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User-Centred Development and Evaluation of a Coconut Husk Processing Prototype: Integrating Design Thinking, QFD, and Techno-Economic Analysis

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ABSTRACT

Small-scale coconut enterprises require processing technologies that are technically functional while remaining compatible with users' operational capabilities, maintenance resources, and economic constraints. This study aimed to develop and evaluate a user-centred coconut husk processing prototype by integrating Design Thinking (DT), Quality Function Deployment (QFD), prototype realization, continuous-feeding operation, and techno-economic analysis. User requirements were elicited from 20 coconut-processing business operators and translated into engineering characteristics through the House of Quality (HoQ). The resulting engineering priorities guided prototype development and testing. Under the tested operating conditions, the prototype produced cocofiber and cocopeat at observed rates of 8.94 and 8.16 kg/h, respectively, with fuel consumption of approximately 1.50 L/h. These observed operating parameters were used as the basis for economic evaluation. Under the baseline assumptions, the break-even volume was approximately 1.92 tons of combined product, corresponding to about 112 operating hours or 14 operating days. The simple payback period was approximately 2.10 months. A five-year discounted cash-flow analysis at a 10% discount rate resulted in a positive net present value (NPV) of approximately IDR 125.92 million and an internal rate of return (IRR) of 571.64%. Sensitivity analysis showed that economic feasibility was most responsive to product selling prices and variable operating costs; a combined 10% reduction in selling prices and 10% increase in variable costs resulted in a negative NPV. The findings demonstrate that the practical suitability of small-scale processing technology depends on the alignment of user requirements, engineering responses, operational performance, and economic conditions. The integrated DT–QFD approach provides a traceable pathway for developing context-responsive processing technology while highlighting the importance of market and cost robustness for technology adoption.

INTRODUCTION

Coconut husk is an abundant lignocellulosic residue with considerable potential for local value creation. Its main fractions, coco fiber and cocopeat, can be used in fiber-based products, horticultural applications, and other bio-based products (Atapattu et al., 2024; Kholik et al., 2025; Shintiavira et al., 2023; Vieira et al., 2024a). However, biomass availability alone does not guarantee that its value can be captured locally. Where appropriate processing capacity is limited, coconut husk may remain underutilized rather than being converted into productive rural outputs. Strengthening local processing capacity is therefore relevant not only to agricultural-residue valorization but also to rural value creation and circular production.

In many rural coconut-processing settings, conversion remains labor-intensive, while available mechanical solutions may be designed for production conditions that differ substantially from those of small enterprises. For rural processors, processing capacity is only one part of technology suitability; affordability, ease of operation, maintenance, energy use, safety, and compatibility with local skills and resources also influence whether a machine can be adopted and sustained(Armando et al., 2025; Rumokoy et al., 2025). Appropriate technology therefore requires more than mechanical functionality. It requires a fit between technical characteristics and the operational and economic realities of its intended users.

This perspective places user experience at the centre of technology development. Evidence from agricultural appropriate-technology studies shows that sustainable utilization is influenced by human factors such as safety, functionality and economics, user-friendliness, physical effort, workspace compatibility, and the clarity of information available to operators (Hasanain, 2024; Khan et al., 2025). Technology development should therefore consider not only what a machine can do, but also how users work, what constraints they face, and which characteristics matter for continued use. Such a perspective shifts technology development from purely technology-driven optimization toward human-centred engineering.

Design Thinking (DT) provides a useful starting point for understanding users' experiences, needs, and operational contexts. Recent agricultural studies have applied DT to incorporate end-user perspectives into technology development (McGrath et al., 2025, 2026). However, insights generated through empathy-based inquiry are primarily qualitative and do not, by themselves, establish how competing user needs should be prioritized as engineering characteristics. Quality Function Deployment (QFD) provides a complementary mechanism by translating the Voice of the Customer (VoC) into technical requirements through the House of Quality (HoQ). Previous studies have demonstrated the use of QFD for translating user requirements into physical design characteristics, including agricultural machinery and other user-centred product-development contexts (Kuptasthien et al., 2025; Prasad et al., 2022). Thus, DT and QFD serve complementary functions: DT helps identify and interpret what matters to users, while QFD provides a structured means of determining how those needs can be addressed technically.

Recent studies show increasing interest in user-centred agricultural technology development. DT has been used to incorporate end-user needs into agricultural innovation (McGrath et al., 2025, 2026), while QFD has been applied to translate user requirements into engineering characteristics for agricultural machinery (Kuptasthien et al., 2025). In coconut processing, recent studies have also explored integrated mechanisms for separating cocopeat and coco fiber (Rumokoy et al., 2025). However, these studies largely address different parts of the technology-development process. Limited attention has been given to an end-to-end pathway that begins with rural processors' needs, translates them into prioritized engineering requirements, embodies those priorities in a fabricated processing prototype, and subsequently examines both operational performance and economic feasibility. This gap is particularly relevant for small-scale enterprises, where technical performance alone does not determine whether a technology is practically adoptable.

To address this gap, this study developed and evaluated a coconut husk processing prototype using an integrated Design Thinking–Quality Function Deployment (DT–QFD) approach. User needs identified through empathy-based inquiry were formalized as the Voice of the Customer and translated into prioritized engineering characteristics through the House of Quality (Al-Mashari et al., 2005; Jaiswal, 2012). These priorities guided prototype development and performance evaluation, after which the resulting operating parameters were used in a techno-economic assessment. The study therefore examines the technology-development pathway from user needs to engineering decisions, prototype realization, operational performance, and economic feasibility.

The study contributes in three connected ways. First, it demonstrates a traceable DT–QFD pathway for translating context-specific user needs into engineering priorities. Second, it shows how those priorities can be embodied in a processing prototype designed for small-enterprise conditions. Third, it links technical development with techno-economic assessment, highlighting the importance of market and operating-cost conditions in determining practical feasibility. Rather than proposing a universally optimal machine configuration, the study demonstrates a context-responsive approach to developing appropriate coconut husk processing technology.

RQ1. How can the needs and operational constraints of rural coconut processors be systematically translated into prioritized engineering requirements through an integrated DT–QFD approach?

RQ2. How can these prioritized engineering requirements inform the development and technical evaluation of an appropriate coconut husk processing prototype?

RQ3. Under what operating and market conditions is the resulting technology economically feasible for rural-scale coconut processing?

MATERIAL AND METHODS

Research Design and Integrated DT–QFD Framework

This study employed a user-centred engineering design approach integrating Design Thinking (DT) and Quality Function Deployment (QFD) to develop and evaluate a coconut husk processing prototype for rural-scale application (Kuptasthien et al., 2025; Teles, 2025). The research followed a sequential process in which the output of each stage informed the next design decision. Four stages were implemented: **(1)** user exploration through the Empathize and Define stages of DT; **(2)** translation of user needs into prioritized engineering characteristics using the Voice of the Customer (VoC) and House of Quality (HoQ); **(3)** prototype design, fabrication, and performance evaluation; and **(4)** techno-economic assessment under the assumed rural operating conditions. This structure maintained traceability from user needs to engineering decisions, prototype realization, and economic evaluation (Schröder et al., 2019; Vieira et al., 2024).

Study Context and Participants

The study was conducted across coconut-processing businesses located in Magelang Regency, Central Java, Indonesia, from July 2025 to February 2026. A census approach was initially adopted, targeting all 23 coconut-processing businesses identified in the study area. During data collection, two businesses were found to have been inactive for approximately two years, while one additional business declined to provide information. The final participant group therefore comprised 20 active coconut-processing businesses. Their direct experience in coconut-husk processing provided the primary basis for identifying and prioritizing the Voice of the Customer (VoC).

An additional focus group discussion (FGD) involved an MSME development representative from the local Industry Office and a business-development facilitator from the Business Development Center Association. Their role was to provide contextual input on operational capability, affordability, and implementation considerations rather than to determine the operators' importance ratings.

Empathize and Define

The Empathize stage combined direct observation of routine coconut-husk processing activities with discussions with the participating business operators. These activities were conducted in the context of the researcher's MSME assistance engagement and focused on practical difficulties related to physical workload, processing time, product separation, equipment operation, energy use, maintenance, safety, and economic considerations (Armando et al., 2025; Rumokoy et al., 2025). Rather than beginning with predetermined machine specifications, the inquiry sought to understand the processing problem from the users' perspective and identify needs emerging from their operating experience (Shija, 2026; Vieira et al., 2024).

During the Define stage, recurring statements and field observations were grouped according to similarity in meaning and operational relevance. Overlapping expressions were consolidated into common need categories while retaining the underlying concerns expressed by the operators (Nurfajriah et al., 2020; Oktavia et al., 2021). An FGD was subsequently conducted as a contextual validation mechanism, involving an MSME development representative from the local Industry Office and a business-development facilitator from the Business Development Center Association. Their role was to provide contextual perspectives on operational capability, affordability, and practical implementation rather than to determine the operators' importance ratings. The resulting need categories were subsequently formalized into VoC attributes and assessed independently through a questionnaire.

Voice of the Customer Identification and Prioritization

The need categories generated during the Empathize and Define stages were reformulated into concise Voice-of-the-Customer (VoC) attributes while preserving the meaning of the operators' concerns (Kuptasthien et al., 2025; Teles, 2025). The resulting attributes were assessed using an importance-rating questionnaire distributed to the 20 participating business operators. Each operator independently rated the importance of each attribute using a five-point Likert-type scale, ranging from 1 (not important) to 5 (very important). The questionnaire was administered with assistance from trained student volunteers who were permitted to explain the questionnaire when clarification was needed but were not permitted to suggest answers or complete the questionnaire on behalf of the participants. The individual ratings were aggregated to obtain the mean importance of each customer requirement. The requirements were treated as conceptually distinct VoC attributes rather than reflective indicators of a single latent construct because they represented heterogeneous aspects of machine suitability, including processing functionality, safety, operability, maintenance, mobility, energy use, and affordability. Therefore, internal consistency was not used as a criterion for retaining or excluding individual requirements. Each requirement was retained as an individual customer input and subsequently used as a customer-priority weight in the QFD analysis.

Quality Function Deployment and House of Quality

Quality Function Deployment (QFD) was used to translate the prioritized Voice of the Customer (VoC) attributes into engineering characteristics through the House of Quality (HoQ). The 12 customer requirements represented the **WHATs**, while the 11 engineering characteristics represented the **HOWs**. The importance of each WHAT was derived from the individual ratings provided by the 20 participating business operators. The relationship between each WHAT and HOW was then coded using the conventional QFD numerical scheme of **9, 3, 1, and 0**, representing strong, moderate, weak, and no relationship, respectively. These values represent relationship-strength codes rather than weights obtained from the respondents.

The assignment of relationship strength was based on engineering judgment concerning the functional relationship between each customer requirement and the corresponding engineering characteristic. This assessment was informed by the identified VoC, the operators' experience with similar machines, and supporting discussions with business-development and industry stakeholders. Several participating business operators had previously used similar processing machines and therefore had practical knowledge of the desired machine configuration and operating characteristics. The FGD served as supporting contextual input and did not determine or modify the individual importance ratings obtained through the questionnaire.

The technical priority for each engineering characteristic was calculated as:

$$\boldsymbol{TP_j = \sum_{i=1}^{12} I_i R_{ij}} \quad \text{……………………………………………………………………… (1)}$$

where TPj is the technical priority of engineering characteristic j, Ii is the mean importance of customer requirement i, and Rij is the QFD relationship code between customer requirement i and engineering characteristic j. The normalized technical priority was then calculated as:

$$\boldsymbol{NTP_j = \frac{TP_j}{\sum_{j=1}^{11} TP_j} \, X\, 100\%} \quad \text{…………………………………………… (2)}$$

The resulting normalized technical priorities were used to rank the engineering characteristics and guide prototype development. The HoQ roof was additionally used to identify interactions among engineering characteristics that could support or constrain design decisions.

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Prototype Development

The prioritized engineering characteristics from the HoQ, together with practical considerations identified during user engagement, were translated into the physical configuration of the coconut husk processing prototype. Several participating operators had prior experience with similar machines, providing practical reference points for the desired machine configuration and operating characteristics. Based on these inputs, the researcher developed the draft prototype configuration and subsequently discussed it with relevant stakeholders before fabrication (Atapattu et al., 2024; Goltiano & Sinon, 2022). The design focused on simultaneous recovery of cocofiber and cocopeat while considering operability, energy use, maintenance accessibility, safety, compactness, and affordability (Shintiavira et al., 2023; Vieira et al., 2024). The prototype consisted of a feeding hopper, a primary decortication mechanism with tiered blades, and a rotary screening mechanism for product separation (Kuptasthien et al., 2025; Teles, 2025). The machine configuration was developed using computer-aided design (CAD) before fabrication in March 2026.

Prototype Performance Evaluation

The prototype was evaluated under continuous-feeding operation to characterize its observed product-output rates and fuel consumption under the tested operating conditions. Coconut husk was continuously introduced through the feeding unit while the machine remained in operation. The output rate for each separated product was calculated as:

$$C_p = \frac{M_p}{T_e} \qquad \text{(3)}$$

where Cp is the observed product-output rate (kg/h), Mp is the mass of separated product obtained during the observation period (kg), and Te is the effective operating time (h). The calculation was applied separately to cocofiber and cocopeat.

Fuel consumption was recorded during the same operating period. The observed hourly output and fuel-consumption values were subsequently used to project monthly production and fuel requirements under an assumed operating schedule of 8 h/day and 25 days/month. These monthly values were treated as projections rather than direct measurements of monthly commercial operation

Techno-Economic Evaluation

The techno-economic analysis assessed the feasibility of adopting and operating the prototype at the rural micro-enterprise scale. The analysis combined observed product-output rates with projected production, product selling prices, initial investment, fixed costs, variable operating costs, and operating revenues. Monthly production was projected from the observed rates using an operating schedule of 8 h/day and 25 days/month. Baseline selling prices were set at IDR 6,000/kg for cocofiber and IDR 4,000/kg for cocopeat, while the machine purchase price was estimated using a cost-plus approach based on a 20% margin.

The economic assessment was conducted from the perspective of a small enterprise adopting the machine. Feasibility was evaluated using break-even point (BEP), simple payback period (PP), net present value (NPV), and internal rate of return (IRR). NPV was calculated over a five-year period using a 10% annual discount rate and an assumed residual value at the end of the project period. Sensitivity analysis examined changes in product selling prices and variable operating costs to assess the robustness of the baseline feasibility result.

RESULTS

User Needs and Voice of the Customer

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The Empathize and Define stages resulted in 12 customer requirements representing the operational concerns of the participating coconut-processing businesses. The requirements covered processing functionality, operating comfort, safety, maintainability, mobility, energy use, affordability, and local serviceability.

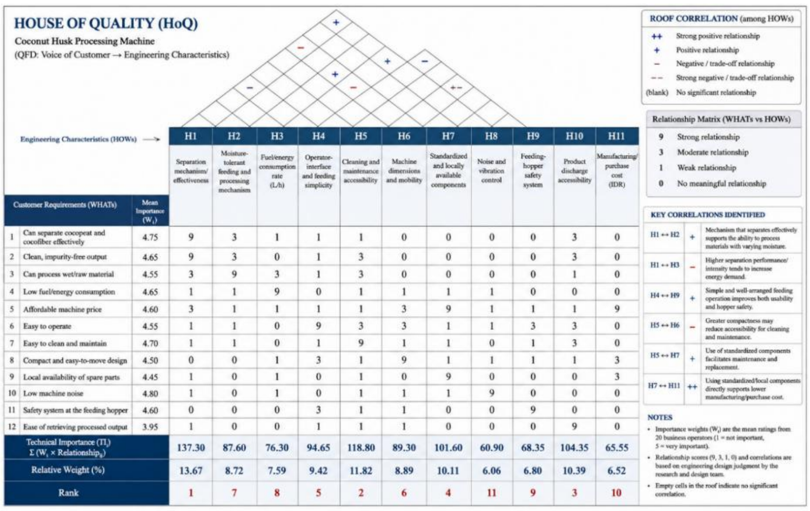
The 12 customer requirements received mean importance scores ranging from 3.95 to 4.80. Low machine noise received the highest mean score (M = 4.80, SD = 0.41), followed by the ability to separate cocopeat and cocofiber (M = 4.70, SD = 0.47). The ability to process wet coconut husk and ease of machine cleaning were jointly ranked next (M = 4.65, SD = 0.49), followed by clean separation output and feeding-hopper safety (M = 4.60, SD = 0.50). Ease of operation and machine mobility both received a mean score of 4.50 (SD = 0.51), while local spare-part availability received 4.45 (SD = 0.51). Fuel efficiency and machine affordability received mean scores of 4.40 (SD = 0.60) and 4.30 (SD = 0.66), respectively. Ease of retrieving processed output received the lowest mean score (M = 3.95, SD = 0.76).

Overall, the results indicate that the operators valued a combination of processing functionality, safety, usability, maintainability, energy efficiency, affordability, and local serviceability rather than a single performance attribute. These 12 requirements were subsequently used as the customer requirements (WHATs) in the House of Quality.

QFD and Engineering Priority Translation

The 12 customer requirements were translated into 11 engineering characteristics through the House of Quality (HoQ). The resulting technical priorities reflected the combined contribution of each engineering characteristic to multiple customer requirements rather than the ranking of individual customer requirements alone. Separation mechanism/effectiveness (H1) received the highest normalized technical priority (13.67%), followed by cleaning and maintenance accessibility (H5; 11.82%), product discharge accessibility (H10; 10.39%), and standardized and locally available components (H7; 10.11%). Operator-interface and feeding simplicity (H4; 9.42%) and machine dimensions and mobility (H6; 8.89%) formed the next priority group. Moisture-tolerant processing (H2), fuel/energy consumption rate (H3), feeding-hopper safety (H9), manufacturing/purchase cost (H11), and noise and vibration control (H8) received normalized priorities of 8.72%, 7.59%, 6.80%, 6.52%, and 6.06%, respectively.

The 12 customer requirements were translated into 11 engineering characteristics through the House of Quality (HoQ). The resulting relationship structure and technical priorities are presented in Figure 1



	Customer Requirements (WHATs)	Mean Importance (W_i)	H1 Separation mechanism/ effectiveness	H2 Moisture-tolerant feeding and processing mechanism	H3 Fuel/energy consumption rate (L/h)	H4 Operator-interface and feeding simplicity	H5 Cleaning and maintenance accessibility	H6 Machine dimensions and mobility	H7 Standardized and locally available components	H8 Noise and vibration control	H9 Feeding-hopper safety system	H10 Product discharge accessibility	H11 Manufacturing/ purchase cost (IDR)
1	Can separate cocopeat and cocofiber effectively	4.75	9	3	1	1	1	0	0	0	0	3	0
2	Clean, impurity-free output	4.65	9	3	0	1	3	0	0	0	0	3	0
3	Can process wet/raw material	4.55	3	9	3	1	3	0	0	0	0	1	0
4	Low fuel/energy consumption	4.65	1	1	9	0	1	1	1	1	0	0	0
5	Affordable machine price	4.60	3	1	1	1	1	3	9	1	1	1	9
6	Easy to operate	4.55	1	1	0	9	3	3	1	1	3	3	0
7	Easy to clean and maintain	4.70	1	1	0	1	9	1	1	0	1	3	0
8	Compact and easy-to-move design	4.50	0	0	1	3	1	9	1	1	1	1	3
9	Local availability of spare parts	4.45	1	0	1	0	1	0	9	0	0	0	3
10	Low machine noise	4.80	1	0	1	0	1	1	1	9	0	0	0
11	Safety system at the feeding hopper	4.60	0	0	0	3	1	1	0	0	9	0	0
12	Ease of retrieving processed output	3.95	1	0	0	1	1	1	0	0	0	9	0
	Technical Importance (TI_j) $\Sigma (W_i \times Relationship_{ij})$		137.30	87.60	76.30	94.65	118.80	89.30	101.60	60.90	68.35	104.35	65.55
	Relative Weight (%)		13.67	8.72	7.59	9.42	11.82	8.89	10.11	6.06	6.80	10.39	6.52
	Rank		1	7	8	5	2	6	4	11	9	3	10

Figure 1 House of Quality translating user-derived customer requirements into engineering priorities for the coconut husk processing system

The engineering-priority ranking differed from the ranking of individual customer requirements. In particular, low machine noise received the highest user-importance rating, whereas noise and vibration control had the lowest normalized engineering priority. In contrast, separation mechanism/effectiveness ranked first because

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it contributed to several customer requirements, particularly separation capability and output cleanliness. Thus, the HoQ translated distributed user priorities into a set of engineering priorities rather than assigning the highest-rated customer requirement directly to a single design feature.

The HoQ also identified complementary relationships and potential trade-offs among engineering characteristics. Complementary relationships were identified between separation mechanism and moisture-tolerant processing (H1–H2), operator-interface simplicity and feeding-hopper safety (H4–H9), cleaning and maintenance accessibility and standardized/local components (H5–H7), and standardized/local components and manufacturing/purchase cost (H7–H11). Potential trade-offs were identified between separation performance and energy demand (H1–H3), and between maintenance accessibility and machine compactness (H5–H6). These relationships were considered when translating the engineering priorities into the prototype configuration.

Prototype Design Realization

The engineering priorities derived from the QFD analysis were subsequently translated into the physical configuration of the coconut husk processing prototype. Rather than assigning one isolated machine feature to each customer requirement, the prototype incorporated combined engineering responses to address processing performance, operability, maintainability, mobility, safety, and affordability.

Table 1 Traceability of user-derived requirements to engineering responses and prototype design realization

User requirement (WHAT)	Engineering response (HOW)	Prototype realization
Separation of cocofiber and cocopeat	H1 Separation mechanism/effectiveness	Rotor-based processing and separation arrangement
Clean separation output	H1	Processing and screening/separation configuration
Wet coconut husk processing	H2	Continuous feeding and processing configuration
Fuel efficiency	H3	Engine-driven processing system
Affordable machine price	H7/H11	Simple frame, mechanical transmission, locally obtainable components
Ease of operation	H4	Direct feeding and mechanically simple arrangement
Ease of cleaning	H5	Open/access-oriented processing configuration
Mobility	H6	Compact integrated frame
Spare parts	H7	Conventional engine, pulley/belt transmission, bearings, structural components
Low noise	H8	Structural frame/component arrangement
Feeding safety	H9	Extended feeding enclosure
Output retrieval	H10	Large, directly accessible discharge area

The separation mechanism, which received the highest technical priority, formed the functional core of the prototype. The processing and screening arrangement was configured to produce separated cocofiber and cocopeat while supporting continuous material flow. Maintenance and product-discharge accessibility were incorporated through an open processing arrangement and directly accessible discharge area. Standardized and locally obtainable components were used where technically feasible to support local maintenance and affordability. Operator-related considerations were incorporated through the feeding arrangement, machine configuration, mobility, and feeding-area safety.

The resulting configuration represented the sequential translation of user requirements into engineering responses and physical design features, as summarized in Table 1.

Prototype Performance under Continuous Operation

Under continuous-feeding operation, the prototype produced cocofiber at an observed rate of 8.94 kg/h and cocopeat at 8.16 kg/h, giving a combined product output of 17.10 kg/h. Fuel consumption was approximately 1.50 L/h, corresponding to a calculated specific fuel consumption of 0.088 L/kg of combined product output. The observed performance parameters are summarized in Table 2.

Table 2 Observed prototype performance and projected monthly operating parameters

Performance parameter	**Observed value**	**Projected monthly value**	**Unit**
Cocofiber output rate	8.94	1,788	kg/h; kg/month
Cocopeat output rate	8.16	1,632	kg/h; kg/month
Combined product output	17.10	3,420	kg/h; kg/month
Fuel consumption	1.50	300	L/h; L/month
Specific fuel consumption†	0.088	—	L/kg combined product
Operating schedule	—	25	days/month

† Specific fuel consumption calculated from observed fuel consumption and combined product output.

Assuming an operating schedule of 8 h/day and 25 days/month, the observed hourly output rates correspond to projected monthly production of 1,788 kg of cocofiber and 1,632 kg of cocopeat, or 3,420 kg of combined product. These monthly values are projections based on the observed hourly performance rather than measurements obtained from month-long operation. The observed production and fuel-consumption values were subsequently used as the empirical basis for the techno-economic analysis.

Techno-Economic Feasibility

The techno-economic feasibility of the developed coconut husk processing system was evaluated using the observed prototype performance as the operational basis for the analysis. The assessment incorporated the initial investment requirement, production capacity, fixed and variable operating costs, product selling prices, and projected revenues. Financial feasibility was subsequently evaluated using break-even point (BEP), payback period (PP), net present value (NPV), and internal rate of return (IRR), followed by sensitivity analysis to examine the robustness of the investment under changes in key economic and operational parameters.

Baseline Economic Parameters and Cost Structure

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The baseline economic model was constructed by combining the observed hourly performance of the prototype with the assumed operating schedule and prevailing cost and product-price parameters. Production volumes were projected using an operating schedule of 8 h/day and 25 days/month. Based on the observed production rates reported in Section 3.4, the baseline monthly production was estimated at 1,788 kg of cocofiber and 1,632 kg of cocopeat. These projected production volumes were used consistently throughout the subsequent financial analysis.

Table 3 Baseline economic parameters and cost classification

Category	Parameter	Baseline value	Treatment
Capital	Coconut-husk processing machine	IDR 6.069.183	Initial investment
Fixed/semi-fixed operating cost	Sewing/packaging service	IDR 650,000/month	Fixed in baseline model
Non-cash	Depreciation	IDR 89.166/month	Accounting/BEP only
Fixed cash	Land rent	IDR 300.000/month	FC
Fixed cash	Routine maintenance	IDR 42.500/month	FC
Fixed cash	Fixed labor	IDR 2.500.000/month	FC
Variable	Raw coconut husk	IDR 500.000/ton basis	VC
Variable	Raw-material logistics	IDR 500.000/ton basis	VC
Variable	Fuel	IDR **877.193/ton basis**	VC, corrected
Variable	Electricity	IDR 41.800/ton basis	VC
Variable	Contract labor	IDR 1.000.000/ton basis	VC
Variable	Packaging	IDR 260.000/ton basis	VC
Revenue	Cocofiber	IDR 6.000/kg	Selling price
Revenue	Cocopeat	IDR 4.000/kg	Selling price
Production	Cocofiber	1.788 kg/month	Projected
Production	Cocopeat	1.632 kg/month	Projected
Financial	Discount rate	10%/year	NPV assumption
Financial	Analysis horizon	5 years	NPV/IRR

The monthly sewing/packaging service cost was treated as a fixed baseline operating cost of IDR 650,000 because the value was reported by the owner as a typical monthly expenditure rather than as a unit- or tonnage-based cost. However, this item may behave as a semi-variable cost in practice because higher production volumes can increase packaging and sewing requirements.

Break-Even Point Analysis

Break-even analysis was performed using the fixed operating cost and the weighted contribution margin generated by the two co-products. Because cocofiber and cocopeat were produced simultaneously and sold at different prices, a weighted average selling price based on the baseline production mix was applied. The resulting weighted selling price was approximately IDR 5.046 million per ton of combined product, while the corrected variable cost was approximately IDR 3.179 million per ton, yielding a contribution margin of approximately IDR 1.867 million per ton.

With monthly fixed costs of approximately IDR 3.582 million, the break-even production volume was estimated at approximately 1.92 tons of combined cocofiber and cocopeat. This corresponded to break-even revenue of ap**pro**ximately IDR 9.68 million. Based on the observed combined production rate of 17.10 kg/h, the break-even volume would be reached after approximately 112 operating hours, equivalent to about 14 operating days under an 8-h working day.

Compared with the projected baseline production of 3.42 tons/month, the estimated break-even volume represents approximately 56% of planned monthly output. This indicates that the operation would reach its break-even threshold before the end of the assumed 25-day operating month under baseline conditions.

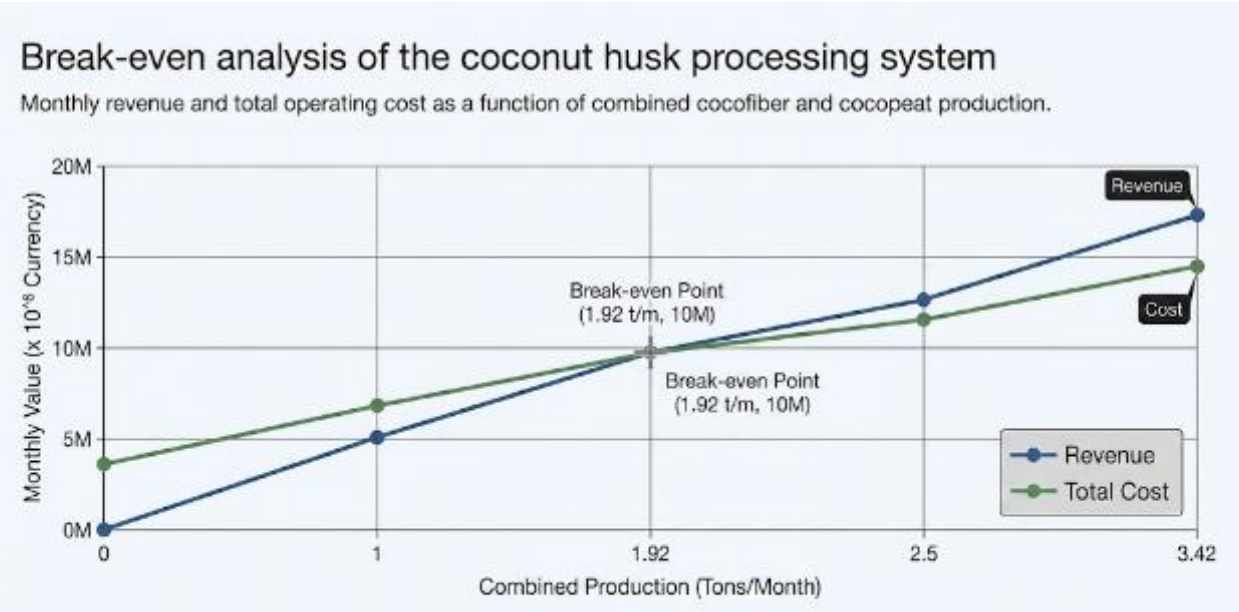

Figure 2 Break-even occur at approximately 1.92 ton/month; baseline projected production in 3.42 ton/month

Payback Period

Under the baseline operating and market assumptions, the simple payback period was estimated at approximately 2.10 months. This relatively short recovery period reflects the projected positive operating cash flow; however, the estimate assumes that the projected production volume can be maintained and marketed at the baseline selling prices.

The simple payback period was estimated using the initial machine acquisition cost and the projected monthly operating cash flow. From the adopter's perspective, the initial investment was represented by the estimated machine purchase price of IDR 6.069 million. Depreciation was excluded from operating cash outflows because it represents a non-cash accounting expense. Based on projected monthly revenue of IDR 17.256 million and monthly cash operating costs, the resulting net operating cash flow was approximately IDR 2.891 million/month. Accordingly, the simple payback period was estimated at approximately 2.10 months under the baseline operating conditions.

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Table 4 Projected cash flow and discounted cash flow over the five-year analysis period

Year	Net cash flow (IDR)	Discount factor (10%)	Discounted cash flow (IDR)
0	−6,069,183	1.0000	−6,069,183
1	34,696,128	0.9091	31,541,935
2	34,696,128	0.8264	28,674,486
3	34,696,128	0.7513	26,067,715
4	34,696,128	0.6830	23,697,922
5*	35,446,128	0.6209	22,009,257
NPV (10%)			Rp125,922,131

*Year-5 cash flow includes the assumed residual value of IDR 750,000. so:

$\mathbf{NPV_{10\%} \approx}$ **Rp125.92 million**

and the IRR calculation results:

IRR ≈ 571.64%

or approximately 5.72 times the initial investment rate per year in terms of the IRR mathematical formula.

Using a five-year analysis horizon and a 10% annual discount rate, the projected cash-flow analysis resulted in a positive NPV of approximately IDR 125.92 million (Table 6). The corresponding IRR was approximately 571.64%, substantially exceeding the assumed discount rate. Under the baseline assumptions, these indicators suggest that the projected operating cash inflows are sufficient to recover the relatively low initial machine investment and generate a positive discounted economic return over the analysis period.

The exceptionally high IRR should be interpreted in relation to the relatively low initial acquisition cost of the prototype compared with the projected annual operating cash flow. It should therefore not be interpreted as a guaranteed investment return, as the baseline model assumes sustained production, product sales at the specified prices, and the operating-cost structure described in Section 3.5.1.

Sensitivity Analysis

Sensitivity analysis was conducted to evaluate the robustness of the baseline investment results against changes in key economic and operational parameters. Three variables were examined independently at ±10% from their baseline values: product selling prices, variable operating costs, and production/sales volume. In addition, a combined adverse scenario was evaluated by simultaneously reducing product selling prices by 10% and increasing variable operating costs by 10%. The five-year analysis horizon, 10% discount rate, initial investment, and residual value were held constant across all scenarios.

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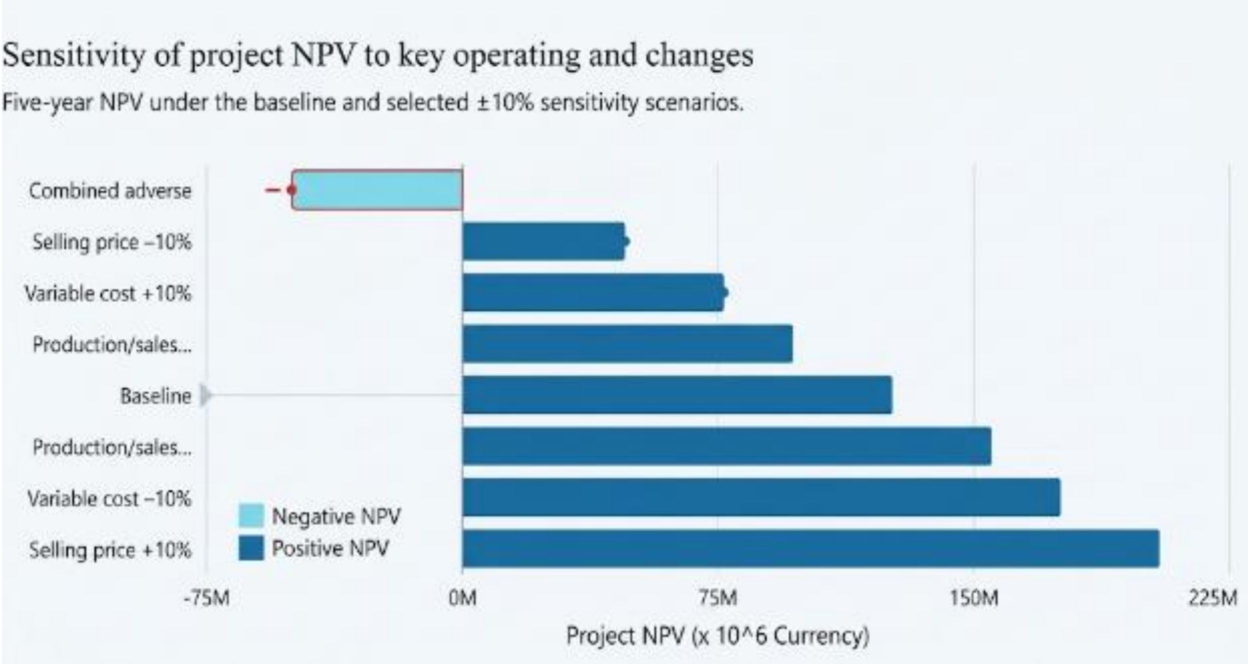

Figure 3 Projected cash flow and discounted cash flow over a five-year analysis period at 10% discount rate, illustrating the declining present value of future cash inflows and resulting Net Present Value (NPV) of Rp125,922,131.

For the selling-price scenarios, the prices of both cocofiber and cocopeat were varied proportionally while maintaining the baseline product mix. Changes in variable operating costs were applied to the baseline cost per ton of combined product. For production-volume scenarios, both revenue and variable costs were adjusted proportionally to the change in output, while fixed operating costs remained unchanged.

Table 5 Sensitivity of investment feasibility to changes in key economic and operational parameters

Scenario	Monthly operating cash flow (IDR)	NPV at 10% (IDR million)	IRR (%)	Feasibility
Baseline	2,891,344	**125.92**	**571.64**	Feasible
Selling price −10%	1,165,744	**47.43**	**229.97**	Feasible
Selling price +10%	4,616,944	**204.42**	**912.86**	Feasible
Variable cost +10%	1,804,128	**76.47**	**356.55**	Feasible
Variable cost −10%	3,978,560	**175.38**	**786.63**	Feasible
Production/sales volume −10%	2,252,960	**96.88**	**445.37**	Feasible
Production/sales volume +10%	3,529,728	**154.96**	**697.88**	Feasible
Selling price −10% + variable cost +10%	78,528	**−2.03**	**−3.14**	**Not feasible**

The results indicate that investment feasibility was most sensitive to changes in product selling prices. A 10% reduction in selling prices decreased the NPV from IDR 125.92 million to approximately IDR 47.43 million, whereas a 10% increase raised the NPV to approximately IDR 204.42 million. Changes in variable operating costs produced the second-largest effect: a 10% increase reduced the NPV to IDR 76.47 million, while a 10% decrease increased it to IDR 175.38 million.
Changes in production and sales volume had a comparatively smaller effect because both revenue and variable costs changed proportionally, while fixed costs remained unchanged. A 10% reduction in production and sales volume resulted in an NPV of approximately IDR 96.88 million, whereas a 10% increase produced an NPV of approximately IDR 154.96 million. Under each of the individual ±10% scenarios, the NPV remained positive and the IRR remained above the assumed 10% discount rate.

A different result emerged under the combined adverse scenario. When selling prices decreased by 10% while variable operating costs simultaneously increased by 10%, the projected monthly operating cash flow declined to approximately IDR 0.079 million. Under this condition, the five-year NPV became negative at approximately IDR −2.03 million and the IRR declined to approximately −3.14%. Thus, although the investment appeared economically robust to moderate changes in individual parameters, its feasibility became vulnerable when adverse market and cost conditions occurred simultaneously.

These findings indicate that maintaining product selling prices and controlling variable operating costs are more critical to economic sustainability than moderate fluctuations in production volume alone. The sensitivity analysis therefore complements the baseline NPV and IRR results by demonstrating that the high baseline return should not be interpreted independently of market conditions and cost-management capability.

DISCUSSION

From User Needs to Engineering Priorities

he findings show that the requirements of small-scale coconut processors extend beyond processing capacity to include noise, separation quality, wet-material handling, cleaning, safety, mobility, component availability, energy use, and affordability. This supports the broader view that agricultural machinery intended for small enterprises should respond to operational and human factors rather than mechanical performance alone (Hasanain, 2024; Khan et al., 2025). Similar user-centred machinery studies have also shown the value of identifying user requirements before defining engineering characteristics (Kuptasthien et al., 2025).

An important contribution of the present study is the distinction between **customer importance and engineering priority**. Low machine noise was the most highly rated user requirement, but noise and vibration control was not the highest-priority engineering characteristic. In contrast, separation mechanism/effectiveness ranked first because it addressed several customer requirements simultaneously. This illustrates the aggregative function of QFD: users define what matters in their operational context, while engineering analysis determines how those needs can be addressed technically. The resulting DT–QFD pathway therefore provides a traceable link between contextual user experience and engineering decisions rather than transferring technical decision-making directly to users.

User-Centred Design Realization and Appropriate Technology

The prototype realization suggests that appropriate technology for small-scale enterprises should be understood as a balance between technical functionality and contextual compatibility. In the present study, the prioritized engineering characteristics were embodied through a relatively simple processing configuration, accessible maintenance points, locally obtainable components, compactness, operational simplicity, feeding-area safety, and product-discharge accessibility. These characteristics are consistent with the broader human-factor dimensions of appropriate agricultural technology identified by Hasanain (2024), particularly functionality and economics, user-friendliness, safety, physical effort, and workspace compatibility.

The use of locally obtainable components also provides a practical advantage for small enterprises because maintainability depends not only on machine design but also on the availability of skills and replacement parts within the local operating environment. This is consistent with Kuptasthien et al. (2025), although the present study stopped at a single QFD deployment and sequential prototype realization rather than extending QFD into part deployment and experimental optimization. The prototype should therefore be regarded as a context-responsive design realization rather than a universally optimal machine configuration.

Prototype Performance in the Context of Small-Scale Processing

The prototype demonstrated continuous production of both cocofiber and cocopeat, with observed output rates of 8.94 and 8.16 kg/h, respectively. These results confirm the functional feasibility of simultaneous product recovery under the tested operating condition. However, the output should not be interpreted as a universal measure of machine capacity because performance depends on raw-material condition, installed power, processing mechanism, feeding method, and the definition of capacity used. Previous coconut-husk processing studies have reported substantially different capacities under different machine configurations and power levels, making direct numerical comparison inappropriate.

More importantly, the observed hourly production and fuel-consumption rates provided empirical inputs for the subsequent economic analysis. The prototype therefore demonstrated not only technical functionality but also generated measurable operating parameters relevant to small-enterprise decision-making. Nevertheless, some design requirements, particularly noise control, safety, and long-term maintainability, were not quantitatively or longitudinally validated. Further development should therefore include systematic safety assessment, longer-duration performance testing, and monitoring of maintenance and component reliability.

Economic Feasibility and Robustness

The techno-economic results indicate that the prototype can be financially feasible under the baseline operating and market assumptions. The positive NPV, short payback period, and high IRR should, however, be interpreted jointly with the relatively modest initial investment and projected operating cash flow rather than as evidence of superior investment performance. Differences in investment scale, process configuration, product prices, and financial assumptions also limit direct comparison with other coconut-processing systems.

Sensitivity analysis provides a more informative indication of economic robustness. Selling price had the strongest influence on project viability, followed by variable operating costs, while individual ±10% changes in the examined parameters did not overturn the baseline decision. However, the combined adverse scenario of a 10% reduction in selling price and a 10% increase in variable operating costs produced a negative NPV. The economic value of the technology therefore depends not only on its ability to produce cocofiber and cocopeat, but also on maintaining adequate product prices and controlling operating costs. This finding places the machine within a broader production–market system in which market access and price stability are integral to technology viability.

Taken together, the findings suggest that the main contribution of the study lies not in proposing a universally optimal coconut-husk processing machine, but in demonstrating a traceable pathway from contextual user needs to engineering priorities, prototype realization, technical evaluation, and economic assessment. The approach provides a practical basis for developing machinery that is technically functional while remaining attentive to the operational and resource constraints of small enterprises. Its applicability beyond the study context remains subject to further validation with larger user groups, longer-term operation, quantitative safety assessment, and more extensive market and cost data.

Practical Implications, Limitations, and Future Development

The practical implication of this study is that small-scale coconut-processing technology should be evaluated as part of a production system rather than as a machine alone. The developed prototype provides a context-responsive configuration in which processing functionality is considered alongside operational simplicity, maintenance accessibility, local component availability, safety, mobility, and affordability. The observed production and fuel-consumption parameters also provide a practical basis for small-enterprise operators to assess expected production and operating requirements under specified utilization conditions. However, the economic results remain dependent on product selling prices, variable operating costs, and the assumed utilization schedule; the sensitivity analysis indicates that unfavorable market and cost conditions can substantially reduce economic attractiveness.

Several limitations should be considered when interpreting the findings. The user assessment involved 20 participating operators within the study context and therefore provides contextual rather than population-level evidence. The design process was sequential and did not include iterative prototype redesign or experimental optimization. In addition, noise and vibration performance were not quantitatively measured, while safety and maintainability were not subjected to long-term or systematic validation. The economic assessment was likewise based on observed hourly performance combined with assumed operating, cost, and market parameters. These limitations do not invalidate the prototype evaluation, but they define the scope within which the findings should be interpreted.

Future development should therefore focus on longer-duration performance testing, quantitative safety and noise assessment, maintenance and component-reliability monitoring, and optimization of separation performance and energy use. Further validation with a broader range of users and operating conditions would also help determine whether the identified engineering priorities remain stable across different coconut-processing contexts. Where sufficient production and market data become available, future economic analysis could incorporate more detailed volume-dependent cost behaviour and alternative market scenarios.

CONCLUSION

This study demonstrated a sequential Design Thinking–QFD approach for developing a user-centred coconut husk processing machine for small-scale enterprises. User requirements identified from participating business operators were translated into engineering priorities through the House of Quality and subsequently embodied in a prototype designed to produce cocofiber and cocopeat while considering operability, maintenance, safety, mobility, energy use, and affordability. The prototype achieved observed combined product output of 17.10 kg/h, providing an empirical basis for subsequent techno-economic evaluation.

The economic assessment indicated financial feasibility under the baseline operating and market assumptions, while sensitivity analysis showed that viability remained particularly dependent on product selling prices and variable operating costs. The main contribution of the study is therefore not the claim of a universally optimal machine, but the demonstration of a traceable pathway linking contextual user needs to engineering decisions, prototype realization, and economic assessment. Further validation through longer-duration operation, quantitative safety and noise assessment, and broader field testing is needed before wider application.

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