



Case study evidence for the bio-circular-green economic model: The case of community-based superworm (*Zophobas morio*) farming

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ABSTRACT

This study explores the potential of superworm (*Zophobas morio*) farming within a rural community in Thailand through the Bio-Circular-Green (BCG) framework. Farm data were integrated with findings from in-depth interviews and production method evaluations. The results show that farmers lack knowledge of the BCG concept. The use of superworm frass as an organic fertilizer for tomatoes demonstrates reduced reliance on chemical fertilizers while enhancing soil conditions. The practice of using biological by-products multiple times shows the farm has developed production methods for achieving zero waste. The limited scientific understanding of superworm breeding methods hinders both production and business growth. The implementation remains limited due to insufficient institutional backing, technical assistance, and market distribution. To address this, farmers, researchers, and policymakers need to work effectively to deliver training programs, knowledge exchange, and supportive systems. Strengthening farmer capacity through technical guidance and training programs, alongside improved market structures and certification systems, is essential for advancing sustainable BCG-oriented superworm farming policies. The farming community demonstrates excellent potential to serve as a sustainable insect-based agricultural model following the BCG framework. Superworm farming will create rural employment through specific support programs and unified policy initiatives while also enhancing agricultural sustainability and helping Thailand achieve its BCG development objectives.

Contribution/Originality: This study contributes to its field by presenting the first qualitative case analysis of community-based superworm (*Zophobas morio*) farming under the BCG framework at the pilot farm scale. By integrating field observations with an examination of production practices, it evaluates how insect-farming innovations can strengthen rural livelihoods and promote sustainable agriculture within a community development context.

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1. INTRODUCTION

Thailand has been working on transforming its economic model for decades, with the aim of creating a more balanced and sustainable future. The recent need for change has arisen from challenges such as climate change,

environmental degradation, the overuse of natural resources, and the rapid transformation of technology. The BCG model (Figure 1) is the national strategic framework for adopting and integrating the bioeconomy, circular economy, and green economy into the country's economic paradigm. The three economic paradigms are tightly interlinked, making them an inseparable model on which Thailand's economy depends. The BCG model, along with its principles and standards, is part of Thailand's National Strategy and is considered one of the key national agendas to transform the country's industries (NSTDA, 2021). The BCG model is being incorporated into every sector through the formation and operation of well-defined public policies, supporting innovative measures, developing and adapting to new technologies, and creating comprehensive economic opportunities across all walks of life (Edyvean et al., 2023). Thailand's focus on the BCG model extends beyond industrial-scale transformation. BCG principles will be provided to smaller communities so they can use locally available resources to become self-reliant, thereby mitigating inequality among people (Sirilertworakul, 2021).

One of the most promising grassroots economic activities that aligns well with the BCG model is insect farming, especially the cultivation of superworms. These insects are gaining international attention as an alternative protein source due to their low environmental impact, high feed conversion efficiency, rapid growth, and ability to thrive on agricultural, food waste, or petroleum-derived polymer materials (Burgos et al., 2024; Kosewska, Porzuc, & Przemieniecki, 2022). Superworms require limited space, produce minimal waste, and contain high nutritional value, making them ideal candidates for sustainable agriculture (Dragojlović et al., 2022). Superworms are high-potential resources that can be refined into various products such as human food, dietary supplements, animal feed, and raw materials for cosmetics and pharmaceuticals (Van Huis & Oonincx, 2017). Their ability to transform into different forms of protein strengthens effective waste management and nutrient recycling (Kuan, Chan, & Gan, 2022). In the green economy, superworm farming minimizes water and energy use, produces lower greenhouse gas emissions, and fosters environmentally sustainable production (FAO, 2013).

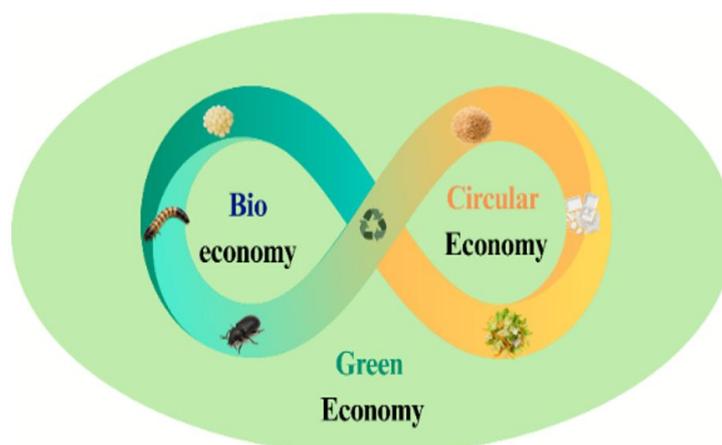


Figure 1. The BCG model

Superworm farming is particularly suitable for examining BCG implementation because it involves biological conversion efficiency, the circular use of organic residues as feed inputs, and low-emission production systems at the household level. Moreover, it supports community development, especially in rural and semi-urban areas where community members aim to increase their income through resource-efficient activities. Their goals align well with small-scale farming systems, which require low initial investments and can grow within households and cooperative ventures. However, the long-term growth of these activities depends on biological feasibility and effective farm management, which includes hygienic practices, value addition, efficient cost management, and reliable market access. Without system development and adaptation to local practices, scaling up and maintaining long-term sustainability may be challenging. Despite increasing policy emphasis on the BCG model in Thailand, empirical research on its farm-level implementation remains limited. The translation of national BCG policy objectives into actionable practices at the farm level is unclear, especially in community-based enterprises operating under resource and knowledge constraints. Existing studies offer limited insights into how farm-level production practices, cost structures, and market coordination mechanisms operationalize the bio, circular, and green dimensions of the BCG framework in small-scale insect farming. This gap underscores the need for farm-level case analysis to understand how BCG practices emerge and play a vital role within Thailand's agricultural context.

This study primarily seeks to understand how BCG principles are practically enacted at the farm level within community-based superworm enterprises. Therefore, this study aims to examine the farming practices and management models of superworm farms in the local community context and evaluate their potential in three dimensions of the BCG model. The study also investigates the enabling factors and limitations affecting the success of superworm farming as a sustainable community enterprise. The research attempts to provide practical guidelines and propose a scalable prototype model that can be adapted to local contexts and strengthen grassroots economic empowerment as part of Thailand's BCG strategy.

2. LITERATURE REVIEW

2.1. The BCG Model

The BCG model has been recognized as a strategic tool to address global challenges such as climate change, resource overexploitation, and socioeconomic inequality. Many studies have examined its conceptual foundations and key areas; however, limited research exists on its practical implications.

Following the COVID-19 pandemic, the BCG model has become well-known as part of Thailand's long-term national recovery strategy (Sirilertworakul, 2021). The utilization of the model mainly focuses on the recovery of the country's economy. The model integrates bio, circular, and green strategies with technological innovations across Thailand's major industries such as agriculture, wellness and medical services, energy and biochemicals, and the creative economy. The main objective of the model is to foster the country's economic recovery from the pandemic. Moreover, the model also aims to achieve the national sustainable goals.

Studies on the BCG model involving different countries (Edyvean et al., 2023) reveal Thailand's efforts in developing its economic models and projects, which align with its national policies and development strategies. The adoption of the BCG model as part of the Thai government's strategies is well-known. However, collaboration with local projects, cross-sectoral coordination, and investment in robust innovation ecosystems are required to meet the targeted objectives. The similarity among circular economy aspirants is identified. Additionally, the critical gap in the BCG strategies at the community level is suggested to be overcome. This is due to circular resource flow and bio-waste vaporization, which can generate practical benefits for small-scale producers.

In a circular economy, it should be emphasized that resource inefficiencies must be kept to a minimum. As a result, researchers need to investigate waste management and recycling methods, which in turn would lead to the development of new products. In circular bioeconomy systems, the BCG model serves as an important tool for promoting circular and zero-waste systems where agricultural residues, organic waste, and even post-consumer materials are all recycled or repurposed. The early materials balance approach and conservation models like the circular economy were based on closed-loop resource flows (Kneese, Ayres, & d'Arge, 2015). Contemporary perspectives on circular bioeconomy systems involve using waste feedstocks and by-products to enhance resource efficiency, reduce environmental impact, and build local resilience (Edyvean et al., 2023). As is evident in rural areas, insect farming and composting through bioconversion convert waste into a supplement for the economy.

The BCG model has received support from empirical research, which applies its framework to different economic sectors in Thailand. The BCG framework serves the policy sector to enhance local agricultural development through GAP (Good Agricultural Practice)-oriented horticulture and smart greenhouse technologies, which improve crop production and community products in Bueng Niam Subdistrict (Chokkuea, Westrattachat, & Khunchuen, 2023). The plant-based agricultural sector implements a zero-waste processing system with carbon-footprint reduction for Phulae pineapple production, demonstrating BCG principles to maximize by-product value and reduce environmental impact in the primary fruit production sector (Suthiluk et al., 2025). The edible insect industry in Thailand has received analysis on its sustainable production systems, which connect industrial growth to the national BCG development plan (Krongdang et al., 2025). Existing research focuses on policy-based and industrial approaches rather than demonstrating BCG concepts for actual farm and household operations.

The BCG model has been proposed as a favorable framework for advancing sustainable development, especially in the agricultural sector, although its farm-level practical application in agriculture and insect farming remains unrevealed. The main function of the BCG model is to highlight its core principles, including resource efficiency, circular waste utilization, and environmentally responsible actions, but only a few studies have successfully transformed these concepts into practical and scalable models under small-scale or community-based contexts. This research addresses the gap by developing a prototype insect farm grounded in BCG principles, prioritizing circular resource use, its low environmental impact, and practical integration into rural farming systems.

2.2. Superworm Farming

The rearing of superworms, a species of insects belonging to the Tenebrionidae family, has emerged as an eco-friendly and economically viable practice for application in food, feed, waste management, bioresource recovery, and bioplastic degradation. There is a growing global demand for alternative protein sources, and superworms might be an excellent option for this purpose due to their unique nutrient composition, high feed conversion efficiency, ability to grow on cheap, low-quality organic substrates, and application in waste management and bioresource recovery. These are the essential features of their application as bio-agents (Dragojlović et al., 2022; Henry, Gasco, Piccolo, & Fountoulaki, 2015). They can be innovative agents in bio-circular economy models and the reuse of waste products (Jung et al., 2023).

The superworm undergoes complete metamorphosis through four stages: egg, larva, pupa, and adult (Gourgouta et al., 2024; Rumbos & Athanassiou, 2021). The larval stage is the longest and most commercially important, lasting 90 to 120 days under optimal conditions (temperature: 26–30°C, humidity: 60–70%, diet) (Zaelor & Kitthawee, 2018). This stage could last more than 150 days if the larvae maintain low temperature or high – density contexts (Tschirner & Simon, 2015). The larval stage is characterized by rapid biomass accumulation, particularly in terms of protein and lipid content, making this phase optimal for harvesting for various feed and food applications.

Superworms possess the unusual feature of resisting pupation under crowded conditions (VandenBrooks, Ford, & Harrison, 2020). Unlike other holometabolous insects, they require isolation to trigger metamorphosis from larva to pupa (Kuan et al., 2022). When an individual larva is separated and maintained in a confined container without food, it typically takes about 7–14 days to pupate. The pupal stage is non-feeding and lasts 7–10 days, followed by the

emergence of adult beetles, which live approximately 1–2 months and serve reproductive purposes. A female adult can lay between 2,200 eggs over its lifespan (Rumbos & Athanassiou, 2021), with the number of eggs being negatively correlated with female maternal age and positively correlated with adult density (Tschinkel, 1993). The complete and controllable life cycle makes superworms suitable for batch production systems, enhancing farm-level planning and scalability.

Superworms are rising stars that can compensate for the loss of the prime animal protein sources of the world, including fishmeal and soybean meal. According to Dragojlović et al. (2022), larvae of *Zophobas morio* contain protein up to 42.8% and lipids up to 44.5%. They also consist of essential amino acids, calcium (66.85 mg/100g), phosphorus, and several healthy polyunsaturated fatty acids. They contain more fat content than *Tenebrio molitor*. Furthermore, they have a favorable fatty acid ratio. As a result, superworms can surpass *Tenebrio molitor* when used as feed for aquaculture, poultry, and pigs. Also, the superworm has good protein digestibility (82–84%) and can be grown on low-cost substrates. It can be an effective source of protein; it is also an eco-friendly procedure (Rumbos & Athanassiou, 2021). Superworm farming contributes positively to environmental health. Superworms contain highly efficient organic waste biodegrading agents, which can be used to convert waste into high-quality insect biomass and frass. Accordingly, these outputs can be used as organic fertilizers. Recent studies have demonstrated that superworm larvae can efficiently biodegrade certain types of biodegradable plastics, such as Polybutylene Succinate (PBS), due to the metabolic activities of their gut microbiota (Jung et al., 2023). This presents a potential method for plastic waste management and reduces the use of natural resources in the circular economy. Superworm farming can serve as a versatile method for environmental cleanup and as a protein source. Superworms are more resistant to pathogens than other edible insects, as noted by Kuan et al. (2022), reducing dependence on chemical control methods while maintaining biosecurity in insect farms.

2.3. Community-Based Agricultural Development and Economic Opportunities

Insect farming is no longer a niche innovation but a feasible solution for rural economic resilience. This practice at the community level protects the community's environment and is economically competitive. The development of the superworm supports livelihood diversification and enhances food security. These larvae are easy to rear at the household or small-farm level, while industrial farming requires high costs and technology. The advanced facilities used in industrial farming are difficult to access for low-level, backward communities and women. When embedded in a participatory framework, these farms become purveyors of learning, community-owned enterprises, and teaching tools, as well as conduits to empowerment (Van Huis & Oonincx, 2017). Community-based superworm farming offers decentralized job opportunities. Options for income generation have been distributed to women, youth, and elderly groups participating in insect agriculture. As a result, this serves as an accessible gateway to economic participation, especially in rural and developing areas (Harsányi et al., 2020). Tasks such as egg collection, pupae selection, larvae packaging, and maintaining simple records could be assigned to household members according to their respective skill levels. Moreover, these businesses create local entrepreneurship opportunities through the development of animal feed products, such as superfine animal feed. Apart from regular feeds and fertilizers, the superworm species are becoming popular as a live or processed food source for exotic animals like amphibians, reptiles, and ornamental birds due to their high protein, fat, and micronutrient content. To meet such demand, community producers prepare various types of merchandise, including freeze-dried larvae, calcium mixtures, and organically grown superworms. Moreover, these products are available on online platforms and pet-specialty networks (Kuan et al., 2022). This source of diversification not only helps enhance income levels but also positions superworm farming within the growing pet industry. Again, there are certain urban markets around the world, and they are turning to a sustainable form of feeding pets, and urban consumers are more willing to pay for ethical and sustainable forms of pet feed.

An effective community-based organization is necessary for the venture's success. The distribution of work becomes possible through multiple elements, including effective local leadership, cooperative systems, and scheduled task assignments. Superworm farming exists as part of educational programs for young people in specific geographic areas. This activity acts as a centre for science-based learning, environmental stewardship, and ecological awareness (Rumbos & Athanassiou, 2021). The partnership enables communities to establish permanent, self-sufficient systems. The system will achieve its highest potential through particular policy backing and strong institutional alliances. Government agencies need to establish training programs that teach disease monitoring systems and certification programs to establish hygiene standards and maintain consistent product quality. In light of Thailand's national strategies, insect farming and smart agriculture villages are recognized as components of rural innovation clusters (Cho, Park, Olawuyi, Nam, & Lee, 2025).

The implementation of superworm farming promotes economic independence while maintaining traditional lifestyles. Through the model, communities can manage small-scale biological systems with potential commercial activities, fostering a future that is equitable, resilient, and locally rooted.

3. METHODOLOGY

3.1. Research Design

A qualitative single-case study approach was applied in this research to analyze the functions of superworm farming activities according to the BCG model. The selected farm was chosen because of its sustainable farming practices by using biological resources, circular production, and green innovation within its local community context. The study emphasizes an in-depth understanding with a focus on complex interrelations between members within the BCG model when applied to realistic farming activities. Although qualitative analysis software was not used, iterative

manual coding, cross-checking among researchers, and validation of themes with field notes and peer discussion ensured methodological rigor. This approach was considered appropriate given the exploratory, single-case design and limited dataset.

3.2. Analytical Framework: BCG Model

The BCG model is a sustainability framework that integrates the efficient use of biological resources (bioeconomy), recycling and the circular economy, and environmentally responsible production (green economy). The BCG model functions as the analytical framework that evaluates how superworm farming practices implement sustainability principles throughout this study. The model enabled researchers to analyze qualitative data through its three-dimensional framework, which classified farm operations into the bioeconomy, circular economy, and green economy categories. The model used three dimensions to analyze farm activities, including bioeconomy for biological resource utilization and agricultural by-product application, the circular economy for superworm frass recycling into organic fertilizer or other farm system inputs, and green economy for sustainable practices like waste minimization and energy-saving housing systems. This study differs from past research by providing a qualitative case analysis of superworm farming in the community context, offering grounded observations of how BCG-aligned practices emerge through daily operations, resource use, and farmer decision-making.

This research applies the BCG model to household farms rather than using it for policy or sectoral analysis as in previous studies, to gain a new understanding of how small-scale insect farming implements BCG principles in real-world operations. The model functions as a research tool, enabling analysts to understand production system sustainability through their interpretation of interview data, observation of results, and documentation of the work.

3.3. Data Collection

Semi-structured in-depth interviews and on-site field observations were conducted at the selected superworm farm. The interview tool was developed by integrating research objectives with the BCG conceptual framework. The interview consisted of eight sections.

- 1) General information on the respondents.
- 2) Farm production and management systems.
- 3) Bioeconomy aspects.
- 4) Circular economy aspects.
- 5) Green economy aspects.
- 6) Potential for BCG-based model development.
- 7) Collaboration and networking.
- 8) Problems and recommendations.

The Index of Item-Objective Congruence (IOC) was used to conduct content validity testing of the semi-structured interview before its implementation. Five experts, highly experienced in agricultural economics, sustainable agriculture, and community enterprise development from Thai academic institutions, were invited to review the content. Modifications were made according to the experts' guidelines on clarity and accuracy to meet the research objectives. The researchers conducted field observations in September 2025 by visiting the selected farm twice to administer in-depth interviews and thoroughly observe the farm's daily operations and environmental conservation activities. The interviews were transcribed verbatim in the original language. Each on-site session lasted approximately 5 hours. Interviews were audio-recorded with the consent of the participants, and all recordings were transcribed verbatim to ensure the accuracy of the qualitative data. When responses were provided in Thai, the transcripts were subsequently translated into English for analytical purposes. Field notes were taken during and after the interviews to capture contextual details that might not appear in audio recordings. The combined use of audio recordings, verbatim transcription, translation checks, and field observations strengthened the credibility and completeness of the qualitative dataset. Three follow-up telephone interviews with the farm owner were made to clarify operational details, update the most current information, and confirm the data accuracy. Primary data collection was conducted through different methods, while secondary information was obtained from academic papers, local development reports, and the BCG model's policy documents to validate the primary findings. Table 1 indicates the basic information of the respondent and farm profile. The farm is located in Khon Kaen Province, Thailand. The farm owner is 43 years old and has approximately 2 years of experience managing superworm farming. He holds a bachelor's degree in a non-agricultural-related field. The rearing facility measures 6×16 meters.

Table 1. Basic information on respondents and farm profile.

Item	Information
Farm location	Khon Kaen Province, Thailand
Age of the farmer	43 years
Experience of superworm farming	Approximately two years
Education	Bachelor's degree (non-agriculture field)
Average age of household labour	50 years
Size of the superworms rearing facility	6×16 metres (divided into two rearing sections)
Banana cultivation area for superworm feed	1,600 square metres
Tomato cultivation area using superworm Frass	8,000–16,000 square metres (rotational cultivation throughout the year)

3.4. Case Selection

The selected case study describes a community-based superworm farm that utilizes the BCG model to achieve practical results in local agricultural activities. The farm was chosen through purposive sampling based on specific criteria.

- 1) Length of operations: a minimum of 12 months.
- 2) Application of bio-based materials, recycling procedures, and eco-friendly innovations in accordance with the BCG model.
- 3) The owner's willingness to conduct an interview or participate in on-site observations.

This selected case study helps to understand the conditions under the BCG framework for achieving sustainable community farming systems.

3.5. Data Analysis

Data analysis was conducted through in-depth interviews, field observations, and field notes within a systematic framework. To gain a comprehensive understanding of the farm environment, several transcripts and notes were reviewed multiple times. The research employed content analysis to identify BCG principles in farm operations by examining operational maintenance practices, existing methods, and established procedures. The research process consists of three stages as follows.

- 1) Data organisation: The research team organized all collected data through the combination of interview results, field notes, and additional research materials, categorized according to production and management areas.
- 2) Synthesis of findings: All data were combined to evaluate how agricultural practices matched the economic, environmental, and social elements included in the BCG model.
- 3) Data verification: The research team verified their findings through triangulation by analyzing the interview data, observed information, and farm documentation (Denzin, 1978). The farm owner conducted member checking to confirm the research results, which improved the study's reliability through independent verification of the obtained results (Lincoln & Guba, 1985).

3.6 Ethical Considerations

The research procedures involving human subjects or data adhered to all necessary ethical guidelines for human research. Research ethics approval was granted by the Maharakham University Ethics Committee for Research Involving Human Subjects, no. 595-592/2025. The study obtained Exemption Review status because it posed no significant danger to participants. It was conducted under the responsibility of the Maharakham Business School, Maharakham University, with the research site located at a community-based superworm farm in Khon Kaen Province, serving as the single case study location. The research received ethical approval on September 1st, 2025, and this approval remains valid until August 31st, 2026.

4. RESULTS AND DISCUSSION

The farm under study in Khon Kaen Province was established after a household member suggested the potential growth of exotic pet sales in Thailand. This case provides empirical insights that have not been documented in prior BCG-related agricultural studies in Thailand. Specifically, it shows how small-scale superworm farming can integrate bio-based production, circular resource flows, and low-impact green practices without formal institutional support. The family began small-scale superworm farming because they recognized the growing market demand for alternative feed and pet insects, and they relied solely on household labor. The farm has been in continuous operation for more than two years. In the first year, breeding expansion and experimental rearing took place before any commercial distribution. In this stage, the worms were grown in an old pigpen rather than special rearing facilities. The stock of initial breeding was approximately 1,000 adult superworms. These became the foundation for future breeding operations.

The learning process of the insect farmer was completed through self-learning methods, such as online learning materials and academic research papers, to acquire technical knowledge. The owner recognized that wheat bran has been an outstanding sustainable food for growing superworms. The research findings align with other studies highlighting that wheat bran is a significant larval rearing food for superworms. As a result, it has become a potential material, along with other agricultural by-products, for feeding animals (Gourgouta et al., 2024). The farm owner applied both scientific knowledge and experiential learning to develop a systematic, adaptive approach for superworm cultivation, minimizing practical resource limitations and offering knowledge-based improvements.

The farmer developed a specialized rearing facility to handle rising production needs while strengthening operational efficiency and biological safety. The size of the facility covers 6 meters in width and 16 meters in length to protect against natural predators such as ants and flies (Figure 2). This facility includes a water channel, which serves as a physical barrier. It measures 30 centimeters in width and depth at the front, and 60 centimeters wide and 30 centimeters deep along the other sides. The facility is divided into two distinct areas: the first section, which is 4 by 6 meters, is used for breeding pupae, adults, and eggs, and is designed as an enclosed room with windows on three sides to control light and humidity. The second section is for late-instar larvae, which hold the highest economic value. This area features mesh ventilation to ensure airflow and reduce the risk of heatstroke or excessive humidity.

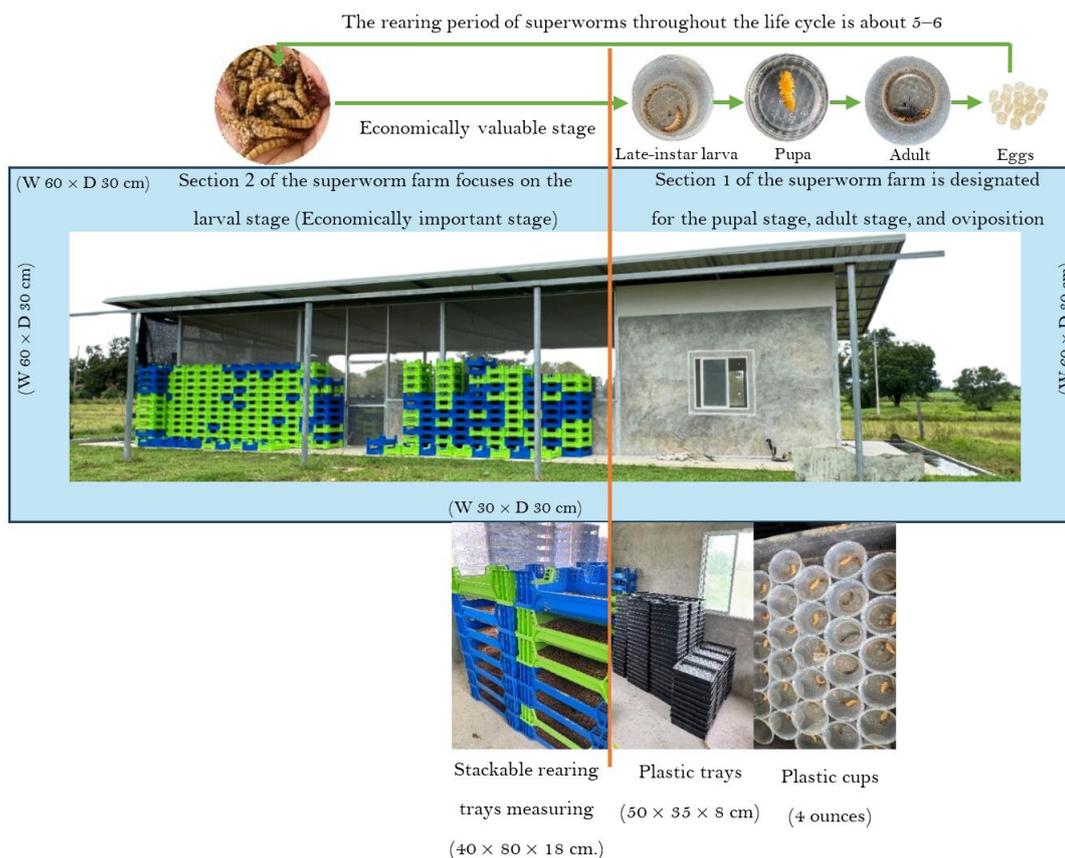


Figure 2. Farm layout and life cycle management of superworms.

With full production capacity, the farm can handle 1,000 stackable rearing trays measuring 40 × 80 × 18 centimeters. These trays hold individual plastic cups. Each tray can hold approximately 30 cups. In total, this facility supports about 24,000 plastic cups (4 ounces each). Later, these cups are then used to separate late-instar larvae, allowing them to pupate and develop into mature beetles for breeding in the next production cycle. This method proves to be a systematic and well-structured strategy for strengthening production beyond regular household activities into a well-organized and semi-commercial operation.

Currently, the insect farm can produce and sell approximately 100 kilograms of fresh superworms per month. As a result, it generates around 935.95 and 1,091.94 USD in revenue. However, the current superworm production level remains below its full capacity due to limited household labor resources.

Superworm cultivation needs to be balanced with other farming activities within the farm. This lowers the capability to meet the full market potential. However, the farm demonstrates how rural households in Thailand can incorporate niche-market insect farming into their broader farm operations. This case study highlights both opportunities and challenges of small-scale insect farming as a sustainable, income-generating activity within the growing exotic pet and alternative protein markets (Deguerry et al., 2023; Krongdang, Phokasem, Venkatachalam, & Charoenphun, 2023).

Currently, over 90% of superworm sales are made through online platforms for exotic pet enthusiasts. These products are purchased as feed for reptiles, amphibians, birds, and other small animals. There are differences in price between bulk and small-scale purchases. For orders of 5 kilograms or more, the selling price is set at 9.36 USD per kilogram, whereas for orders of less than 5 kilograms, the prices range between 9.98 and 10.92 USD per kilogram. This represents higher transaction costs for lower-volume sales.

Despite the rising market demand for fresh superworms, logistical problems have been reported as significant challenges. The maximum weight of a parcel is one kilogram due to packaging and mortality concerns. The average shipping cost is around 1.56 USD per kilogram.

High mortality is caused by shipping larger volumes in a single package, especially in Thailand’s tropical climate. This limitation results in higher unit costs of sales, reducing overall profitability and becoming a barrier to expanding online distribution channels in the superworm farming sector.

Superworm farming can be classified into four different stages based on the insect’s life cycle. At the initial stage, it begins with an egg, during which the breeder places adult beetles into rearing trays containing wheat bran as a medium. The beetles are cared for in the trays for 14–20 days before being removed. This allows oviposition to occur. Normally, each broodstock can produce eggs for 3–4 reproductive cycles (Oonincx, Van Broekhoven, Van Huis, & Van Loon, 2015).

After oviposition, first-instar larvae are moved to the other side of the rearing house, where they are cared for until they reach the late-instar larval stage. Even though superworms are ready to be sold at the age of 4 months, the farmer

in this study decided to wait five months, as the size of the larvae would be larger and develop greater body mass. As a result, they can achieve a higher market value. For breeding purposes, several larvae are kept at the farm. They are individually kept in 4-ounce plastic cups, with one larva per container, to maintain their transformation into pupae and eventually into reproductive adults within 10–20 days. Each larva's physiological condition affects the length of pupation, given that temperature and other environmental factors in the facility are not strictly controlled (Rumbos & Athanassiou, 2021).

The superworm's ability to remain in the larval stage for extended periods when kept under crowded conditions is known as its significant advantage over mealworms (*Tenebrio molitor*) in that pupation is delayed. On the other hand, mealworms will be ready to pupate even under high-density rearing conditions. A slower transformation process to the pupal stage offers an important advantage for farmers in terms of greater timing flexibility to sell the larvae, lowering the pressure to immediately sell during periods of price fluctuation or market downturn (Sanz, Tran, & Kainer, 2024).

4.1. Economic Assessment of Superworm Farming

An economic assessment of the farm, based on its actual operational data, provides a clear picture of its financial performance (Table 2). With a monthly output of approximately 100 kilograms and a wholesale price of 9.36 USD per kilogram, variable costs range from 2.45 to 3.13 USD per kilogram, mainly for feed, packaging, and shipping. This yields a contribution margin of 6.23 to 6.91 USD per kilogram (revenue minus variable costs, before fixed costs). Additionally, the farm has made substantial fixed investments in the rearing facility, including 1,000 stackable trays, pupation trays, and the initial breeding stock, totaling 22,025.95 to 22,337.93 USD. The break-even point falls between 3,191 and 3,584 kilograms of cumulative sales, based on these figures and the contribution margin. At the current production rate of 100 kilograms per month, this indicates approximately 31.9 to 35.8 months (about 2.6 to 3.0 years) to recover the initial capital outlay.

The farmer also earns additional economic value from using superworm frass as an organic fertilizer for tomatoes, amounting to approximately 935.95 to 1,247.93 USD by reducing fertilizer costs and increasing yields. This benefit allows the farmer to achieve faster payback periods because frass reduces production costs, resulting in higher profits than from selling insects.

Therefore, even while operating below full capacity due to household labor limitations, the enterprise appears to be economically viable. The use of frass shows promise for making insect farming an integral part of smallholder operations, creating economic stability and improving resource management.

Table 2. Economic snapshot and break-even analysis of the superworm farm.

Category	Item	Amount (USD)	Explanation
Production and Price	Monthly sales volume	–	Approximately 100 kg of fresh superworms are sold per month.
	Wholesale selling price	9.36 USD/kg	Price applied to bulk orders (≥ 5 kg).
	Retail selling price	9.98–10.92 USD/kg	Price applied to small online orders.
	Monthly revenue	935.95–1,091.94 USD	Actual revenue range based on current operations.
Variable Costs	Feed cost per kg	1.04–1.72 USD/kg	Based on actual wheat bran cost (per ton) and usage over 2–3 months.
	Packaging cost per kg	0.16 USD/kg	Cost of one shipping box per kilogram.
	Shipping cost per kg	1.25 USD/kg	Actual logistics cost borne by the farm.
	Total variable cost per kg	2.45–3.13 USD/kg	Sum of feed, packaging, and shipping.
	Total monthly variable cost	245–313 USD/month	Calculated for a 100 kg monthly production level.
Contribution Margin	Contribution margin per kg	6.23–6.91 USD/kg	The difference between the wholesale price and the actual variable cost.
	Monthly gross margin	624–692 USD/month	Before recovering fixed capital investment.
Fixed Investments	Rearing building	7,175.59–7,487.58 USD	Based on the current actual construction cost.
	Rearing trays (1,000 units)	14,039.20 USD	Long-term equipment for larval rearing.
	Pupation trays (1,000 units)	717.56 USD	Used in the pupation process.
	Initial breeding stock	93.59 USD	Initial investment in parent beetles.
	Total fixed investment	22,025.95–22,337.93 USD	Total start-up capital at current prices.
Break-Even Analysis	Break-even sales volume	$\approx 3,191$ – $3,584$ kg	Cumulative sales required to recover all fixed investment.
	Break-even time	≈ 31.9 – 35.8 months	At the actual output level of 100 kg/month.

Note: All monetary values are converted into USD using the exchange rate of 1 USD = 32.0531 THB (Bank of Thailand, 2025).

4.2. Application of Bioeconomy in Superworm Farming

At the superworm farming site, farmers use bioeconomy principles to run operations daily. There are wheat bran and other local agricultural by-product mixes. The farm should produce affordable feed through the combination of

banana stems with wheat bran. The local markets provide watermelon rinds, which serve as food residues for use. The implemented strategies enhance multinutrition levels while introducing natural moisture, creating an optimal environment for larval development to take place (FAO, 2013).

However, challenges may arise when using some vegetable by-product, especially discarded Chinese cabbage (*Brassica rapa subsp. pekinensis*) leaves from local markets (Figure 3). The researchers observed that pesticide residues probably survive washing because they cause most of the larval deaths. Farmers have switched to using ingredients that have proven pesticide-free status.

The bioeconomy aims to decrease waste and close resource loops, but chemical residues in waste streams pose risks to productivity and to food and feed safety (Halloran, Roos, Eilenberg, Cerutti, & Bruun, 2016). The micro-level method can be demonstrated through the conversion of inexpensive biomass resources into higher-value agricultural products. The farm achieves its two main objectives through the agricultural product substitution of commercial feed to enhance resource efficiency and support circular economy principles. The observed constraints show that insect farming needs to implement specific protection measures to integrate bioeconomy principles, which include dependable material acquisition, waste identification, and defined product management systems. The quality and safety of organic waste inputs must be ensured at the same level as their reuse promotion. The benefits of waste valorization could be diminished by productivity losses and biosecurity concerns when screening or certification mechanisms are absent.

This case study identifies two conflicting perspectives on bioeconomy implementation practices. The investigation shows how bioeconomy principles create the actual possibilities of strengthening sustainability while minimizing agricultural waste in rural areas. From this case study, two major barriers require further solutions to achieve large-scale adoption. These can be categorized into food safety risks, inconsistent input quality, and insufficient standardized guidelines. Bioeconomy principles can promise growth in superworm farming. However, their successful application requires proper management approaches and institutional and regulatory support to ensure sustainability, safety, and productivity.



Figure 3. Chinese cabbage and banana stem as superworm feed.

4.3. Application of the Circular Economy in Superworm Farming

Due to the large production of superworm frass in the farm operation, the farmer could apply the frass as an organic fertilizer for his crops, such as tomatoes, instead of being discarded (Figure 4). By doing this, it helps reduce waste and encourages farming efficiency simultaneously. In addition, residual substrates and dead larvae from the rearing process were transformed into feed for the fish in the farm as well. As a result, it promotes resource efficiency and reinforces practices of farming integration.

This action reduces reliance on chemical fertilizers while demonstrating how biological waste can be reused to generate additional value in production cycles. With the intention to follow zero-waste principles, superworm frass can be used as a nutrient-rich resource and for full utilization of rearing residues (Gan, Phua, Yeo, Heng, & Xing, 2021).

The farm data showed that using frass as a fertilizer improved soil health and promoted tomato plant development. Research findings indicate that this potential exists. Ainta, Attasopa, Kaomuangmoon, Khongdee, and Khomampai (2023) discovered that superworm frass contains substantial amounts of macronutrients, including nitrogen at 4%, phosphorus at 6.64%, and potassium at 1.47%, while supporting various beneficial microbial species (58 isolates, including bacteria, fungi, actinomyces, and yeast) that promote plant development. This composition highlights its role as both a nutrient source and a biofertilizer. However, while promising, the farmer noted that the monthly frass production volume was only sufficient for internal use and was not yet adequate for broader commercial distribution.



Figure 4. Superworm frass and tomato plots fertilized with frass.

From a critical stance, several limitations exist. Firstly, the productivity scale restrains the circular benefits at the farm level. This raises questions about the possibility of scaling up the business and its economic feasibility from a broader perspective. Secondly, the standardized quality control mechanisms have not been clearly defined, for example, nutrition certification, pathogen monitoring, and processing guidelines, challenging farmers to ensure safety and market standardization. Unregulated use of frass can cause related risks such as microbial contamination or variable nutrient content. Consequently, this could harm farmers' confidence. Thirdly, the possibility of frass commercialization is still unclear. Additional costs may arise from collection, storage, packaging, and distribution without any governmental support.

While superworm frass is characterized as an innovative example of circular-economy practice in small-scale farming, careful attention should also be paid to structural, regulatory, and economic barriers. Future studies should combine scientific research, farmer training activities, and market development to remodel this by-product from an internal soil improver into a commercially viable biofertilizer. Such collaboration would not only support sustainable community-based farming concepts but also offer practical circular economy activities in a more systematic and scalable manner (Ainta et al., 2023).

4.4. Application of the Green Economy in Superworm Farming

This case study highlights how the farm owner implemented various green economy practices in management. The rearing facilities for both early-instar and late-instar larvae featured mesh walls that enabled natural ventilation (Figure 5), reducing reliance on electric fans or mechanical systems and lowering energy use. In the future, the farmer plans to install solar panels to power the air-conditioning system in the breeding room during a heatwave. The adoption of renewable energy indicates a forward-thinking approach to minimizing the farm's carbon emissions. Material waste in the cultivation unit can be reduced by using reusable plastic rearing trays in production cycles. Additionally, eco-friendly, reusable packaging for product sales represents a sustainable practice to reduce environmental impact and encourage responsible resource use. Another innovative practice near superworm rearing houses is the construction of water channels for fish farming (Figure 5). These channels act as protective barriers while also serving as biological control systems. The fish population in the channels can protect superworms by eating insects, which can lower the risk of pest invasion. Natural pest control systems reduce chemical pesticide requirements while producing extra protein to support resource efficiency principles and circular utilization in green farming systems (Pretty et al., 2018).

These activities demonstrate how superworm farming aligns with green-economy principles by efficiently using resources, complementing renewable inputs where feasible, and minimizing waste (UNEP, 2011).

The implementation of natural ventilation in rearing rooms demonstrates how simple, cost-effective building design can promote a suitable microclimate while reducing electricity costs, operating expenses, and the farm's carbon footprint, instead of energy-intensive cooling systems, supporting sustainable production (Pretty et al., 2018). The future plan for solar energy installation reflects the farm's recognition of renewable energy as a pathway to long-term environmental and economic sustainability (Owusu & Asumadu-Sarkodie, 2016). The reusable equipment reduces the need to use fresh plastic materials while decreasing environmental impact from agricultural waste. The system's success depends on continuous investments in renewable technologies and technical knowledge to ensure production efficiency. According to this case study, small-scale insect farms can apply green economy principles to minimize environmental impact without compromising production efficiency.



Figure 5. Ventilated net-house and surrounding water trenches.

4.5. The Potential of the Superworm Farm as a BCG Model

According to the research findings, the superworm farm has high potential to align with the BCG model since its farming practices work well under BCG principles, even though the owner lacks BCG knowledge, especially in resource recycling, waste reduction, and the conversion of organic materials into insect protein. This shows the farm's possibility to become a prototype of sustainable agricultural models in rural areas.

One of the major drawbacks is that farmers do not have sufficient understanding of superworm rearing practices. The lack of a standardized method, traditional knowledge, and experiential learning creates challenges for production efficiency, biosecurity, and scalability. To fulfill the existing knowledge gap, systematic training programs, technical guidelines, and collaborations with academic and research institutions are required to strengthen science-based management practices (Dobermann, Swift, & Field, 2017).

Table 3. Summary of BCG-aligned practices and observed operational gaps.

BCG Dimension	BCG-Aligned Practices Observed on the Farm	Operational Gaps / Limitations
Bioeconomy	Use of biological inputs (vegetables, fruits) sourced locally	Lack of standardized quality control for frass nutrients
	Waste-to-protein conversion through superworm feeding	No laboratory testing for pesticide residues in feed materials
	Use of frass as an organic fertilizer for tomato production	
Circular Economy	Reuse of plastic rearing trays across cycles	Limited scale restricts circularity benefits
	Repurposing dead larvae and feed residues as fish feed	No formal system for waste segregation and quality tracking
	Waste valorisation integrated into multiple farm processes	
Green Economy	Natural ventilation from mesh-walled rearing rooms	Absence of carbon measurement or environmental monitoring
	Water-channel fish system for natural pest control	No official certification for eco-friendly or green practices
	Plans to install solar panels for air-conditioning	
Institutional / Market Dimension	Growing market demand for exotic pet feed and alternative protein	Weak institutional support for training, technical guidance, and certification
		Limited access to stable markets and e-commerce infrastructure

The absence of institutional support has become another main obstacle. Currently, farming operations are not supported by any public agencies or private organizations regarding technical extension services, financial incentives, market development, and the creation of value-added products. Without structural support, it will be more difficult for superworm farming to become a BCG prototype beyond localized areas (Halloran et al., 2016). With its strengths, the farm can serve as a grassroots-level BCG integration model. However, its success will depend on addressing the knowledge gap and multi-stakeholder engagement.

Table 3 presents a structured summary of BCG-aligned practices observed on the focal farm in Thailand and the operational gaps that continue to constrain the sector. The local farm uses vegetables and fruit scraps that are easy to find in Khon Kaen and produces superworms as a source of protein. The owner reuses trays and connects the frass and dead worms to fish feeding and tomato growing in simple, everyday ways. The buildings depend on natural airflow, and the farmer plans to add solar power to handle heat during the dry season. Most of these choices come from the farmer's own experience, not from advanced equipment. However, limited scale, the absence of standardized testing and certification, and weak institutional and market support restrict transferability and broader expansion.

5. CONCLUSIONS

This case study indicates that superworm farming can become the showcase for applying the BCG model across Thailand. Even though farmers may not be familiar with the BCG principles, their actual practices match all dimensions. Superworm farming supports bioeconomic activities by transforming biological resources into valuable products. The organic by-products conversion process into high-quality protein enables circular economy development and green economy growth because it uses environmentally friendly production techniques that create minimal environmental impact.

This study highlights the key challenges to implementation. The lack of scientific and technical understanding about superworm breeding prevents farmers from properly handling their production, which results in unsuccessful long-term farm operations. The solution to this knowledge deficit requires specific training programs and extension services focused on particular areas. The other important barrier is insufficient institutional support to further promote the adoption of BCG-aligned insect farming practices. Without these supports, the prototypes of superworm farms are at risk. Overall, these farming practices represent both possibilities and challenges of a grassroots model for BCG implementation. The overall success relies on collaborating with practical local farming practices and scientific and institutional support to ensure that local farmers can turn their businesses into long-term socio-economic and environmental benefits.

In conclusion, this study demonstrates the importance of policies to support farmer training and knowledge transfer for superworm rearing management. It also highlights the significance of institutional support, technical extension services, market creation mechanisms, and certification systems to strengthen sustainable development and encourage BCG model-based businesses.

For this model to be successfully implemented in other contexts, several essential preconditions must first be in place. Farmers need clean feed they can trust; otherwise, everything they try to do gets shaky. They also need to understand the basics well enough, through ongoing training, not just a one-time session, and they need someone they can actually talk to when problems show up. On the community side, it helps a lot if local groups, whether cooperatives or extension staff, are active enough to help farmers sell their products and keep the quality consistent. Beyond that, each community has to be willing to reuse what they already have and set up small systems for handling waste or circulating materials. When these pieces fall into place, the superworm model can spread more naturally and provide rural areas with a practical way to work with BCG ideas, instead of just talking about them. Policy recommendations include strengthening farmer capacity through coordinated training led by the Ministry of Agriculture and Cooperatives, focusing on practical modules such as breeding techniques, environmental control, waste-to-resource utilization, and product safety. Market-support mechanisms should be enhanced by establishing community-level collection and grading points, developing buyer-producer matching platforms through the Ministry of Commerce, and providing small-scale financial support and introducing basic certification guidelines for insect-based products to help farmers access formal markets. These coordinated measures are essential for advancing sustainable BCG-oriented superworm farming in Thailand. In addition, for the model to be transferable to other communities, several enabling conditions must be in place. Firstly, the availability of reliable input sources, such as clean feed materials free from pesticide contamination, is essential for maintaining production quality and reducing biological risks. Secondly, knowledge readiness among farmers must be strengthened through continuous training, standardized technical guidelines, and access to advisory support. Thirdly, institutional structures, including local cooperatives, extension networks, and certification systems, must be sufficiently developed to provide market access and safeguard product quality. Finally, scalability depends on community-level commitment and the presence of basic infrastructure that can support circular resource flows, such as waste collection, renewable energy options, and integrated farming systems. When these conditions are met, the superworm farming model has strong potential to be adopted widely as a grassroots pathway for BCG implementation across rural Thailand.

6. RESEARCH LIMITATIONS

This study has several limitations. First, superworm farming in Thailand is still at an early development stage. Therefore, large-scale and long-term quantitative data have not yet been collected. The second limitation is the scope of this study. The data relied on only a single farm, which may not fully capture the diversity of farm management practices across regions and environments. As a result, it limits the generalizability of the findings. Third, the economic

assessment is exploratory. It focuses on potential implications under the BCG economic framework rather than detailed economic modeling. Future research should incorporate larger datasets, longitudinal monitoring, and more comprehensive cost-benefit analyses to validate and extend the findings presented here.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

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