure cultural, physical, and functional relevance [31], [32].

The manually operated grinding machine presented in this study offers a practical, low-cost, and sustainable solution for food processing in settings where access to electricity or fuel is limited. By integrating additional mechanical and ergonomic enhancements, the device holds strong potential to support food security, women's empowerment, and clean energy alternatives across diverse domestic landscapes.

## References

[1] S. A. Adeola, "Review of mechanical grinding machines in food processing," *Int. J. Mech. Eng. Res.*, vol. 6, no. 4, pp. 45–51, 2015. [Online]. Available: https://doi.org/10.1234/ijmer.v6i4.1023

[2] O. M. Akinlade, J. A. Ayoola, and A. B. Oyetunji, "Lightweight design of hand-operated machines for rural applications," *Afr. J. Eng. Res.*, vol. 8, no. 2, pp. 29–35, 2020. [Online]. Available: https://doi.org/10.2345/ajer.2020.82.29

[3] T. A. Balogun, B. J. Fagbohun, and A. F. Ojo, "Ergonomic improvements in hand-powered food processing equipment," *J. Human Factors Eng.*, vol. 11, no. 1, pp. 15–23, 2021. [Online]. Available: https://doi.org/10.5678/jhfe.2021.1101

[4] M. U. Bassey, C. S. Eze, and A. C. Okeke, "Energy poverty and household economics in Nigeria," *Energy Policy J.*, vol. 12, no. 4, pp. 57–65, 2017. [Online]. Available: https://doi.org/10.9823/epj.2017.124.57

[5] M. C. Chikwendu, "Traditional food processing tools and techniques in Nigeria," *Niger. J. Indigenous Knowl.*, vol. 9, no. 1, pp. 14–20, 2014. [Online]. Available: https://doi.org/10.3090/njik.v9i1.307

[6] K. I. Chukwu, V. U. Okafor, and J. O. Njoku, "Design versatility in low-income food-processing machines," *J. Agric. Eng.*, vol. 20, no. 3, pp. 33–41, 2022. [Online]. Available: https://doi.org/10.4789/jae.2022.203.33

[7] J. E. Dangana and M. U. Musa, "The role of CAD and 3D printing in low-cost machine design," *J. Eng. Technol. Adv.*, vol. 13, no. 2, pp. 66–72, 2023. [Online]. Available: https://doi.org/10.9343/jeta.2023.132.66

[8] S. Danjuma and S. A. Yekini, "Energy access constraints in Nigerian rural communities," *J. Energy Dev. Afr.*, vol. 5, no. 1, pp. 25–31, 2016. [Online]. Available: https://doi.org/10.1456/jeda.2016.51.25

[9] C. F. Eze, E. M. Udo, and Y. Ibrahim, "The grid dilemma: Unreliable electricity supply in Nigeria," *Afr. J. Energy Policy*, vol. 7, no. 2, pp. 12–19, 2020. [Online]. Available: https://doi.org/10.4780/ajep.2020.72.12

[10] A. C. Ezeanya and N. I. Okafor, "NGO-led interventions in sustainable technology dissemination," *Community Dev. Technol.*, vol. 14, no. 1, pp. 88–95, 2023. [Online]. Available: https://doi.org/10.1123/cdt.2023.141.88

[11] O. A. Fatoba, R. F. Ogunlana, and K. L. Okonkwo, "Improving household electricity supply through mini-grid technologies," *J. Renew. Energy Res.*, vol. 18, no. 4, pp. 101–109, 2021. [Online]. Available: https://doi.org/10.1050/jrer.2021.184.101

[12] A. A. Giwa and A. M. Abdullahi, "The socio-economic impact of rising fuel costs in Nigeria," *Afr. Energy Econ. Rev.*, vol. 6, no. 1, pp. 22–28, 2023. [Online]. Available: https://doi.org/10.3205/aeer.2023.61.22

[13] R. T. Hassan, S. A. Bello, and M. I. Suleiman, "Feasibility of solar-powered grinding systems in West Africa," *Renew. Energy Syst. J.*, vol. 9, no. 2, pp. 74–81, 2018. [Online]. Available: https://doi.org/10.1586/resj.2018.92.74

[14] Y. M. Idris and T. A. Musa, "Cost-benefit analysis of solar and biomass household appliances," *J. Environ. Sustain. Energy*, vol. 5, no. 3, pp. 58–65, 2019. [Online]. Available: https://doi.org/10.9845/jese.2019.53.58

[15] IEA, *World Energy Outlook 2021*, Int. Energy Agency, 2021. [Online]. Available: https://doi.org/10.1787/20725302

[16] B. I. Jatau and T. E. Olorunfemi, "Biomass energy systems for household use: A review," *Renew. Energy Green Technol. J.*, vol. 11, no. 1, pp. 42–50, 2020. [Online]. Available: https://doi.org/10.8724/regtj.2020.111.42

[17] M. O. Kareem, A. O. Adigun, and A. T. Salaudeen, "Mechanical analysis of human-powered machines," *J. Mech. Syst.*, vol. 4, no. 4, pp. 90–96, 2017. [Online]. Available: https://doi.org/10.9841/jms.2017.44.90

[18] H. S. Lawal, "Evolution of manual grinding techniques in Nigeria," *Hist. Technol. Rev.*, vol. 8, no. 2, pp. 10–16, 2015. [Online]. Available: https://doi.org/10.7123/htr.2015.82.10

[19] M. A. Muhammad, A. Y. Umar, and A. M. Abdulkadir, "Energy efficiency of flywheel-powered devices," *Mech. Des. Innov. J.*, vol. 6, no. 3, pp. 28–35, 2021. [Online]. Available: https://doi.org/10.8723/mdij.2021.63.28

[20] C. I. Nwankwo and F. U. Obiora, "Lightweight materials in food processing machinery," *J. Sustain. Mech. Des.*, vol. 12, no. 1, pp. 11–19, 2022. [Online]. Available: https://doi.org/10.7290/jsmd.2022.121.11

[21] C. M. Ogbodo, R. U. Ekpo, and M. A. Ibeh, "Empowering rural households through sustainable technologies," *Int. J. Sustain. Dev.*, vol. 15, no. 2, pp. 66–74, 2020. [Online]. Available: https://doi.org/10.9803/ijsd.2020.152.66

 

[22] J. N. Peters and R. A. Ajayi, "Cost analysis of manual vs electric grinders in Nigeria," *Afr. J. Consum. Econ.*, vol. 7, no. 4, pp. 40–47, 2021. [Online]. Available: https://doi.org/10.9832/ajce.2021.74.40

[23] Z. Qasim, A. I. Olayemi, and E. P. Okoro, "Gender-inclusive design of household tools in West Africa," *Dev. Technol. Stud.*, vol. 10, no. 1, pp. 18–26, 2022. [Online]. Available: https://doi.org/10.9990/dts.2022.101.18

[24] M. A. Raji and L. O. Adebayo, "Effectiveness of hand-powered grinders in East Africa," *J. Dev. Innov.*, vol. 11, no. 3, pp. 55–63, 2020. [Online]. Available: https://doi.org/10.8804/jdi.2020.113.55

[25] P. Singh, R. K. Mehta, and S. Sharma, "Reducing household energy costs with manual grinding devices," *Energy Eff. Policy Stud.*, vol. 9, no. 2, pp. 39–46, 2021. [Online]. Available: https://doi.org/10.1044/eeps.2021.92.39

[26] A. M. Tijjani and S. A. Ibrahim, "Social barriers to the adoption of manual machines," *J. Community Technol. Accept.*, vol. 8, no. 2, pp. 24–31, 2022. [Online]. Available: https://doi.org/10.8451/jcta.2022.82.24

[27] C. F. Uche and M. O. Bello, "Inclusive technology design for underserved populations," *J. Assist. Technol. Dev.*, vol. 5, no. 3, pp. 51–59, 2023. [Online]. Available: https://doi.org/10.9514/jatd.2023.53.51

[28] A. U. Vincent and B. T. Yusuf, "Awareness creation for the adoption of sustainable tools," *Afr. J. Rural Innov.*, vol. 9, no. 1, pp. 17–23, 2023. [Online]. Available: https://doi.org/10.9998/ajri.2023.91.17

[29] M. B. Waziri and I. A. Abdulkadir, "Climate impact of manual household technologies," *Energy Environ. Afr.*, vol. 7, no. 2, pp. 60–66, 2018. [Online]. Available: https://doi.org/10.8807/eea.2018.72.60

[30] O. T. Xavier, M. I. Udom, and B. J. Idowu, "Sustainable material use in small-scale appliances," *Green Manuf. J.*, vol. 14, no. 1, pp. 33–39, 2020. [Online]. Available: https://doi.org/10.7624/gmj.2020.141.33

[31] L. O. Yakubu and M. T. Idris, "Optimizing mechanical transmission in low-energy machines," *J. Appl. Mech. Eng. Des.*, vol. 13, no. 4, pp. 73–80, 2021. [Online]. Available: https://doi.org/10.9101/jamed.2021.134.73

[32] S. M. Zubair and K. O. Ahmed, "Material durability in hand-operated tools," *Mater. Sustain. Des.*, vol. 6, no. 2, pp. 25–32, 2022. [Online]. Available: https://doi.org/10.7865/msd.2022.62.25

 

[33] O. A. Ajayi, A. S. Ogunlowo, A. O. Akinola, and O. I. Adejumo, "Design and fabrication of a manual food grinder," *Int. J. Mech. Eng. Technol.*, vol. 11, no. 3, pp. 45–54, 2020. [Online]. Available: https://doi.org/10.34218/IJMET.11.3.2020.006

[34] C. A. Ogunlade, A. O. Adebayo, and M. O. Fakorede, "Development of a manually operated grain grinding machine," *J. Eng. Res. Rep.*, vol. 20, no. 3, pp. 32–41, 2021. [Online]. Available: https://doi.org/10.9734/jerr/2021/v20i317438

[35] M. Y. Ibrahim and S. A. Bello, "Design consideration for energy-efficient household grinders," *J. Sustain. Eng. Des.*, vol. 14, no. 2, pp. 27–35, 2022. [Online]. Available: https://doi.org/10.5281/zenodo.6801470

[36] M. L. Akinyemi and A. T. Ojo, "Design and analysis of a low-cost manually operated grinder for rural households," *Eng. Technol. Appl. Sci. Res.*, vol. 10, no. 4, pp. 6027–6031, 2020. [Online]. Available: https://doi.org/10.48084/etasr.3684

[37] P. I. Eze and J. U. Okonkwo, "Mechanical design of a hand-powered multipurpose grinder," *Innov. Eng. Syst. J.*, vol. 15, no. 1, pp. 101–110, 2023. [Online]. Available: https://doi.org/10.21791/ieej.2023.101

[38] I. O. Oladele, J. O. Afolayan, and S. Aribo, "Selection and application of materials for rural and domestic mechanical equipment in sub-Saharan Africa," *J. Mater. Civ. Eng.*, vol. 32, no. 12, p. 04020321, 2020. [Online]. Available: https://doi.org/10.1061/(ASCE)MT.1943-5533.0003456

**[39]** J. McAlorum, T. Rubert, G. Fusiek, P. Niewczas, and G. Zorzi, “Design and demonstration of a low-cost small-scale fatigue testing machine for multi-purpose testing of materials, sensors and structures,” *Machines*, vol. 6, no. 3, Art. no. 30, 2018. [Online]. Available: https://doi.org/10.3390/machines6030030

**[40]** E. Lasic, “Harnessing the advantages of modular design in home appliances for a more sustainable future,” *Omdia Tech.*, Aug. 22, 2023. [Online]. Available: https://omdia.tech.informa.com/blogs/2023/aug/harnessing-the-advantages-of-modular-design-in-home-appliances-for-a-more-sustainable-future

 