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Design of A Home Industry Scale Maggot Cultivation System for Pellet Production

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Abstract

The Indonesian fisheries sector faces critical challenges regarding feed availability due to fishmeal scarcity. This study aims to design an ergonomic, five-tier Hermetia illucens cultivation system for household-scale production and analyze its economic feasibility. Engineering design methods integrated with Indonesian Anthropometric Data were employed to enhance operational efficiency, while financial analysis calculated the cost of production (HPP). Field trials demonstrated that a 40-day cycle yields 10 kg of maggots per batch, with a production cost of IDR 6,400 per kg. This cost is 20% lower than the current market price, offering significant savings. The system successfully integrates organic waste bioconversion with economic resilience for smallholder fish farmers.

Keywords:Anthropometric Design; Economic Analyze; Fish Feed; Household-scale Production, Maggot cultivation.

INTRODUCTION

Waste generation is a critical global challenge affecting both developing and developed nations. Without effective management, accumulating waste causes severe environmental degradation. Rapid urbanization and population growth drive this escalation, complicating sustainable disposal (Triani et al., 2024); (Nurkhin et al., 2024). Therefore, robust waste management frameworks are essential to build ecological resilience and prevent societal disruption. Poorly managed waste breeds pathogenic microorganisms, increasing public health risks and potentially triggering epidemiological outbreaks (Nurkhin et al., 2024).

Furthermore, inadequate waste processing produces leachate, which contaminates groundwater and aquatic ecosystems, threatening ecological balance and human health (Syahrizal et al., 2022). Concurrently, the anaerobic decomposition of organic waste in landfills releases methane, a potent greenhouse gas that accelerates climate change (Herawati et al., 2023); (Rifai & Permata, 2023). These compounding hazards necessitate the deployment of sustainable waste management strategies.

Effective waste management also reflects ethical stewardship and adherence to divine injunctions to preserve the biosphere, as articulated in Surah Al-Baqarah, verse 205:

وَاِذَا تَوَلّٰى سَعٰى فِى الْاَرْضِ لِيُفْسِدَ فِيْهَا وَيُهْلِكَ الْحَرْثَ وَالنَّسْلَ ۗ وَاللّٰهُ لَا يُحِبُّ الْفَسَادَ ٢٠٥

"And do not cause corruption on earth after it has been set right, and invoke Allah with fear and hope, for indeed, Allah's mercy is near to those who do good." (QS. Al-Baqarah: 205)

This scripture mandates humanity to function as custodians (*khalifah*) of the Earth, an obligation that includes preventing environmental degradation caused by poor waste disposal. The concept of corruption extends to environmental pollution, landfill overflow, and illegal dumping. Consequently, the mandate to restore the environment requires pragmatic interventions, such as reducing waste through conscientious consumption, recycling, composting, and eliminating littering.

Waste comprises discarded materials from human or natural processes, typically lacking economic value. It is broadly classified into inorganic and organic categories. Inorganic waste includes synthetic or non-biodegradable materials like metals, glass, and plastics, whereas organic waste consists of biodegradable plant, animal, and human matter (Loliwu et al., 2021). For instance, Pekanbaru City, Riau, generates diverse organic waste, reflecting the complex municipal refuse composition typical of rapidly urbanizing areas.

Table 1: Total population and waste volume produced/day in Pekanbaru

No.	Year	Total Population	Waste Volume (Ton/day)
1	2013	903.464	215
2	2014	976.105	217
3	2015	999.031	365
4	2016	1.011.467	395
5	2017	1.145.542	407
6	2018	1.189.643	432

Source: BPS (2019)

As shown in Table 1, waste accumulation in Pekanbaru has grown alongside population expansion, particularly in densely populated residential areas where uncollected refuse remains a chronic issue. These annual increases in population and waste volume highlight the municipality's persistent management challenges. A promising intervention is utilizing organic waste for maggot cultivation. This method mitigates disposal constraints and bioconverts refuse into high-value protein for animal feed, advancing circular economy principles (Putri et al., 2023); (Sinaga & Masjud, 2023).

Cultivating Black Soldier Fly (BSF) larvae significantly reduces waste volumes while producing protein-dense feed for livestock and aquaculture (Gunawan et al., 2022); (Agustin et al., 2023). This dual utility highlights the need for waste management frameworks that integrate biological remediation, such as using natural predators during waste processing (Handayani et al., 2021). Furthermore, community-based education and training in maggot cultivation can optimize urban waste processing and reduce landfill dependency (Kenis et al., 2014); (Noviadi et al., 2023). Adopting these sustainable methods can alleviate the waste crisis, stimulate economic development, and promote environmental conservation.

Existing literature identifies BSF larvae as highly effective organisms for organic waste bioconversion. They efficiently digest organic substrates, reducing organic mass by 65.5% to 78.9% daily. A population of 15,000 larvae can consume nearly two kilograms of food waste within 24 hours. Beyond waste decomposition, maggots provide an economically viable alternative protein source for animal feed, particularly in aquaculture (Wahyuni et al., 2020).

Although commercial animal feed guarantees consistent quality and volume, rising prices create significant financial barriers for farmers. Commercial feed prices increased from Rp 8,500/kg in 2016 to Rp 9,500/kg in 2018 (Yunaidi et al., 2019). By 2024, fish pellet costs surged to approximately Rp 18,000/kg, severely eroding profit margins. Consequently, incorporating BSF larvae into feed formulations offers a sustainable, economically viable strategy to offset inflating feed costs.

BSF larvae are an optimal substitute for conventional fish feed, primarily due to their high crude protein content (30%–45%) (Amandanisa & Suryadarma, 2020). Additionally, these larvae synthesize antimicrobial and antifungal compounds that significantly enhance fish immunity against pathogens. Cultivating *Hermetia illucens* thus facilitates sustainable waste management through bioconversion while yielding a renewable protein source, reinforcing circular bioeconomy principles (Masrufah et al., 2020).

Successful maggot cultivation requires consistent and meticulous management. The challenges of conventional feed procurement highlight the need for sustainable, cost-effective, and eco-friendly protein alternatives in aquaculture. *Hermetia illucens* larvae offer a highly promising solution, providing several advantages as a protein substitute:

- A high protein profile comparable to conventional fishmeal.
- Rapid growth rates and superior feed conversion efficiency.
- The ability to be reared exclusively on organic waste, reducing environmental impact.
- Suitability for small-scale, household production with minimal capital investment.
- Significant contributions to the circular economy through organic waste valorization.

The viability of BSF larvae in aquaculture feed is well documented. (Camargo & Amorim, 2020) reported that substituting up to 30% of fishmeal with maggot meal in tilapia diets produced no significant differences in growth performance or feed conversion efficiency. Furthermore, (Belghit et al., 2019) demonstrated that diets containing BSF larvae significantly improved the immune resilience of Atlantic salmon against pathogens. However, while previous research has focused on the nutritional composition and waste-reduction efficacy of maggot cultivation, a significant gap remains regarding the ergonomic design and economic feasibility of household-scale systems. This study bridges that gap by integrating engineering design principles with a rigorous techno-economic analysis.

Although the potential of *Hermetia illucens* as a protein source is widely recognized, empirical analyses of its technical implementation and economic feasibility remain limited, particularly in the Indonesian aquaculture sector. Consequently, this study aims to:

1. Engineer an optimized *Hermetia illucens* cultivation system tailored for scalable production.
2. Evaluate the simple economic viability of household-scale maggot aquaculture by calculating the total production cost and comparing it to current market prices.

The findings will provide small-scale aquaculturists with a practical approach to organic waste management through larval bioconversion, while establishing an accessible, sustainable protein source for fish feed formulations.

RESEARCH METHODS

This study employs a design engineering approach to develop a maggot cultivation cage, systematically integrating anthropometric data to optimize usability. Fundamentally, design engineering is a multifaceted process aimed at formulating optimal solutions to constrained problems; it encompasses procedural frameworks, creative problem-solving, and the rigorous application of available information. Through this methodological framework, a prototype cage was fabricated to serve as the primary test object for household-scale maggot cultivation. Crucially, the spatial placement of maggot cultivation enclosures requires careful consideration and cannot be determined arbitrarily. Such facilities must be situated away from densely populated residential areas while maintaining specific environmental parameters. These include high-humidity air circulation, protection from direct sunlight, and a fully enclosed structure that still permits adequate access for feeding and larval transfer. To meet these criteria, the experimental cage in this study was constructed adjacent to the UIN Suska campus. This location was specifically selected because its environmental characteristics closely mirror those of local fish farming areas. Consequently, this climatic similarity is expected to yield experimental outcomes that are highly relevant to the practical conditions experienced by local aquaculture practitioners.

The stages of the research conducted can be seen in Figure 1:

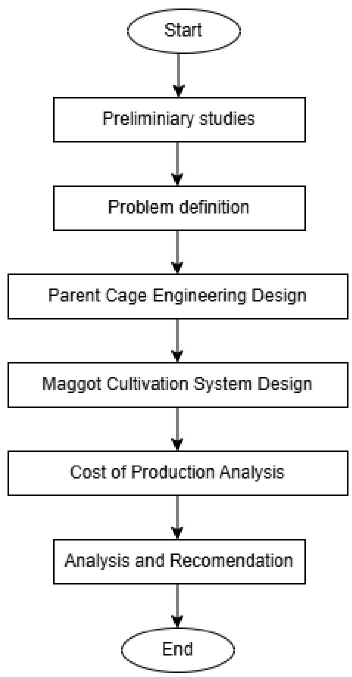

Figure 1: Flowchart of The Maggot Cultivation System Design

RESULT AND DISCUSSION

Engineering Design

The cage design for black soldier fly (*Hermetia illucens*) maggot cultivation was developed through a comprehensive engineering approach based on Shigley's methodology. The design process encompassed the following sequential steps:

1. **Problem Definition and Clarification**

   The initial phase involved comprehensively defining the challenge. Specifically, recognizing the necessity for a habitat that supports the complete life cycle of the maggots—from eggs to adult flies—was deemed vital for an effective design (Nugroho et al., 2025).

   The cultivation of Black Soldier Fly (BSF) larvae presents several biological and operational challenges. A critical issue is designing a cage system capable of supporting the complete life cycle of BSF—from egg to adult—in a way that optimizes space utilization, facilitates maintenance, and ensures environmental conditions suited for each developmental stage. Additionally, the system should minimize pest intrusion and contamination while providing ergonomic access for workers. Defining these requirements sets the foundation for engineering a suitable, scalable cage design.

2. **Gathering Information and Identifying Needs**
   The primary requirement for Black Soldier Fly (BSF) cultivation is a proper enclosure tailored to the intended production scale. Recent research indicates that an exclusive and adaptable design can

support scalable farming while preventing the spatial disorder typically associated with conventional cage designs, thereby facilitating improved management practices (Alifia et al., 2025).

Table 2: Technical Requirements and Ergonomic Considerations in BSF Cage Design

No	Aspect Analyzed	Data Description and Findings	Actions to Realize Relevance	Ergonomic and Operational Implementation Details
1	BSF Life Cycle	Eggs, larvae, prepupae, pupae, and adults require temperature 27–30°C and humidity 60–70%. Each stage needs space and separation to prevent contamination	Design tiered cages with appropriate sizes for each stage, using partitions and separate trays	Vertical tier spacing adjusted based on Indonesian anthropometric vertical reach (P50 = 200.01 cm)
2	Ventilation Requirements	Larvae and pupae need sufficient ventilation to avoid excessive humidity, while eggs require higher humidity	Use adjustable ventilation openings, and design for natural air flow	Natural air circulation and temperature control integrated into cage location and design
3	Cage Materials	Frame resistant to corrosion (powder coated steel or aluminum), trays made from food-grade plastic or stainless steel	Use locally available material, like treated wood or bamboo frames	Materials selected for local availability, ease of assembly, and replacement; regular treatment to avoid rot and contamination
4	Ergonomics and Operator Access	Caretakers need easy access for cleaning, harvesting, and media replacement without injury risk	Incorporate hinged wooden doors and easily removable trays crafted from local materials	Cage dimensions modeled in AutoCAD using local anthropometric data (e.g., body height and hand span)
5	Contamination and Pest Risk	Strict separation between life stages and barriers to pests and dirt are necessary	Implement tier system with covers and fine mesh screening	Cage located behind residence for pest protection and optimized environmental control
6	Waste Management	Waste must be removed and cleaned daily to prevent disease	Drainage system and waste disposal slots at each tier	Waste management facilitated by easy access positioned according to ergonomic reach and workflow

To further refine the selected design, anthropometric data were employed to ensure that the cages could be effectively and safely handled by workers, thereby enhancing overall operational efficiency (Prastiwi et al., 2024). Integrating these ergonomic principles not only optimizes spatial utilization but also significantly reduces worker physical strain during daily operations. Specifically, anthropometric data representative of the Indonesian population (Table 3) was integrated into the modelling process to optimize the cage dimensions for ergonomic handling.

Table 3: Anthropometric Data of Indonesian

No.	Anthropometric Data	Percentile	Value (cm)
1	Vertical Reach	P50	200.01
2	Body Height	P50	165.34
3	Hand Span Distance	P95	165.74
4	Forward Arm Reach	P50	69.45

3. **Concept Generation**
This step investigated unresolved operational aspects, particularly the disorganization of maggot life stages within previous cage models, which frequently disrupts cultivation efficiency.

Table 4: Concept Generation Activities and Results for Design

No.	Activity	Result/Output of Activity Related to BSF Cage
1	Brainstorming Ideas	Developed multiple design concepts focusing on tiered cage structures that utilize local materials (wood, bamboo) combined with ergonomic handling needs for workers based on anthropometric data of Indonesians.
2	Sketching and Modeling	Created precise cage models using AutoCAD incorporating anthropometric data: dimensions optimized for an adult population with consideration for vertical reach (200 cm), body height (165 cm), and hand span (165+ cm).
3	Feasibility Check	Verified that the cage size (70 cm $\times$ 166 cm $\times$ 200 cm) accommodates five tiers with appropriate vertical spacing to allow ergonomic handling, natural ventilation, lighting, and internal systems for climate control.
4	Identifying Trade-offs	Balanced the benefits of ergonomic vertical spacing and tier designs against environmental factors such as optimal site placement (away from residences, humidity, airflow), accessibility, and pest protection.
5	Selection of Promising Concepts	Chose a five-tier modular cage system optimized for home industry scale that integrates ergonomic dimensions for easy worker interaction, supports natural ventilation and climate control, and fits the strategic site placement.

4. **Analysis and Evaluation of Concepts**
   The decision made in the fourth step of Shigley's engineering design methodology, based on an in-depth evaluation of the BSF maggot cage design concepts, is to select a modular five-tier cage system using local materials such as wood and bamboo. This concept was chosen because it ergonomically fits the anthropometric data of the workers, provides easy access, and supports operational efficiency. Moreover, the design meets criteria for strength, ease of maintenance, and optimal natural ventilation, while also considering cost and sustainability aspects. This selection is backed by trade-off analysis confirming that this design is the best solution for small-scale home industry production, balancing user comfort, technical function, and environmental considerations. All considerations and analysis results have been documented to ensure transparency and alignment with the project objectives.

5. **Detailed Design and Development**
   Utilizing precision software such as AutoCAD for accurate modelling, the final maggot cultivation system was developed to comprise three primary components: 1) Breeding Cage: Measuring $70cm166cm200cm$, this unit is dedicated to the maintenance of adult black soldier flies. It is equipped with mechanisms for air circulation and natural lighting, an oviposition area containing fermented organic media, and a temperature and humidity control system. 2) Organic Waste Processing System: This component consists of a temporary organic waste storage unit, an organic waste shredder, and a media moisture control system. 3) Maggot Harvesting and Processing System: This final component includes a maggot drying mechanism, a dry maggot grinder, and a pelletizing machine.

   Based on the primary dimensions derived from the anthropometric data, the vertical spacing was precisely adjusted to accommodate the five distinct tiers. The final cage design resulting from this process is illustrated in Figure 2.

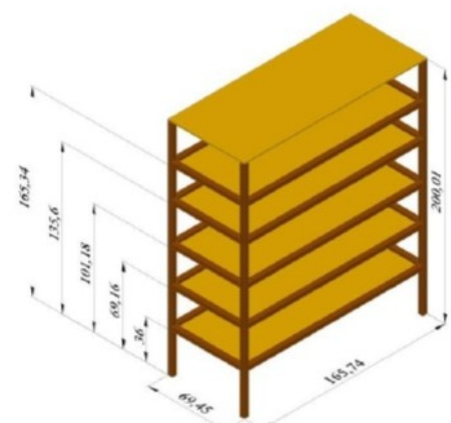

Figure 2: Cage Design

6. **Implementation and Testing**
   Design validation was conducted through in-depth interviews with a total of four respondents, including two local maggot farmers and two research experts specializing in BSF cultivation. The evaluation utilized a structured qualitative approach with standardized questionnaires and direct field observations to gather practical feedback on the application of the modular five-tier cage system. Validation instruments focused on assessing operational effectiveness, ease of use, and production costs suitable for household-scale cultivation. The results indicated that the cage system is highly practical and well-suited for small-scale operations, effectively balancing efficiency, cost, and usability. This structured engineering approach ensures that the cage supports the entire maggot lifecycle while enhancing both usability and economic feasibility for small-scale fish feed production. Additionally, the vertical spacing between tiers was precisely adjusted based on primary anthropometric data to accommodate the five distinct cage levels optimally.

   Beyond the physical design, the cage must be strategically located to ensure optimal environmental conditions for maggot cultivation. Specifically, it should be situated away from residential areas to minimize disturbance, yet placed in an environment characterized by naturally high humidity and adequate air circulation. Furthermore, the installation site must allow easy access for feeding and maggot transfer activities, offer protection from direct sunlight, and remain securely enclosed to prevent pest infiltration. Based on these stringent criteria, a site located behind the primary residence was selected for the cage installation, as it fulfilled all necessary environmental and operational conditions. This careful site selection supports robust maggot development and maximizes operational efficiency. Ultimately, this holistic approach—combining ergonomic design with strategic placement—aligns with best practices for sustainable maggot farming, emphasizing both environmental control and ease of management to optimize overall productivity.

Maggot cultivation

Maggot cultivation is straightforward, relying on naturally reproducing, easily sourced insects. The process follows the insect's natural life cycle. Typically, fermenting a substrate of sugar, effective microorganisms (EM4), probiotics, flavor enhancers, and bran for four to five days attracts adult flies to oviposit. However, this study procured eggs directly from established breeders.

This study inoculated 5 g of eggs onto a pellet-based medium in a shaded, top-tier container to prevent direct sunlight exposure. Within three days, the eggs turned yellowish-brown and hatched. Researchers transferred the newly emerged larvae (2 mm) to the fourth tier, where they grew to 5 mm. After 18 days of successive molting, the larvae reached an optimal fish-feed length of 20–25 mm. post-feeding, researchers sieved and moved the mature larvae to the third tier for a 14-day prepupal stage. The insects then pupated, developing a hardened, dark exoskeleton. This dormant stage lasted approximately three days before adult emergence. The environmentally dependent adult phase is brief; males die shortly after mating, and females die immediately after oviposition. The experimental setup housed adult flies in the bottom tier, providing dry banana leaves as perches. Ultimately, systematically managing each developmental stage within this multi-tier architecture optimizes maggot production and supports sustainable aquaculture feed practices.

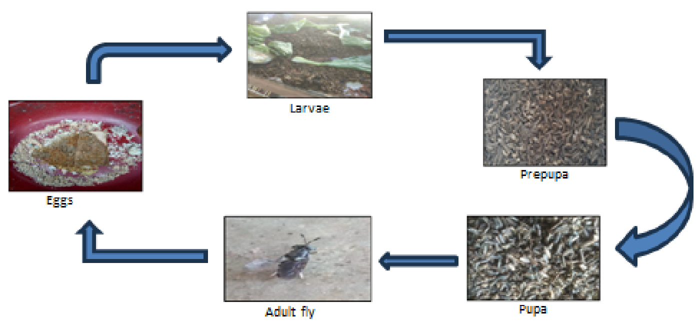

Figure 3: Maggot Life Cycle

Pest Management in Maggot Cultivation

Effective pest management in maggot farming is crucial, as pests significantly reduce yield quality and quantity. Ants, rats, and fungal pathogens severely disrupt Black Soldier Fly (BSF) (*Hermetia illucens*) cultivation (Reguzzi et al., 2021). Ants specifically target BSF eggs, larvae, and pupae, necessitating targeted interventions. However, chemical pesticides like Regent lack sufficient empirical backing in BSF farming, highlighting the need for further research (Reguzzi et al., 2021). Rats pose another major threat demanding comprehensive control. Although literature suggests natural repellents like black pepper and garlic, empirical evidence supporting their efficacy in BSF farming remains scarce (Reguzzi et al., 2021).

Fungal pathogens primarily infect egg incubation media, directly hindering larval development. Treating these media with hot water during preparation effectively eliminates fungal spores (Reguzzi et al., 2021). While applying Effective Microorganisms (EM4) shows promise in other contexts, direct evidence of its benefit for BSF larval development remains limited (Cicilia & Susila, 2018).

Implementing integrated pest management (IPM) is vital to sustain optimal BSF production. Effective IPM enhances yield quality and consistency, which are increasingly essential for sustainable aquaculture feed (van Huis et al., 2024). Ultimately, while a comprehensive pest management approach is critical, the efficacy of specific interventions requires further empirical validation.

Table 5: Implementation protocol and schedule for pest management in BSF cultivation research

Time	Activity	Methods	Results
Day 1	Preparation of egg incubation	Soak the media in hot water at 60–70°C for 10 minutes	Fungus-free media, no spore growth
Day 1	Application of EM4 on cultivation media	Spray EM4 according to the recommended dose	Media is ready to use
Daily	Ant control	Spray soapy water in the cultivation area	The number of ants has decreased significantly
Daily	Rat control	Set up mechanical traps around the cultivation area	Found signs of rat activity, but they can't access the cultivation media
Every 3 days	Spraying natural rat repellent	Spray a mixture of black pepper and garlic extract	The rats seem to be avoiding the cultivation area
Daily	Pest and cultivation monitoring	Observe and record the development of larvae and pests	The larvae grow healthy and active
Weekly	Evaluation and adjustment of control methods	Analyze monitoring data and adjust protocols	The decrease in pest population was recorded

As detailed in the preceding table, this protocol outlines the monitoring and evaluation framework for pest management during Black Soldier Fly (BSF) cultivation. During the initial phase, treating the incubation media with hot water effectively eradicated fungi capable of impeding larval development. Subsequently, the systematic application of soapy water proved highly efficacious in suppressing ant populations that target BSF across all life stages, from eggs to pupae. Concurrently, rodent mitigation strategies—employing both mechanical traps and natural repellents—yielded positive outcomes, as evidenced by diminished rodent activity and successful captures within the cultivation facility. Furthermore, the continuous monitoring of BSF development ensures that these pest control interventions do not adversely affect larval growth. Consequently, weekly evaluations facilitate timely adjustments to the control strategies, thereby promoting optimal and sustainable production yields. Collectively, these measures demonstrate the effective implementation of Integrated Pest Management (IPM) frameworks within BSF research

Cost of Production as Part of Simple Economic analysis

The economic analysis canters on the cost of production (COP) in this BSF maggot cultivation use a simple calculation, broken down into three primary components: raw material costs (RMC), direct labor costs (DLC), and factory overhead costs (FOC). In this home-scale operation, the RMC is limited to the cost of maggot eggs, amounting to approximately Rp 25,000. Direct labor costs are negligible, assumed to be zero due to the small-scale, family-run nature of the operation. Overhead expenses include a variable cost of Rp 35,000 and fixed costs of Rp 4,000. Summing these components results in a total COP of Rp 64,000 per 10 kg batch, equating to Rp 6,400 per kilogram of maggots. When compared to the market price of Rp 8,000/kg, in-house cultivation yields a saving of Rp 1,600 per kilogram. This cost advantage not only improves profitability at small scales but also becomes more significant when production is scaled up, as fixed overhead costs are spread over larger quantities, lowering average production costs further. Over a 6 to 12-month period, the cumulative savings accelerate, enabling a faster recovery of initial investment and the potential for additional income through surplus sales. Moreover, the breakeven point is achievable in a relatively short timeframe, highlighting the financial viability and sustainability of home-based BSF maggot farming, particularly as a strategic complementary feed source for livestock or aquaculture enterprises.

Table 6: Comparison of BSF Maggot Cultivation Costs and Benefits

Description	Maggots Cultivation	Purchased from Market	Different
Cost per kg	Rp 6.400,-	Rp 8.000,-	Rp 1.600,-

Based on the analysis, cultivating black soldier fly (BSF) maggots independently offers significant economic advantages compared to purchasing them commercially. With a production cost of IDR 64,000 yielding 10 kg of maggots, the cost per kilogram is IDR 6,400—substantially lower than the market purchase price of IDR 8,000/kg. This results in an immediate saving of IDR 1,600 per kilogram. When scaled up for commercial or long-term operations, the cost efficiency increases further due to economies of scale, where fixed costs are distributed over larger output volumes. Extended over a 6- to 12-month period, this self-sufficiency model leads to substantial cumulative savings, faster return on initial investment, and even potential revenue if surplus maggots are sold. Additionally, the analysis indicates a reachable break-even point within a short timeframe, making in-house maggot cultivation a financially sustainable and strategically beneficial practice, especially for livestock or fish farming operations dependent on high-protein feed.

CONCLUSION

The designed ergonomic five-tier Hermetia illucens cultivation system offers a practical and cost-effective solution to the feed scarcity challenges faced by Indonesian smallholder fish farmers. By integrating anthropometric data into the engineering design, the system enhances operational efficiency and usability at the household scale. Economic analysis demonstrates that the production cost per kilogram of maggot is significantly lower than the current market price, indicating promising financial feasibility and potential savings. Field trials confirm the system's ability to produce sustainable maggot yields within a 40-day cycle, contributing to organic waste bioconversion and supporting local aquaculture resilience. Continued research and scaling may further optimize the design and economic benefits, strengthening its role in sustainable fish feed production.

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