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RESEARCH ARTICLE
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Application of Blockchain Technology for Commercial Grasshopper Farming Supply Chain Traceability in Thailand

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ABSTRACT

This qualitative research study examines the supply chain of commercial grasshopper farming in Thailand. It focuses on the upstream to downstream, with 30 farm representatives throughout Thailand participating in interviews and observations. The results for the upstream reveal that the farmers use a variety of rearing cages and housing designs, while the rearing process includes breed selection, egg incubation, food and care, a breeding site, and harvesting for which essential materials and equipment are required. In the midstream, the grasshopper farmers carry out product aggregation, distribution, and transportation, with intermediary traders playing a significant role. The downstream involves local and non-local buyers, with farmers diversifying their sales channels through group networks, community markets, street vendors, and various online channels. The application of blockchain technology in the farm products supply chain has the potential to increase inspection efficiency and consumer confidence but within certain limitations. The issues to be addressed include data collection between farmers and consumers, information standards, digital literacy, and writing. Collaboration between public and private sector stakeholders is essential to achieve sustainable production, ensure food safety standards, and raise consumer awareness.

Keywords: Commercial grasshopper farming, Supply chain, Blockchain technology, Edible insects, Thailand.

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INTRODUCTION

The insect market is estimated to reach US$ 3.80 billion by 2024 and US$ 9.04 billion by 2029, growing at a CAGR of 18.89% during the forecast period (2024 to 2029) (Global Market Insights, 2022; Mordor Intelligence, 2022). The market of edible insect in Thailand has expanded significantly in recent years, with special emphasis on the export and import of various products, such as frozen and processed goods. Thailand exported 1 million US dollars of insects and insect products in 2020, categorized into four main categories: live insects, edible insects, fresh, chilled, or frozen insects, and prepared or processed insects. Key markets included the United States, the United Kingdom, and the United Arab Emirates. The exports were primarily made to Hong Kong, the United States, Myanmar, Malaysia, and Mexico (Customs Department of Thailand, 2024).

Food insect farming is growing in Thailand, where crickets are in high demand, (Hanboonsong, 2010; Hanboonsong et al., 2013; Phankaew, 2019; Kreca, 2021; Krongdang et al., 2023) with more than 28,000 farmers in the country adopting them as a business (Department of Agricultural Extension, 2022). However, the large number of cricket farmers has created price competition, leading to lower market prices. It is, therefore, challenging and interesting to investigate the production of other insect species as an alternative. Grasshoppers have become very

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popular in the last two or three years, and many farmers are turning to commercial grasshopper farming for several reasons: minimal space requirement for rearing, ability to raise various breeds, low investment in building infrastructure, ease of finding natural food sources, and higher purchase prices compared to crickets (200 to 350baht/kg for grasshoppers, while crickets fetch only 80 to 120baht/kg). In addition, grasshopper manure can also be sold as fertilizer and for soil structure improvement at 20baht/kg (Manager Online, 2023). Moreover, grasshoppers have more marketing channels than crickets since they are the only insects permitted for consumption by Muslims according to Islamic law (The Halal Standard Institute of Thailand, 2008). Currently, the grasshopper market is showing growth trends both domestically and internationally, driven by the rising popularity of healthy and environmentally sustainable food consumption. In 2022, domestic production was insufficient to meet demand, resulting in imports of up to 115tons (National Food Institute, 2023). This situation highlights the opportunities for commercial farming and the increasing consumer demand in Thailand.

The situation described above illustrates the growing demand for consumer grasshopper goods in Thailand. However, improvements in quality and standards are necessary for acceptance in the domestic market and future export markets. Therefore, the study of the up-down commercial grasshopper supply chains is required to fill the information gap, maximize support for grasshopper consumption, and meet international standards. The findings of such a study can then be used to establish reliable standards and evaluation systems in the future (Müller et al., 2016; Halloran et al., 2018; Krongdang et al., 2023). However, traceability in the grasshopper supply chain remains a challenging issue due to the multiple processes involved, resulting in scattered, non-transparent, and disconnected data throughout the system. The inability of consumers to trace the origin, cleanliness, safety, and quality of grasshoppers can lead to concerns and may affect their confidence in the products. Therefore, an efficient traceability system needs to be developed (Yiannas, 2018).

Blockchain technology is considered a solution for enhancing transparency, security, and traceability in the food supply chain due to its key characteristics, including decentralization, data reliability, transparency, and auditability (Kamilaris et al., 2019). Nevertheless, applying blockchain technology to small-scale grasshopper farmers involves the consideration of certain costs and obstacles (Tian, 2018). Accordingly, it is evident that studying the supply chain and applying blockchain technology in commercial grasshopper farming are important. Therefore, the objectives are to study the commercial grasshopper farming supply chain of farmers and propose guidelines for utilizing blockchain technology to enhance traceability efficiency, covering upstream, midstream, and downstream aspects, in order to present feasible development approaches that align with the Thai context in the future.

MATERIALS & METHODS

Study Area and Sample

This qualitative research study was conducted from October 2023 to April 2024. A total of 30 representative farms willing to collaborate in the research were selected from different regions across Thailand: ten each from the Northern, Central, and Northeastern regions (purposive selection). The research focused on these regions of Thailand, where grasshopper farming is popular. Due to the unregistered status of insect farming, unlike other edible insects in Thailand, the non-probability sampling technique was the most practical approach under these circumstances, and the interviewed sample size was given little weight (Crouch and McKenzie, 2006).

Data Collection

Quantitative data was collected through well-structured questionnaires and face-to-face interviews with grasshopper producers, traders, and consumers. The questionnaires were tailored to each participant in the supply chain, considering their specific roles and responsibilities:

i. Socio-economic Profile: This section gathers information about the respondents' gender, age distribution, highest education level, household size and occupation.

ii. Operations: This part focuses on the involvement and responsibilities of individuals and organizations at different stages of the supply chain, such as production, processing, and marketing. It also explores their access to support services and the specific organizations involved.

iii. Market Features:

Popularity: The demand and preference for grasshopper products.

Packaging and sales: How grasshopper products are packaged and sold in bulk quantities.

Consumption patterns: The consumption habits and preferences of different consumer groups.

Pricing: The current market prices for grasshopper products.

Price determinants: Factors that influence the pricing of grasshopper products.

iv. Market access: Market access refers to the ability of producers, traders, and other participants to enter and operate within various distribution channels. This includes access to markets, transportation networks, and other essential infrastructure that enables the efficient movement of grasshopper products from producers to consumers.

Data Analysis

After all the data had been comprehensively collected and its accuracy verified, the information was analyzed by categorizing it into relevant themes and interpreting the grouped data. Subsequently, an overarching analysis was conducted. When presenting the data, quotes from the informants were cited to support and validate the findings.

RESULTS & DISCUSSION

This research aims to investigate the interconnected activities involved in the commercial grasshopper-rearing practices of farmers, encompassing the upstream,

midstream, and downstream stages, as detailed in the following findings:

The Upstream of the Farmer's Grasshopper Rearing Supply Chain

Rearing Cages: There are various styles of rearing cages for grasshoppers. Normally, mesh cages typically have approximate dimensions of 100x120x100cm or more (width x length x height), with a capacity to accommodate 50 to 500g of grasshopper eggs. Rearing cages are typically constructed using wood, bamboo, plastic PVC, or metal. Its height from the ground should be about 50cm. The rearing area should be able to protect the grasshoppers during the rainy season, provide good ventilation, and provide adequate humidity and adequate sunlight for larvae to thrive.

Housing: Most grasshopper farms are outdoor operations, featuring open structures on all four sides with a roof to shield against rain. While the housing design is not fixed, it should be sturdy, capable of preventing excessive rainfall, well-ventilated, free from odors and pathogens, easy to clean, and able to protect against grasshopper predators. The housing structure is generally made from wood, bamboo stalk or metal.

Rearing techniques:

1. Selection of the Grasshopper Specie: For the commercial grasshopper species raised in Thailand is the Asian Migratory Locust, *Locusta migratoria*. Farmers typically purchase eggs within their local groups. Current egg prices range from 1,200 to 2,000baht/kg.
2. Egg Incubation: Incubation trays can be obtained from local construction material suppliers and prepared by creating a 10cm layer of loose soil, approximately half the height of the incubation container. Next, a thin layer of cocopeat (coconut husk fiber) should be added on top. The acquired eggs should be carefully placed on the first layer of cocopeat and covered with another. A spray bottle should be used to moisten the setup, which is then lightly covered with loose soil before the container is sealed and kept in a warm area. Hatching typically begins after around 14 days.
3. Food and Caring: Grasshoppers consume tender greens such as sugarcane, bamboo, corn leaves, or protein-rich Napier grass. Fresh food should be provided once daily at approximately seven days after hatching. For every kilogram of eggs, 8 to 10kg of food should be provided twice a day, totaling 16 to 20kg. However, food intake may vary by season, decreasing in winter and increasing during the summer heat. Food sources can be obtained from the farmer's own land. When fresh greens are unavailable, ground corn, rice bran, and soybean meal from animal feed suppliers can serve as substitutes.

The grasshopper life cycle is counted from the day of hatching (day 1). The growth stage from nymph to adult takes approximately four weeks, during which they undergo four to five moults (harvesting occurs during this stage). Four to five days after reaching adulthood, mating begins for about two weeks, followed by the egg-laying stage (Fig. 1).

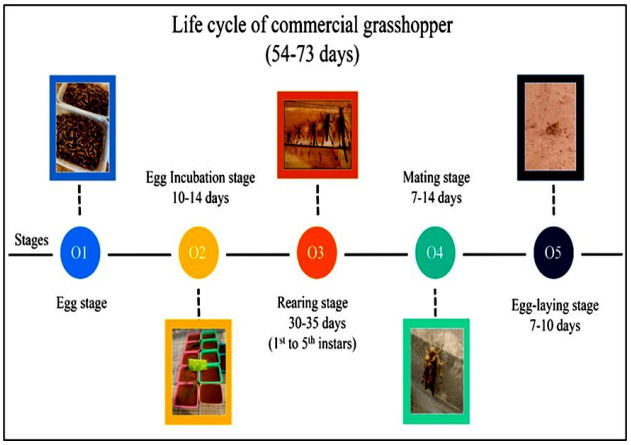

Fig. 1: Life cycle of commercial grasshopper in the study.

4. Breeding site: During the mating period, breeding trays similar to those used for incubation should be prepared, with a 10cm layer of a 1:1 soil and cocopeat mixture, within the rearing house. Female grasshoppers will burrow 5cm deep into this mixture to lay their eggs.
5. Harvesting: Harvesting occurs 30 to 35 days after hatching before the grasshoppers reach adulthood (after the fourth moult). Netting and hand-catching into mesh bags obtained from agricultural or construction material suppliers are common practices. The yield can be estimated based on the initial egg quantity—1kg of eggs typically yields 25 to 30kg of live grasshoppers, depending on the feed quality and hatch rate. The grasshopper manure is collected every three days to maintain cleanliness. After collection, it is gathered and sun-dried in preparation for sale as fertilizer or soil conditioning material. Once the grasshopper manure has been sun-dried, it is packed into plastic bags, each containing 1kg, or into fertilizer sacks, each holding 20kg, and then stored in readiness for sale. The materials and equipment necessary for the rearing process, such as plastic trays, soil, and cocopeat mixture, can be sourced from local agricultural material suppliers in the area.

The upstream stage involves the establishment of rearing cages and housing, breed selection, rearing processes, and harvesting activities. The research indicates that farmers employ simple, low-cost infrastructure and adapt available materials, often learning from experienced pioneers in their communities. This approach aligns with the principles of frugal innovation, where resource-constrained entrepreneurs leverage locally available resources to develop affordable and sustainable solutions (Vellema et al., 2023). Frugal innovation has gained traction in various sectors, including agriculture since it enables farmers to optimize their operations and enhance productivity with limited resources (Khan, 2016).

However, the lack of standardized practices and guidelines for commercial grasshopper rearing could hinder the industry's growth and broader acceptance. Implementing agricultural practices (GAP) specific to grasshopper rearing, similar to existing standards for other insect farming, could be beneficial. GAP guidelines typically cover aspects such as breeding stock management, feed and water quality, housing

conditions, and pest control measures (Halloran et al., 2016; FAO, 2021; FAO, 2022). The adoption of GAP principles can enhance product quality, food safety and environmental sustainability, aligning with consumer expectations and facilitating market access (National Food Institute, 2023).

The Midstream of the Farmer's Grasshopper Rearing Supply Chain

The midstream encompasses activities relating to product aggregation, like distribution and transportation, primarily involving intermediary traders. The research findings are as follows:

Distribution: Farmers sell live or frozen grasshoppers. For live sales, they catch, weigh, and load them into the trader's mesh bags. For frozen sales, farmers capture the grasshoppers into mesh bags, seal them tightly, and submerge them in ice water ("knocking" the grasshoppers) or place them in freezers to preserve freshness.

In addition to manure, grasshopper eggs can also be sold to breeders within and outside the community. This exchange of genetic material helps reduce the problem of inbreeding among grasshoppers, which can lead to smaller grasshoppers and reduced egg production. The eggs are weighed and sold in bags or boxes, ranging from 100 to 1,000g in capacity.

Transportation: Most farmers sell living grasshoppers in bulk to their main customers—intermediary traders who visit the farms to buy and resell to street vendors or within communities. They sell larger volumes to cold storage traders, packing the grasshoppers into 1kg bag for freezing. Wholesale prices range from 200 to 300baht/kg and 300 to 350baht/kg for retail. Purchase frequency depends on the farmer's supply. Small local traders from within and outside the area visit farms directly, or farmers deliver with a distance-based transport fee added.

Grasshopper Manure: Most interested buyers purchase grasshopper manure themselves. Retail sales within the community: 1kg bag: 20 to 25baht/bag and 20kg sacks: 15baht/kg.

Grasshopper eggs: Breeders within the community and new interested breeders buy the eggs. Eggs are sold by weight per baht (100gs) or in kilograms. Price range: 150 to 200baht/100g or 1,500 to 2,000baht/kg.

In the midstream stage, the research highlights the role of intermediary traders as the primary buyers and distributors of grasshoppers. While this arrangement provides a relatively stable market for farmers, it also exposes them to potential price fluctuations and limited bargaining power. Exploring alternative distribution channels, such as direct-to-consumer sales or collective marketing strategies, could empower farmers and improve their profit margins (Grisanaputi and Srila 2020). Additionally, leveraging digital technologies and e-commerce platforms could expand market reach and facilitate direct connections between producers and consumers (Forbes et al., 2020).

The Downstream of the Farmer's Grasshopper Rearing Supply Chain

The downstream comprises end customers or consumers within the area, other provinces, and Bangkok. Currently, rearing farmers have formed groups using webpages to facilitate intra-group trading, direct sales to consumers by setting up stalls along roads or community markets, and online e-commerce platforms to increase sales channels. This allows easier consumer access and attracts new customer groups. Sales peak during long holidays when tourists visit communities.

Based on the research findings, the commercial grasshopper-rearing practices in Thailand involve a relatively unstructured supply chain with three main stages: upstream, midstream, and downstream (Fig. 2). This discussion analyses the key aspects of each stage and provides insight from relevant academic literature and industry best practices.

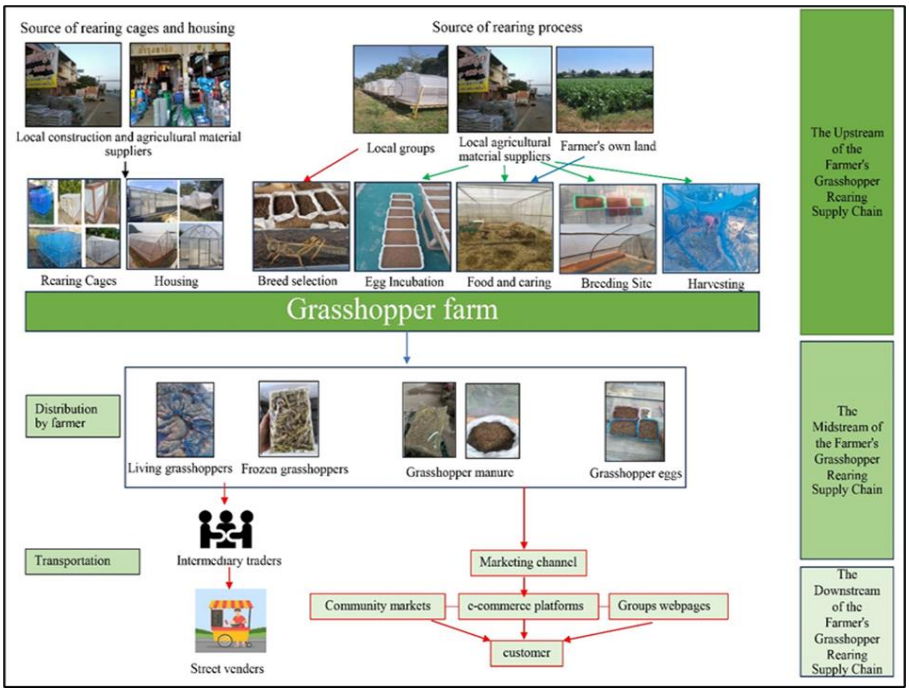

Fig. 2: shows the supply chain of grasshopper rearing from upstream to downstream of the Farmer's Grasshopper Rearing Supply Chain in Thailand.

The downstream stage reveals promising initiatives by farmers to diversify their sales channels, including roadside stalls, community markets, and online platforms. These efforts align with the concept of disintermediation, where producers bypass traditional intermediaries and connect directly with consumers. Disintermediation can increase transparency, reduce transaction costs, and potentially improve profit margins for farmers (Doherty and Ellis-Chadwick, 2010). However, successful implementation requires effective marketing strategies, product differentiation, and the ability to reach and engage with target consumers (Dobermann et al., 2017).

Furthermore, the research highlights the potential for grasshoppers to become an important edible insect for domestic consumption and export in Thailand. This aligns with the growing global trend of insect consumption, driven by factors such as sustainability, nutritional value, and cultural acceptance (Tapscott and Tapscott, 2016; Van Huis, 2016; Van Huis et al., 2021; Krongdang et al., 2023). To capitalize on this opportunity, collaborative efforts between farmers, researchers, and relevant government agencies could prove invaluable in developing sustainable production practices, ensuring food safety standards, and promoting consumer awareness (Demartini et al., 2017; Halloran et al., 2018; Krongdang et al., 2023).

The Role of Blockchain in the Grasshopper Supply Chain

Blockchain is a decentralized, distributed ledger technology that records transactions across a network of computers (Demestichas et al., 2020). It is essentially a chain of blocks, each containing a list of transactions and linked to the previous block using cryptographic methods. This creates a secure, tamper-proof, and transparent system for recording and verifying transactions without the need for intermediaries (Halloran et al., 2017; Iansiti and Lakhani, 2017).

In a blockchain network, each participant maintains a copy of the ledger, and any changes or additions to the ledger must be validated and agreed upon by the majority of participants through a consensus mechanism (Underwood, 2016; Mirabelli and Solina, 2020). This ensures that the ledger remains accurate and immutable since any attempts to alter or tamper with the records would be quickly detected and rejected by the network.

One of the key features of blockchain technology is its ability to provide a secure and transparent way of tracking the movement of assets, whether they be financial transactions, goods in a supply chain, or data exchanges (Raheem et al., 2019; Singh and Vishwakarma, 2023). By recording each transaction on the blockchain, stakeholders can access a complete and auditable history of the asset's journey, enhancing trust, efficiency, and accountability in various industries and applications.

The application of blockchain in the grasshopper supply chain can increase efficiency at every stage, from upstream to downstream. In the production (upstream) part, blockchain helps record important data such as the source of grasshopper breeds, rearing methods, feeding, housing environment, and good agricultural practices (Halloran et al., 2018; Xiong et al., 2020). This enables traceability to verify that the grasshoppers come from quality sources and have gone through hygienic, reliable, and safe production processes for consumption (Qian et al., 2020).

Upstream Part

In the upstream part, the application of blockchain focuses on recording data on the source of grasshopper breeds, breeding methods, feed used, housing environment, and GAP to enable traceability and demonstrate that the grasshoppers come from quality sources and have gone through hygienic rearing processes (Halloran et al., 2018). Farmers can use blockchain to record growth history, feed conversion ratio, survival rate, and the overall health of grasshoppers in each generation to help manage farms for maximum efficiency and provide important data for developing a good traceability system (Qian et al., 2020). Additionally, a system should be developed to link data from the upstream to consumers via QR codes or RFID so that buyers can access complete background information on the grasshoppers (Reddy and Kumar, 2020). However, data collection may present a challenge for small-scale farmers who lack the necessary knowledge and tools. Therefore, the feasibility and benefits farmers could potentially receive from using the technology should be considered (Sogari et al., 2019).

Midstream Part

In the midstream part of the grasshopper supply chain, blockchain can be applied to record and track information in the transportation, distribution, and processing of grasshopper products, such as temperature, humidity, and transportation time, to ensure they are fresh, meet the required standards, and are safe (Tian, 2018). The blockchain can also trace the sold grasshoppers back to the farm they came from and through whose hands they passed, preventing product counterfeiting (Qian et al., 2020). The use of blockchain also helps to improve the efficiency of warehouse management and inventory because the information flow in the supply chain can be seen in real-time, reducing the time spent communicating between producers and traders, increasing flexibility, and better responding to customer needs (Behnke and Janssen, 2020). However, the application of blockchain with agricultural products like grasshoppers still requires common data standards to be developed, as well as investment in supporting technologies among partners in the chain.

Downstream Part

In the downstream part of the grasshopper farming supply chain, the application of blockchain will help increase consumer confidence because it can be traced back to where the grasshoppers came from and how they were reared and transported before reaching the buyer. Consumers can access this information by scanning a QR code on the packaging or checking a designated website to ensure the freshness, cleanliness, and safety of grasshopper products (Qian et al., 2020). Moreover,

consumers can use blockchain to track detailed information on the nutritional benefits of each type of grasshopper product, promoting quality insect consumption (Zhao et al., 2019). The application of blockchain in the downstream also helps create engagement with consumers through collection points for purchasing grasshopper products and exchanging them for rewards, incentivizing consumption while supporting grasshopper farmers (Behnke and Janssen, 2020). However, providing information to a wide range of consumers through blockchain requires digital tools and skills, which may present an obstacle for some farmers and consumers. Providing knowledge and designing easy-to-understand systems are important for applying this technology (Reddy and Kumar, 2020). Fig. 3 provides an overview of using blockchain technology to record and track data throughout the grasshopper supply chain, from upstream to downstream.

The commercial grasshopper farming supply chain in Thailand offers a promising opportunity to develop a sustainable and economically viable edible insect industry. This study provides valuable insights into the current practices and challenges faced by grasshopper farmers across the upstream, midstream, and downstream stages of the supply chain.

The upstream findings highlight the resourcefulness and adaptability of farmers in establishing a low-cost rearing infrastructure and leveraging locally available materials. However, the lack of standardized practices and guidelines for commercial grasshopper rearing poses a potential barrier to the industry's growth and wider acceptance. Implementing Good Agricultural Practices (GAP) specific to grasshopper rearing could enhance product quality, food safety, and environmental sustainability, aligning with consumer expectations and facilitating market access.

In the midstream, their reliance on intermediary traders as the primary buyers and distributors of grasshoppers exposes farmers to potential price fluctuations and limited bargaining power. Exploring alternative distribution channels, such as direct-to-consumer sales, collective marketing strategies, and digital technologies, could empower farmers and improve their profit margins.

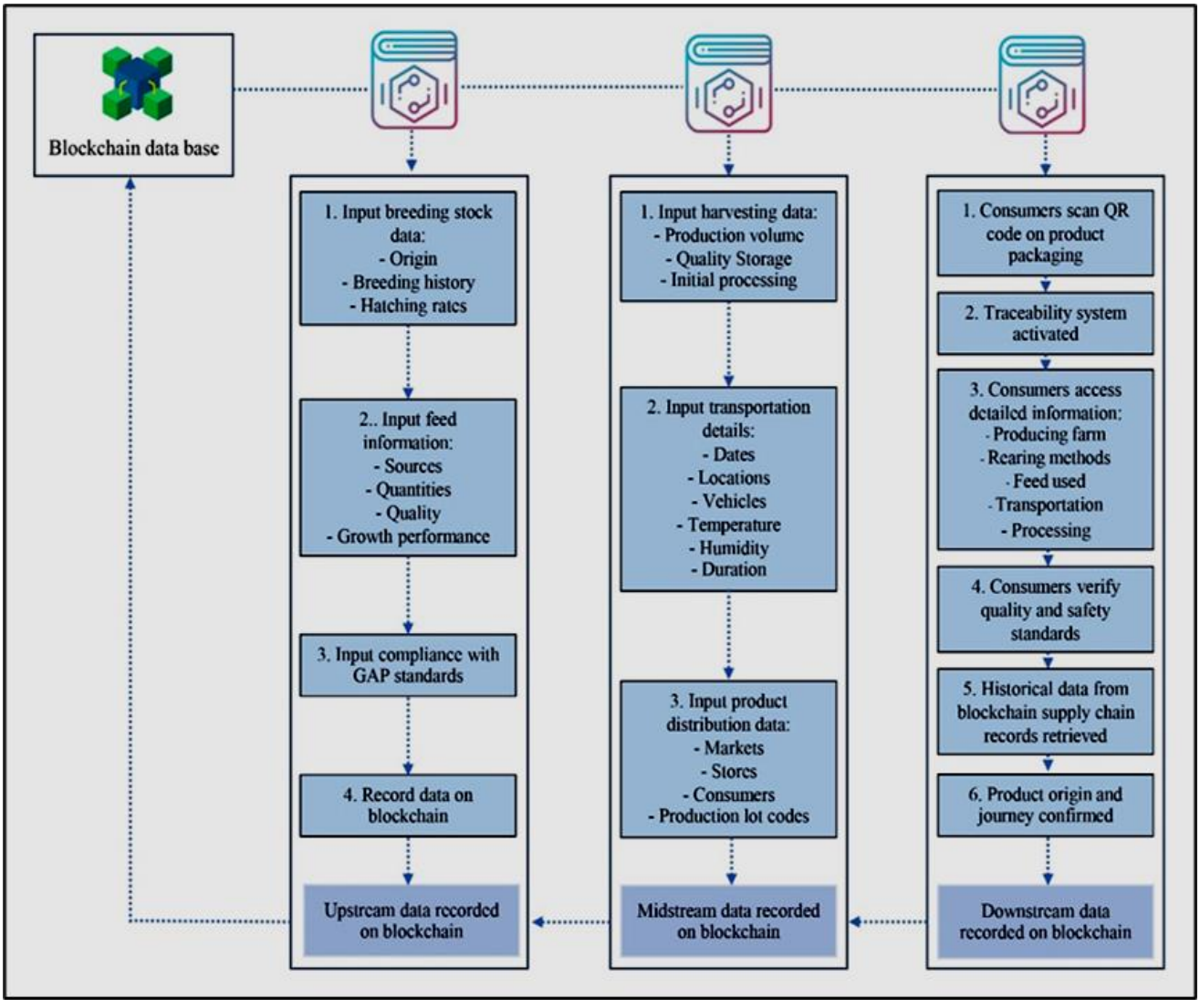

Fig. 3: The Application of Blockchain throughout the Grasshopper Supply Chain, from Upstream to Downstream.

The downstream stage reveals promising initiatives by farmers to diversify their sales channels, including roadside stalls, community markets, and online platforms. These efforts align with the concept of disintermediation, allowing producers to connect directly with consumers, increase transparency, and potentially improve profit margins. However, successful implementation requires effective marketing strategies, product differentiation, and the ability to engage with target consumers.

Applying blockchain technology in the grasshopper supply chain can increase efficiency, traceability, and consumer confidence. Blockchain enables traceability by recording data on the source of grasshopper breeds, rearing methods, feed used, housing environment, and GAP. It demonstrates that the grasshoppers come from quality sources and have undergone hygienic rearing processes. In the midstream, blockchain can track information relating to transportation, distribution, and processing, thereby ensuring product freshness and safety while preventing counterfeiting. In the downstream, blockchain allows consumers to access detailed information on grasshopper products' origin, rearing practices, and nutritional benefits, promoting quality insect consumption and creating consumer engagement.

However, this study also acknowledges the challenges associated with implementing blockchain technology in the grasshopper supply chain. These include data collection, the need for common data standards, and digital literacy among farmers and consumers. Addressing these challenges requires collaborative efforts between stakeholders, including farmers, researchers, and relevant government agencies.

This study on the commercial grasshopper farming supply chain in Thailand reveals significant implications for economic development and the edible insect industry:

Economic Aspect: Commercial grasshopper farming generates income and economic opportunities for small-scale farmers. It utilizes low-cost inputs and local resources, aligning with the concept of frugal innovation—a model well-suited to developing countries. This approach allows farmers to maximize returns with minimal investment.

Agricultural and Entomological Considerations: There is a pressing need to develop GAP specifically tailored to grasshopper farming. Such standards would enhance product quality, food safety, and environmental sustainability. Farmers can increase consumer acceptance and expand market opportunities by implementing these practices.

Agribusiness Management: Farmers should be encouraged to diversify their distribution channels. This could include direct-to-consumer sales, collective marketing strategies, and the use of digital technologies. By reducing dependence on intermediaries, farmers can strengthen their bargaining power and potentially increase profit margins.

Supply Chain Dynamics: The application of blockchain technology shows promise in improving efficiency, transparency, and consumer confidence throughout the supply chain. However, challenges remain in data collection, establishing common data standards, and improving digital literacy among farmers and consumers.

Policy Recommendations: Government agencies should promote research and development to establish sustainable production methods, set food safety standards, and raise consumer awareness. This effort should leverage collaboration between the public and private sectors, as well as producers, following the Public-Private-Producer Partnership (4P) model.

Marketing Strategies: It is crucial to develop marketing strategies that highlight the strengths of grasshoppers, such as their nutritional value, sustainability, and traceability. These efforts can create added value and expand markets both domestically and internationally.

Conclusion

This study explores Thailand's commercial grasshopper farming supply chain, revealing significant potential for sustainable economic development. Low-cost inputs and frugal innovation enable small-scale farmers to maximize returns. However, standardized Good Agricultural Practices are needed to enhance product quality and food safety. Diversifying distribution channels through direct sales and digital technologies could empower farmers and improve profit margins. Blockchain application shows promise in increasing efficiency and transparency, though challenges in data collection and digital literacy persist. Collaboration between public and private sectors is crucial for establishing sustainable production methods, food safety standards, and consumer awareness. Marketing strategies highlighting nutritional value and sustainability can expand domestic and international markets. Future research should focus on optimizing rearing techniques, developing value-added products, and addressing regulatory challenges to fully capitalize on the growing edible insect market.

Authors Contributions

Sonthaya Sampaothong: Writing – original draft, Writing – review & editing, Investigation, Methodology. Paradorn Dokchan: Visualization, Investigation, Methodology. Pruetthichat Punyawattoe: Data curation, Visualization, Investigation, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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