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Development and Evaluation of a Bone Litter Grinding Machine for Sustainable Community Service

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ABSTRACT

This study aimed to develop and evaluate a bone litter grinding machine as a sustainable tool for community-based waste management. A developmental-experimental design was used to design, fabricate, and test the machine. Evaluation focused on functionality, efficiency, durability, usability, and stability, assessed through expert feedback and performance testing. Results revealed highly favorable ratings across all indicators, with durability receiving the highest mean, followed by usability and efficiency. The findings confirm that the machine consistently performs its intended purpose, is user-friendly, and withstands regular use. This innovation is significant because it addresses the problem of discarded animal bones by transforming them into a usable resource, thereby reducing waste and supporting sustainable agricultural practices. The impact of this study extends to community service by promoting resource efficiency, environmental stewardship, and the application of appropriate technology for local agricultural development.

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1. INTRODUCTION

Community service plays a vital role in bridging the gap between technological innovation and the practical needs of society. Many reports regarding community service have been well-documented (Qotrunnada & Nurani, 2022; Ariyanti & Nandiyanto, 2022; Hartanto & Nandiyanto, 2022; Rivky *et al*., 2022; Shaffiyah *et al*., 2022; Giani *et al*., 2022; Artawati *et al*., 2022; Febriani & Nandiyanto, 2022; Wijaya & Nandiyanto, 2022; Hidayat & Nandiyanto, 2022). The application of engineering solutions in local contexts shows how research outputs can directly benefit communities by addressing pressing issues such as waste management, agricultural productivity, and environmental sustainability. When technologies are designed with accessibility, usability, and durability in mind, they become tools of empowerment that enable people to take an active role in improving their livelihoods. In this sense, the development of practical machines such as grinders for organic waste is not only a scientific achievement but also a form of service that promotes resource efficiency and sustainable practices at the community level.

Within this context, bone litter (particularly from poultry) represents a significant agricultural waste stream, despite its potential to be repurposed into valuable resources (Nandiyanto *et al*., 2023; Nandiyanto *et al*., 2020). Without proper management, discarded animal bones contribute to environmental problems such as landfill accumulation and soil degradation. The idea of creating a bone litter grinding machine reflects the broader vision of linking sustainable agriculture with community service, where technological innovation is applied to reduce waste and transform it into useful by-products. By providing a machine capable of converting bones into fine powder, this study highlights an opportunity to align agricultural practices with environmental stewardship and resource efficiency, while simultaneously empowering local communities through accessible and sustainable technology.

Previous studies have emphasized the significance of grinders in recycling and sustainable farming. Machines specifically designed for bone processing have been shown to effectively recycle abattoir waste into bone meal, a product valuable in agriculture and industry (Oyejide *et al*., 2022). The integration of grinding and pulverizing functions has also been proven to improve efficiency and reduce operational costs (Ogedengbe & Abadariki, 2018). In the Philippine context, locally built machines have been developed for small to medium farms to process tough chicken bones in cost-effective and energy-efficient ways (see https://www.scribd.com/document/700110245/chapt-2). Related innovations in recycling fish waste into fertilizer in General Santos City further underscore the importance of local solutions for sustainable soil rehabilitation (Llanes *et al*., 2020). These studies provide strong evidence that small-scale technological interventions can play a vital role in addressing agricultural and environmental challenges.

In this context, the present study aimed to develop and evaluate a bone litter grinding machine that supports sustainable waste management and agricultural productivity. The novelty of the research lies in designing a durable, efficient, and user-friendly machine that can be adapted for community use, especially in rural areas where resources are limited. The study's impact extends beyond technological development because it promotes sustainable agricultural practices, advances community service through appropriate technology, and addresses environmental concerns by transforming waste into a beneficial resource.

2. METHOD

This study employed a developmental-experimental research design. Detailed information regarding this method is explained elsewhere (Susilawati *et al*., 2025). The developmental aspect involved the design and fabrication of the grinding machine, while the experimental part focused on its evaluation. This approach was appropriate because it allowed the researchers to create a technological prototype and assess its performance under controlled conditions. The machine was designed to process discarded chicken bones into fine powder. The evaluation was conducted using five indicators: functionality, efficiency, durability, usability, and stability. These indicators were carefully selected because they represent the essential qualities of an agricultural machine intended for community service and sustainable practice.

To ensure a systematic assessment, a five-point Likert scale was used, where a rating of five corresponded to "Strongly Agree" and one to "Strongly Disagree." We analyzed statistics to get a better understanding of the results. Detailed information on how to analyze using statistical analysis is reported elsewhere (Fiandini *et al*., 2024; Rahayu *et al*., 2024; Afifah *et al*., 2022).

This method enabled evaluators to provide structured feedback based on their observations. Three engineering professionals from Sultan Kudarat State University were purposively selected as evaluators, chosen because of their expertise in machine design and agricultural technology. Their professional judgment was essential in ensuring that the evaluation reflected both technical accuracy and practical usability.

The performance testing was carried out by operating the machine repeatedly with varying bone sizes to observe consistency, output quality, energy consumption, and ease of operation. Feedback from the evaluators, combined with direct observations during the testing, served as the primary basis for determining the machine's effectiveness. The use of expert validation, together with hands-on performance data, strengthened the reliability of the findings and ensured that the machine's potential for sustainable community application could be properly evaluated.

3. RESULTS AND DISCUSSION

3.1. Functionality of the Bone Litter Grinding Machine

Table 1 presents the evaluation of the bone litter grinding machine in terms of functionality. The results show that the machine performed highly effectively across the criteria of crushing, grinding, and consistency of operation. The section mean of 4.73, interpreted as "Strongly Agree," confirms that the evaluators considered the grinder to be highly functional. Specifically, two of the statements ("The grinder effectively crushes and grinds bones into powder" and "It performs its tasks consistently and meets expected output standards") both received a mean of 4.67. These findings demonstrate that the machine consistently delivered on its intended purpose of transforming bones into fine powder suitable for agricultural use. The high score indicates that the machine did not merely perform once under optimal conditions but rather maintained reliable operation over repeated tests, which is critical for sustainable applications.

Equally notable is the perfect score of 5.0 for statements assessing the proper functioning of the components and the machine's ability to deliver reliable performance during repeated use. This outcome demonstrates mechanical stability and structural soundness, key aspects of any machine meant for community deployment. When a machine is to be used in rural or

local agricultural contexts, it must withstand both continuous use and varied environmental conditions. The evaluators' strong agreement that the components function without frequent malfunctions suggests that the design incorporated durable materials and appropriate engineering principles.

The slightly lower mean score of 4.33 for the statement regarding smooth operation without jamming when processing bones of various sizes indicates that occasional challenges may arise when the machine handles bones that are too large or irregularly shaped. Nevertheless, the score still falls within the "Strongly Agree" interpretation, highlighting that the problem is not a recurring issue but rather an area for minor improvement. Such findings are important because they inform future iterations of the machine, suggesting that a refinement in the feeding mechanism or blade configuration might help the grinder handle irregular sizes more seamlessly.

From a community service perspective, functionality is particularly relevant because local users, such as smallholder farmers or community cooperatives, often lack the resources for frequent repairs or replacements. A machine that can reliably perform its tasks reduces downtime, enhances productivity, and ensures that agricultural waste is consistently converted into usable bone meal. This aligns with the broader goals of sustainability, as it reduces waste accumulation and provides a low-cost, locally accessible soil amendment product.

Table 1. Evaluation of the bone meal grinding machine in terms of functionality.

Statement	Mean	SD	Verbal Description
The grinder effectively crushes and grinds bones into powder.	4.67	0.47	Strongly agree
It performs its tasks consistently and meets expected output standards.	4.67	0.57	Strongly agree
The components function properly without frequent malfunctions or delays.	5.00	0.00	Strongly agree
The machine operates smoothly without jamming, even with various bone sizes.	4.33	0.40	Strongly agree
It demonstrates reliable performance and efficiency across multiple uses.	5.00	0.00	Strongly agree
Section Mean	**4.73**	**0.29**	**Strongly agree**

3.2. Efficiency of the Bone Litter Grinding Machine

Table 2 shows the evaluation of the machine's efficiency. The results yielded a section mean of 4.47, classified as "Strongly Agree." This demonstrates that evaluators considered the grinder to be highly efficient in its operation. The statements with the highest mean ratings of 4.67 included the ability to process bones quickly, maintain consistent performance during extended use, and use time, electricity, and labor efficiently. These indicators emphasize that the grinder not only accomplishes its tasks but does so in a way that optimizes productivity.

One of the notable strengths of the grinder is its ability to process bones rapidly while minimizing waste. This outcome is critical because efficiency in machine performance directly influences adoption in community settings. When a tool is able to provide quick results with minimal resource inputs, it becomes more attractive for users who prioritize cost-effectiveness. The consistent performance observed during extended use also demonstrates reliability, as machines that overheat or slow down during long operations are often unsuitable for practical agricultural applications.

The mean score of 4.33 for the production of uniform bone meal with minimal manual intervention is another positive indicator. This suggests that the grinder requires little operator effort once in operation, which enhances usability and reduces labor costs. In many community service projects, one of the barriers to technology adoption is the complexity of operation. A machine that requires minimal intervention removes this barrier, making it accessible to individuals with limited technical training.

Table 2. Evaluation of the bone meal grinding machine in terms of efficiency.

Statement	Mean	SD	Description
The grinder operates at optimal speed with minimal power consumption.	4.00	0.00	Agree
It processes bones quickly, maximizing output and minimizing waste.	4.67	0.47	Strongly agree
The machine maintains consistent performance even during extended use.	4.67	0.47	Strongly agree
It produces a uniform bone meal with minimal need for manual intervention.	4.33	0.47	Strongly agree
The grinder uses time, electricity, and labor efficiently to boost productivity.	4.67	0.47	Strongly agree
Section Mean	**4.47**	**0.26**	**Strongly agree**

The lowest mean score in this section, 4.0, was given to the statement "The grinder operates at optimal speed with minimal power consumption." Although still positive, this indicates that evaluators recognized room for improvement in energy optimization. In regions where electricity costs are high or where power supply is limited, energy-efficient designs can significantly increase machine viability. From a research and development standpoint, this finding provides valuable feedback: future prototypes could explore modifications in the motor design or blade system to maximize grinding speed without additional energy expenditure.

In terms of broader impact, the efficiency of the grinder is crucial for environmental and community service reasons. A machine that maximizes output while minimizing waste directly contributes to sustainability. Moreover, efficient use of electricity and labor resources ensures that the technology is both environmentally and economically beneficial. This aligns with sustainable development goals focused on responsible production and community empowerment.

3.3. Durability of the Bone Litter Grinding Machine

Table 3 provides the evaluation results concerning durability. This section received the highest overall mean score at 4.80, indicating strong confidence among evaluators in the machine's ability to withstand long-term and repeated use. Notably, three of the statements ("It withstands frequent and extended use without easily breaking down," "The machine maintains solid structure and performance over time," and "Normal environmental conditions do not significantly affect its function") all received a perfect mean of 5.0. These ratings strongly confirm that the grinder was perceived as extremely durable and structurally resilient.

Durability is a central feature for any technology intended for sustainable community service. Machines that frequently require repairs are costly and impractical for smallholder farmers or local cooperatives. The findings here suggest that the bone litter grinding machine was constructed with high-quality materials and designed with stability in mind. The mean rating of 4.67 for "The grinder is built with sturdy and high-quality materials" supports this conclusion.

The slightly lower rating of 4.33 for minimal maintenance requirements still falls under "Strongly Agree," indicating that while the grinder may require some upkeep, it is not considered burdensome. This finding reflects the realistic expectation that any mechanical device will need periodic maintenance. Importantly, the high overall rating demonstrates that the machine is not only durable but also designed to function reliably even under normal community usage conditions.

The durability of the grinder enhances its potential as a tool for community service and sustainable agriculture. Because it does not break down easily, it reduces the risk of technology abandonment: a common issue in development projects where machines provided to communities fail prematurely. Long-lasting equipment fosters trust and encourages continued use, thereby maximizing the benefits of the innovation. Moreover, durability ensures that communities can rely on the grinder as a consistent solution for bone waste management, contributing to long-term environmental sustainability and agricultural productivity.

Table 3. Evaluation of the bone meal grinding machine in terms of durability.

Statement	Mean	SD	Verbal Description
The grinder is built with sturdy and high-quality materials.	4.67	0.47	Strongly agree
It withstands frequent and extended use without easily breaking down.	5.00	0.00	Strongly agree
The machine maintains solid structure and performance over time.	5.00	0.00	Strongly agree
Normal environmental conditions do not significantly affect its function.	5.00	0.00	Strongly agree
It requires minimal maintenance and continues to work reliably over time.	4.33	0.47	Strongly agree
Section Mean	**4.80**	**0.27**	**Strongly agree**

3.4. Usability of the Bone Litter Grinding Machine

Table 4 presents the evaluation of the machine in terms of usability. The results yielded a section mean of 4.60, interpreted as "Strongly Agree." This demonstrates that evaluators regarded the grinder as highly user-friendly and accessible even for operators with minimal training. Usability is a critical feature because, regardless of a machine's technical strength, adoption depends on how easily people can use it. In the context of community service and sustainable agriculture, technologies that are too complicated often end up underutilized.

The statement "The grinder is easy to operate, even with minimal training" received the highest mean rating of 5.0. This result highlights the accessibility of the design and its suitability for deployment in communities where technical expertise may be limited. The ability to operate the grinder with little prior instruction ensures that individuals such as farmers, students, or members of local cooperatives can confidently use the machine without requiring intensive training sessions. This feature is particularly valuable in rural areas, where technical support and after-sales service are not always readily available.

Another statement that also scored a perfect 5.0 was "The design allows comfortable and safe use by a single operator." This is a significant strength because it shows that safety was integrated into the design. Safety is not only a mechanical issue but also a social one—accidents in community projects can lead to resistance against adopting new technologies. By ensuring that a single person can operate the grinder safely, the machine addresses both productivity and trust issues.

Table 4. Evaluation of the bone meal grinding machine in terms of usability.

Statement	Mean	SD	Verbal Description
The grinder is easy to operate, even with minimal training.	5.00	0.00	Strongly agree
Instructions, labels, and indicators are clear and user-friendly.	4.67	0.47	Strongly agree
Loading, unloading, and cleaning processes are simple and manageable.	4.00	0.00	Agree
The design allows comfortable and safe use by a single operator.	5.00	0.47	Strongly agree
Parts are accessible for easy maintenance and upkeep.	4.33	0.47	Strongly agree
Section Mean	**4.60**	**0.39**	**Strongly agree**

The statements regarding clarity of instructions, labels, and indicators also received strong ratings, with a mean of 4.67. Clear labeling and intuitive instructions are essential for usability because they reduce the cognitive load on the operator. When users can easily understand machine functions, the risk of misuse or damage is significantly minimized.

The lowest score in this section was 4.0 for "Loading, unloading, and cleaning processes are simple and manageable." While this still indicates agreement, it suggests that the machine might require slight improvements in ergonomics and maintenance design. For example, operators may have found it somewhat laborious to clean certain components or to unload the bone meal after grinding. Although not a critical flaw, this feedback provides valuable insight into how usability could be further enhanced in future versions of the machine.

From a community service perspective, usability ensures inclusivity. If the machine can be operated by diverse groups (students, farmers, women, and even older community members), it broadens participation and increases the machine's impact. Access to technology is a form of empowerment, as it allows communities to take ownership of sustainable practices.

3.5. Stability of the Bone Litter Grinding Machine

Table 5 shows the evaluation of the machine in terms of stability. The section mean was 4.27, which is slightly lower compared to other indicators but still within the "Strongly Agree" interpretation. Stability refers to the machine's ability to remain steady during operation, ensuring both safety and consistency of output. A stable machine minimizes the risk of accidents and prevents mechanical stress that may lead to breakdowns.

Two statements scored the highest mean rating of 4.67: "The components function properly without frequent malfunctions or delays" and "The machine operates smoothly without jamming, even with various bone sizes." These results reinforce the earlier findings under functionality, demonstrating that the grinder can handle different operational demands without compromising stability. This is critical in real-world applications, where bone sizes and shapes are not always uniform.

Another statement ("The product works properly without going out of alignment") received a mean of 4.33. This suggests that, while the grinder maintains proper alignment during operation, slight adjustments may be needed over prolonged use. Mechanical alignment is a common issue in grinding machines, and the relatively high score indicates that such problems are minimal in this case.

Table 5. Evaluation of the bone meal grinding machine in terms of stability.

Statement	Mean	SD	Verbal Description
The grinder effectively crushes and grinds bones into powder.	4.00	0.00	Agree
It performs its tasks consistently and meets expected output standards.	3.67	0.57	Agree
The components function properly without frequent malfunctions or delays.	4.67	0.57	Strongly agree
The machine operates smoothly without jamming, even with various bone sizes.	4.67	0.57	Strongly agree
It demonstrates reliable performance and efficiency across multiple uses.	4.33	0.57	Strongly agree
Section Mean	**4.27**	**0.45**	**Strongly agree**

The lowest scores were for "The grinder effectively crushes and grinds bones into powder" (4.0) and "It performs its tasks consistently and meets expected output standards" (3.67). Interestingly, these statements overlap with those already measured under functionality, yet the slightly lower scores under stability may reflect evaluators' concern with external conditions such as vibrations or minor shaking during operation. Although shaking did not significantly disrupt performance, it may have influenced evaluators' perception of stability.

This finding provides useful feedback for design refinement. For example, stabilizing the base with reinforced materials, adding anti-slip feet, or increasing the machine's weight at the bottom could reduce vibrations. Such adjustments would enhance both stability and operator confidence.

From a sustainability and community service perspective, stability directly influences adoption. Users are more likely to trust and repeatedly use a machine that feels secure during operation. Instability, even if minor, may discourage use because of perceived risks. Therefore, addressing these issues not only improves technical performance but also strengthens community acceptance.

3.6. Synthesis of Functionality, Efficiency, Durability, Usability, and Stability

The results across the first five evaluation indicators (functionality, efficiency, durability, usability, and stability) paint a comprehensive picture of the bone litter grinding machine's performance. Each indicator received a mean score within the "Strongly Agree" category, highlighting the overall success of the machine.

The highest-rated indicator was durability, with a mean of 4.80, suggesting that the machine can withstand prolonged and repeated use without breaking down. This aligns with the need for community-based technologies that are low-maintenance and long-lasting. Usability followed closely with a mean of 4.60, confirming that the machine is accessible and user-friendly, even for non-experts. Efficiency, with a mean of 4.47, indicates that the machine delivers rapid results while optimizing resource use. Functionality, with a mean of 4.33, shows that the machine fulfills its intended purpose effectively. Stability, though slightly

lower at 4.27, still falls within a highly favorable range, affirming that the machine maintains performance under different operational conditions.

This synthesis is particularly important when considering the machine's potential role in community service and sustainability. A machine that is not only functional but also efficient, durable, user-friendly, and stable is more likely to be adopted in rural or low-resource settings. These qualities together ensure that the machine is not just a prototype confined to academic testing but a practical tool that can contribute to waste reduction and agricultural productivity in real communities.

The evaluation results also reflect the broader concept of technology as a driver of community empowerment. By providing a reliable tool for waste management, the machine promotes local initiatives to recycle bone waste into soil enhancers. This supports sustainable farming practices, reduces reliance on chemical fertilizers, and addresses environmental concerns such as waste accumulation and soil degradation.

3.7. Grand Mean of the Evaluation Indicators

Table 6 summarizes the grand mean of all evaluation indicators: functionality, efficiency, durability, usability, and stability. The overall grand mean was 4.57, interpreted as "Strongly Agree." This high rating affirms the success of the bone litter grinding machine across all critical dimensions of performance. Among the indicators, durability received the highest mean of 4.80, reflecting strong agreement that the machine is capable of withstanding extended use. Usability followed at 4.60, showing that the machine is easy to operate and maintain. Efficiency was rated at 4.47, demonstrating that it maximizes output while minimizing resource use. Functionality received a mean of 4.33, confirming that it fulfills its intended purpose. Stability, though the lowest at 4.27, still falls within "Strongly Agree," highlighting that the machine remains secure during operation despite minor issues such as vibration.

Table 6. Grand mean of each indicator.

Indicator	Mean	SD	Verbal Description
Functionality	4.33	0.29	Strongly agree
Efficiency	4.47	0.26	Strongly agree
Durability	4.80	0.27	Strongly agree
Usability	4.60	0.39	Strongly agree
Stability	4.27	0.45	Strongly agree
Grand Mean	**4.57**	**0.29**	**Strongly agree**

The pattern of scores is telling: evaluators placed the greatest value on durability, indicating that long-term reliability is critical for this type of community-oriented machine. Durability often determines whether a machine will be consistently adopted in rural or local settings, as frequent breakdowns can discourage users and render a project unsustainable. Usability's high rating reflects the design's accessibility, making it suitable for community service projects where users may have limited technical knowledge. Efficiency and functionality, while slightly lower, still demonstrate strong agreement, confirming that the grinder effectively converts waste bones into usable powder. Stability, while somewhat weaker, remains acceptable and points to areas for refinement in future iterations of the

prototype. These findings validate the machine as not only a successful prototype but also as a viable community technology that can contribute to agricultural sustainability.

3.8. Discussion in the Context of Community Service

The evaluation results hold significant implications for community service. The primary purpose of developing a bone litter grinding machine is not limited to demonstrating engineering ingenuity but extends to addressing practical problems faced by communities. In many rural areas, chicken bones and other animal remains are often discarded as waste. Without proper disposal, these contribute to environmental challenges such as unsanitary conditions, pest attraction, and soil degradation. By introducing a grinder that transforms these bones into fine powder, the project provides a practical solution that directly benefits local communities.

From the perspective of community service, the machine embodies the principle of appropriate technology. Appropriate technology emphasizes the design of tools that are simple, affordable, and tailored to the needs of local communities. In this case, the grinder meets these criteria by being easy to operate, durable, and efficient. Its potential lies not only in its capacity to recycle bone waste but also in empowering communities to take ownership of waste management practices.

Moreover, the grinder can serve as an educational tool in extension programs and school-based community service initiatives. By demonstrating how waste can be transformed into valuable resources such as bone meal fertilizer, the project cultivates awareness and encourages sustainable practices among students and farmers alike. The usability and safety features highlighted in the evaluation make it especially suitable for integration into such community-based educational programs.

The role of this machine in community service also extends to economic empowerment. Bone meal is a recognized soil enhancer and acid neutralizer, meaning that communities can use the product for their farming or sell it to neighboring farms. In this way, the grinder does not simply solve a waste problem; it creates opportunities for livelihood, resource efficiency, and local enterprise.

3.9. Contribution to Sustainability and Environmental Stewardship

The findings also align strongly with sustainability goals. Waste reduction and resource efficiency are at the heart of environmental stewardship, and the grinder directly addresses both. By converting bone waste into bone meal, the machine reduces the volume of waste sent to landfills while simultaneously creating a product that enhances soil fertility. This dual function strengthens the sustainability of agricultural systems by reducing reliance on synthetic fertilizers, which are often costly and environmentally damaging.

The grinder also contributes to the circular economy concept, where waste materials are reintroduced into the production cycle as valuable inputs rather than being discarded. By doing so, the project exemplifies how simple technological innovations can support resource cycles at the community level. The durability of the machine ensures that this cycle is sustainable over time, while the usability ensures that communities can continue to operate it without specialized technical support.

Sustainability also requires social acceptance, and this is where usability and stability play critical roles. When a machine is safe, comfortable, and reliable, communities are more likely to adopt it. The positive evaluations across these indicators confirm that the grinder meets the practical needs of local users, thereby enhancing its potential for sustainable use.

3.10. Alignment with the Sustainable Development Goals (SDGs)

The development and evaluation of the bone litter grinding machine can be mapped onto several Sustainable Development Goals (SDGs).

(i) SDG 2: Zero Hunger. By producing bone meal as a natural soil enhancer, the grinder supports sustainable agriculture and enhances food production. Improved soil fertility translates to healthier crops and contributes to food security.
(ii) SDG 12: Responsible Consumption and Production. The grinder promotes resource efficiency by converting agricultural waste into a usable product, minimizing waste, and advancing circular economy practices.
(iii) SDG 13: Climate Action. By reducing reliance on chemical fertilizers, the grinder indirectly contributes to lowering greenhouse gas emissions associated with synthetic fertilizer production.
(iv) SDG 15: Life on Land. Bone meal application supports soil rehabilitation and prevents degradation, aligning with efforts to sustainably manage terrestrial ecosystems.
(v) SDG 17: Partnerships for the Goals. The machine provides opportunities for collaboration between universities, local governments, and communities in implementing sustainable practices.

By directly addressing these SDGs, the grinder demonstrates that even small-scale, community-based innovations can have broad implications for sustainable development.

3.11. Theoretical and Practical Implications

Theoretically, the study contributes to the growing literature on locally developed technologies for sustainable agriculture. It validates earlier findings that bone milling and grinding machines can transform waste into valuable by-products (see see https://www.scribd.com/document/700110245/chapt-2) (Oyejide *et al*., 2022; Ogedengbe & Abadariki, 2018; Llanes *et al*., 2020). At the same time, it extends this body of knowledge by emphasizing the importance of community service and usability in technology evaluation. The findings show that beyond technical performance, indicators such as usability and stability are essential for technology acceptance in real-world contexts.

Practically, the study demonstrates that universities and local institutions can play a leading role in developing appropriate technologies for their communities. By engaging experts in engineering design and evaluation, the project ensured technical accuracy. At the same time, by focusing on accessibility, durability, and safety, it ensured that the resulting machine could serve communities effectively. This dual focus on theory and practice illustrates how academic research can directly contribute to sustainable community development.

3.12. Broader Implications for Agricultural Communities

The results of this study demonstrate that the bone litter grinding machine is more than an engineering prototype; it is a practical intervention that addresses pressing agricultural and environmental issues. In many rural communities, the disposal of animal bones poses challenges, not only in terms of waste management but also in lost opportunities for resource recovery. By transforming bones into bone meal, the machine offers a pathway to close this gap and establish a sustainable cycle of production and consumption.

For agricultural communities, particularly smallholder farmers, the implications are significant. The ability to produce bone meal locally reduces dependency on commercial fertilizers, which are often costly and sometimes unavailable in remote areas. Access to an

affordable soil amendment can improve soil fertility, increase crop yields, and ultimately contribute to household food security. These outcomes resonate with the long-standing goals of agricultural development, where productivity improvements must be achieved in ways that are affordable, sustainable, and community-driven.

Furthermore, the machine strengthens resilience by enabling communities to diversify their sources of soil nutrients. When communities are empowered to convert waste into fertilizer, they reduce vulnerability to fluctuations in the prices and availability of synthetic fertilizers. This resilience is essential in the face of global challenges such as supply chain disruptions and climate change, which disproportionately affect rural farming communities.

Another important implication of the project lies in education and capacity-building. The usability and safety of the machine, as shown in the evaluation results, make it suitable for training programs and community demonstrations. Universities, schools, and extension services can integrate the grinder into their community service initiatives, not only to demonstrate technical innovation but also to promote environmental awareness.

For students, exposure to such technologies builds skills and encourages innovation. It also cultivates environmental consciousness, as learners see firsthand how waste can be converted into valuable resources. For farmers, training sessions involving the machine can enhance technical knowledge and inspire greater participation in sustainable practices. In this sense, the grinder becomes both a tool and a platform for education, capacity development, and long-term behavior change.

This educational dimension aligns with the broader mission of higher education institutions, particularly those with mandates for extension and community service. By developing and deploying machines such as the bone litter grinder, universities demonstrate their role not only as centers of knowledge creation but also as catalysts for community transformation.

3.13. Limitation of the Study and Recommendations

Despite its promising outcomes, the study has several limitations that should be acknowledged. First, the evaluation was conducted with a relatively small group of expert evaluators (three engineering professionals) whose feedback, though valuable, may not fully represent the perspectives of end users such as farmers or students. Future research should include a broader range of stakeholders to ensure that the evaluation captures diverse user experiences.

Second, while the evaluation focused on five critical indicators (functionality, efficiency, durability, usability, and stability), other aspects such as cost-effectiveness, scalability, and environmental impact over the long term were not formally measured. These dimensions are important for assessing whether the machine can be widely adopted and maintained across different contexts.

Third, the study did not report detailed field trials involving actual community users operating the grinder over extended periods. While performance testing under controlled conditions was valuable, real-world usage may reveal additional challenges, particularly in cleaning, energy consumption, and long-term wear of components. Addressing these limitations through field trials would strengthen the case for widespread adoption.

Lastly, the grinder was evaluated only on chicken bones. While poultry bones are among the most common agricultural wastes, testing with other types of animal bones could expand the utility of the machine and provide further evidence of its versatility.

Based on the findings and limitations, several recommendations can be made for future development.

(i) Expand User Testing. Future evaluations should involve farmers, students, and other community members to capture a wider range of perspectives. Their feedback would help refine usability features and ensure that the machine meets the needs of diverse users.
(ii) Optimize Energy Efficiency. Since efficiency ratings for power consumption were slightly lower, improvements could focus on designing motors or blade systems that reduce energy use without compromising grinding speed. Exploring renewable energy options, such as integrating the grinder with solar power, may also enhance sustainability.
(iii) Enhance Stability. Minor vibrations observed during testing suggest that reinforcing the base or adjusting the machine's weight distribution could further improve stability. Such modifications would increase operator confidence and safety.
(iv) Improve Ergonomics. Simplifying loading, unloading, and cleaning processes would enhance usability. Design adjustments that minimize manual effort can make the machine more appealing for community use.
(v) Field Trials and Long-Term Testing. Conducting extended trials in actual community settings would provide insights into durability, maintenance needs, and real-world performance. Such trials would also generate data on cost savings, productivity impacts, and environmental benefits.
(vi) Diversification of Applications. Testing the grinder with other types of animal bones could expand its use, making it relevant for communities engaged in livestock production beyond poultry.

The potential of the bone litter grinding machine extends beyond individual use; it can be integrated into larger community development programs. Local governments, cooperatives, and non-governmental organizations can deploy the machine as part of initiatives to promote waste management, soil rehabilitation, and sustainable agriculture. By institutionalizing the use of such technologies, communities can achieve greater impact at scale. For example, cooperatives could use the grinder collectively, producing bone meal in larger quantities for distribution or sale. Local governments could incorporate the machine into environmental management programs, reducing waste in public markets and abattoirs. Non-governmental organizations working in sustainable agriculture could use the grinder as part of training and livelihood programs. These collaborative models not only enhance the machine's utility but also strengthen community ownership and sustainability.

At the research level, this study contributes to the field of agricultural engineering by demonstrating how developmental-experimental designs can be applied to create appropriate technologies. It also highlights the importance of evaluating technologies not only in terms of technical performance but also in terms of usability, stability, and relevance for community service. These dimensions are critical for ensuring that innovations transition successfully from prototypes to real-world solutions.

At the policy level, the grinder provides evidence for the value of supporting local innovation. Policies that encourage the design and deployment of appropriate technologies can strengthen agricultural productivity, reduce environmental waste, and empower communities. In this sense, the study can serve as a model for linking academic research, policy frameworks, and community service in pursuit of sustainable development.

Overall, the results confirm that the bone litter grinding machine is a highly functional, efficient, durable, usable, and stable innovation. The grand mean of 4.57 underscores strong user satisfaction across all evaluation criteria, while the individual indicators highlight both the strengths of the design and areas for refinement. The findings show that the machine is

not only a technical success but also a socially relevant tool with implications for community service, sustainability, and agricultural development.

The study's novelty lies in its dual contribution: advancing engineering design for waste management and promoting sustainable practices at the community level. Its impact is magnified because it demonstrates how local resources, expertise, and ingenuity can generate solutions that address both environmental and agricultural challenges.

The discussion underscores that the grinder is more than a machine; it is a catalyst for change. By recycling bone waste into a resource, it reduces environmental burdens, supports food production, and empowers communities to embrace sustainable practices. With further refinement, broader testing, and integration into community programs, the bone litter grinding machine can become a cornerstone of sustainable agricultural innovation and community development.

4. CONCLUSION

The study successfully developed and evaluated a bone litter grinding machine that demonstrated strong performance across functionality, efficiency, durability, usability, and stability. The grand mean rating of 4.57 indicated that the machine effectively meets its intended purpose and is suitable for community use. Its durability and user-friendliness make it a practical tool for waste reduction, soil enhancement, and sustainable agriculture. The novelty of this research lies in linking engineering innovation with community service, because the machine not only addresses environmental concerns but also empowers communities to transform waste into a valuable resource for agricultural development.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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