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Design of a liquid organic fertilizer composter device utilizing pineapple waste based on voice of customer and technical responses

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ABSTRACT
Pineapple peel waste in Kutai Kartanegara Regency poses a significant environmental burden with a food waste accounting for 73.92%. One method which can be employed to reduce this pineapple peel waste is by producing liquid organic fertilizer (LOF). This research aims to design a LOF composter device utilising pineapple peel waste which tailored to the needs and preferences of local farmers. Quality function deployment (QFD) was used by collecting voice of customer (VOC) and translating it into technical response (TR) as the basis of the design. The resulting LOF composter device's design, incorporate mobility features using wheels and brake plates, equipped with fermentation temperature monitoring via a digital monitor or sensor, and a transparent container for visual monitoring. Stainless steel was selected for its corrosion resistance. Furthermore, the device is designed to be equipped with semi-automatic or automatic shredder blade for optimal texture and a mixer blade designed for even distribution throughout the container. This device is expected to provide an effective solution for managing pineapple peel waste while producing high-quality LOF.

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1. INTRODUCTION

Waste is defined as any material discarded from production or consumption activities that has the potential to cause negative environmental and public health impact if not properly managed [1]. Kutai Kartanegara Regency is one of the largest waste-producing districts in East Kalimantan. Based on the data from the National Waste Management Information System (SIPSN) in 2023, as shown in Figure 1, the dominant type of waste in this region is food waste, accounting for 73.92% of total waste generated.

Unmanaged food waste will undergo anaerobic decomposition in landfills, generating methane gas, a greenhouse gas which approximately 28 times more potent than carbon dioxide. Indonesia is the second-largest food waste producer globally, generating approximately 57.4% food waste of total national waste [2]. Based on interview with the pineapple farmers in Kutai Kartanegara Regency, pineapple production zone in

Kutai Kartanegara contributing 95.40% of total regional output, equivalent to 138,205 quintals in 2023. Farmers in Kutai Kartanegara, sell up to 500 kg of pineapples per day, producing approximately 5 kg of pineapple peel waste daily. This waste is currently discarded without processing, resulting in continuous accumulation and associated environmental risk.

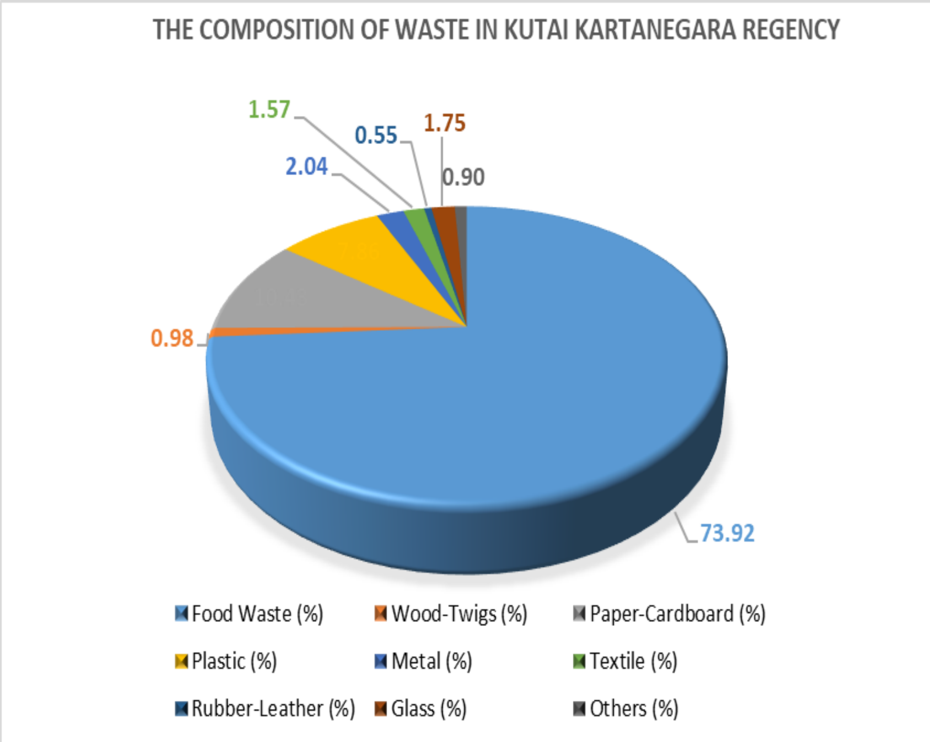


Figure 1. Waste in Kutai Kartanegara

Despite the environmental risk, organic waste such as fruit peel retains considerable agronomic value. In previous study, utilising pineapple peel waste in vermicomposting system, resulting on retention of 24.2%-32.6% nitrogen, 90.4%-91.2% phosphorus, 67.5%-79.3% kalium, and 41.1%-46.1% carbon, in batch and continuous system [3].

LOF production from pineapple peel waste is technically feasible, but its quality is highly dependent on the processing equipment used. However, most of the design were considering the engineering aspect only and did not include end-user preferences. In previous study, quality function deployment (QFD) was used to design a composter, but this design was only focusing on the nutrient analysis results of LOF [4]. In the other hand, previous study revealed that eliciting user preferences gives users a sense of control over their profile, thus making system outcomes more comprehensible and trustworthy [5]. This gap indicate that a user design approach is needed to bridge the divide between technical capability and practical farmer adoption.

QFD is a structured product development methodology that translating voice of customer (VOC) into a technical response (TR), subsequently breaking them down into component parts, and specific manufacturing processes and widely used in several design [6], [7]. This study applying QFD approach to the design of an LOF composter device for pineapple peel waste. It is important to note that this research operates at technology readiness level (TRL) of 2-3, representing the conceptual design stage with the primary objective to identify and translate user needs into technical design specifications. This study applied the first phase of QFD without constructing a full house of quality (HOQ) matrix. This approach has also been employed by previous study with a primary objective of translating the voice of the customer into design requirements, answering what the customer really wants and how expectations can be met [8]. This study therefore aims to design a Liquid Organic Fertilizer (LOF) processing tool utilizing pineapple peel waste using a first phase QFD approach, grounded in farmer VOC data collected in Kutai Kartanegara, East Kalimantan. QFD is used to understand farmers' needs through the Voice of Customer (VOC) and translate them into technical response (TR) to address the shortcomings of simple composters.

2. MATERIALS AND METHODS

2.1. Research Location and Participants

This research was conducted in Kutai Kartanegara Regency, East Kalimantan Province. Data collection was done via questionnaire which was conducted among one of the pineapple farming groups in the regency. Respondents were selected using purposive sampling, since it is appropriate for a user centred design studies where the goal is to capture operational preferences from the actual target users of the product being designed [9].

Inclusion criteria for respondents were: (1) active pineapple farmers in Kutai Kartanegara with a minimum of one year of cultivation experience, and (2) direct involvement in post-harvest pineapple handling, including awareness of peel waste disposal practices. Ten (10) respondents meeting these criteria were recruited from one established farmer group in the village. This sample size is acknowledged as a limitation of the study. However, at conceptual design stage, small criterion based sample is an accepted approach in user centred design QFD study [9].

2.2. Data Collection Instruments

The VOC questionnaire attributes were developed in two stages. Initially, a review of quality dimensions established in the product design and equipment literature was conducted, yielding six dimensions applicable to agricultural processing tools which are performance, features, reliability, durability, serviceability, and aesthetics. Second, these six dimensions were operationalized into nine specific questionnaire items to ensure that each item reflected an actual operational concern of the target users. The final VOC questionnaire used both closed-ended items (Likert scale, 1 = not important to 4 = very important) and open-ended items, allowing respondents to provide qualitative feedback beyond the structured response options.

Following the VOC questionnaire, a TR questionnaire was distributed. This TR questionnaire consists of a series of questions systematically organized based on the results of the VOC analysis to meet the specific needs of the user, which will be incorporated into the design of the LOF composter device. This TR questionnaire use a Likert scale, which is designed to measure the opinions, attitudes, and perceptions of individuals our groups regarding the phenomenon.

2.3. Validity and Reliability Testing

Validity was assessed using Pearson product moment correlation with a significance level of 5% (α=0.05), and the number of data is ten (n=10), resulting in the critical value of r-table = 0.6319. Questionnaire items with r-count > r-table were considered valid [10].

Reliability was assessed using Cronbach's Alpha computed across all nine VOC items as a single construct, reflecting the internal consistency of the full instrument. Cronbach’s Alpha is commonly used to assess the internal consistency of a multi-item scale, and it is computed from the set of items rather than as a standalone coefficient for each item. Thus, it is reasonable to report one overall alpha for all nine VOC items as they are being treated as a single construct. The more common Cronbach’s Alpha is 0.70 but a value of more than 0.60 can be considered adequate in exploratory work [11].

It is acknowledged that with n = 10, both validity and reliability estimates carry greater sampling error than would be obtained with larger samples. The high critical r-value (0.6319) at this sample size means that borderline items have little margin. These results should therefore be interpreted as indicative of instrument adequacy within this exploratory conceptual design context, rather than as definitive psychometric validation.

3. RESULTS

3.1. Questionnaire Validity and Reliability Testing

The VOC questionnaire data were subjected to validity and reliability testing prior to use as the basis for design decisions. Validity testing confirm that each questionnaire item measures its intended construct; reliability testing confirm that the instrument produces consistent responses across respondents.

3.1.1. Validity Test

The validity test was conducted with 10 respondents from the pineapple farmer group in Kutai Kartanegara, at a significance level of 5% (α = 0.050) with n=10, and the critical value r-table = 0.6319. An item is considered valid if r-count > 0.6319. Table 1 shows the validity test results of VOC.

Table 1. Validity test results of the VOC questionnaire (n=10, r-table=0.6319, α=0.05)

Instrument	r-count	r-table	Description
P1	0.6713	0.6319	Valid
P2	0.7357	0.6319	Valid
P3	0.8078	0.6319	Valid
P4	0.7789	0.6319	Valid
P5	0.7597	0.6319	Valid
P6	0.7529	0.6319	Valid
P7	0.7789	0.6319	Valid
P8	0.6347	0.6319	Valid
P9	0.7357	0.6319	Valid

All nine-instrument returned r-count > 0.6319, confirming that each item measures its intended attribute at an acceptable level for this sample size. Table 2 presents dimensions-level average correlation coefficients, computed by averaging the r-count value of items within each quality dimension. These dimension-level averages correspond to the value reported in the conclusion section.

Table 2. Results of the VOC questionnaire validity test

Quality Dimension	VOC Items	Average r-count	Description
Tool Performance	P1	0.6902	Valid
Additional Features	P2, P3, P4, P5	0.7518	Valid
Operational Capability (Reliability)	P6	0.7529 (mean)	Valid
Product Durability	P7	0.7557	Valid
Ease of Repair (Serviceability)	P8	0.6916	Valid
Product Aesthetics	P9	0.7172	Valid

All six quality dimensions exceeded the validity threshold (r-table = 0.6319), with product durability (r = 0.7557) and operational capability (r = 0.7529) showing the strongest average correlations and tool performance (r = 0.6902) and ease repair (r = 0.6916) the lowest-thought still valid. These dimensions-level values are used in the conclusion to characterize overall instrument validity by construct.

3.1.2 Reliability Test

Table 3 presents the overall reliability test results of VOC questionnaire. Values ranging from 0.876 to 0.885 confirm that no single item substantially degrades overall reliability, and that all items contribute meaningfully to construct measurement.

Table 3. Reliability test results of VOC questionnaire

Instrument	Number of respondents	Cronbach's Alpha	Description
P1	10	0.885	Reliable
P2	10	0.882	Reliable
P3	10	0.876	Reliable
P4	10	0.878	Reliable
P5	10	0.879	Reliable
P6	10	0.879	Reliable
P7	10	0.878	Reliable
P8	10	0.885	Reliable
P9	10	0.882	Reliable

The validity and reliability results confirm that the VOC questionnaire is an adequate instrument for this exploratory design study. However, due to the small sample size, these findings are interpreted as suggestive rather than conclusive, and the psychometric properties of the instrument should be re-evaluated in the future validation study with a larger sample.

3.2. Quality Function Deployment (QFD) Approach

The QFD approach in this study covers the elicitation and analysis of VOC data and its translation into Technical Response (TR).

3.2.1 Voice of Customer (VOC)

The LOF composter device was designed based on VOC indicators with a rate of 3 (important) or 4 (very important) by respondents across all six quality dimensions. Items rated below 3 were excluded from the design basis. Result is presented in Table 4.

Table 4. Responder assessment results

No	VOC Indicators and Attributes	Score	Description
Performance			
1.	The LOF composter device functions according to needs	4	Very Important
Features			
2.	The LOF composter device has a temperature controller	3	Important
3.	The LOF composter device has a LOF controller	3	Important
4.	The process of making LOF can be done easily	4	Very Important
5.	The LOF composter device is easy to move	3	Important
Reliability			
6.	The LOF composter device produces consistent output	4	Very Important
Durability			
7.	The material of the LOF composter device	4	Very Important
Serviceability			
8.	The LOF composter device is easy to repair	4	Very Important
Aesthetic			
9.	The LOF composter device has a color	3	Important

3.2.2 Technical Response (TR)

TR translate responder's needs into actionable design requirements. TR items were identified through VOC analysis results and direct structured interviews with respondents. Table 5 presents each TR alongside its specification and an indicative target parameter derived from comparable LOF and compost machine designs in the literature [12]–[14].

Table 5. Technical specification responses

No	Technical Response	Specification	Indicative Target Specification
1	Producing LOF	The tool is designed to produce LOF with optimal nutrient quality for plants.	Output quality referencing SNI 261/2019 minimum standard (N+P+K $\geq$ 2%)
2	Digital Monitor or Temperature Sensor	Equipped with a sensor to measure and monitor fermentation temperature in real-time.	Monitoring range: 25-60^{o}C (mesophilic fermentation range)
3	Transparent LOF Collection Section	LOF collection section designed with transparent material for visual monitoring.	Visual access to liquid level without disassembly

No	Technical Response	Specification	Indicative Target Specification
4	Semi-automatic or Automatic	Tool operates via semi-automatic or automatic mechanism to reduce manual labor.	Motorized shredding and mixing; operator input limited to loading/unloading
5	Wheels with Lockable Brake Plates	Tool equipped with wheels and lockable brake plates for mobility and stability	6 wheels; brake lock engageable during operation
6	Improved Mixing System	Mixer blade designed to reach all parts of the container for even mixing.	Full-coverage rotation; blade clearance $\leq$ 10 mm from container wall
7	Stainless Steel Material	Tool constructed from stainless steel for corrosion resistance and long service life.	Grade 304 stainless steel (food/agricultural grade)
8	Availability of Spare Parts	Spare parts readily available in local market for ease of maintenance.	All component available in East Kalimantan regional market
9	Bright and Calm Colors	Tools uses bright, soft colors for modern and attractive appearance	Pastel palette (light blue, mint green, cream or pastel yellow); industrial enamel paint

Above indicative target provides a first technical frame of reference consistent with the conceptual design stage. Exact specifications will be confirmed by future prototype fabrication and performance testing.

Based on the identified TR, an evaluation was conducted to obtain user feedback. The design of the composter in this study is based on technical responses that were rated 3 and 4, indicating levels of agreement categorized as "agree" and "strongly agree" by the respondents. The results of the partner assessment for the technical response questionnaire show in Table 6.

Table 6. Responder's assessment results on TR

No.	Attribute	Value	Description
1	Producing LOF	4	Strongly Agree
2	Digital Monitor or Temperature Sensor	4	Strongly Agree
3	Transparent LOF Collection Section	4	Strongly Agree
4	Semi-automatic or Automatic	4	Strongly Agree
5	LOF composter device with Lockable Brake Plate Wheels	3	Agree
6	Improved Mixing System	4	Strongly Agree
7	LOF composter device Material from Stainless Steel	3	Agree
8	Availability of Spare Parts	3	Agree
9	LOF composter device with Bright and Calm Colors (Pastel Yellow, Light Blue, Mint Green, or Cream)	3	Agree

3.3. Design of the LOF Composter Device

The design of the LOF composter device is based on the analysis of the relationship between VOC and TR to ensure that the analyzed TR align with consumer needs. The design of the LOF composter device includes both the conceptual design of the device and the detailed design of the LOF composter device.

3.3.1. Designing the Tool Concept

Designing the concept of a tool is the initial stage in creating a product aimed at developing a tool that can meet the needs and expectations of users. In the creation of a Proof of Concept, it is not only important to consider user requirements but also to adhere to the principles of LOF development. The principles of LOF creation have a basic concept that can be seen in Figure 2.

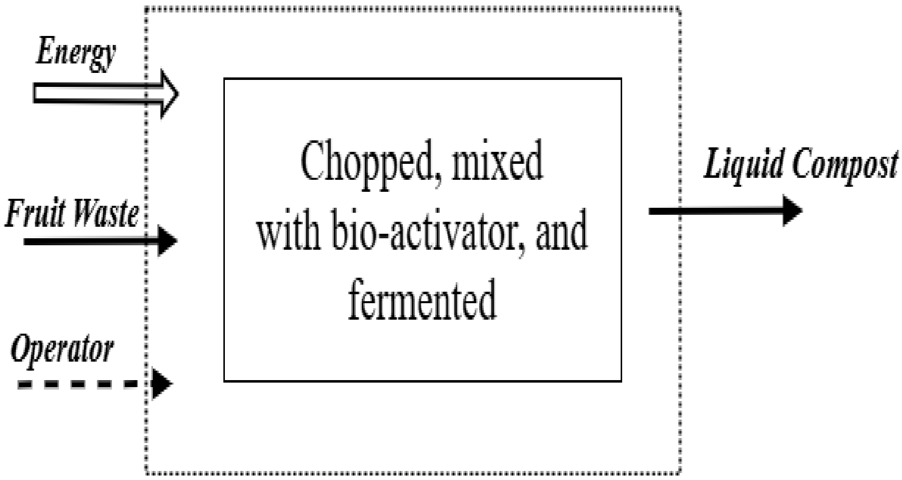


Figure 2. Basic principles of the LOF composter device

Figure 2 serves as a reference for the process of designing the LOF composter device's concept, which will then be adjusted to customer needs that have been translated into technical responses according to user preferences. The results of the concept design, aligned with technical responses and user preferences, can be seen in Figure 3.

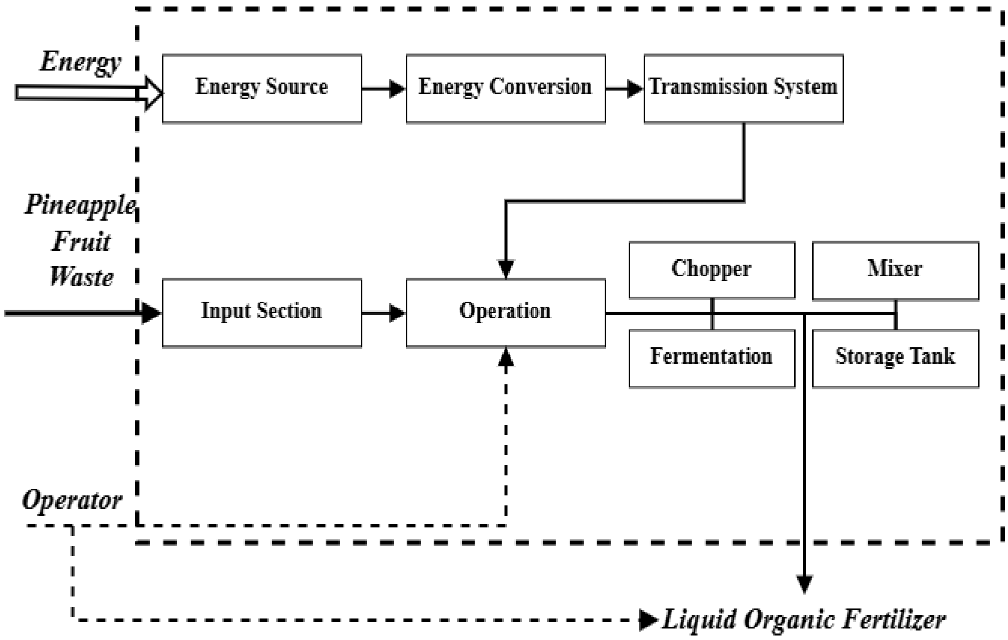


Figure 3. Overall design of the LOF composter device

The process of making liquid organic fertilizer using pineapple fruit waste begins with the preparation of the energy source required to operate the machine. The energy conversion system transforms electrical energy into a form suitable for powering the machine's components. The transmission system then distributes this energy to various parts of the tool, including the chopper and mixer. The operator inputs fruit waste into the system through an intake section designed for ease of use, making the process more efficient. Chopping, mixing and fermentation are the three primary steps that make up the operational stage of the systems. To speed up the fermenting process, the fruit waste is chopped into tiny pieces by the chopping machine, then combined with additional chemicals and additives like bio-activators. During the fermentation stage, microorganisms convert the organic material into liquid organic fertilizer. A special container collects the produced liquid fertilizer for further use. The operator operates the tool by managing the materials, controlling the machine, and ensuring the final output meets the specified requirements. This system produces liquid organic fertilizer that can be utilized for agricultural purposes or other applications.

3.3.2. Designing the LOF Composter Device

The LOF composter device is designed based on the results of the VOC and TR, aligned with the principles of LOF creation. The processed VOC data, translated into TR, serves as the foundation for determining the tool's specifications, features, and functionality to meet user needs.

1. Components of the LOF Composter Device

The components of the LOF composter device are divided into three main parts: the LOF frame, the chopping component, and the composter. The following is an explanation of each LOF component.

a. LOF Tool Frame

The frame is one of the key components that functions as the support structure for the entire tool, ensuring stability and strength during the LOF production process. The design of the LOF tool frame can be seen in Figure 4.

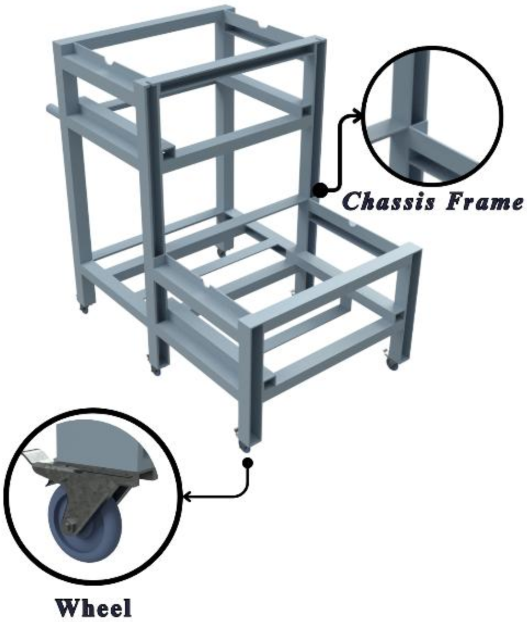


Figure 4. Design of the LOF composter device's frame

The frame was designed using VOC-TR response which shown in Table 7.

Table 7. Design of the LOF composter device's frame based on VOC-TR response

No	Image Code	VOC	TR	Description
1	A	Aesthetic – LOF device has colors	The LOF device has bright and calm colors (pastel yellow, light blue, mint green, or cream)	The body frame is designed with light blue, which is a bright and soft colors, to provide an aesthetic deemed attractive to users.
2	B	Features – LOF device is easy to move	The LOF device uses wheels equipped with lockable brake plates	The device frame is equipped with wheels for easy movement and lockable brake plates to ensure the device remains stable during use.

b. Chopping Component

The chopping component is a part used in the initial stage of LOF production before the pineapple fruit waste enters the Composter Component. The design of the chopping component in the LOF tool can be seen in Figure 5.

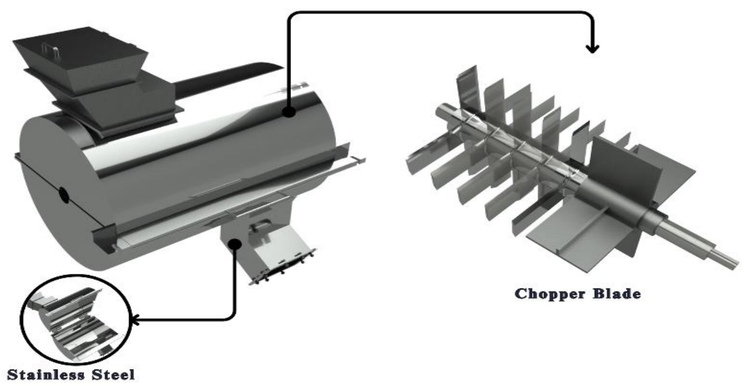


Figure 5. Design of the chopping component

Figure 5 is the design of the Chopping Component, created based on the VOC-TR response as presented in Table 8.

Table 8. Design of the LOF composter device's chopping component based on VOC-TR response

No	Image Code	VOC	TR	Description
1	A	Performance – LOF composter device functions according to needs Features - LOF production process can be done easily	Produce LOF Semi-automatic or automatic	The shredder blade is designed to simplify the process of chopping pineapple fruit waste to produce a fine texture, aiming to yield LOF with optimal quality according to the required nutrient composition standards for plants.
2	B	Durability - LOF composter device's material	LOF composter device is made of stainless steel	The shredder component is designed using stainless steel to ensure corrosion resistance and guarantee a long service life.

c. Composter Component

The composter component is designed to optimally support the decomposition of waste into liquid organic fertilizer. The design of the composter component in the LOF tool can be seen in Figure 6.

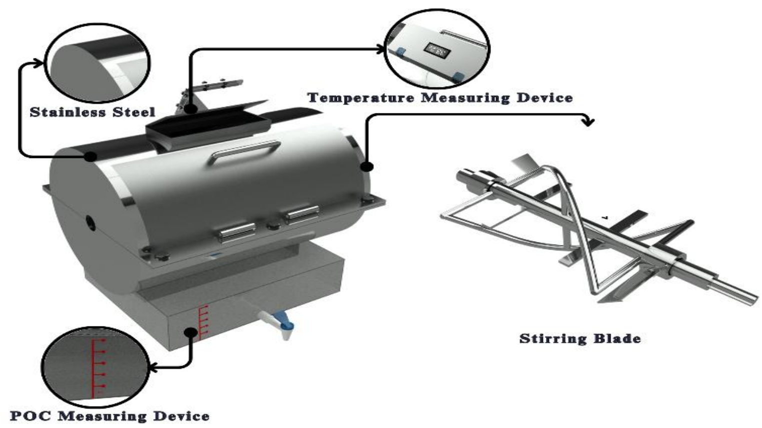


Figure 6. Design of the composter component

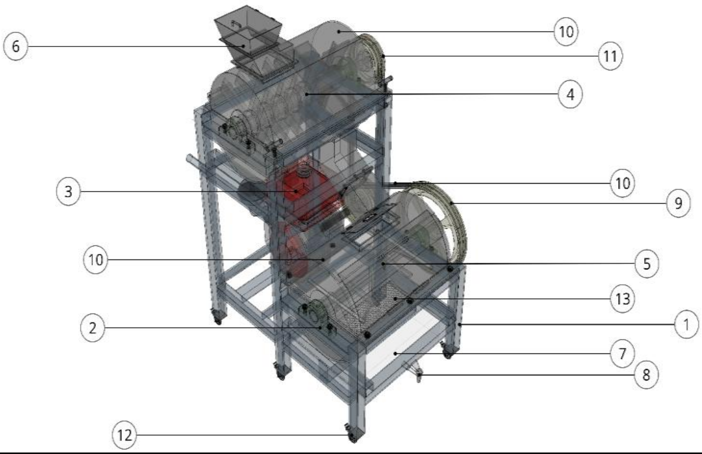
Figure 6 is the design of the composter component, created based on the VOC-TR response as presented in Table 9.

Table 9. Design of the LOF composter device's composter component based on VOC-TR response

No	Image Code	VOC	TR	Description
1	A	Reliability – LOF composter device produces consistent output	Improvement in the Stirring System	The stirring blade is designed to reach all parts of the container to ensure even mixing.
2	B	Features – LOF composter device has temperature control	Digital Monitor or Temperature Sensor	The composter component is designed with a digital monitor or sensor to measure and monitor fermentation temperature.
3	C	Features – LOF composter device has LOF control	The LOF collection part is designed transparently for easy viewing	The LOF collection part is designed with transparent material, allowing users to easily monitor LOF droplets and their volume.
4	D	Durability – LOF composter device material	LOF device material is made of stainless steel	The composter component is designed using stainless steel to ensure corrosion resistance and guarantee a long service life.

2. Design of the Bill of Materials for the LOF Tool

The equipment design was formulated based on user requirements analysis obtained through the VOC approach, which was subsequently translated into a Technical Response. The identification of the design visualization produced a list of components and materials, which were then compiled into a Bill of Materials (BOM) as presented in Figure 7.



No.	Component	Material	Description	Qty
1	Frame	Mild steel hollow section	50x50x2 mm	1
2	Pillow Block Bearing	Cast iron	Shaft Diameter 25 mm	4
3	Drive Motor	Cast iron / aluminium housing	3.5 HP 170 FD	1
4	Shredding Blade	S45C	-	1
5	Stirring Blade	S45C	-	1
6	Input Section	Stainless steel	3,0 mm Plate	1
7	Leachate Outlet	Stainless steel	3,0 mm Plate	1
8	Water Tap	Brass / stainless steel	Diameter 20 mm	1
9	Large Pulley	S45C	Type A2, 16-inch diameter	1
10	Belt	Rubber composite	V-Belt Type A	4
11	Small Pulley	S45C	Type A2, 8-inch diameter	2
12	Wheel	Polyurethane / rubber	RE-F5-080-SSF-N	6
13	Output Sieve	Stainless steel	3,0 mm Plate	1
14	Tube	Stainless steel	600 x 400	2

Figure 7. Bill of materials for the LOF composter device

3. Overall LOF Composter Device's Design

The LOF composter device is designed according to user preferences, which are then translated into technical responses and developed in alignment with the principles of LOF production. Figure 8 below is the overall design result of the LOF tool.

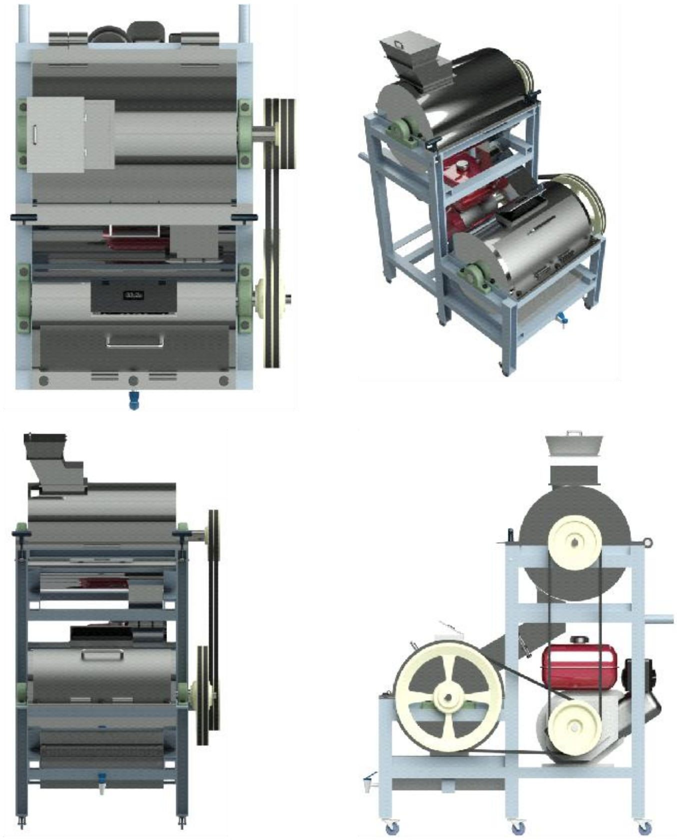


Figure 8. 3D Visualization of the LOF composter device using American projection

4. DISCUSSION

4.1. Comparison with Previous LOF Composter Device Designs

The present study explicitly grounds each design decision in farmer-stated priorities. Most of non-QFD LOF and fertilizer-machine which have been previously studied is predominantly engineering-centred, focusing on the motor specification, shafts, crushers, aerators, and fabrication layouts, but does not report VOC capture or any formal user-priority translation framework [15]–[17].

Hardware package, in the other hand, overlapping with prior work on mixing, shredding and sensing. Earlier fertilizer machinery already combine shredders and mixers in one processing line [18]. LOF composter device automation studies already use temperature and pH sensing, automatic mixing, and real-time monitoring [19], [20]. Also in the prior study already designed a composting device with a more detailed machine specification like using 3 HP electric motor at 1400 RPM [21].

The durability concern, rated as the top VOC attributes by farmers, can be alleviated by using stainless steel as the primary structural and contact material. This is unlike the painted mild steel or repurposed plastic containers that are usually used in the simple bucket composters documented by previous study, which is prone to corrosion, chemical degradation from organic acids in LOF, and structural failure from repeated use [22].

Furthermore, the contrast in this study's design targets features that matter for farmer adoption, not only process completion. Training and extension studies show that machinery uptake depends on operation, troubleshooting, safety, maintenance and broader technology dissemination among farmers [23].

In conclusion, earlier studies already supported shredding, mixing, sensing and automated compost control, but this study contributes a clearer VOC-TR linked rational for durability, monitoring and operational usability, which is the main advantage over prior engineering-centric LOF composter device's design.

4.2. Practical Implications for Farmers

The design options produced from the VOC-TR responses process are of direct practical relevance to smallholder pineapple farmers in Kutai Kartanegara. The lockable brake-plate wheel system solves the reality of operation of small-scale farm plots where the processing equipment is moved from loading to fermentation and storage areas without disassembly. The digital temperature sensor solves the problem of ideal conditions for fermentation without special knowledge in agriculture, so the LOF production process can be performed by farmers who are not trained in composting technology. The transparent part of the LOF collection area eliminates the necessity of opening the composters to check the output's volume. Prior study revealed that proper fermentation conditions eliminate E.coli, ensuring the LOF meets agricultural safety standards [24]. Thermophilic temperatures during anaerobic fermentation destroy pathogenic microflora and neutralize odors [25]. Thus, eliminating the necessity of opening the composter, can avoid the risk of contamination and operational disruption during the period of anaerobic fermentation.

4.3. Limitations and Future Research Directions

Several limitations stemming from the early conceptual stage (TRL 2-3) should be noted. First, the small sample size (n=10) constrains statistical precision, and validity estimates for the VOC rankings. Second, a full house of quality matrix was omitted in this study, as defining technical trade-offs without physical prototype data would produce unreliable outcomes. Third, performance targets rely on the literature benchmark, still needs empirical validation. Finally, the lack of cost modelling and local component sourcing limits current insight into economic feasibility for smallholder farmers in Kutai Kartanegara.

Future research should address these limitations through: (1) prototype fabrication based on the Bill of Materials, (2) field performance testing covering shredding particle size, mixer coverage efficiency, fermentation temperature stability across cycles, and LOF nutrient output against SNI 261/2019, (3) a full HOQ analysis with prototype performance data and an expanded respondent sample, and (4) economic feasibility assessment covering fabrication cost, operational cost per LOF batch, and estimated financial return for farmer groups.

5. CONCLUSION

This study designed a LOF composter device utilizing pineapple peel waste using a first-phase QFD approach, conducted with a specific farmer group in Kutai Kartanegara. The design was using VOC-TR response correlation based which translating the farmer need into specification response. The resulting LOF composter device's design, incorporate mobility features using wheels and brake plates, equipped with fermentation temperature monitoring via a digital monitor or sensor, and a transparent container for visual monitoring. Stainless steel was selected for its corrosion resistance. Furthermore, the device is designed to be equipped with semi-automatic or automatic shredder blade for optimal texture and a mixer blade designed for even distribution throughout the container. Compared to prior designed, this study adds a clearer VOC-TR linked rationale for durability, monitoring and operational usability, which is the primary advantage over previous engineering-centric LOF composter design, and furthermore focusing on direct practical relevance to smallholder pineapple farmers in Kutai Kartanegara. Based on the limitation of this study, a further and more detailed analysis should be conducted in the future study and need to consider making a prototype for higher TRL.

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DECLARATION OF AI-TOOL USAGE

During the preparation of this manuscript, the author (s) used an AI-based language model solely to assist with language editing, grammar refinement, and improving the clarity and readability of the English text. The AI tool was not used to generate original research data, conduct data analysis, produce experimental results or formulate the scientific conclusions presented in this paper.