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Integrated Black Soldier Fly Bioconversion and Biodrying for Community-Based Organic Waste Management: A Circular Economy Model in Kota Padang, Indonesia

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ABSTRACT

Padang City produces over 660 tons of waste each day, and more than 60% of it is organic. Most of this ends up at the Air Dingin landfill, which has long exceeded its capacity and still operates through open dumping. While Black Soldier Fly (BSF; Hermetia illucens) larvae have attracted growing research attention as an organic waste processor, studies combining BSF bioconversion with biodrying (TOSS) and digital market development within a single community-scale program are scarce. This study reports the implementation and evaluation of such an integrated program, carried out with the Smarkgood Farmer Group in Kota Padang. Working through a participatory action framework, the team executed five sequential stages: partner identification, knowledge dissemination, technical training, technology application, and field mentoring. Key interventions included constructing BSF biopond units, providing a waste shredder calibrated to optimal larval substrate size, introducing the TOSS biodrying method for residual organic material, building a waste supply partnership with the Padang BSF Maggot Association (Agodang), and guiding the group through e-commerce onboarding. Following these interventions, the group operated a more functional and productive facility, maintained a stable organic waste supply, and actively sold products through online platforms. This program illustrates how science-based bioconversion technology, waste valorization, and digital market access can be combined into a community model that is practically transferable to other urban settings facing similar waste pressures.

Keywords: biodrying, black soldier fly, circular economy, community empowerment, digital marketing, hermetia illucens, organic waste management, TOSS

INTRODUCTION

Organic waste management has long posed serious difficulties for urban local governments in developing countries, particularly as city populations grow faster than waste infrastructure can keep pace. Globally, food waste accounts for roughly one-third of all food produced for human consumption, and its decomposition in poorly managed landfills generates substantial greenhouse gas emissions and leachate that contaminates surrounding soil and water (Gustavsson et al., 2011). In Indonesia, food waste makes up more than 60% of total municipal solid waste, yet disposal systems in many cities still rely on open dumping. The Ministry of Environment and Forestry has formally prohibited this

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practice through Circular Letter No. SE.14/MENLHK/PSLB3/PLB.0/2/2025, citing 306 regional governments for non-compliance. Kota Padang was among them. The city generates over 660 tons of waste per day, and 64.67% of it is directed to the Air Dingin landfill, a site that has long surpassed its operational capacity (DLH Padang, 2024). Responding to this pressure, the Mayor of Padang launched a 100-day priority program with a target of reducing organic waste by 10 tons per day, placing community-based management at the centre of that effort.

Black Soldier Fly (Hermetia illucens) larval bioconversion has become one of the more thoroughly studied biological approaches to organic waste processing over the past decade. BSF larvae actively consume wet organic material for two to three weeks during their growth phase, reducing waste mass by up to 84.5% over 21 days under suitable conditions, while converting it into protein-rich biomass usable as animal feed and organic fertilizer (Amin et al., 2024; Cammack & Tomberlin, 2017). Substrate properties influence this process substantially. Wang et al. (2024) found that particle sizes between 4 mm and 10 mm produce 38% greater larval biomass compared to finer fractions below 2 mm, because coarser particles support better aeration and microbial activity within the substrate. Not all organic waste fractions, however, are suitable for larval consumption. High-fiber, low-nutrient residues such as dry leaves, garden trimmings, and coconut shells require a different processing pathway. The Waste Processing at Source method, known locally as TOSS (Teknologi Olah Sampah di Sumber), handles these fractions through biodrying: an aerobic microbial process that brings moisture content down to between 5% and 11% within four to five days, producing bio-pellets with calorific values of up to approximately 3,500 kcal/kg (Dewilda et al., 2023). Together, these two technologies cover a wider range of organic waste fractions than either could manage alone.

The circular economy offers a practical framework for thinking about how these technologies fit into a broader system. Instead of discarding organic waste as a disposal problem, circular economy principles redirect material flows back into productive use: larval biomass becomes feed, processing residue becomes fertilizer, and non-bioconvertible fractions become fuel. This shift changes how community groups organize their operations and engage with markets, moving them from waste recipients to active participants in a value-generating chain (Asgari & Asgari, 2021). Several community programs in Indonesian urban settings have documented measurable improvements in waste volumes processed and in community awareness following BSF-based interventions (Febiola et al., 2024; Abdirahman et al., 2023). Most of these initiatives, though, have focused on a single technology or on education alone. The downstream question of how groups sustain operations economically once formal program support ends has received far less attention.

What the literature lacks is a documented program that combines BSF bioconversion, biodrying, supply chain development, and digital product marketing within a single community-scale implementation, with enough methodological transparency to allow other practitioners to replicate it. Product commercialization is a known barrier to long-term operational independence for community waste management groups, yet it is rarely built into program design from the outset. This study reports the design, implementation, and evaluation of such an integrated program, carried out with the Smarkgood Farmer Group in Kota Padang through a participatory action framework. The goal was to build the group's technical and economic capacity across the full value chain, and to produce a documented model that other urban communities facing similar organic waste pressures could adapt and apply.

METHOD

Partner Identification and Selection

The program began with the identification and selection of a suitable community partner among active BSF maggot practitioners in Kota Padang. Candidate groups were assessed against four criteria: ownership of an existing but underutilized maggot facility with expansion potential; proximity to Kitchen Organic Residue (KOR) sources such as restaurants, food stalls, cafes, and hotels; limited production capacity requiring systematic improvement; and demonstrated willingness to commit to the program and sustain activities independently afterward. The Smarkgood Farmer Group, located in Rimbo Kaluang, Kota Padang, was selected based on these criteria. Following selection, the team conducted a structured field assessment to document baseline facility conditions, map key operational challenges, and establish the starting point against which post-intervention progress would later be compared.

Program Implementation Stages

The program was carried out through five sequential stages between June and September 2025. The first stage, knowledge dissemination, provided the partner with foundational understanding before any physical intervention began. Sessions covered the urgency of organic waste reduction, the biological basis of BSF larval bioconversion, the TOSS biodrying process, circular economy principles, and the role of digital marketing in sustaining product sales beyond the program period.

The second stage, technical training, translated theoretical content into hands-on practice. The team guided the partner through BSF colony management, larval feeding protocols, substrate preparation with attention to particle size, biodrying procedures using locally available dry organic material such as coconut shells and garden trimmings, and basic production record-keeping.

The third stage, technology application, focused on upgrading the physical infrastructure of the cultivation facility. Key interventions included the installation of structured bioconversion units (biopond) to replace the previously disorganized rearing setup, the provision of a waste shredder to produce substrate at optimal particle sizes, and a spatial reorganization of the facility to improve workflow and reduce cross-contamination. In parallel, the team facilitated a formal supply chain agreement between Smarkgood and the Padang BSF Maggot Association (Agodang), securing a regular supply of KOR from restaurants, hotels, food stalls, and cafes.

The fourth stage, mentoring and evaluation, ran alongside and following the technology application stage. The team conducted fortnightly field visits and maintained remote coordination through online messaging platforms. Each visit documented progress across key activity areas including facility condition, waste volume processed, production output, and marketing activity, and identified any operational issues requiring adjustment.

The fifth and final stage, sustainability planning, focused on securing the partner's capacity to operate independently after formal program support ended. This included finalizing the Shopee e-commerce store setup, establishing a dropshipping arrangement with Agodang, and reinforcing standard operating procedures for daily facility management.

Program Evaluation Approach

Progress was tracked through direct field observation during each visit, supported by production records maintained by the partner group. Evaluation compared conditions before and after intervention across four activity areas: facility infrastructure, waste processing volume, supply chain stability, and digital market access. This evaluation approach was designed to document the practical outcomes of the program and to provide a basis for reporting results that other practitioners could reference when designing similar community-based programs.

RESULTS AND DISCUSSION

Development of Maggot Facility and Provision of Production Equipment

Prior to the program, the Smarkgood Farmer Group operated its maggot cultivation facility at roughly 20 to 25 percent of its potential monthly capacity. Waste input was irregular, averaging between 5 and 10 kg per day, and operations had halted entirely on multiple occasions due to inconsistent feedstock supply and inadequate infrastructure. The facility lacked structured rearing units, and larvae were maintained in a disorganized setup that limited both yield and biosecurity.

Following the infrastructure intervention, the team installed structured bioconversion units (biopond) for organized larval rearing, provided a waste shredder calibrated to produce substrate at optimal particle sizes, and reorganized the facility layout to improve operational flow. The physical transformation of the facility is documented in Figure 1, which shows the pre-intervention condition alongside the post-intervention setup with biopond installation and improved spatial organization. By the end of the program period, facility utilization had increased to approximately 75 percent of monthly capacity. Total organic waste processed during July and August 2025 reached 6,156 kg, of which approximately 80 percent was directed to BSF bioconversion. This represents a substantial improvement from the pre-intervention baseline and demonstrates the direct effect of infrastructure upgrading on processing throughput.

Figure 1. Transformation of the Smarkgood facility: (before) pre-intervention condition showing underutilized space; (after) post-intervention condition with improved layout and biopond installation.

The role of the waste shredder deserves specific attention. Wang et al. (2024) reported that substrate particle sizes between 4 mm and 10 mm increase larval biomass yield by up to 38 percent compared to finer particles below 2 mm, because coarser substrate supports better aeration and microbial activity. The shredder provided in this program was selected and calibrated with this finding in mind. Similarly, Grosso et al. (2024) emphasized that structured facility design promotes natural BSF mating behaviors such as lekking, improving reproductive efficiency and colony continuity. The biopond installation addressed this by giving adult flies a defined and stable environment for reproduction. Together, these hardware improvements laid the biological foundation for the production gains observed.

Compared to previously reported BSF community programs in Indonesia, which have typically focused on distributing larvae or conducting awareness activities without accompanying infrastructure support (Febiola et al., 2024; Abdirahman et al., 2023), this program took a more integrated approach by linking physical facility improvement directly to biological production outcomes. The result was a faster and more measurable increase in operational capacity than education-only interventions typically produce.

Knowledge Dissemination on Biodrying and TOSS

The TOSS biodrying training addressed an important gap in the partner's previous practice. Before the program, the group had no established method for handling dry organic fractions such as coconut shells, garden trimmings, and other high-fiber residues that are not suitable as BSF larval substrate. These materials were either discarded or left unused, representing a missed opportunity within the circular material flow.

Figure 2. Knowledge transfer session on the Biodrying/TOSS method for processing residual organic waste.

Through the training sessions, the partner learned to process these residual fractions through biodrying, which uses aerobic microbial activity to reduce moisture content significantly within four to five days. Dewilda et al. (2023) documented that this process produces biomass with moisture levels of 5 to 11 percent and calorific values reaching approximately 3,500 kcal/kg, meeting basic standards for use as alternative fuel. During the practical demonstration, the team showed the partner how to convert dried coconut shells and garden waste into charcoal using a biomass stove, producing a product with direct economic value as a fuel substitute. Figure 2 documents the knowledge transfer session, showing participants engaged in both the theoretical and practical components of the biodrying training.

Following training, the partner demonstrated the ability to carry out the full biodrying procedure independently, with a documented competency rate of 100 percent by program close. This outcome shifted the group's approach from a single-stream operation focused on BSF larvae alone to a dual-stream model in which wet organic waste feeds bioconversion while dry residues are valorized through biodrying. The practical implication is that a greater proportion of incoming organic material now generates usable output, reducing the volume that would otherwise be discarded.

Establishing Sustainable Organic Waste Supply Chains

Before the program, the Smarkgood Farmer Group had no formal arrangement with any waste-producing establishment. Feedstock was obtained informally and inconsistently, which directly contributed to the production halts described earlier. The absence of a reliable supply chain was identified during the baseline assessment as the single most disruptive factor affecting the group's ability to sustain cultivation.

To address this, the team facilitated a formal collaboration between Smarkgood and the Padang BSF Maggot Association (Agodang). Through this partnership, the group gained access to a coordinated supply of Kitchen Organic Residues (KOR) sourced from restaurants, hotels, food stalls, and cafes in Kota Padang. Figure 3 shows the joint collection and sorting activities carried out by Smarkgood and Agodang members, illustrating the operational form that this supply chain collaboration took in practice. By the end of the program period, this arrangement was fully operational and functioning at 100 percent of the planned scope.

Figure 3. Collaborative organic waste collection and sorting activities involving Smarkgood and the Agodang Association.

The biological significance of this feedstock improvement is supported by the literature. Sulaiman et al. (2024) reported that maggots reared on restaurant and hotel waste achieve greater final weight and length compared to those fed on vegetable market waste alone, indicating that the nutritional profile of KOR from food service establishments produces superior larval growth. Meneguz et al. (2018) further noted that irregular or interrupted feeding negatively affects larval development and extends production cycles, underscoring why supply chain stability is not merely a logistical concern but a direct biological variable. With a consistent and nutritionally suitable feedstock now secured, the conditions for sustained high-volume production are in place.

Digitalization and Market Expansion

Before the program, the group's sales were conducted entirely through informal word-of-mouth channels. This approach resulted in stock mismatches, where customer demand would arise during periods of low production, and in limited geographic reach that restricted the group's potential customer base and income.

The digital marketing training guided the partner through setting up an online store on Shopee, creating product listings with supporting visual content including product photography, and understanding the basics of content-driven customer engagement.

Figure 4 documents the mentoring session, showing participants from both Smarkgood and Agodang working through the Shopee store activation process with guidance from the program team. Maier and Wieringa (2020) noted that online marketplace presence generally expands customer reach by removing geographic barriers, while Cai et al. (2022) found that rich product display content, including multimedia and detailed seller information, directly influences purchasing decisions. Sun et al. (2020) further reported that live chat features on e-commerce platforms improve conversion rates by helping customers clarify product information before purchase.

Figure 4. Mentoring session on digital marketing strategies and Shopee store activation for partner group (Smarkgood) and Agodang.

By program close, the partner had an active Shopee store and demonstrated a working understanding of digital sales procedures, with a self-assessed competency level of approximately 50 percent. While this figure indicates that further capacity building is still needed, it represents a meaningful shift from zero digital presence at the start of the program. The collaboration with Agodang also opened the possibility of a dropshipping arrangement, in which Agodang members could sell Smarkgood products through their own channels without holding inventory, extending market reach without requiring additional production investment from the partner.

Synthesis: From Facility to Market

Taken together, the four intervention areas formed a connected chain rather than a set of independent activities. Facility improvement increased the physical capacity to process organic waste. Supply chain development ensured that this increased capacity was met with a consistent and biologically suitable feedstock. The TOSS biodrying component ensured that waste fractions unsuitable for larvae were not discarded but converted into a saleable product. And digital marketing training provided the partner with the tools to convert improved production into expanded economic reach. Each component reinforced the others: a larger, better-equipped facility with unreliable feedstock would not have sustained higher output, and improved production without market access would not have translated into income. The 6,156 kg of organic waste processed in the first two months of full operation, compared to the intermittent 5 to 10 kg per day recorded before the program, reflects the cumulative effect of all four interventions working in combination.

This integrated design distinguishes the program from most community-based BSF initiatives reported in the Indonesian literature, which have addressed one or two of these dimensions but rarely all four within a single program cycle. The addition of TOSS biodrying as a complementary pathway for non-bioconvertible fractions, and the inclusion of structured market access training, extended the program's reach along the full value chain in a way that prior single-technology programs have not.

Limitations

Several limitations should be acknowledged. The data reported here cover only the first two months of full operation following the main intervention phase, and it is not yet possible to determine whether the production and supply chain gains will be maintained over the longer term. The supply chain arrangement with Agodang, while functional during the program period, depends on continued coordination between groups and could be disrupted by changes in membership, waste sorting practices at source establishments, or shifts in local waste management policy. The digital marketing competency level of 50 percent at program close also indicates that the group will require continued guidance before it can manage online sales fully independently. Finally, this report documents the experience of a single partner group in a specific urban context in Kota Padang, and the extent to which the model's outcomes would transfer to groups in different settings, with different baseline capacities or waste compositions, cannot be determined from this data alone.

CONCLUSION

This program demonstrated that organic waste reduction at the community level is achievable when technical, logistical, and economic dimensions are addressed together rather than in isolation. The integration of BSF larval bioconversion and TOSS biodrying within a single program cycle allowed the Smarkgood Farmer Group to process 6,156 kg of organic waste over two months of full operation, compared to the irregular 5 to 10 kg per day recorded before the intervention. Facility utilization rose from approximately 20 to 25 percent of monthly capacity to 75 percent, a supply chain partnership with the Padang BSF Maggot Association (Agodang) secured consistent feedstock access, and the group established an active presence on the Shopee e-commerce platform. These outcomes were not the product of any single intervention but of the four components working in combination across the full value chain.

From a theoretical standpoint, this program contributes to the growing body of evidence on community-scale circular economy models. It shows that circular economy principles, which are often discussed at the level of industrial systems or national policy, can be operationalized at the neighbourhood scale through practical technology transfer and supply chain facilitation. The dual-stream design, in which wet organic fractions feed bioconversion while dry residues are valorized through biodrying, offers a more complete approach to organic waste valorization than single-technology programs provide. The addition of digital market access as a program component further extends the circular logic by connecting production to consumption, closing a loop that most prior BSF community programs have left open.

From a policy standpoint, the program's outcomes are relevant to Indonesian urban local governments facing pressure to reduce landfill dependence and comply with national open dumping prohibition directives. The model demonstrated here does not require large capital investment or specialized infrastructure beyond what community groups with modest support can realistically access. Its replicability makes it a viable candidate for scale-up through local government waste reduction programs, particularly in cities where organic waste constitutes a large share of total municipal solid waste and where community groups are already engaged in informal waste management activities.

Future programs building on this model should prioritize three areas. First, the digital marketing component requires further development; a competency level of 50 percent at program close indicates that ongoing mentoring beyond the formal program period is necessary for the group to manage online sales independently. Second, product diversification into maggot flour, maggot oil, and certified organic fertilizer would strengthen the economic viability of the model and reduce dependence on fresh larvae as the primary income source. Third, longitudinal monitoring beyond the initial two-month period would provide a more reliable basis for assessing whether the production and supply chain gains observed here are sustained over time, and for identifying the conditions under which similar programs succeed or struggle in different community contexts.

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