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Edible insect farming as an emerging and profitable enterprise in East Africa

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In East Africa, insect farming is a rapidly growing business providing access to 'climate-smart' protein, other nutrients, and income. With the continental drive to transform existing food systems that are becoming continuously unsustainable due to scarcity of arable land and water, and high ecological imprint, insect farming for food and feed with circular economy potential has gained remarkable interest. In this review, we report on the recent research trends on key substrates and insect species commonly farmed, map of commercial enterprises, insect nutritional values, processing techniques, marketing, regulatory framework, and lessons learnt on insect farming. These findings provide important answers to both technical and economic factors of insect farming and provide a clear roadmap for scaling these technologies in a phased approach through effective public-private partnerships offering interesting opportunities for implementing a circular food economy.

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Introduction

The population of Africa is anticipated to reach about 2.53 billion people by 2050 [1] and the demand for food and protein would increase significantly, which the current linear food system might not be able to satiate. Hence, underutilized traditional foods, including edible insects need to be improved and promoted. The edible insects are rich in proteins (50–82%) [2–4], calcium, iron, and zinc [5]. These nutrient-rich biomasses make them a crucial source of ingredients in human and animal nutrition [6••]. The edible insects are largely sourced from the wild, but studies have pointed out the advantages of insect farming over wild gathering [6••,7,8]. In East Africa, insect farming for food and feed is relatively new, however over 75% of the farmers and feed millers have expressed willingness to adopt these technologies [9•]. Thus, introducing cost-effective rearing and processing methods of insects through value-addition would be a game-changer to ensure year-round availability and enhanced profitability. In Kenya and Uganda, all potential edible insect species have been approved for use as food and feed compared to Europe, where only seven species are allowed for animal feed [10••].

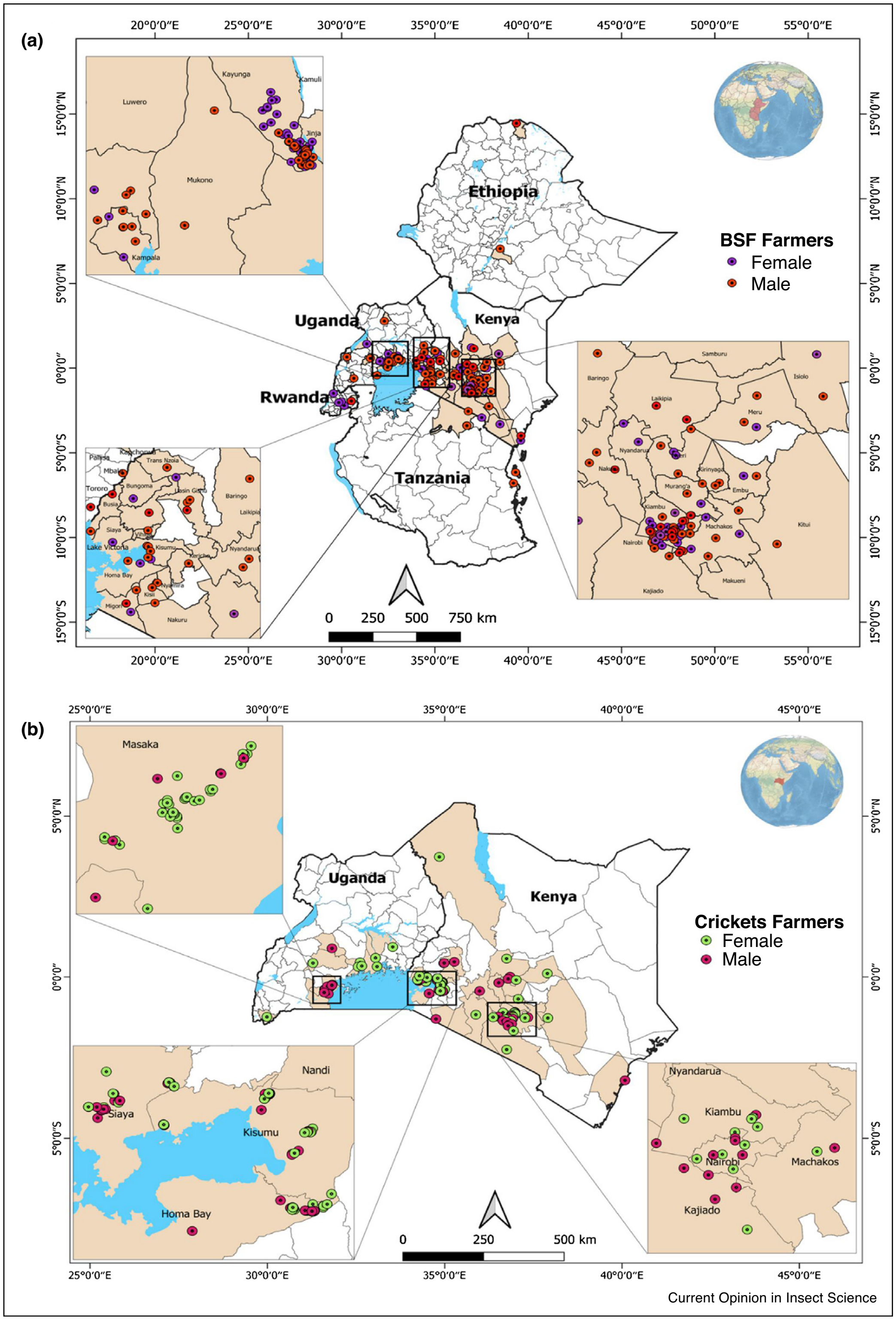
This paper provides a comprehensive review on insect farming enterprises in East Africa to guide investors and entrepreneurs who wish to invest in insect farming activities or enterprises. The paper emphasizes the role insect farming can play in attainment of Sustainable Development Goals (SDGs) [11••].

The status of insect farming enterprises

In East Africa, there is potential for farming several edible insects which include *Acheta domesticus*, *Scapsipedus icipe*, *Gryllus bimaculatus*, *Schistocerca gregaria*, *Ruspolia differens*, *Hermetia illucens*, *Tenebrio molitor* and *Rhynchophorus phoenicis* [12,13]. However, there is limited research attention to the rapidly growing industry. The benefits of breeding insects strongly outweigh that of most livestock and crop production [5,14]. Insect farming is still in its infancy, though it is becoming a fast-growing and expanding agribusiness [15••], as in other parts of the world [5,16•].

In less than one decade, insect farming has increased dramatically in East Africa due to the potential to farm insects at low-cost and on readily available organic waste [9•,17]. Several companies have emerged in Kenya, Tanzania, and Uganda. Over 95% of these farms operate as microenterprises with opportunities to be transformed into more automated systems in the future as the market for edible insects grows in the region. This paper will focus on key species of insects widely farmed in East Africa: crickets and black soldier fly (BSF). There are nearly 1000 black soldier fly and cricket farms in East

Figure 1



Distribution map of black soldier fly **(a)** and cricket **(b)** farms in East Africa.

Africa (Figure 1a and b, respectively) and new entrants continue to emerge each year.

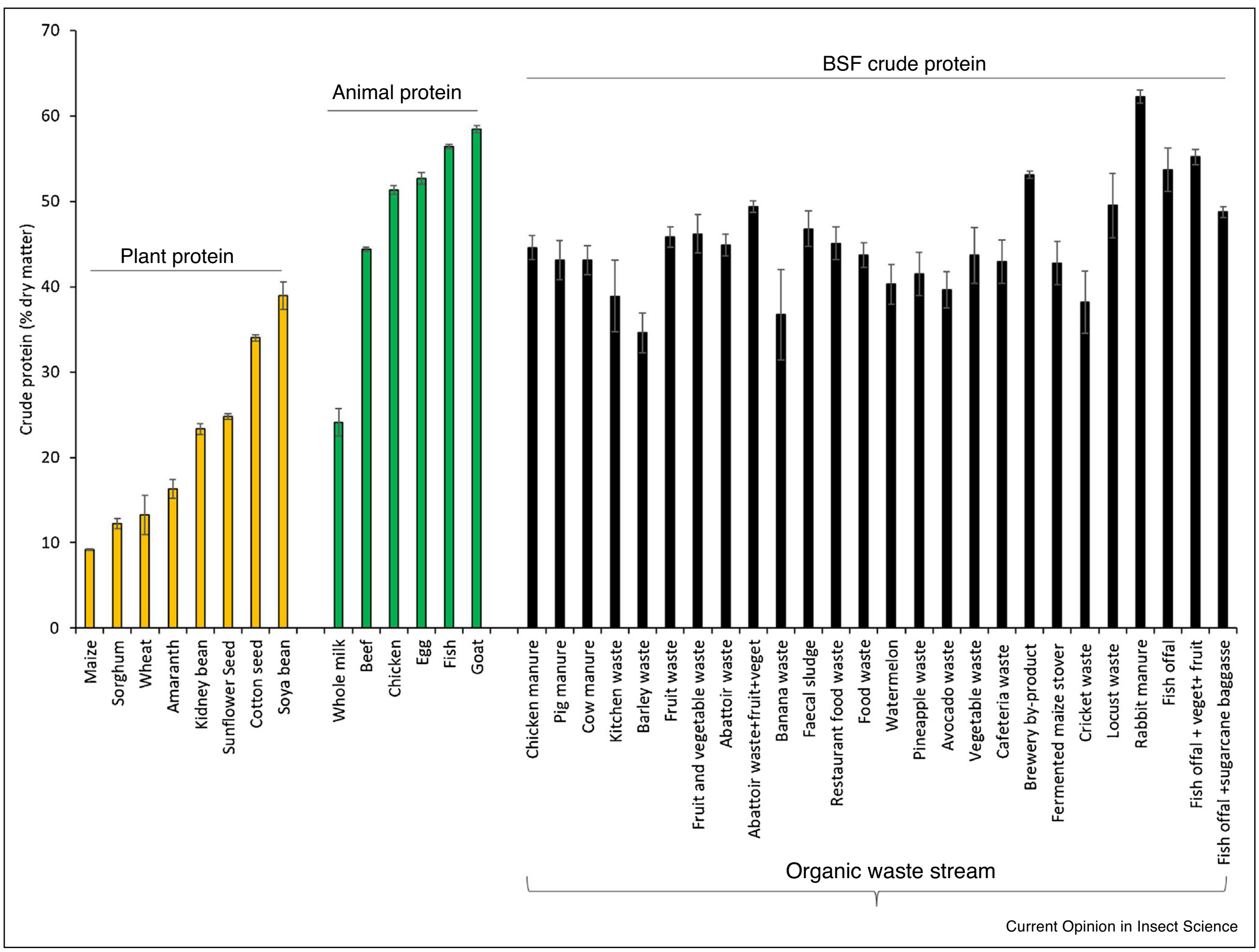
Enterprises farming scavenging flies

Several medium to large scale farms of black soldier fly (BSF) have emerged, that include: Sanergy Ltd., InsectiPro Ltd., Marula Proteen Ltd., Biobuu Ltd., Bugslife Protein Limited, Chanzi Ltd., The Bug Picture Ltd., The Insectary Ltd., Protein Kapital Ltd. among others. Some of these companies utilize mechanization and automation to lower the cost of insect farming. These insect farming enterprises recycle organic waste recipes into nutrient-rich biomass that can be incorporated into various feed formulations providing opportunities for income generation [9•,18,19,20••]. The nutritional value of fly larvae largely depends on the diet, stage harvested, and environmental factors [21] (Figure 2). Besides BSF, extensive research on mass production of other scavenging flies such as blowfly species (e.g. *Lucilia sericata*) and red-tailed flesh fly (e.g. *Sarcophaga haemorrhoidalis*) are ongoing.

Economic and ecological benefits of black soldier fly farming

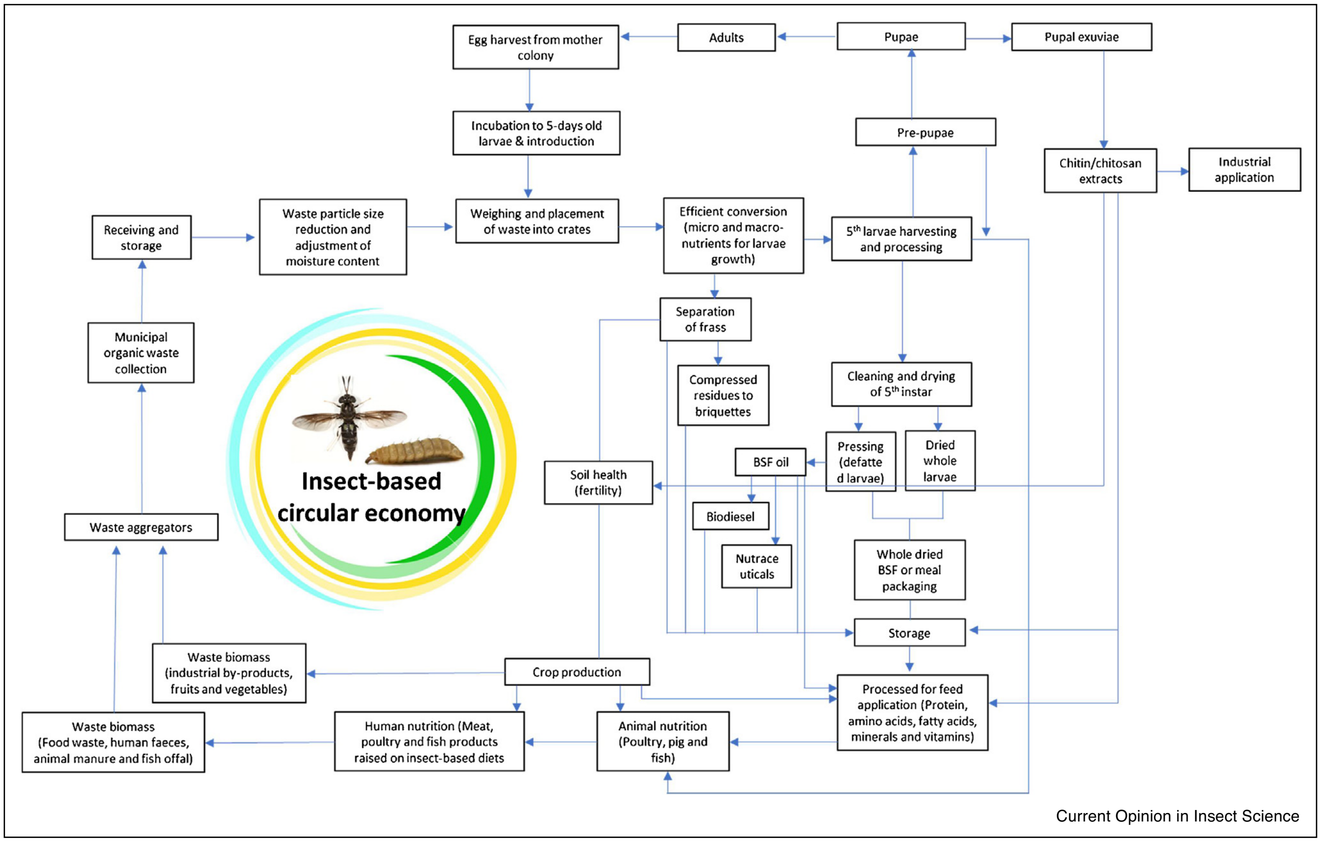
Currently, BSF production by the top nine insect farms through a circular economy approach (Figure 3) is estimated at approximately 9780 metric tons of dried protein annually. This is sufficient to substitute fish or soyabean meal in animal feeds with the capacity to produce 4.7 million chickens. The market price of dried BSF larvae and frass fertilizer ranges between US\$ 1.1–1.4 kg^{-1} and US\$ 0.3–0.35 kg^{-1}, respectively. This is further supported by Verner *et al.* [22], who modelled the annual BSF production in Africa and projected that BSF farming alone could generate crude protein and biofertilizer worth over US \$2.6 billion and US\$19.4 billion, respectively. This protein resource is enough to meet 5–14% of the crude

Figure 2



Comparative analysis of black soldier fly crude protein when reared on various waste stream compared to that of plant and animal origin.

Figure 3



Nutrition upcycling from waste streams and circular economy of black soldier fly farming enterprise in East Africa.

protein needed to produce pigs, fish, and chickens on the continent [22]. It's further stated that through BSF farming, the continent could substitute over 60 million tons of insect-based animal feed production annually, leading to 200 million tons of recycled organic waste, 60 million tons of organic fertilizer production, and 15 million jobs while saving 86 million tons of carbon dioxide emissions [22]. This is consistent with the observation made by Abro *et al.* [15••], who reported that adoption and replacement of 5–50% of the conventional feed sources with insect protein in Kenya would generate a potential economic benefit of US$69−687 million for the entire poultry sector. This would increase the availability of fish, soya and maize that can feed 0.47–4.8 million people at the current per capita of fish and maize consumption, which will translate to reducing poverty by 0.32–3.19 million people, increasing employment by 25 000–252 000 people and recycling 2–18 million tons of biowaste [15••]. The frass fertilizer from waste bioconversion can significantly increase soil health, crop yields and nutrient quality [23••,24,25,26••,27,28]. Using insect protein in livestock and fish feeds can contribute to 25–30% increase in egg production with better yolk quality, rapid growth rate of broiler chicken and pigs to market size (1–2 weeks and 1.5–2 months earlier, respectively), improved carcass quality of catfish (72–75% crude protein), Nile tilapia, pigs, and chicken [18,19,29].

The conversion of waste to energy has recently attracted a lot of research attention [29]. Sanergy Ltd has also developed innovative automated ways of producing high-energy fuel briquettes from compressed BSF residues incorporating sawdust and post-consumer plastics with the potential to provide energy, while simultaneously reducing wastes and their environmental health risks [30,31].

To strengthen the insect-farming based enterprises, *icipe* and partners (i.e. private, and public sector agencies, cooperatives, non-governmental organizations (NGOs), community-based organizations (CBOs) and Universities, etc.) have trained over 57,000 beneficiaries (i.e. approximately 170 000 farming households) with varying multiplier effects along the value chains. Across the BSF farming enterprises in East Africa, out of the total numbers of people recruited to work in insect farms, over 70% of them are women, who have secured dignified and fulfilling employment in the sector. Based on the immense potential of BSF larvae, we postulate that its farming and the various products obtained thereof can directly meet eight (1, 2, 3, 6, 7, 8 9 and 12) out of the seventeen United Nations Sustainable Development Goals (SDGs) and indirectly promote the rest in Africa [11••].

Farming insects for food

Among the insects farmed for food, cricket farming is expanding rapidly in Kenya (378 farmers) and Uganda (140 farmers). This is attributed to the long-standing history of entomophagy in these countries. Crickets commonly farmed include, *S. icipe*, *A. domesticus* and *G. bimaculatus*. Small and medium-sized enterprises (SMEs) currently produce over 30 tons of cricket powder annually [12]. InsectiPro Ltd., Kenya using its automated system produces approximately one ton of cricket powder monthly within optimal temperature range of 30 and 32°C, and relative humidity from 55 to 75%. However, the rearing technology of other insects such as locusts, grasshoppers, palm weevil, other scavenging flies, mealworm and African fruit beetles are still under different stages of optimization in the laboratory.

The most expensive cost of cricket farming is related to high cost of feed [32], hence research on more cost-effective alternative diets for rearing is needed to render production profitable [33]. Adoption of cricket farming in the region has been significantly influenced by awareness creation, ownership of mobile phones, the degree of risk averseness [34], and better sales. The price of 1 kg dried whole or powdered cricket products range between US $10.9–18.2, which is more than the price of wild-caught grasshopper (*R. differens*) products widely consumed in Tanzania and Uganda (i.e. retail price range of US $ 4.2–4.5 and US $ 2.8–3 kg^{-1}, respectively [35•]. Hence, the price related to farmed and wild-caught edible insects is quite high, which is consistent with the report by Madau *et al.* [10••], who showed that insect meal price was higher than fishmeal in Europe. In Africa, it is clear that as the industry matures and mass production increases, these prices will go down as farms embrace the new concept of circular economy, making insect protein a more favorable option than vertebrate livestock US$ 4–5 kg^{-1} [35•]. Currently, there is limited information on costs and profitability related to edible insect farming in Africa.

Value addition of insects for food and feed

Edible insects are mostly used in the form of dried whole or ground meals, which can be added as an ingredient to baked products and as animal feed protein [19,36••,37–39]. Some common food products fortified with insect meal include crackers, buns, cupcakes, samosas, chapatis, biscuits, bread, cookies, cereal-based porridge among others to enhance their nutrition and increase consumer acceptability [40,41]. Different processing techniques such as oven baking, boiling, smoking, roasting, pan-frying, vacuum cooking, and extrusion have been used to significantly improve the nutritional properties, decrease microbial contamination, enhance palatability, and improve consumer acceptability [42]. Thus, advanced processing technologies must be aligned to develop a new generation of products with extended shelf life and better safety quality. Other value-added products include nutraceutical compounds, biodiesel, chitin, chitosan, and oils from diverse African edible insects.

Pathogen and pest risks associated with insect farming systems

So far, no major disease outbreaks have been reported in BSF farming systems probably because they express a broad spectrum of antimicrobial peptides (AMPs) [43] to overcome or significantly reduce bacterial loads in rearing substrates [44]. Though studies on entomopathogenic fungal infections of BSF larvae are limited, there's evidence that their larvae are highly susceptible to microbial infections in substrates contaminated with more than 8 isolates of *Metarhizium anisopliae* and *Beauveria bassiana* (Tanga *et al.* in preparation). Lecocq *et al.* [45] reported the pathogenicity of *B. bassiana* to adult BSF in laboratory trials. Other key natural enemies attacking BSF during rearing include the pupal parasitoid, *Eniacomorpha hermetiae* Delvare, which inflict over 70% parasitism [46], phoretic mite Macrocheles muscaedomesticae (Scopoli), postharvest pests (*Tribolium castaneum* Herbst and Necrobia rufipes DeGeer), pathogenic gut bacteria (*Campylobacter*, *Morganella*, *Wohlfahrtiimonas*, and *Providencia*) and fungi (*Cyberlindnera* sp. and *Trichosporon* sp.) [47•,48].

Advanced stages of mycosis have been observed in adult crickets, *G. bimaculatus* and *Modycogryllus* sp., infected with *M. anisopliae and B. bassiana* (Tanga *et al.* in preparation). Furthermore, lethal bacterial pathogens such as *Rickettsiella grylli* have recently been reported in adult crickets, *Teleogryllus* sp. and *G. bimaculatus* in Kenya and Uganda [49]. The absence of the cricket paralysis virus called *A. domesticus* Densovirus (AdDNV) in cricket farming facilities is surprising given the occurrence of *A. domesticus* in the region but requires continuous surveillance and vigilance given the potential detrimental impact in the cricket production industry [49]. In many cases, viruses like AdDNV are incurable [49]. The above observation highlights the urgent need for continuous monitoring, prevention measures and enhanced quality control to minimize the impact of pathogens and pests in farmed edible insects.

Legal framework

In Kenya and Uganda, standards have been developed largely based on evidence-based data generated by *icipe* and partners, to regulate production, handling, and processing of edible insects for food and feed, while Rwanda is currently drafting similar standards. These standards have facilitated mass rearing of insects, thus greatly opening opportunities for the use of insects to close the nutrient loops in Agrifood systems in Africa. While the European legislation approves only seven species of insects and prohibits the use of certain substrates as feed to farm them, that of Kenya and Uganda are open to all available potential edible insects and all types of accessible waste substrates [11••].

Lessons learnt

Some main lessons learnt include: (1) The growing interest of youth and women entrepreneurs entering the commercial edible insect agribusiness; (2) Lack of enabling environment for youth to access financing, input and output markets for their products, and information services through digital solutions, marketplaces, and business-to-business linkages (3) Biosafety of insect-based products remains a major concern; (4) Training and technical backstopping of insect farming activities significantly reduces dropout; (5) financing insect farming innovation at the very early stages is relevant for effective take-off of businesses.

Future prospects

Large scale insect farming ventures in East Africa can be achieved through several key actions, such as adequate training of farmers, creation of insect producer groups, providing access to financial services; enhancing awareness and demand among consumers, especially younger generations/feed millers for insect-based food and feed products; raising awareness among the public and policy makers on social, economic, and environmental benefits of insect farming enterprise and its impacts to a circular economy, diversification of scavenging insects for feed, harmonization of regulatory frameworks and development of a digital information exchange platform to enhance youth and partners' access to tailored technical and market information, as well as experience through public-private partnerships. Furthermore, the development of marketplaces and strengthening of value-chain is critical and has enormous potential benefits for large processors and exporters to obtain sufficient quantities and quality insect products as required.

Conflict of interest statement

Nothing declared.

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This paper provides the first insight into market opportunities of including insect meals in the animal feed value chain. It assessed the characteristics of smallholder farmers' knowledge and willingness to use and pay for insect-based feeds for their poultry, pig and fish compared to that of conventional fishmeal-based feeds. The study showed that over 70% of farmers are willing to grow insect, integrate in the feed or pay a premium for insect-based feeds. They suggested that increased extension services to educate famers on the nutritional benefits of insect meals in animal feeds and existing market opportunities will improve farmers' attitude towards utilization and significantly reduce the existing pressure on conventional fishmeal feed resources.

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