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Optimization of Ergonomic and User-Safe Organic Waste Shredding Machine Design Using Quality Function Deployment (QFD)

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Abstract

The increasing volume of waste in Indonesia, especially from households and traditional markets, necessitates innovative technological solutions for effective waste management. This study presents the development of an ergonomic organic waste shredding machine prototype, designed with a focus on safety and ease of use. By applying the Quality Function Deployment (QFD) method, user needs were translated into technical specifications using the House of Quality (HoQ). Primary data was collected through questionnaires, while anthropometric and design data were used to ensure ergonomic suitability. The results indicate that key user priorities include ease of cleaning, minimal noise, and ergonomic height. The design phase includes material selection, component acquisition, and prototype modeling. This innovation supports SDG 11: sustainable cities and communities, and SDG 12: responsible consumption and production.

1. Introduction

Waste is the result of human activities consisting of materials that are basically similar to valuable goods but lose their value because they are mixed and not properly organized. Based on data from the Ministry of Environment and Forestry, four provinces experienced the most serious waste problems in 2022 based on waste volume: Central Java with 4,250,599.92 tons, DKI Jakarta with 12,382.40 tons, East Java with 1,637,819.77 tons, and Riau with 1,051,938.16 tons (Kholili et al., 2021). In 2020, Indonesia generated around 67.8 million tons of waste annually, with approximately 60% consisting of organic waste. The continuous increase in waste volume threatens environmental quality and public health (Ary et al., 2025).

Household waste is the largest contributor, with a proportion of 38.3%, followed by waste from traditional markets (27.7%) and trade centers (14.4%). Meanwhile, waste from offices, public facilities, and other sources remains below 10% (Budiarto & Prasetyo, 2023). This growing waste problem requires effective management strategies, one of which involves the use of a waste shredding machine to reduce the physical volume of waste and facilitate further processing (Setyono & Wibowo, 2021).

A waste shredding machine functions to reduce the size of materials so they are easier to process through recycling or composting (Sukmawati & Pratama, 2023). The shredding process increases surface area, accelerating decomposition and improving waste handling efficiency. With appropriate design and mechanisms, waste shredders can reduce manual effort, minimize waste accumulation at final disposal sites, and support decentralized waste management (Nugraha & Sidiq, 2021). Hence, developing an efficient and safe waste shredder is important to support sustainable waste management systems (Jaelani & Sidiq, 2021).

However, many conventional shredders currently in use exhibit operational and ergonomic issues. Field users often report discomfort due to machine dimensions that do not match operator body postures, leading to awkward bending and fatigue during operation. Excessive vibration and noise also reduce comfort and may contribute to long-term health risks (Ary et al., 2025). In addition, limited safety features such as blade covers and emergency stop mechanisms increase the risk of work accidents, particularly among inexperienced users (Kholili et al., 2021). These findings indicate that ergonomic aspects are important in machine design, especially those related to user posture, comfort, and safety during operation.

Although this study does not employ direct anthropometric measurements, ergonomic considerations are addressed through qualitative insights from operator interviews. These interviews provide practical information about user discomfort and operational challenges, which form the basis for identifying design priorities. This approach allows ergonomic principles to be conceptually integrated into the design stage without requiring extensive anthropometric data collection.

To translate user requirements into measurable design improvements, this research applies the Quality Function Deployment (QFD) method. QFD enables designers to systematically prioritize technical attributes that reflect user needs, such as safety, ease of maintenance, and operational comfort (Ramadhan et al., 2025). Integrating QFD with ergonomic design concepts ensures that the resulting waste shredder not only functions efficiently but also improves operator safety and supports sustainable waste management in line with the Sustainable Development Goals (SDGs) 11 and 12 (Wulan, Saputra, & Nirmala, 2025).

2. Materials and methods

2.1 Material

The waste shredder machine prototype mainly uses iron material for its frame structure. The frame is made of square hollow iron bars that serve as the main support for all machine components. This metal frame provides stability and durability, ensuring the machine remains strong during the shredding process. At the bottom part of the frame, there is an electric motor (washing machine dynamo type) that functions as the main power source to rotate the shredder blades. The shredding blades are made of stainless steel, which is resistant to corrosion and has high hardness to cut or crush various types of waste effectively.

Figure 1. Waste Shredder Machine Frame Structure

In the assembly process, the iron frame is first welded to form a stable rectangular structure. Then, the motor is securely mounted to the base using bolts and brackets to minimize vibration during operation. The blades are attached to the motor shaft using a coupling system, allowing direct rotation when the motor is powered. Finally, the electrical wiring and power cord are connected to supply electricity to the motor. Overall, the combination of iron for the frame and stainless steel for the blades ensures that the waste shredder is sturdy, durable, and suitable for long-term use in waste processing applications.

Figure 2. Waste Shredder Machine Chamber

The upper part of the waste shredder machine uses a large plastic container as the main waste chamber. This container functions as the input and processing area, where organic or inorganic waste is placed before being shredded. The container is made of high-density polyethylene (HDPE) plastic, which is lightweight, durable, and resistant to corrosion and moisture, making it suitable for use in waste processing environments. It is firmly attached to the metal frame using bolts to ensure stability during operation and prevent vibration or movement while the motor is running. On the side of the container, there is a control switch panel consisting of a power button and an indicator light for turning the machine on and off. A flexible plastic hose is also connected to the lower part of the container to help with drainage or cleaning after use. The overall design allows the waste to be shredded efficiently inside the container, with the blades rotating to cut and reduce the waste size.

Figure 3. Exit Pathway for Shredded Waste

This part of the waste shredder machine features a metal discharge chute installed at the bottom of the plastic container. The chute functions as the exit pathway for shredded waste, allowing the processed material to flow out smoothly after being cut by the internal blades. The manufacturing process involves several steps. First, the steel frame is cut, welded, and polished to ensure it can firmly support the container. Next, the plastic bucket is fitted onto the frame, and a hole is cut at the bottom to attach the stainless-steel discharge chute, which is shaped and bent using a sheet metal folding machine.

Figure 4. Waste Shredder Machine Finishing Process

The increase in height was made intentionally to match the average hip level of the user, providing a more ergonomic working position and reducing the need to bend over when inserting or pushing waste into the shredder. The waste pusher, visible as the vertical rod extending upward from the lid, is made of metal to ensure durability and strength when pressing organic waste toward the shredding blades. The pusher handle is welded to a circular lid that covers the container, preventing waste from being ejected during operation while also keeping the process cleaner and more efficient.

2.2 Methods

The research applied a descriptive method with a quantitative approach, focusing on the use of the Quality Function Deployment (QFD) method to design an ergonomic waste shredder that aligns with user needs. This approach was chosen because it enables a structured analysis of user expectations and their translation into measurable technical requirements, ensuring that the product design is both functional and user-centered. Data collection was carried out through open-ended questionnaires distributed to individuals who have direct experience using conventional waste shredders, such as farmers, livestock breeders, and small-scale waste processors. These respondents were selected purposively because their familiarity with waste processing tools made them the most relevant sources of input. The questionnaire was designed to explore user needs, difficulties, and preferences regarding machine operation, comfort, and safety. The responses were then evaluated using a five-point Likert scale, allowing the researchers to determine the degree of importance of each user requirement.

The data obtained from the questionnaires were analyzed using the QFD method, which serves as a systematic framework for translating the Voice of Customer (VOC) into technical specifications. The main tool in this method, the House of Quality (HOQ) matrix, was developed to connect the qualitative data from user feedback with quantitative product characteristics. In this process, each user requirement was matched with the corresponding technical function that could fulfill it. The HOQ also helped identify which design aspects should be prioritized based on their relative importance to users

Through the HOQ analysis, several key insights were obtained. The attributes most valued by users were machine height, operating comfort, and safety features such as a protective lid and waste pusher. These findings indicated that ergonomic design elements such as appropriate height to avoid bending, a secure waste cover to prevent direct contact with blades, and a noise-reducing structure should become the main focus of product development. By relying on QFD and HOQ, the research ensured that the design decisions were data-driven and accurately reflected real user needs, resulting in a shredder concept that is efficient and safe for sustainable waste management practices.

3. Result and discussion

This study aims to design an organic waste shredder by prioritizing user safety, operational comfort, and efficiency. The research has reached the data processing stage using the Quality Function Deployment (QFD) method, specifically through the development of the House of Quality (HoQ). The HoQ was built based on data obtained from questionnaires using a Likert scale, completed by 40 respondents from various backgrounds related to organic waste management and utilization activities. Most respondents were fruit sellers, while the rest included students, employees, housewives, and three fruit farmers. Industrial engineering students were selected because of their knowledge related to design functionality and user interaction, and they were also briefly interviewed to assess their understanding of organic waste shredding machines. Additionally, an interview was conducted with one farmer who already owned a shredder to gather practical insights from real users. The respondents' ages ranged from 20 to 57 years, with a higher proportion of male respondents. The collected data were used to identify user expectations and functional needs for the waste shredder design. Based on the processed questionnaire results, the following section presents the interpretation of user requirements and their respective weights:

Table 1. Voice of Customer

Voice of Customer	RII	Rating	Rank
Easy to clean after use	0.90	4.54	1
Easy to fill waste into the machine	0.88	4.49	2
Low noise during operation	0.88	4.49	2
Operation without bending	0.87	4.46	3
Removable shredder blades	0.87	4.46	3
Waste pusher combined with lid	0.87	4.45	4

Easily reachable control button	0.87	4.44	5
Protective cover for sharp parts	0.87	4.43	6
Ease of removing shredded waste	0.86	4.38	7
Ease of use while standing	0.82	4.21	8

Table 1 shows the results of questionnaires distributed to 40 respondents regarding their needs for an organic waste shredder machine. Each requirement was evaluated and its value calculated using the Relative Importance Index (RII) to determine which factors were considered the most important. The results show that the most important requirement according to respondents was "Easy to clean after use," with the highest RII value of 0.90. This was followed by "Easy to fill waste into the machine" and "Low noise during operation," both with an RII value of 0.88. The requirement with the lowest RII value was "Ease of use while standing," with a score of 0.82, but it was still considered important by users.

The next step after identifying customer needs is to translate these needs into product functions. These functions are developed to address and fulfill what users expect from the product. Each customer requirement is converted into a corresponding technical function that can be applied in the product design process to ensure the machine truly meets user needs. Based on the interpretation of the identified customer requirements, Table 2 shows the product functions that support these findings.

Table 2. Product Function

Voice of Customer	Function
Easy to clean after use	Lightweight machine with detachable blades
Easy to fill waste into the machine	Large and low-positioned inlet
Low noise during operation	Rigid frame with rubber vibration dampers
Operation without bending	Machine height adjusted to a comfortable level
Removable shredder blades	Blades that can be easily removed and reattached
Waste pusher combined with a lid	A lid that also functions as a waste pusher
Easily reachable control button	Clearly visible button positioned within reach
Protective cover for sharp parts	Internal cover and barrier within the machine structure
Ease of removing shredded waste	Small outlet door at the bottom of the machine
Ease of use while standing	Machine height is neither too low nor too high

After the customer needs (Voice of Customer) and product functions were successfully identified, the next stage was constructing the House of Quality (HoQ). The HoQ is the main component of the Quality Function Deployment (QFD) method, used to link customer requirements with the functions that the product must fulfill. At this stage, each customer's need was matched with the corresponding product functions to determine the strength of their relationships. Based on the identified Voice of Customer and product functions, Figure 5 is the resulting HoQ of this study.

Based on the comparison between customer needs and product functions in the House of Quality (HoQ), it can be concluded that several functions effectively meet user requirements. The function with the highest score is "Machine height not too low," with a value of 126. This indicates that users prefer a machine that is comfortable to operate without the need to bend over. The function "Machine height not too low or high" received a score of 103, which also supports comfort during standing operation. Another significant function is "Lid that also functions as a waste pusher," which obtained a score of 99, showing that users also expect the machine to be both safe and practical. Overall, these product functions align well with customer needs, particularly in terms of comfort, ease of use, and safety. These results quantitatively demonstrate the application of QFD in transforming user priorities into measurable technical responses through the HoQ matrix, confirming that the method was implemented systematically rather than conceptually.

The results from the House of Quality (HoQ) served as the main reference in designing a user-friendly and safe waste shredder. The HoQ analysis showed that users preferred a machine that is comfortable, safe, and easy to operate. The main issues with conventional shredders are their low height, which forces users to bend while working, and the lack of safety and convenience features. Therefore, the product design emphasized improving user comfort, operational safety, and ease of use. The machine was equipped with an easily reachable power button, allowing users to turn it on or off quickly and safely. It also includes a waste outlet chute that enables shredded material to come out neatly without scattering. The blade and waste container are designed to

be detachable, making cleaning and maintenance easier. These features make the machine safer and more practical for everyday use.

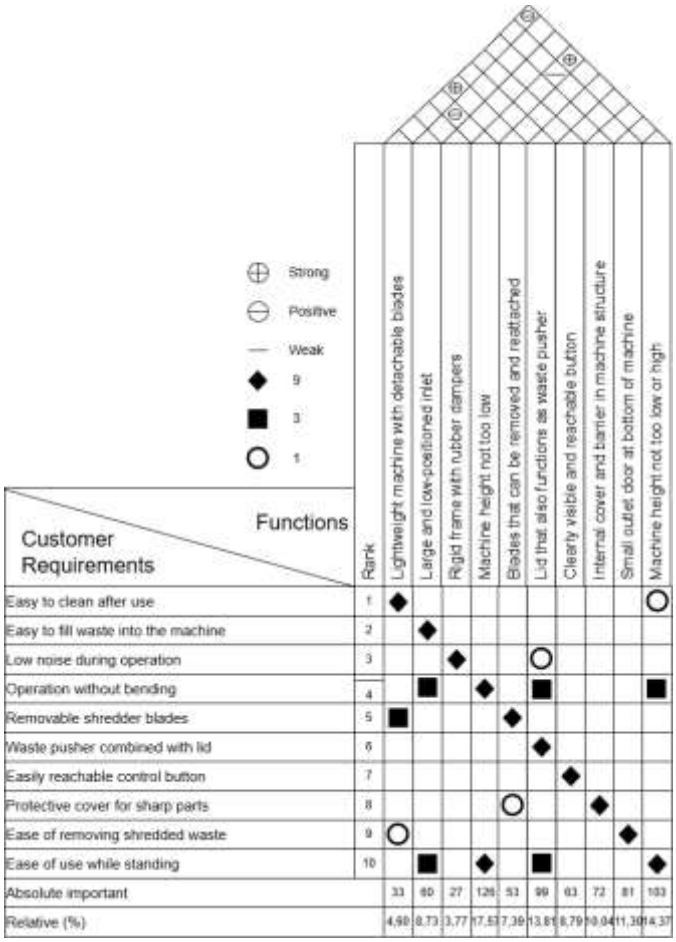

Figure 5. House of Quality Matrix

Figure 6. Ergonomic Waste Shredder Machine

The new design features an increased height adjusted to the average standing posture of users, providing a more natural and comfortable working position. This adjustment helps reduce fatigue, particularly in the lower back area, which commonly occurs when operating machines that are too low. A metal waste pusher was added at the top of the machine to help users push waste downward more easily without direct hand contact. This

pusher also functions as a protective lid, preventing accidental contact with the blades during operation. These modifications make the waste shredder safer and more convenient compared to conventional models. From a material standpoint, the iron frame provides strong structural support and minimizes vibration during use. The HDPE plastic container was chosen for its lightweight, rust-resistant, and easy-to-clean properties. The stainless-steel discharge chute ensures smooth disposal of shredded waste, reducing manual handling. The combination of these materials ensures reliability, safety, and durability. Overall, the improved waste shredder design enhances user comfort, reduces operational effort, and increases safety during waste processing.

4. Conclusion

The development of this ergonomic waste shredder shows that using the QFD and HOQ methods can help connect what users need with how the product is designed. The study proves that applying ergonomic principles can make work safer, more comfortable, and more efficient when processing waste. Besides improving user experience, this product also supports Sustainable Development Goals (SDGs) 11 and 12. SDG 11 relates to building sustainable cities and communities, while SDG 12 focuses on responsible consumption and production. The ergonomic waste shredder supports these goals by helping reduce waste, improving recycling activities, and creating a safer and easier waste processing tool for users. Overall, this product is expected to make waste management more effective and sustainable while keeping users safe and comfortable during operation. Despite these results, the study still has some limitations related to direct ergonomic measurement and prototype testing, which open opportunities for further research.

For future research, further studies are recommended to include anthropometric measurements and detailed ergonomic evaluations to validate user comfort more accurately. Expanding the QFD framework with other design methods, such as Kano or TRIZ, could also provide deeper insights into product innovation and user satisfaction. Moreover, the waste shredder can be developed further by integrating Internet of Things (IoT) technology to enable real-time monitoring, automatic control, and performance data tracking, which would enhance both usability and operational efficiency.

Credit authorship contribution statement

Dr. Dino Rimantho: Supervisor

Zulkarnain Almaidah Pasha: Data Analysis, Writing, Material Preparation

Muhammad Raafi Diefa Putra: Prototype Designer, Material Preparation, Data Collection

Dellianna Nadine: Writing, Data Collection, Data Analysis

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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