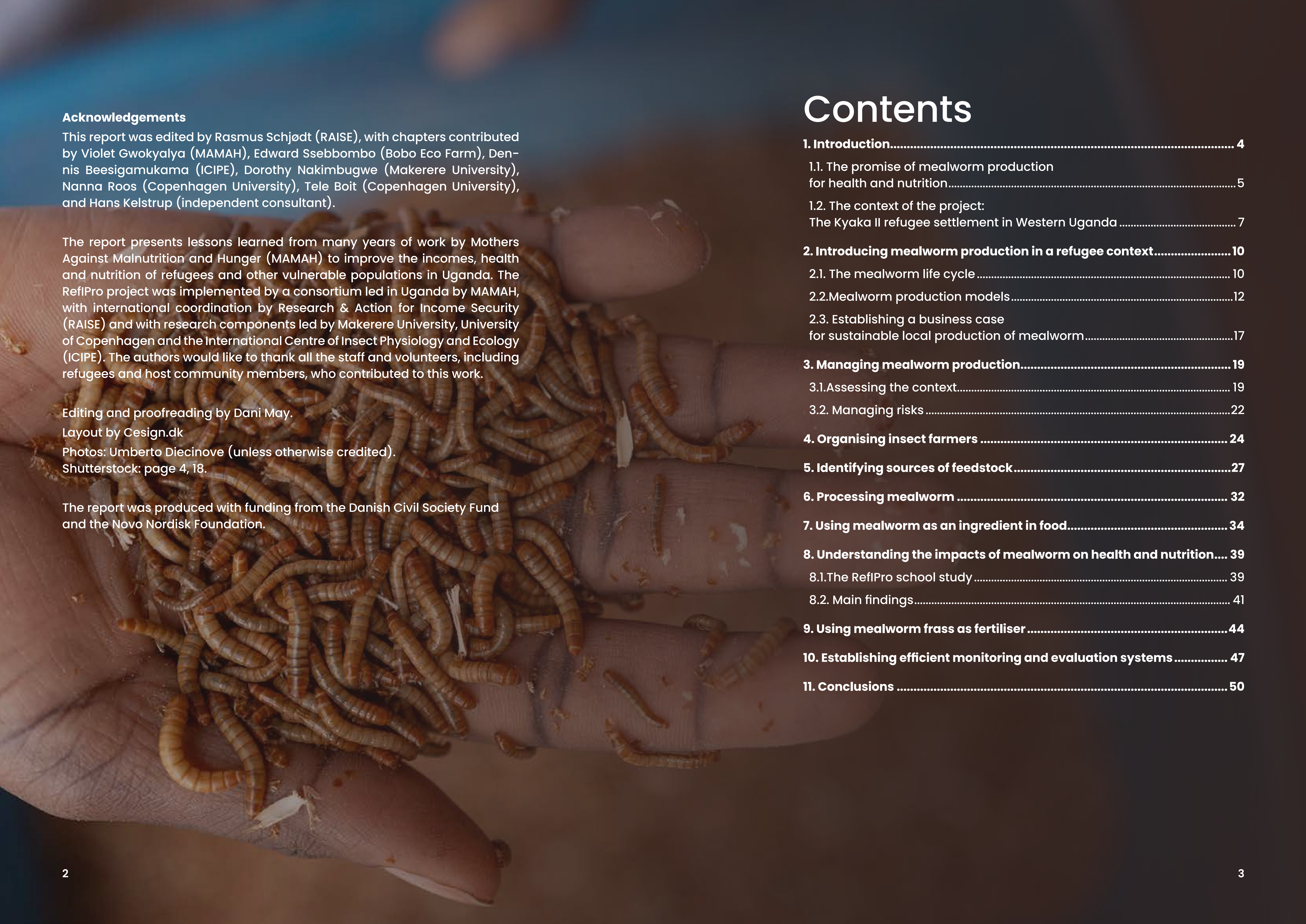
Refugee Insect Production for Food and Feed

Mealworm

An Innovative Intervention for Improved Health and Nutrition



Acknowledgements

This report was edited by Rasmus Schjødt (RAISE), with chapters contributed by Violet Gwokyalya (MAMAH), Edward Ssebbombo (Bobo Eco Farm), Dennis Beesigamukama (ICIPE), Dorothy Nakimbugwe (Makerere University), Nanna Roos (Copenhagen University), Tele Boit (Copenhagen University), and Hans Kelstrup (independent consultant).

The report presents lessons learned from many years of work by Mothers Against Malnutrition and Hunger (MAMAH) to improve the incomes, health and nutrition of refugees and other vulnerable populations in Uganda. The ReflPro project was implemented by a consortium led in Uganda by MAMAH, with international coordination by Research & Action for Income Security (RAISE) and with research components led by Makerere University, University of Copenhagen and the International Centre of Insect Physiology and Ecology (ICIPE). The authors would like to thank all the staff and volunteers, including refugees and host community members, who contributed to this work.

Editing and proofreading by Dani May.

Layout by Cesign.dk

Photos: Umberto Diecinove (unless otherwise credited).
Shutterstock: page 4, 18.

The report was produced with funding from the Danish Civil Society Fund and the Novo Nordisk Foundation.

Contents

1. Introduction

According to the United Nations High Commissioner for Refugees (UNHCR), in September 2025, Eastern and Southern Africa hosted more than 25 million forcibly displaced people, including 6.3 million refugees and asylum seekers and 18.1 million internally displaced persons (IDPs).[1] This displacement is a result of protracted conflicts in Sudan, South Sudan, the Democratic Republic of the Congo (DRC) and Mozambique, as well as climate-induced disasters.

Uganda, the country with the largest refugee population in Africa, faces escalating tensions and protracted conflicts in neighbouring regions like the DRC and South Sudan. These conflicts have forced millions to flee, leading to a significant influx of refugees into Uganda. As an example, the Kyaka II refugee settlement in Western Uganda has seen its population grow from 50,000 to over 138,000 refugees in a few years, straining resources and social systems. In all the affected countries, the burden of caring for refugees and IDPs has overstretched the resources of the humanitarian system. In Uganda, the World Food Programme (WFP) has reduced rations by 40% due to funding shortfalls, and many refugees now face food insecurity.

The situation calls for urgent implementation of innovative approaches to empower refugees and reduce their dependence on external aid. In settlements like Kyaka II, where population pressures are growing, traditional livelihood options like large-scale agriculture are no longer viable. Innovative, land-efficient interventions are required to address refugees' challenges, while promoting sustainability and resilience.

> "In Uganda, the World Food Programme (WFP) has reduced rations by 40% due to funding shortfalls, and many refugees now face food insecurity.

Promoting edible insect production is one such way of contributing to better access to protein to improve the livelihoods of both refugees and host communities. The 'Refugee Insect Production for Food and Feed' (ReflPro) project, implemented in Kyaka II settlement between 2022 and 2026, supported the introduction of mealworm and black soldier fly larvae (BSFL) in the settlement. The project had two distinct objectives:

1. **Improved nutrition and health of refugee and host community children through the production of mealworm.** This objective focused on production of mealworm for food in both communities and schools. The project implemented an intervention study in two schools in and around the Kyaka II settlement and documented how adding mealworm to school meals affected the health and nutrition indicators of school children. This study is the first ever to examine the use of mealworm for enrichment of school meals.

2. **Improved incomes of refugees and host community members through production of black soldier fly larvae (BSFL).** The project trained a total of 965 refugees and host community members to produce BSFL to sell as feed, with the aim of providing a novel income-generating opportunity for refugees. Currently 500 are actively producing. The project also strengthened the capacity of local farmers associations and local authorities to provide continuous support to local BSFL producers.

Mealworm production promises to provide a novel source of protein and other nutrients that can be produced locally, while Black Soldier Fly Larvae (BSFL) farming provides a way to transform organic waste into high-protein feed for livestock and fish. This report presents lessons learned from the project related to Objective 1: Mealworm production, while a separate report presents lessons learned for Objective 2: Black soldier fly larvae.

Despite the growing interest in edible insect production, limited public knowledge is available in an accessible format aimed at practitioners. This is particularly the case when it comes to insect production in a refugee context, and especially for mealworm production. The aim of this report is to present the lessons learned from the Refugee Insect Production for Food and Feed project in a way that provides a useful starting point for others wishing to engage in mealworm production as a way to boost the nutrition and health of refugee populations.

1.1. The promise of mealworm production for health and nutrition

Mealworms present several advantages that make them an attractive option for food production in refugee settlements. They can be reared at very high densities within a small area using stacked trays, and they have low water requirements, allowing for efficient use of limited space and infrastructure.

Their dry substrate diet reduces risks of mould, microbial growth, and disease, making management simpler and safer in environments where sanitation resources are constrained. Mealworms, at all their

Continued on next page

[1] www.unhcr.org/where-we-work/regions/eastern-and-southern-africa

life stages, can be reared in simple trays and be fed the same single-source diet (e.g. wheat or maize bran), which streamlines operations and reduces training requirements.

Nutritionally, mealworms are a rich source of protein, essential amino acids, and micronutrients and they can be processed through simple roasting, requiring minimal equipment and energy inputs.[2] Mealworms are often noted for their relatively short life cycle and capacity for rapid reproduction compared to conventional livestock – in principle, this can support scaling of production for household consumption and potential surplus.

Moreover, their development is very plastic[3]: by simply manipulating diet inputs one can suspend or accelerate growth, depending on needs. Mealworms are also generally tolerant of a range of temperatures and humidity levels, offering flexibility across different environments and reducing reliance on intensive climate-control systems.[4]

Beyond direct nutrition, mealworms can be fed on agricultural by-products or food waste, turning low-value inputs into high-value protein.[5] They also have the capacity to detoxify contaminated feedstocks,

Roasted mealworm from Bobo Eco Farm in Mityana, Uganda. Mealworm are a rich source of protein, essential amino acids, and micronutrients. They can be roasted and consumed as a crunchy snack or ground into flour and used as an ingredient in various food products.

such as grains affected by mycotoxins, converting unsafe crops into safe, edible food.[6] These qualities add resilience to refugee settlement food systems where crop contamination may occur.

Finally, surplus production offers opportunities for income generation and livelihood development, providing refugees with economic agency and supporting inclusive participation across households.

1.2. The context of the project: The Kyaka II refugee settlement in Western Uganda

The Kyaka II Refugee Settlement, located in Kyegegwa District in Western Uganda, is one of the country's fastest-growing refugee settlements. The settlement hosts predominantly refugees from the DRC, alongside smaller populations from South Sudan, Burundi, Rwanda, and other neighbouring countries affected by conflict and instability. Continued insecurity and protracted regional conflicts have driven a sustained influx of refugees into the settlement in recent years, bringing the population to approximately 138,623 people.[7] This rapid population growth has placed immense pressure on humanitarian systems, social services, natural resources, and livelihood opportunities.

The humanitarian situation in Kyaka II is marked by widespread food insecurity, poverty, unemployment, and high household vulnerability. Due to global funding shortfalls, the WFP has significantly reduced food assistance to refugees. The most vulnerable households now receive only 40% of their food ration, down from 60%, while moderately vulnerable households have seen rations reduced from 30% to 22%.

These reductions have left many families unable to meet their minimum food and nutritional needs, contributing to declining dietary diversity, inadequate protein intake, and heightened nutritional vulnerability, particularly among women and children. Chronic malnutrition remains a major public health concern, with stunting among children estimated at approximately 42.5% in the settlement, reflecting prolonged nutritional deprivation and poor feeding conditions.[8]

Upon arrival in the settlement, refugee households are allocated small plots of land intended for shelter construction and limited household food production. Historically, these plots measured approximately 30 by 30 metres, but the rapid increase in refugee numbers is leading to growing constraints on the amount of land available, leading to further subdivision of

Continued on next page

[2] Kröncke N, Benning R. Influence of Dietary Protein Content on the Nutritional Composition of Mealworm Larvae (Tenebrio molitor L.). Insects. 2023 Mar 6;14(3):261. doi: 10.3390/insects14030261. PMID: 36975946; PMCID: PMC10053216.

[3] Morales-Ramos JA, Rojas MG, Shapiro-Ilan DI, Tedders WL. Developmental Plasticity in Tenebrio molitor (Coleoptera: Tenebrionidae): Analysis of Instar Variation in Number and Development Time under Different Diets. Journal of Entomological Science. 2010 Apr;45(2):75–90. doi:10.18474/0749-8004-45.2.75.

[4] Morales-Ramos JA, Macchiano A, Rojas MG. Estimating optimal temperature conditions for growth, development, and reproduction of Tenebrio molitor (Coleoptera: Tenebrionidae). J Econ Entomol. 2025 Feb 11;118(1):71-82. doi: 10.1093/jee/toae298. PMID: 39720996.

[5] López-Gámez G, Del Pino-García R, López-Bascón MA, Verardo V. Improving Tenebrio molitor Growth and Nutritional Value through Vegetable Waste Supplementation. Foods. 2024 Feb 16;13(4):594. doi: 10.3390/foods13040594. PMID: 38397571; PMCID: PMC10887794.

[6] Ochoa Sanabria C, Hogan N, Madder K, Gillott C, Blakley B, Reaney M, Beattie A, Buchanan F. Yellow Mealworm Larvae (Tenebrio molitor) Fed Mycotoxin-Contaminated Wheat—A Possible Safe, Sustainable Protein Source for Animal Feed? Toxins. 2019, 11, 282. https://doi.org/10.3390/toxins11050282.

[7] UNHCR refugee status report, April 2026.

[8] Uganda Demographic and Health Survey, 2022.

The central mealworm production and research facility at Bobo Eco Farm in Mityana, Uganda. The facility provides a setting for testing and optimising mealworm-rearing practices while generating knowledge and breeding stock to support the introduction and expansion of mealworm production within communities.

plots to accommodate new arrivals. As a result, many households now have insufficient land to produce enough food for their families. Traditional agriculture, which depends on larger land areas and favourable climatic conditions, has therefore become increasingly unsustainable and inadequate as a livelihood strategy within the settlement.

At the same time, opportunities for formal employment and income generation remain extremely limited. Many refugees have low levels of formal education and limited vocational skills, while language barriers further constrain economic integration. A significant proportion of refugees in Kyaka II are French-speaking Congolese living within an English-speaking national context, which limits access to employment opportunities. Consequently, many households remain heavily dependent on humanitarian aid despite declining assistance levels.

The settlement therefore faces a complex combination of nutritional, economic, and livelihood challenges that require innovative and context-appropriate solutions. There is a growing need for interventions capable of producing nutritious food and generating income within highly constrained environments characterised by limited land, limited capital, and limited technical capacity. Such interventions must also be simple to adopt, affordable, scalable, and suitable for vulnerable populations with minimal formal training.

2. Introducing mealworm production in a refugee context

2.1. The mealworm life cycle

Despite its name, the yellow mealworm (Tenebrio molitor) is not a worm at all, but rather the larvae stage of the darkling beetle. Tenebrio molitor undergoes complete metamorphosis through four distinct life stages: egg, larva, pupa, and adult. The combination of its high reproductive capacity and ability to thrive on low-cost organic substrates has made the yellow mealworm an important species for animal feed, food production, waste bioconversion, and scientific research. Its full life cycle is typically between two to four months, with significant variation depending on temperature, humidity, food availability, and population density.

The life cycle begins when an adult female beetle lays eggs in a suitable substrate such as grain, bran, or organic matter. A single female may lay between 200 and 500 eggs during her lifetime, each about 1.5-2 millimetres (mm) long. Eggs hatch within roughly four to eight days at favourable temperatures (25–30°C), though development slows considerably in cooler conditions, extending to two weeks or more.

After hatching, the insect enters the larval stage, and at this point of its life it is commonly known as the mealworm. This is the longest and most economically important phase of the life cycle. The larvae are cylindrical, yellowish-brown, and segmented, with a hard exoskeleton. As they grow, they repeatedly shed their exoskeleton through moulting.

During this stage, the larvae actively feed on grains, cereals, vegetable matter, and other organic materials growing and accumulating the nutrients and energy reserves needed for metamorphosis. Depending on environmental conditions, the larval stage can last from several weeks to many months. Mature larvae typically reach 20–30 mm in length and store sufficient energy reserves for metamorphosis.

When the larva has completed its growth, it is either harvested for food or allowed to transform into a pupa in order to maintain reproduction. During this non-feeding stage, the insect undergoes major internal and external reorganisation. The pupa is initially creamy white and gradually darkens as development progresses. Under optimal conditions (25–30°C), the pupal stage generally lasts about one week, extending to three weeks or more at cooler temperatures.

The adult mealworm beetle emerges from the pupal case as a soft, pale insect. Within a few days, its exoskeleton hardens and darkens to a shiny dark brown or black colour. Adult beetles typically measure 12–18 mm in length. The primary role of the adult

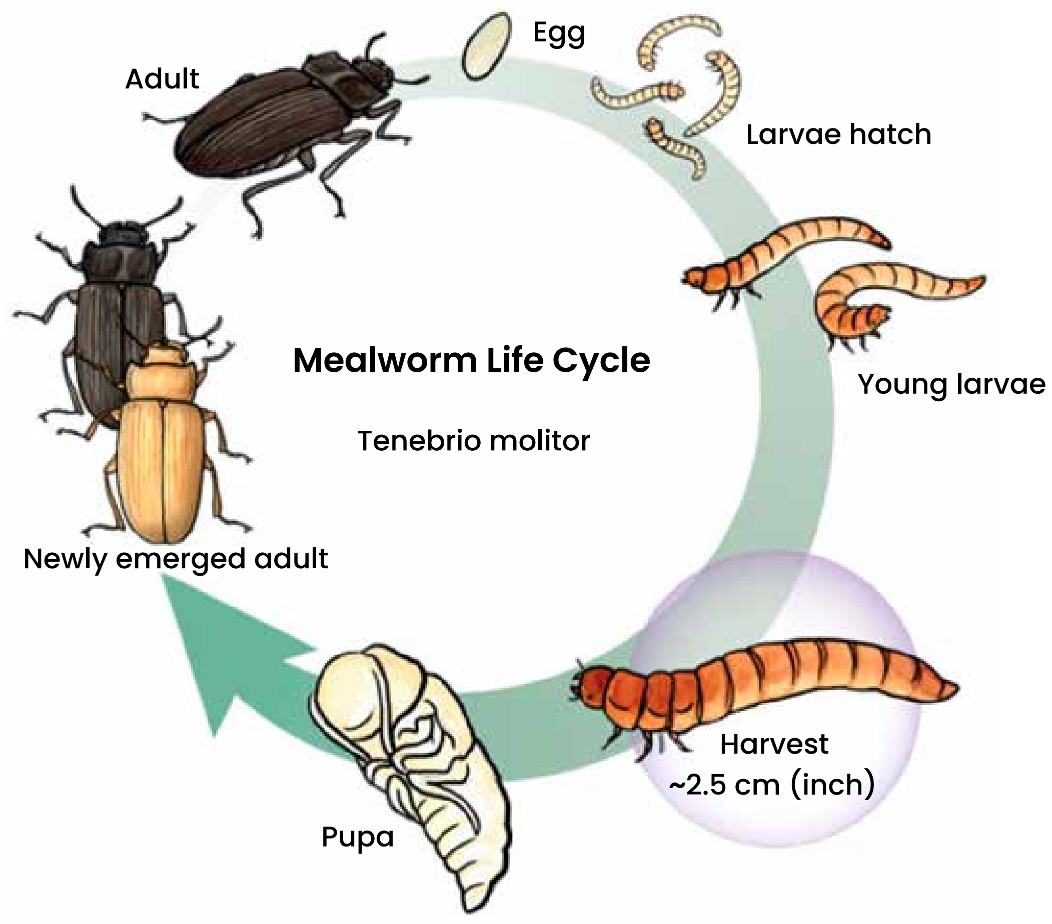


Figure 1: *The mealworm life cycle.*

stage is reproduction. Adults feed less actively than larvae but continue to consume organic materials. Mating usually occurs within a few days of emergence, and females begin laying eggs shortly thereafter. Adult beetles generally live for two to three months, during which they produce the next generation, with egg production gradually declining with age.

As is apparent from the above, the time required for development of each life stage can vary significantly depending on many different variables, including temperature and humidity, type and quantity of feeds, density of the insects in trays, presence of pests or diseases in the production, and many others.

A notable drawback of mealworms compared to other insect species (notably the black soldier fly) is their tendency towards cannibalism. Pupae are especially vulnerable to predation by both larvae and adults. This challenge is compounded by the fact that metamorphosis occurs within the same rearing trays, increasing the risk of losses if not carefully managed. The consequence is that trays have to

Continued on next page

Educational materials displayed at a community mealworm breeding centre illustrate the different stages of the mealworm life cycle and key rearing practices. Combined with hands-on demonstrations using live production trays, these materials support practical farmer training and strengthen the skills needed to manage mealworms through the different stages of production.

be monitored regularly in order to separate pupae from larvae. If the production is not managed effectively, the process risks resulting in trays that serve as feed for pests rather than producing insects for food.

2.2. Mealworm production models

Different models of mealworm production can be considered in the refugee settlement context, each with distinct advantages and limitations. These include centralised production, household production, and a combination where reproduction is managed centrally and the rest of the life cycle is managed in households.

Regardless of the model chosen, success ultimately hinges on whether the costs of diet and materials, space required (for both broodstock and the grow-out population), and labour can be justified by the returns. This requires careful monitoring of production outputs and inputs.

Centralised production: Larger, centralised facilities can streamline operations, achieve economies of scale, and concentrate pestcontrol measures in a single location. Largescale production offers clear advantages in cost efficiency, labour specialisation, and consolidated expertise. However, such systems often require significant upfront investment relative to the local context, as well as time to adapt infrastructure to environmental and logistical conditions.

Moreover, they carry inherent risks: disease outbreaks can spread rapidly in a single facility and potentially wipe out the entire colony. In addition, to be efficient, large-scale facilities need to be properly managed and staffed, which implies that a relatively high level of technical expertise is needed.

An effective large-scale production requires a very systematic approach in order to keep labour costs down and maintain effective processes.

Household production: At the other end of the spectrum, household production offers greater flexibility and can be adapted to meet family needs. If demonstrated to be viable, this model could spread organically within communities, providing households with both a reliable source of protein and a potential stream of income.

In the ReflPro project, small-scale household mealworm production systems are managed directly at the household level in refugee and host community families. Through the establishment of a community mealworm breeding centre, households were able to access practical training, technical guidance, and starter rearing stock to begin producing mealworms within their homes using very simple and highly improvised production systems.

Many households adopted low-cost production approaches using locally available materials such as plastic basins, buckets, wooden shelves, trays, and simple covered containers to rear mealworms within limited household spaces. The flexibility of the production system allowed families to adapt mealworm farming to their own conditions, capacities, and available resources. In most cases, production was initially intended primarily for home consumption to reduce food costs and improve household nutrition, especially for children.

An important lesson from the project was the strong organic spread of knowledge and demand within the community. Farmers who had acquired skills through the project frequently shared their experiences with neighbours and friends, many of whom visited the community breeding centre to request access to starter stock. This informal farmer-to-farmer learning became an important pathway for expanding awareness and adoption of mealworm farming beyond the originally trained and targeted beneficiaries.

Similarly, parents whose children participated in the ReflPro school mealworm feeding trials, and who subsequently observed improvements in their children's health, also became interested in household mealworm production. Many approached the breeding centre seeking rearing stock so they could produce mealworms at home for the benefit of all children within their households. In this way, the school feeding intervention indirectly

Continued on next page

stimulated broader community-level demand for mealworm production.

The trade fairs and exhibitions organised by the Kyegegwa Insect Farmers' Cooperative with support from the lead organisation in Uganda, Mothers Against Malnutrition and Hunger (MAMAH) also played an important role in promoting household mealworm farming. These events created opportunities for public awareness, knowledge sharing, demonstration of production technologies, and interaction between farmers and potential adopters. The exhibitions significantly increased the visibility of mealworm farming within the settlement and generated additional interest from households wishing to begin production.

Currently, a small informal community market for mealworms has started to emerge. While most production remains focused on household consumption, some farmers with greater experience have begun selling surplus mealworms to neighbours and community members who were not directly involved in production. This demonstrates the potential for mealworm farming not only as a nutrition intervention, but also as a small-scale livelihood opportunity.

The household production model is largely farmer-driven. Some experienced farmers are capable of managing the full mealworm life cycle independently, including breeding beetles, managing eggs, rearing larvae, and separating pupae. Other farmers, particularly newer entrants, remain dependent on the community breeding centre for periodic supply of breeding stock or young larvae. This variation largely reflects differences in skill levels, experience, confidence, and access to appropriate materials.

The project also revealed that small-scale household production benefits from closer attention and care by individual farmers compared to large-scale facilities. Farmers managing lower stocking densities and maintaining better hygiene and feeding practices often achieve improved productivity.

However, new entrants sometimes face technical challenges, particularly related to feeding management. For example, excessive use of wet feed is occasionally observed. Continuous learning, peer support, and follow-up technical guidance by the project team therefore remain important components for strengthening household production.

A further advantage of household-level mealworm production is that farmers can more easily access and manage locally available feed resources required for small-scale rearing. Dry feed materials such as cassava peels, potato peels, maize bran, and other household or farm by-products are generally feasible for individual households to collect and utilise in relatively small quantities. This makes household production systems more practical and affordable than large-scale production within resource-constrained refugee settings.

An additional benefit observed from household mealworm production is the use of frass, the organic waste generated by mealworms, as fertiliser for household vegetable gardens. Farmers increasingly apply frass to produce vegetables and other crops within small backyard spaces, further contributing to dietary diversification and household food security. In this way, mealworm farming has contributed not only directly through protein production, but also indirectly through improved household crop production.

Broodstock management at a centralised mealworm production facility. Managing the reproductive stages of the mealworm life cycle requires greater technical expertise than simply growing larvae to harvest. Centralised breeding facilities can therefore provide eggs or young larvae to household producers while offering ongoing technical support to farmers.

Generally, the household mealworm production model has demonstrated that mealworm farming can be highly adaptable and scalable even within resource-poor settings such as refugee settlements where land, water, and formal technical capacity are limited.

The main challenge for households is likely to be the management of a reproductive population (i.e. broodstock) separate from the larvae reared for consumption (or the 'grow-out' population intended for sale or consumption). To achieve this, careful monitoring of egg production from adults and the proper preparation of trays for the next generation are essential steps. These tasks, however, demand additional equipment and oversight.

Effective broodstock management requires specialised expertise offered through both training materials and onsite troubleshooting support from local practitioners or trained extension workers. Without efficient conversion of broodstock larvae into healthy pupae and adults, the system risks becoming locked in a cycle of reproduction that yields minimal quantities of edible insects.

On the other hand, another advantage of small-scale household productions is that they are much less complex, and that household members are likely to be able to easily monitor every tray regularly. As such, there is less risk of trays being neglected than in a large-scale facility. This is particularly important for mealworm production, where success hinges on closely monitoring the production.

***Hub-and-spokes model*:** A third option is a hybrid model, in which the more complex pupae, adult, and egg stages are managed by a company or cooperative. In this system, households receive mealworm larvae, which are relatively easy to rear, along with basic guidance on how to raise them to harvest weight using agricultural by-products or food waste.

This approach combines the efficiency of centralised expertise with the accessibility of household-level engagement, harnessing the potential to balance productivity with community participation and the advantages of the small-scale household production mentioned above.

A potential drawback of this approach is the need for regular transportation of young or partially grown larvae from the central production facility to the households, which introduces risks (e.g. overheating in transport) and costs. Consequently, the location of the central production facility must be carefully factored into the overall strategy. This 'hub-and-spokes' model is likely to be more viable in densely populated areas, including refugee settlements, than in areas where transportation is more time-consuming and costly.

This model works best where the grow-out households or farms have their own local feedstock, since the central facility then needs only to supply young larvae rather than both larvae and substrate. Where satellite producers can feed larvae on organic waste already available to them, the logistical burden on the hub is limited to biological inputs, and the proximity of each grow-out site to its own waste stream becomes a structural advantage rather than a cost.

It is also possible to combine these models in various ways. A centralised community production facility in one or two locations in a refugee settlement or district, can serve as both a demonstration and training centre, as well as providing larvae for households to raise. Over time, the most successful farmers can then be trained to manage the whole life cycle, while others may continue to receive larvae from the centre. Using a training-of-trainers approach, the more experienced farmers can train others, and potentially even with time establish their own demonstration and training centres.

***School-based mealworm production*:** The ReflPro project also introduced school-based mealworm production aimed at enriching school meals while simultaneously creating practical science learning opportunities for students. The school-based model combined nutrition, education, livelihood learning, environmental awareness, and community participation within a single integrated system.

The mealworm production facility established at Bukere Primary School within the Kyaka II refugee settlement, represents the strongest example of the model envisioned under the project. The facility is managed on a day-to-day basis by a parent from the refugee community, demonstrating strong local ownership and participation. The school administration supports the operation through provision of space and security arrangements.

Students actively participate in some production activities, particularly during break time and supervised learning sessions. Pupils assist in pupae sorting and carry from home wet feed materials, but they are also involved in the observation of insect life stages during supervised learning sessions at the mealworm facility. This practical engagement has transformed the facility into a hands-on educational resource rather than merely a food production unit.

Teachers have integrated the facility into science learning activities, using the displayed educational charts and live insect production systems to teach concepts related to biology, nutrition, environmental sustainability, waste utilisation, life cycles, and food systems. MAMAH has organised science fairs where students from different schools present science concepts around nutrition, insects, and the environment. The mealworm facility therefore serves both as a nutrition intervention and as a practical science laboratory that stimulates curiosity, participation, and experiential learning among students.

Another important experience from the school model is the strong institutional support demonstrated by school leadership structures. The School Management Committee actively oversees the initiative and holds the school administration accountable for proper supervision and management of the facility. The school has also expressed willingness to initiate discussions with parents regarding small contributions that could support operational costs such

School children enjoy porridge enriched with mealworm protein. Under the RefIPro project, school-based mealworm production and feeding were introduced to explore the potential of locally produced mealworms to contribute to children's nutrition and health.

as purchasing dry feed materials, including wheat bran or maize bran, for the mealworms. This willingness to locally support operational sustainability represents a significant achievement and is an encouraging sign of long-term ownership.

The project further demonstrated that school-based mealworm farming can create strong community engagement around nutrition. Parents, teachers, students, and community leaders increasingly view the facilities as valuable educational and nutritional assets capable of contributing positively to children's nutrition and learning outcomes.

In addition, the school-based model provides opportunities for introducing children to innovative food systems and sustainable agriculture technologies at an early age. Students develop familiarity with insect farming, nutrition concepts, and circular food production systems, helping to reduce stigma and increase acceptance of edible insects within the community over time.

2.3. Establishing a business case for sustainable local production of mealworm

Regardless of the production model chosen, a successful intervention ultimately hinges on whether the costs of feeds and

Continued on next page

materials, space required (for both broodstock and the grow-out population), and labour can be justified by the returns.

The cost of producing mealworm should be compared to the cost of other local sources of protein, such as eggs, milk, or poultry. An often overlooked but important factor that should also be considered as part of the business model of mealworm production is the yield and performance of frass fertiliser, which is often the deciding factor that makes the economics of insect production attractive.

For large-scale, professionally run facilities, labour is likely to be the largest cost, followed by the purchase of dry feeds such as wheat or maize bran. Labour requirements are likely to mostly revolve around the manual removal of pupae, and also include feeding and refeeding, wet feeding, egg collection (which involves resetting trays with adults and laying substrate), harvesting, and drying.

For community-managed production facilities, it may be possible to lower labour costs by engaging community volunteers, although at least one part-time paid assistant is likely to be necessary to oversee production. In a volunteer-based facility, the purchase and transport of dry feed may make up the bulk of the costs of production.

For small-scale household production, there will most likely not be labour costs. Costs of feed may also be lower than in the other models, since households can use smaller quantities of different sources of feed that they have available, including various types of food waste. However, it is likely that some quantity of maize bran or wheat bran will still be necessary, and as such that is likely to be the main cost of production.

An important lesson is that establishing mealworm production in a new location where the practice has been previously unknown is likely to require significant subsidies in the research and development phase, which may require several years to ensure sustainable production.

With limited available know-how to draw on, a new intervention will have to develop production models that are suitable to the specific context more or less from scratch, which includes prolonged processes of trial and error.

The experience of introducing insect production in Kyaka II has shown that establishing sustainable insect production – in particular with a novel species such as mealworm – requires a concerted effort over several years, and is unlikely to succeed as a short-term project.

3. Managing mealworm production

Overall, the experiences from both community, household, and school-based mealworm production demonstrate that mealworm farming can be effectively integrated into refugee settlement contexts through flexible, low-cost, and community-centred approaches.

The models piloted under the ReflPro project highlight the strong potential of mealworm production to simultaneously support nutrition improvement, practical learning, livelihood development, environmental sustainability, and community resilience within humanitarian settings. This section presents some of the main lessons learned in assessing the context for mealworm production and managing key risks.

3.1 Assessing the context

While the different production models come with different advantages and challenges, success with insect production requires careful consideration of several key factors.

First, the local environment: factors like temperature, humidity, and seasonal variation have important consequences for what buildings are necessary and what precautions should be taken to regulate the production environment with the means available locally. Optimal mealworm development occurs at temperatures between 25°C and 30°C and moderate relative humidity. Lower temperatures slow growth and extend the larval stage, and unfavourable conditions can delay pupation and reproduction. There may be an advantage to keeping different life stages in different rooms, with different temperatures and humidity.

In the ReflPro project, simple, low-cost forms of climate control were adopted: a metal cage primarily used to enclose and protect the rearing area from pests was also used as a support for large tarpaulins with flaps that could be opened or closed to regulate temperature and humidity. (The metal cage even serves a third purpose, providing an extra layer of defence against thieves.) When temperatures began to rise, fans were activated to reduce trapped heat. During colder periods, light bulbs, too, served a dual purpose – providing illumination while also generating enough warmth to stabilise the environment.

Second, access to feed: access to low-cost or ideally free nutritive feed inputs is probably the most important factor in evaluating whether it makes sense to produce mealworm in the first place. This is particularly the case for large-scale production facilities which will most likely have to purchase the main dry feed substance such as maize or wheat bran. Section 5 has more information on identifying sources of feedstock.

Continued on next page

The large-scale mealworm production facility at Bobo Eco Farm in Mityana, Uganda serves as a research and development facility, while also supplying eggs and young larvae to community production facilities and farmer's groups.

Third, availability of local materials: access to e.g. trays and metal screens for sifting, which may not be readily available in all areas or countries, is essential. If they are not available, time and resources have to be allocated to experiment with constructing effective production tools using locally sourced materials, or for purchasing and transporting materials from elsewhere.

Fourth, infrastructure: the effectiveness of mealworm production will depend on infrastructure such as access to water, electricity, and security.

Fifth, regulation and expertise: the relevant regulatory requirements should be considered, as should the availability of local technical expertise to train and support farmers.

Sixth, market and business case: regardless of the production model chosen, the cost of production needs to be estimated in order to assess whether the production makes economic sense for households, can be financed by donors, and/or if there is a demand for mealworm. This exercise may look different for community/large-scale production centres, households, and schools.

Among these factors, two in particular deserve to be settled first rather than discovered later in the process: securing access to substrate, and establishing a preliminary business case, should precede decisions about model, site, or facility size – not follow them.

Successful operations secure their feedstock before investing in sites, infrastructure, or training, and pair that with an early business case that defines breakeven points, minimum viable production, and pricing against local alternatives.

The model that commonly fails is the reverse: choosing a production model first and then searching for the substrate and market conditions to justify it. The more effective sequence is to read the conditions and let them point to the model.

If operating within a context with dispersed household waste and no reliable buyer, this points toward household production for on-farm feed and fertiliser savings. A concentrated, reliable waste stream with an accessible market may justify a centralised or hybrid facility.

Where households have their own local feedstock but lack technical capacity, a hybrid model that supplies young larvae for them to grow out can fit best. A project that confirms its substrate base and a plausible path to breakeven before committing resources has therefore done more than remove the two risks most likely to make mealworm production unviable; it has also identified which model those conditions actually support.

Because all of these factors are likely to vary from place to place, it is essential to start any project with a small-scale pilot farm to test assumptions. There are likely to be unforeseen challenges that may have implications for whether mealworm farming is feasible and desirable or not.

If feasibility is established, each factor and cost can be systematically analysed, allowing a path to profitability to be mapped, with risks and opportunities clearly identified. Ultimately, stakeholder confidence depends on the availability of reliable data – whether on feed costs, labour requirements, or biological performance metrics.

Continued on next page

A woman in Kyaka II refugee settlement use insect frass to produce vegetables in her backyard garden.

3.2. Managing risks

The main risks involved in mealworm production are related to farm management, the environment, and worker safety.

Farm management: Establishing and maintaining healthy mealworm production, especially in large-scale production facilities, requires significant technical expertise. For a novel production such as mealworm, there is no inherited local know-how that farmers can draw on, such as would be the case for rearing more traditional livestock such as poultry or pigs. There is also no ecosystem of local expertise that can be relied on for support. This means that it is critical from the beginning to involve people with demonstrated hands-on experience of managing mealworm production.

In general, the most important aspect of insect farm management is consistency. Each day or week should follow the same rhythm, with every step standardised so that tasks are evenly distributed across the schedule.

Especially in large-scale facilities, without control, operations quickly spiral into problems: production surges become unsustainable and disrupt other activities (such as innovating solutions for increased capacity), triggering further instability. The result is chaos, neglected trays (which pests will infest), and a breakdown of the system that will take months to recover from for an insect with a two- to four-month life cycle.

In a large facility, the less a tray of insects is handled, the lower its cost, given the high share of labour. Farms should therefore aim to minimise touchpoints wherever possible, and this too can be approached experimentally. For example, removing frass and adding new feed to a cohort of larvae consumes significant time, making it critical to explore methods that reduce touchpoints without compromising too much on biological performance. The lead farmer should be highly focused on assessing and testing these sorts of trade-offs.

When bottlenecks in manual processes are identified, timely action becomes an important driver of progress. A proactive approach allows farms to maintain stability while also creating opportunities to reflect and implement improvements. Strong operations anticipate challenges, respond decisively, and work to minimise inefficiencies that can undermine long-term sustainability. Continuous innovation and adaptation are therefore essential to ensuring that insect farming remains viable.

Environmental risks: Temperature and humidity extremes throughout the year are also an important consideration. In the African context, constructing environmentally controlled rooms with costly heating, ventilation, and air conditioning systems is generally not economically viable – and in many cases, not even necessary. This represents a significant advantage compared to Europe, where climate control is often essential for insect farming due to the need to handle both cold winters and hot summers.

Another critical aspect of insect farming, for both large facilities and households, is protection against ants, rats, and birds. Rats, in particular, can devastate a small farm by chewing through plastic rearing trays and destroying infrastructure. Addressing this threat requires more than simple rat traps, which are insufficient to safeguard the colony.

Finally, arthropod pests such as the Indian Meal Moth can infiltrate and outcompete mealworms. The Indian Meal Moth can easily enter a farm with contaminated feed and establish itself in neglected trays. Controlling this pest is particularly challenging when the diet cannot be treated (for example, roasting all feed before use is impractical).

However, farms can manage pests by carefully inspecting feedstocks for signs of infestation, reducing feed in vulnerable trays while keeping them accessible for monitoring, providing wet feed to accelerate mealworm growth and help them outcompete meal moths, and promptly discarding trays where Indian Meal Moth pupae are detected. Without proper surveillance and being more reactive than proactive, the Indian Meal Moth can destroy the entire colony after a few generations.

Worker safety: Especially in large-scale facilities, but also in household productions, worker safety must be prioritised. Airborne frass (insect manure) represents the primary hazard in mealworm farming. Handsieving trays containing frass often generate dense clouds of allergenic particles, leading to both immediate and cumulative health risks. Prolonged and heavy exposure can trigger severe pulmonary issues and debilitating reactions.

Dust masks and open air are essential to protect workers from harm, but mechanised separation or sifting and frass containment also help. These hazards require more protective measures when handled frequently in large quantities in a large-scale facility, but household producers should also be aware of the importance of handling frass outside and in a way that minimises the risk of inhalation of the frass dust.

Continued on next page

4. Organising insect farmers

An important component of the ReflPro project involved supporting insect farmers to organise into structured farmers associations and a cooperative as a strategy for strengthening collective action, knowledge sharing, market access, and long-term ownership of the insect production systems. The project demonstrated that farmer organisation was not only essential for facilitating community mobilisation and coordination of trainings, but also particularly important within a refugee setting characterised by fragmented social structures, economic vulnerability, limited institutional support, and weak market integration.

At project inception, the Kyegegwa District Production Office, in collaboration with the District Community Development Office, linked the project team to existing farmer groups within the host community. Similarly, the Office of the Settlement Commandant referred the project to active community groups within the Kyaka II Refugee Settlement. These groups became the initial entry points for introducing mealworm and black soldier fly larvae (BSFL) farming activities.

The experience highlighted that organising farmers into groups provides several important advantages for insect production systems. Farmer groups create platforms for peer learning, collective problem solving, and experience sharing, all of which are particularly valuable when introducing relatively new and technically unfamiliar production systems such as insect farming.

Group structures also simplify coordination of trainings, distribution of starter stock and equipment, follow-up support, and monitoring activities. In refugee settings, where households often have limited individual assets and support systems, collective organisation further helps reduce isolation and strengthen social support networks among participants.

However, the project also found that many existing community groups initially possessed limited organisational and managerial capacity. Several groups were informal, lacked written constitutions, and had limited experience in leadership, accountability, financial management, and conflict resolution. Without strong governance systems, farmer groups risk becoming inactive, experiencing internal conflicts, or failing to manage shared resources effectively.

The project therefore invested in organisational capacity strengthening alongside technical insect farming training. Participating groups received training in group dynamics, leadership, governance, accountability, conflict management, record keeping, savings culture, and financial management. The groups were also supported to develop constitutions and internal regulations to guide membership, decision-making processes, benefit sharing, and conflict resolution mechanisms. This organisational strengthening proved critical for improving group cohesion, transparency, and long-term functionality.

Formal registration of farmer groups at sub-county and district level enhanced the legitimacy and visibility of the groups within local government structures and among external stakeholders. It also improved their ability to engage with development partners, participate in government livelihood programmes, mobilise resources, and access future support opportunities. In refugee settings, where many livelihood initiatives remain informal and short-lived, formal organisation helped establish more stable and sustainable community institutions capable of continuing beyond the project period.

As the project progressed, the individual farmer associations were further encouraged to pool their financial and human resources into a larger umbrella structure: the Kyegegwa Insect Farmers' Cooperative. The cooperative was established to strengthen the collective bargaining power and voice of insect farmers while promoting coordinated development of the emerging edible insect sector within the region. The cooperative assumed responsibility for managing shared insect breeding facilities established under the project, organising input supply systems, facilitating market access, and representing farmers in engagements with stakeholders.

One of the most notable experiences from the project was the successful integration of both refugee and host community farmers within the same cooperative structures and leadership systems. Refugees and host community members serve together on the cooperative leadership committee and work collaboratively despite differences in nationality and language.

Continued on next page

The Board of Kyegegwa Insect Farmers Cooperative comprise both refugees and Ugandan nationals skilled in insect farming and business development. The cooperative strengthens farmer organisation, knowledge sharing, access to inputs and markets, and local ownership of insect-production activities.

While many refugees are predominantly French-speaking Congolese living within an English-speaking environment, the cooperative experience demonstrates that shared economic interests and collective livelihood goals can create strong social cohesion and practical collaboration across communities. This represents an important lesson for refugee livelihood programming, showing that cooperative-based economic activities can contribute not only to livelihoods, but also to social integration and peaceful coexistence.

The cooperative has also played a critical role in strengthening the operational sustainability of insect farming activities. For example, the cooperative supported members to organise under Savings and Credit Cooperative (SACCO) mechanisms that enable farmers to access small loans and savings services to expand their operations. The aim is to support members to utilise these small credits to purchase additional production containers, improve housing structures, expand production space, and strengthen their insect farming enterprises. This access to locally managed financial services has been particularly important in a refugee setting where formal credit access is extremely limited.

The cooperative also assumed responsibility for distributing mealworm for rearing to member farmers. Interestingly, the project witnessed an organic expansion of insect farming beyond the originally trained groups, with new farmer groups and individuals expressing interest in joining the movement. The cooperative now manages this expansion process by administering membership fees for new entrants seeking access to insect starter stock and technical support. This demonstrates growing local ownership and demand for the technology beyond the original direct project beneficiaries.

Furthermore, the cooperative, with support from the project team, organised exhibitions and demonstration events in the settlement to showcase insect products, technologies, and experiences. These exhibitions attracted potential buyers, input suppliers, helping strengthen visibility and market linkages for the emerging insect sector within the region.

The experience from ReflPro clearly demonstrates that farmer associations and cooperatives are essential sustainability mechanisms in community-based edible insect production systems. Through capacity strengthening, local farmer institutions are increasingly taking ownership of technical, organisational, and operational functions initially supported by the project. Leaders of the cooperative have benefited from leadership and governance training, as well as exchange visits to more established farmer cooperatives to learn practical lessons in cooperative development, management, and sustainability.

Overall, the project experience shows that organising edible insect farmers into structured associations and cooperatives is not simply an administrative exercise, but a critical foundation for building resilient, locally owned, and economically viable insect production systems within refugee and host community settings.

5. Identifying sources of feedstock

Central to evaluating the feasibility of insect farming in any context is the availability and suitability of feedstock. Mealworms are particularly attractive because they can thrive on single agricultural by-products. In practice, most industrial mealworm farms worldwide rely almost exclusively on a dry base diet such as wheat bran, which supports both the grow-out larvae and the reproductive segment of the colony.

The choice of feedstock is determined by several factors: cost, consistency of supply, nutritional quality, and the biological performance of the mealworms on the selected substrate. While bran is generally effective, variability in source material can influence growth outcomes, with some types of bran leading to reduced performance. This underscores the importance of careful feedstock selection and monitoring to ensure reliable production.

Mealworms are capable of completing their life cycle without direct access to water or wet feed; however, the inclusion of a moisture source significantly accelerates development.[9] For this reason, identifying and incorporating suitable wet feed is recommended.

In Uganda, banana plant by-products – particularly the pseudo-stems – are an obvious choice. These stems can be easily chopped to the desired size and introduced as feed for both larvae and adults. Other options include uneaten or slightly spoiled plant by-products from household gardens. It is also possible to grow fast-growing, water-rich plants specifically for mealworm wet feed. However, as this requires space, soil, and maintenance that could be used for other activities, the costs and benefits have to be considered.

Market waste is probably best avoided altogether for mealworms reared as food. Its composition cannot be controlled, and ensuring it is safe for human consumption requires testing and handling capacity rarely available in these settings. As a general rule, where the product is food, use only feedstocks of known, clean provenance and avoid any input whose safety cannot be assured. Moreover, the variable nutritional composition of market waste can result in inconsistent growth performance from week to week, which is undesirable in any farming system.

Full vegetables or fruits such as carrots or potatoes are commonly used in mealworm farming and can provide consistent moisture and nutrients, but their use would not be justifiable in food-scarce settings where such produce is needed for human consumption. Thus, locally available agricultural by-products remain the best option.

Continued on next page

[9] Deruytter D, Coudron CL, Claeys, J. The influence of wet feed distribution on the density, growth rate and growth variability of Tenebrio molitor. *Journal of Insects as Food and Feed.* 2021 7.2: 141-150.

Lead farmers like Mopao Bikanyari manage the community breeding centres and ensure there is enough feedstock for continued production. Identifying feedstocks that are affordable, consistently available and nutritionally suitable is critical to making mealworm production economically viable and sustainable.

The larger challenge is that mealworm farmers in refugee settlements are far away from wheat and corn mills, meaning feed must be purchased, transported, and stored within the settlement – adding significant costs. If locally available waste or byproducts cannot provide a viable base diet, then identifying a sustainable and affordable feedstock strategy in refugee contexts is not guaranteed and requires careful consideration before investing in establishing production.

In the RefIPro project, wheat bran was used as the main base dry diet for mealworm, as it turned out to be cheaper than maize bran. However, wheat bran has to be transported from Kampala, and for the small-scale farmers in and around the Kyaka II settlement, many of whom grow maize, maize bran is likely to be more accessible and affordable.

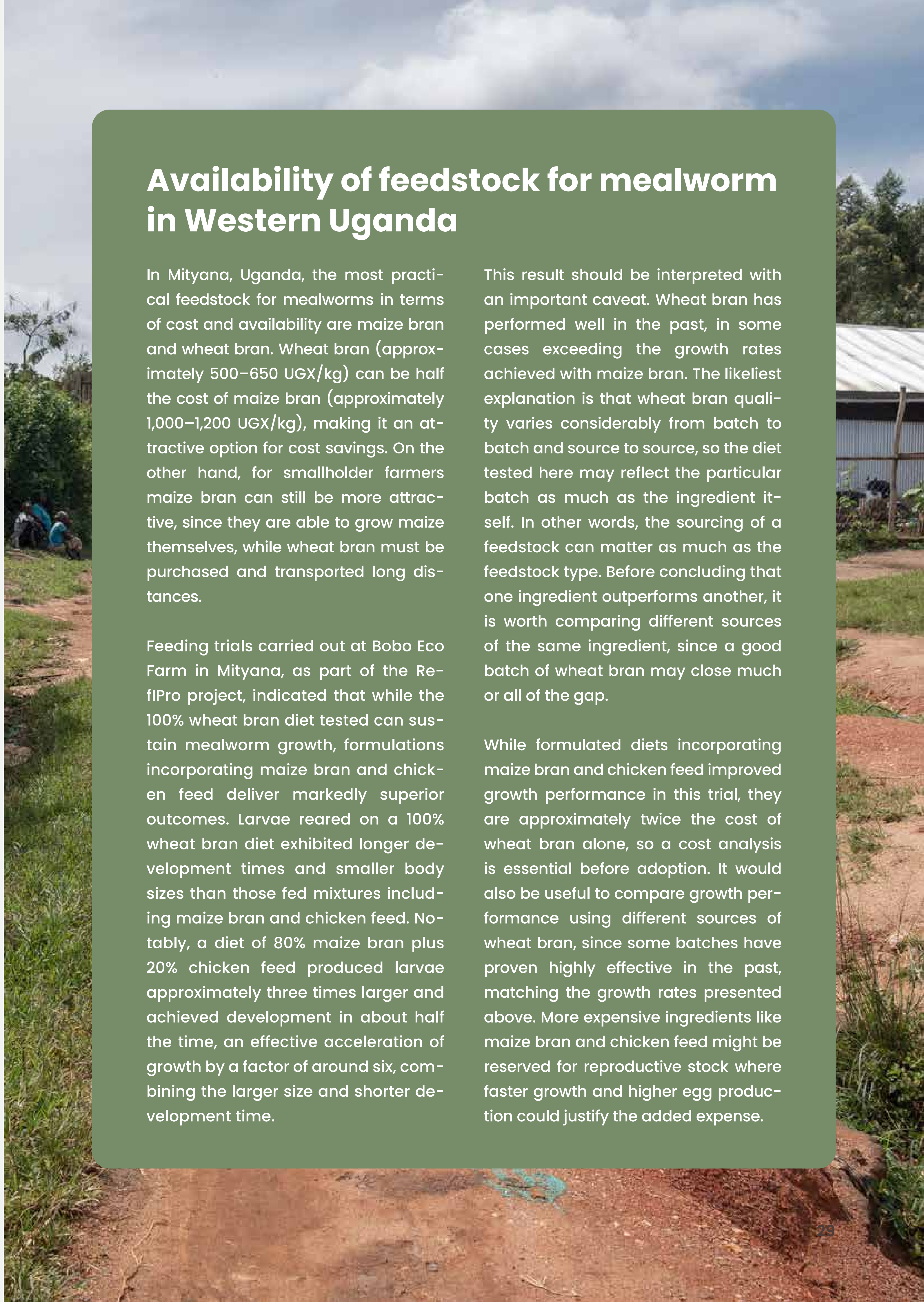
Wet feeding also requires a reliable supply. Banana stems and peels are commonly used in Uganda, but availability can fluctuate, leading farmers to supplement with fast-growing grasses or purchase banana stems from neighbours. These activities add further logistical and financial burdens.

It is important to evaluate the benefits of producing mealworm versus alternative uses for the feedstock used. In some farms, insects are deployed to address an obvious waste issue, converting low-value residues into usable protein and fertiliser. In other farms, particularly those conceived for human food, commodity feedstocks are sourced with the expectation that insects will convert these into protein more efficiently than conventional livestock.

While the environmental benefits of insect consumption are well established, the oft-quoted metrics comparing feed conversion rates between chickens and insects assume the best-case scenarios for insect farming.

What truly matters is the farm-level reality: with the feedstock available, how much does it cost to produce one kilogram of dried, sellable insect? And how long does it take for the conversion to happen? From there, one can add costs such as labour, energy, and consumables to calculate the true cost of production.

As described above, the rationale for production is likely to vary for large-scale production, household production, and school-based production. Even if large-scale production turns out not to be financially viable, household or school-based productions can still make sense.



Availability of feedstock for mealworm in Western Uganda

In Mityana, Uganda, the most practical feedstock for mealworms in terms of cost and availability are maize bran and wheat bran. Wheat bran (approximately 500–650 UGX/kg) can be half the cost of maize bran (approximately 1,000–1,200 UGX/kg), making it an attractive option for cost savings. On the other hand, for smallholder farmers maize bran can still be more attractive, since they are able to grow maize themselves, while wheat bran must be purchased and transported long distances.

Feeding trials carried out at Bobo Eco Farm in Mityana, as part of the RefIPro project, indicated that while the 100% wheat bran diet tested can sustain mealworm growth, formulations incorporating maize bran and chicken feed deliver markedly superior outcomes. Larvae reared on a 100% wheat bran diet exhibited longer development times and smaller body sizes than those fed mixtures including maize bran and chicken feed. Notably, a diet of 80% maize bran plus 20% chicken feed produced larvae approximately three times larger and achieved development in about half the time, an effective acceleration of growth by a factor of around six, combining the larger size and shorter development time.

This result should be interpreted with an important caveat. Wheat bran has performed well in the past, in some cases exceeding the growth rates achieved with maize bran. The likeliest explanation is that wheat bran quality varies considerably from batch to batch and source to source, so the diet tested here may reflect the particular batch as much as the ingredient itself. In other words, the sourcing of a feedstock can matter as much as the feedstock type. Before concluding that one ingredient outperforms another, it is worth comparing different sources of the same ingredient, since a good batch of wheat bran may close much or all of the gap.

While formulated diets incorporating maize bran and chicken feed improved growth performance in this trial, they are approximately twice the cost of wheat bran alone, so a cost analysis is essential before adoption. It would also be useful to compare growth performance using different sources of wheat bran, since some batches have proven highly effective in the past, matching the growth rates presented above. More expensive ingredients like maize bran and chicken feed might be reserved for reproductive stock where faster growth and higher egg production could justify the added expense.

A member of the production team operates a mechanical sifting system at the central mealworm facility at Bobo Eco Farm in Mityana. Mechanisation of labour-intensive processes such as separating larvae, frass and residual feed can reduce handling time, improve efficiency and support the transition from small-scale to larger-volume mealworm production. The team designed small appropriate machines inhouse.

Mealworms are carefully managed in rearing trays at the central production facility. Good post-harvest handling begins with clean harvesting and separation of the larvae from feed residues and frass before washing, heat treatment and further processing for human consumption.

6. Processing mealworm

Processing yellow mealworms into safe, nutritious, and acceptable food products requires careful attention to each step of post-harvest handling. Mealworms are highly perishable, and improper processing can lead to microbial contamination, nutrient loss, or reduced sensory quality.

The process begins with harvesting, where feed, frass, and other foreign materials are removed. Clean harvesting ensures that subsequent steps, including washing and roasting, are effective. Following harvesting, mealworms are fasted for 24 hours. This starvation period empties the gut of residual feed and waste, reducing microbial load and preventing off-flavours during cooking, which is particularly important for community-level processing.

Washing and draining are critical steps that further enhance hygiene. Mealworms are washed at least three times with clean or portable water to remove frass, dust, and feed residues. Excess water is then drained to prevent spoilage and ensure even roasting. Care must be taken to avoid using contaminated water, especially in areas where toxins such as fluoride are prevalent, as these can compromise product safety.

The next step is blanching, often combined with high-temperature sterilisation, to deactivate enzymes and kill pathogenic microorganisms. The temperature and duration must be sufficient to ensure safety, which is the overriding requirement. Excessive heat should still be avoided, since it can degrade the product's quality and palatability, but the safety threshold comes first: when in doubt, err towards fully ensuring a safe product.

Pan roasting is used to reduce moisture and develop flavour and aroma. Mealworms are roasted until brittle, making them easier to mill, but uneven heat distribution can result in burnt products and loss of essential fatty acids. At the community or household level, pan roasting is the preferable method, but alternatives such as oven drying or solar dehydration can also be applied, with careful attention to temperature and time to maintain nutrient retention and prevent microbial growth.

After roasting or drying, mealworms can be consumed immediately or cooled to prevent condensation and microbial proliferation, then milled into powder. Powdered mealworms are more shelf-stable and versatile for incorporation into value-added products such as flour, porridge, soups, and concentrates.

Strict hygiene and sanitation, including clean hands, tools, and surfaces, must be maintained throughout the process to ensure safety and quality.

Storage in covered, dry containers is essential to prevent moisture absorption, contamination, and spoilage. As part of the ReflPro project, a storage stability study was conducted by researchers from the Department of Food Technology and Nutrition at Makerere University to assess the safety and quality of yellow mealworm-enriched flour under ambient storage conditions. The flour was periodically analysed for microbial load, moisture content, and lipid oxidation parameters in accordance with the Uganda National Bureau of Standards (UNBS) guidelines.

The results showed that the flour remained microbiologically safe and chemically stable for up to six months. Pathogenic microorganisms, including Escherichia Coli and Salmonella, were not detected throughout the storage period.

Although slight increases in moisture content, total microbial counts, yeast and moulds, and lipid oxidation indicators were observed over time, all values remained within acceptable UNBS safety and quality limits. These findings suggest that yellow mealworm-enriched flour could be safely stored for at least six months without significant deterioration in quality.

By carefully managing each of the above steps, communities can consistently produce safe, nutritious, and appealing yellow mealworm products that contribute to local food security and nutrition.

7. Using mealworm as an ingredient in food

Yellow mealworms offer a versatile, nutrient-dense, and sustainable protein source with applications ranging from household consumption to school feeding programmes and the emerging commercial insect-based food market. In school feeding programmes, yellow mealworm flour can be incorporated into porridge, biscuits, or ready-to-eat snacks.

Yellow mealworm has high nutritional quality, with high levels of protein and essential fatty acids. This makes it a good ingredient for improving the micronutrient density of school meals and other food products without compromising acceptability.

At the household level, mealworms can be simply roasted, fried, or milled into flour and incorporated into traditional meals, as described above. However, developing proper insect-enriched snacks and porridge requires careful consideration of several factors that influence nutritional quality, sensory acceptability, safety, and shelf stability.

As part of the RefIPro project, yellow mealworm-enriched flour and snacks were developed to improve the nutritional quality of foods for children aged six to nine years in refugee settings. The products were designed to provide at least 30% of the daily energy requirement (1,572 calories), in line with WFP school feeding recommendations.

The first product was an extruded composite flour containing 25% yellow mealworm powder. Extrusion is a processing method that uses heat and pressure to produce a ready-to-cook product. This product was more nutrient-dense, had a lower microbial load due to the heat treatment during extrusion, and required less preparation time. However, products with higher levels of yellow mealworm are generally less acceptable to consumers, likely because of differences in taste, smell, or appearance.

The second product was a community-adapted product containing 15% yellow mealworm. This product was made using locally available maize flour purchased from the market and pan-roasted yellow mealworms, without extrusion or additional fortification. The advantage of this product is that it is simpler and more practical for community-level preparation using locally available resources and

Continued on next page

Photo: Kelvin Atuhaire

The project explored whether incorporating locally produced mealworms into a familiar school meal could provide a practical and acceptable way of increasing the nutritional quality of children's diets.

Nutritional content of yellow mealworm-enriched flour for porridge

The nutritional analysis of the flour used for school meal porridge in the RefIPro project shows that yellow mealworm-enriched flour is nutrient-dense, with high macronutrient quality. The protein content is high at 19.5%. Fat is also high at 9.31%, while the carbohydrate content is 60.33%. The flour provides 403.35 calories per 100 grams (g).

The results indicate iron content at 7.76 milligrams (mg) per 100 g, which is 111% of the WFP requirement. The flour also contained 2.5 mg of zinc per 100 g. The Content of Magnesium (10.56 mg per 100 g.), Iodine (31.2 micrograms (µg) per 100 g) and Calcium (18.52 mg per 100 g) were all relatively low compared to recommended daily intake.

Preparation of mealworm-enriched porridge for sensory evaluation. Product development under ReflPro considered not only nutritional value, but also taste, aroma, texture, appearance and overall acceptability to ensure that mealworm-enriched foods were suitable for children and practical for preparation within local settings.

minimal equipment. However, compared to the extruded product, it may have lower nutrient density, a shorter shelf life, and a potentially higher microbial load due to less intensive processing.

Once formulations are prepared, sensory screening is essential. Sensory evaluation captures human perception, which is critical because even the most nutrient-dense product will fail if not palatable. Sensory perception involves activation of taste receptors for sweet, bitter, and umami sensations, as well as texture and mouthfeel.

Such evaluations can be done with untrained panels of children and adults who assess attributes such as taste, appearance, texture, colour, aroma, and overall acceptability, typically using five- or nine-point hedonic scales. Feedback from these panels is important to inform the refinement of prototypes, allowing adjustments in ingredient ratios, sweetness, or flavour enhancers to improve acceptability without compromising nutritional content.

For the two mealworm porridges developed, sensory acceptability was assessed by 107 pupils from the two schools involved in the ReflPro school meal trial: Kako Primary School, mostly Batooro children from the local community, and Bukere Primary School, mainly Congolese children from the Kyaka II refugee settlement.

Formulation of mealworm-enriched products

Mealworm-enriched products can be efficiently formulated using software such as NutriSurvey. This allows precise targeting of protein, energy, and micronutrient levels including iron, zinc, and vitamin A to meet the Recommended Dietary Intakes (RDIs) of particular groups, including children. Such targeted formulation ensures that the products are energy-dense, nutritionally adequate, and support growth and cognitive development. The software calculates ingredient proportions from nutrient databases, balancing macronutrients and micronutrients while avoiding excessive concentrations that could negatively affect taste or texture.

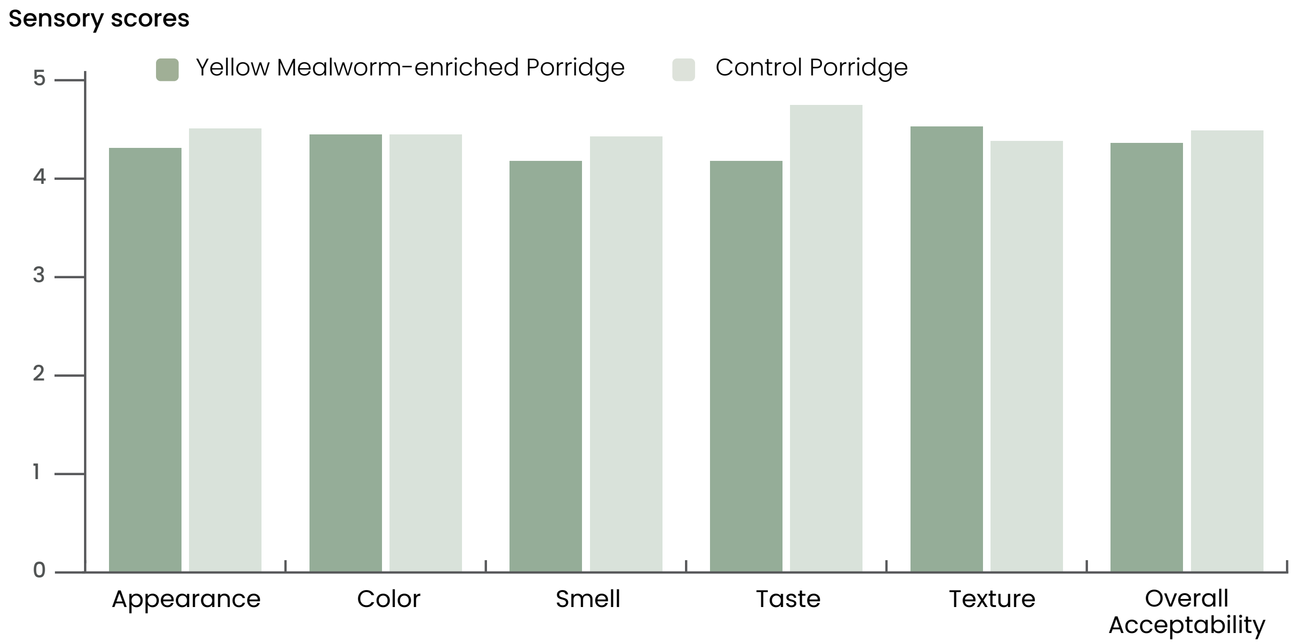


Figure 2: *Combined sensory evaluation for yellow mealworm enriched and control porridges for kako and Bukere primary schools.*

Before testing, panellists were instructed on how to use the sensory scale and its purpose and then recorded their scores on a specially designed evaluation form. A five-point hedonic scale was used, with one meaning 'dislike extremely' and five meaning 'like extremely'. Facial expression pictures were used to aid interpretation for the pupils. Panellists rated both the yellow mealworm-enriched and control porridge for appearance, colour, smell, taste, texture, and overall acceptability.

Porridge with 15% mealworm flour achieved high sensory ratings for taste, aroma, texture, and overall liking among children, with mean scores on the five-point hedonic scale ranging between 4.0 and 4.7. The control porridge without mealworm tended to score slightly higher than the yellow mealworm-enriched porridge across most attributes, but the difference was small. However, significant differences were observed in the categories of taste and smell between the two formulations. Some pupils noted a slight lingering aftertaste after consuming approximately 150 millilitres (mL) of the porridge with mealworm.

The results of the sensory evaluation of yellow mealworm-enriched porridge and control porridge without yellow mealworms are presented below. As the graphs show, the mealworm flour porridge overall received a very high rating.

In conclusion, yellow mealworm products provide versatile, nutrient-rich options for household consumption, school feeding, and commercial markets. Success requires rigorous attention to formulation, sensory optimisation, processing, safety, and storage.

Scientific understanding of protein denaturation, starch gelatinisation, lipid oxidation, mineral bioavailability, and water interactions ensures that products are both safe and palatable, supporting sustainable food systems and local nutrition initiatives.

School feeding did not only address the research gap but served as a motivator for children to continue attending school.

Photo: Kelvin Atuhaire

8. Understanding the impacts of mealworm on health and nutrition

Malnutrition during school years stunts children's physical growth, cognitive development, and academic performance, and increases their risk of adverse health outcomes later in life. It is well established that school feeding can be an efficient strategy to help meet the nutritional requirements of school-aged children, contributing to enhancing education and health outcomes.

Kyaka II has a high prevalence of childhood malnutrition. The Food Security and Nutrition Assessment (FSNA) in 2024 found that stunting affected 55.4% of children under five years of age in the refugee settlement, and 39.2% of children under five were stunted in the host district Kyegegwa. Across the refugee settlement and host communities, 33% of children under five were anaemic. The dietary diversity is low and dominated by cereal staple foods, while the consumption of animal-sourced foods is limited in both the refugee and host communities.[10]

8.1. The RefIPro school study

In order to assess the potential impacts of mealworm consumption on health and nutrition, the RefIPro project included a randomised controlled trial (RCT) with 342 school children in two schools. The trial assessed the effects of providing mealworm in daily servings of porridge on school days plus Saturdays (six days a week) over a 14-week school term for children in primary level one (P1). The age range of the children was from six to nine years. The study was conducted in two schools, Bukere Primary School located in Kyaka II refugee settlement and Kako Primary School located in the host community near the settlement.

All children in P1 were individually randomised to receive a daily serving of either the experimental maize-based porridge including powdered mealworm, or a control porridge of pure maize flour. The mealworm porridge included mealworm corresponding to efficient intake of 7.5g of protein per serving. Both types of porridge were prepared using maize flour fortified with micronutrients following the standards for mandatory fortification in Uganda.

The primary objective was to assess the intervention's effect on the children's linear growth (height), while a set of secondary objectives focused on the impact on other growth and nutritional outcomes,

Continued on next page

[10] Food Security and Nutrition Assessment (FSNA) in Refugee Settlements, Refugee Host Districts and Kampala 2024. Kampala, Uganda: Government of Uganda; 2025.

including body composition (fat and fat-free body mass), biochemical measures, micronutrients, and gut health.

8.2. Main findings

Prior to the trial, we hypothesised that the consumption of yellow mealworm porridge would improve growth and lean mass accretion in children. Low levels of linear growth are an indication that children are at risk of stunted growth.

The results showed that children in the mealworm porridge group grew 0.24 centimetres higher than those in the regular maize porridge group, after statistically controlling for the children's age, sex, and energy intake. This finding was statistically significant. When turning the height into height-for-age Z-scores (HAZ) relative to the global growth reference for normal growth, the children increased 0.05 in HAZ compared with the control group. These results show that enhancing the school meal with mealworm promoted the growth of the children. The improved HAZ showed that the children were in a 'catch-up' stage of reversing stunted growth.

The mealworm intervention group had significant increases in the blood concentration of Insulin-like Growth Factor 1 (IGF-1), a biomarker for growth stimulation. IGF-1 stimulation has in other studies been documented for consumption of dairy protein, but not for intake of meat. Indicatively, the mealworm appears to have similar effects to dairy upon growth in children.

There was no difference in weight gain between the two groups. However, when disintegrating weight gain into fat mass and fat-free body mass, the growth pattern differed. Fat-free mass, representing healthy gain in muscle and organs, increased by 0.34 kilograms (kg) more in the mealworm group, compared to the control group. The changes in fat mass were not significantly different between groups, however the mealworm group accumulated a higher proportion of the weight gain as fat-free mass, while the inverse was observed in the control group.

These results align with the finding of linear growth. The group consuming the mealworm-enhanced porridge for 14 weeks gained more height and fat-free mass, while the group consuming standard maize porridge gained fat mass rather than muscle mass. These growth patterns potentially have long-term health implications. Fat accumulation in early age is associated with higher risks of cardiovascular and other NCDs (life-style related non-communicable diseases).

For the effect of the mealworm school intervention on micronutrient status it is notable that the iron and vitamin A deficiencies were less prevalent than expected, based on the FSNA 43 survey data from 2024. The prevalence of anemia[11] and iron deficiency[12] was 9.3 and 4.6%, respectively. The prevalence of vitamin A deficiency was less than 5%.[13]

Continued on next page

[11] Defined as haemoglobin < 11.5 g/decilitre (dL).

[12] Inflammation adjusted serum ferritin < 15 µg/litre (L).

[13] Defined by serum retinol-binding protein (S-RBP) < 0.7 micromoles (µmol)/L.

Photo: Kelvin Atuhaire

Mealworm-enriched porridge was provided to participating children during the 14-week ReflPro randomised controlled trial. Children received either mealworm-enriched or control porridge six days a week, enabling researchers to assess effects on growth, nutritional status and other health outcomes.

Research staff collect anthropometric measurements from children participating in the ReflPro school-feeding study. Standardised measurements were used to assess children's growth and nutritional status and to determine whether regular consumption of mealworm-enriched porridge contributed to measurable improvements over the intervention period.

Both the experimental mealworm porridge and the pure maize porridge serving as the control were made with maize flour fortified with micronutrients according to the mandatory fortification standard in Uganda. There were no measurable impacts on either anaemia, iron deficiency, or vitamin A status in either of the groups. It cannot be concluded if the intervention could have different impacts if more children were iron and/or vitamin A deficient at baseline.

As expected, the children were generally burdened with infection. About half of them were positive for malaria and a proportion had elevated acute-phase biomarkers for infections.[14] (None tested HIV positive.) This general challenge with infections is associated with increased protein demand for immune response.

The background diet was assessed three times: at baseline, after 4 weeks, and at endline after 14 weeks, using a 24-hour recall method of asking caregivers to recall all foods consumed by the child the previous day.[15]

The results of the dietary assessment showed that the children had low energy intake, and particularly low protein intake, not meeting the recommended intakes for protein requirements.

The general living conditions and food security situation in the community align with the assessed low protein intake. The effects on growth of providing mealworm strongly indicate that the children are protein deficient. The protein from mealworm is of animal origin and is considered of high quality in terms of digestibility and amino acids composition.

In addition to providing important nutrients, animal studies have shown that insects might provide additional bioactive compounds. Specifically, the chitin from the insect exoskeleton may have beneficial effects on the gut by alleviating inflammatory conditions. The effects

[14] C-reactive protein, CRP and Alpha-1 Acid Glycoprotein, AGP.

[15] The recall relies on the caregivers' memory and estimation of the portions the child consumed the previous day. The 24-hour recall is a standard methodology for assessing dietary intakes. The method has – as any dietary recall method – inherent limitations byrelying on reported intake, limiting the accuracy. The method is valid for the comparison between the intervention groups, and changes between baseline and endline, considering that any bias due to inaccurate recall or portion estimation is equal and not affecting the group averages.

[16] The study assessed relevant biomarkers in blood (citrulline) and faeces samples (neopterin and myeloperoxidase).

Children enjoying porridge made with maize and mealworm flour in one of the schools that participated in the school feeding trial.

of the intervention on gut health were assessed by biomarkers[16] for Environmental Enteric Dysfunctionality (EED), an inflammatory condition hampering nutrient absorption, associated with poor hygienic environments.

The preliminary data analysis shows that the overall level of EED in the children at baseline – before the intervention started – was less than expected considering the living conditions, including the limited access to safe drinking water in the settlement. The moderate baseline occurrence of EED conditions detectable with the biomarkers limited the ability to detect intervention effects on improving gut health. Further data analysis will investigate effects in sub-groups of the most health challenged children.

9. Using mealworm frass as fertiliser

Apart from food and feed products, the mealworms also produce frass consisting of a combination of uneaten substrate, faeces from the mealworm, and exuviae. This frass is an excellent source of fertiliser for soil health management and crop production.

Using the frass for fertiliser does not only complete the nutrient loop by returning the nutrients contained in organic waste back to agricultural lands; it also ensures food security and income diversification by boosting yields of vegetables for household consumption and/or sale.

Local production of fertilisers using mealworm provides a sustainable solution to the challenge of scarce and costly fertilisers which also have deleterious effects after continuous application. It thus offers a promising avenue to reverse land degradation and contribute to sustainable soil health management.

Promoting local fertiliser production using biowastes as raw materials aligns with the African Union's 2024 Nairobi Declaration which aims to triple the local production and distribution of fertilisers using climate-smart technologies.

Studies carried out as part of the ReflPro project showed that frass fertiliser yield and quality varies with the organic waste fed to mealworms. The yield of mealworm frass ranged between 0.9 and 2.8 kg, with the highest and lowest values achieved using sole chicken droppings and maize cob diets, respectively. Based on these findings, the bioconversion of 1,000 kg of each feedstock would yield between 3.9–149 kg of dry mealworm larvae and 266–934 kg of frass fertiliser over a period of 84–120 days. The frass yields increased with the rate of inclusion of chicken dropping or maize cobs in the maize bran used for feed, with higher values achieved using chicken droppings.

Diets made of mixtures of chicken droppings and maize bran produced frass with a good balance of nitrogen, phosphorus, and potassium, indicating higher suitability for soil fertility enhancement and improved crop production.

On the contrary, the amendment of maize bran with maize cobs produced frass with the lowest nutrient levels. This implies that for production of nutrient-rich frass fertiliser, it is key to select substrates with higher nutrient levels and/or blend different substrates to optimise nutrient balance.

Compared to conventional organic fertilisers such as poultry manure, cattle manure, and composts, the frass fertilisers were of superior nutritional value. Moreover, the macronutrient levels of the frass fertilisers were comparable to those of commercially available organic fertilisers on the Ugandan market, indicating that these products can compete favourably in mainstream markets. This highlights business opportunities related to the

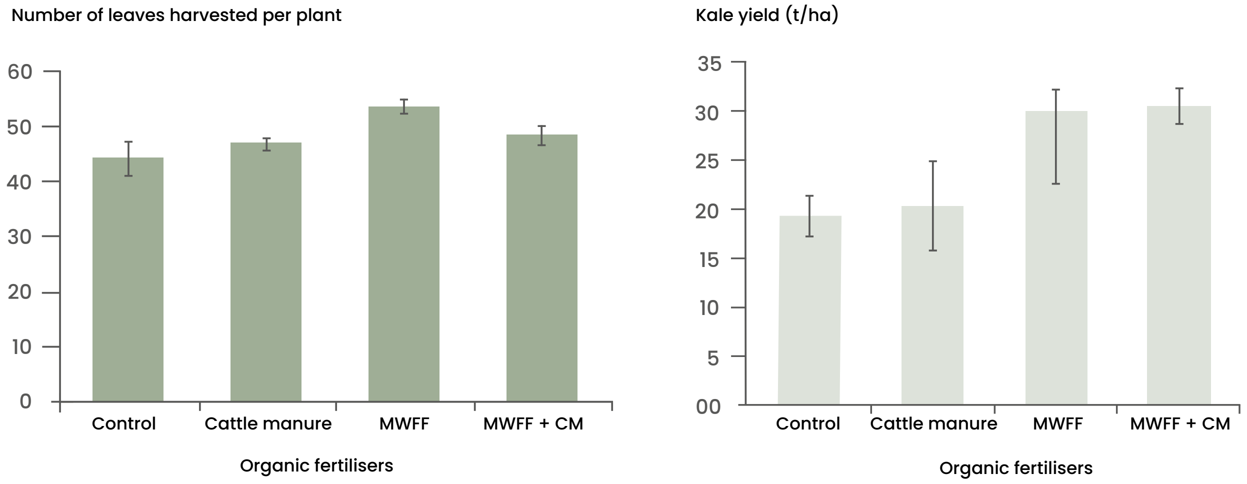


Figure 3: *Growth and yield parameters of kale grown in soil amended with BSF frass fertilisers, cattle manure, and their combinations.*

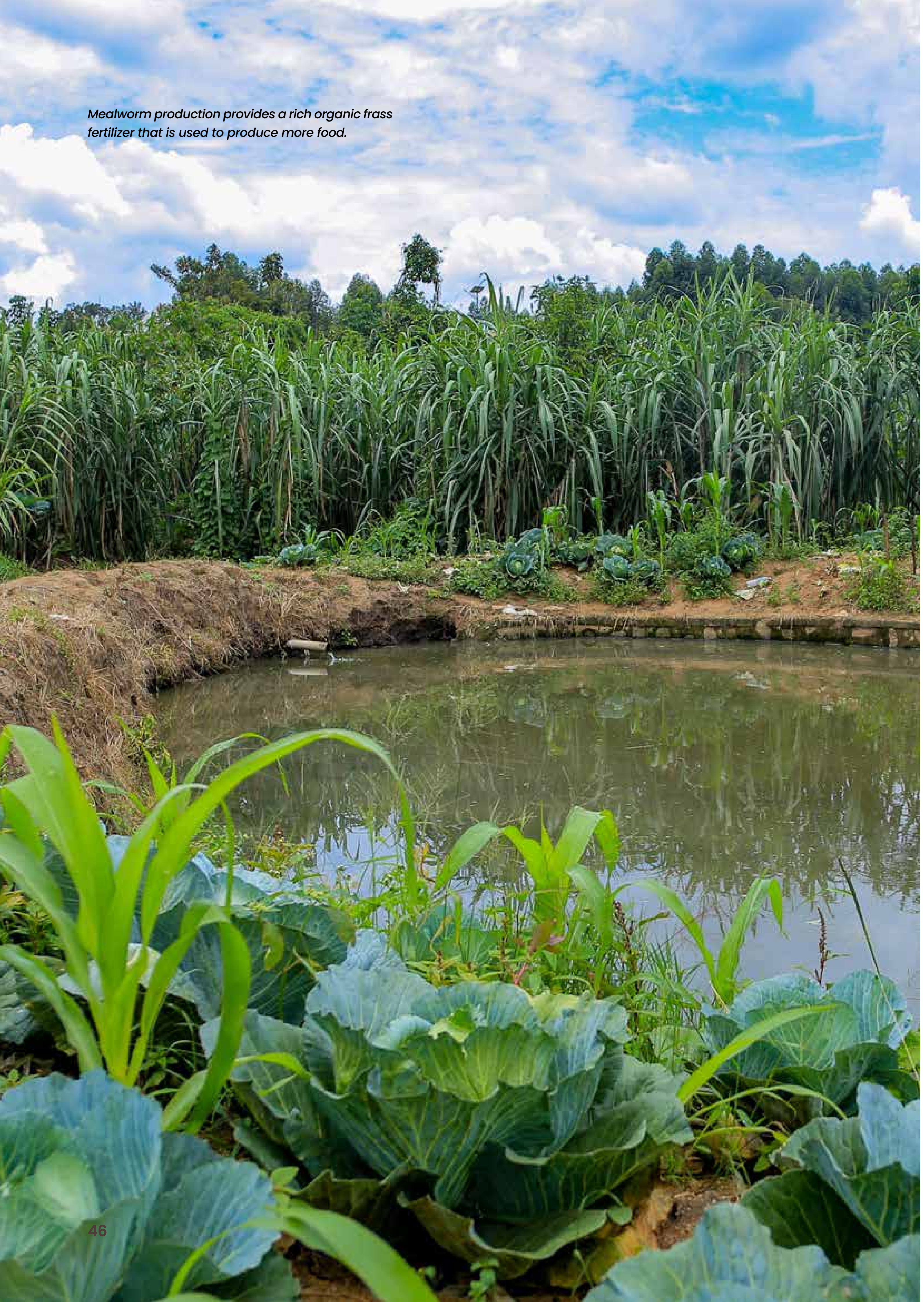
commercialisation of mealworm frass fertilisers. The higher nutritional value of the frass fertilisers implies that farmers can apply lower quantities to achieve higher yield gains. Adopting such high-quality frass fertilisers relieves farmers the burden of high fertiliser purchase costs and contributes to improved farm productivity.

To support vegetable production, the frass is converted into organic fertiliser by composting for five weeks to improve maturity and stability for field application.

The project compared the effects of mealworm frass fertilisers versus cattle manure (a conventional organic fertiliser) upon vegetable (kale) production. We found that the application of the mealworm frass fertiliser or its combination with cattle manure enhanced kale height, leaf area, and number of leaves better than solely cattle manure (Figure 3). Soil amended with mealworm frass fertiliser produced kale with the highest number of leaves, and unfertilised soil produced kale with the lowest number of leaves (Figure 3).

All fertiliser treatments produced higher kale yields than the unfertilised soil. The highest kale yield was produced by soil amended with a combination of mealworm frass fertiliser and cattle manure, up to 65% higher than the values achieved using other treatments. Application of sole mealworm frass fertiliser improved kale yield by 48% compared to sole cattle manure treatment.

The high vegetable yield achieved using mealworm frass fertilisers indicates superiority over cattle dung, which is currently what most farmers use. This could be attributed to the high nutrient levels arising from wheat bran used in mealworm production compared to cattle dung. These findings highlight the circular economy benefits of insect farming recycling nutrients contained in organic wastes into fertilisers for crop production.



Mealworm production provides a rich organic frass fertilizer that is used to produce more food.

10. Establishing efficient monitoring and evaluation systems

Effective insect farming, like any agricultural enterprise, relies on careful monitoring of key performance indicators (KPIs) to maintain control of the colony. However, collecting excessive data at every opportunity can be burdensome and drive-up labour costs. A balanced, targeted approach is therefore recommended, supported by a robust set of data-collection methods that can be deployed strategically when troubleshooting specific issues.

In the early phase of a mealworm farm, data collection is essential for establishing a baseline. Once defined, these metrics can be compared with those from other farms – whether published, shared informally, or observed locally – to identify the greatest opportunities for improvement. For example, if survival from egg to hatched larvae is 50%, survival from larvae to pupae is 70% over 12–16 weeks, survival from pupae to adults is 50%, and adult survival to four weeks is 50% – where should the farmer focus?

For this species, hatch rates are expected to exceed 80%, so in this case improving early survival represents the largest opportunity to strengthen overall productivity. In addition, a 20-week development cycle is slow for this species and reduces output capacity, making it important to examine both feedstock quality (dry and wet) and the stocking density of larvae.

While pupae-to-adult survival is also relatively low in this example, this outcome is to be partly expected in a mass-rearing facility given the vulnerability of pupae during metamorphosis. Improvements at this stage tend to be incremental rather than dramatic, so in this example, efforts are best concentrated on egg hatch rates and reducing development time.

Monitoring temperature and relative humidity is essential, particularly in farms exposed to outside air. To improve egg hatch rates, one practical approach is to test environmental effects by dividing a clutch of eggs into rooms with different conditions and tracking their development.

The same principle applies to other life stages: when adult egg production declines, temperature and relative humidity should be the first variables examined. Over time, data on environmental conditions can be used to establish optimal ranges – or at least to anticipate seasonal shifts from hot and dry to rainy and temperate – and adjust management practices and planning accordingly.

Rearing density across all life stages is a critical factor in insect farming. Higher densities generally slow growth: larval growth rates are particularly sensitive to

Continued on next page

density, but adult egg production is also influenced by density.

Striking the right balance between available space (trays) and performance is therefore essential. Published reports can provide useful starting points, but establishing appropriate densities in locally purchased trays of locally acquired feed or substrate requires onsite testing. In farms without advanced environmental controls, the individual weight and survival of larvae from nursery trays can vary considerably. If this variation is not monitored, it may lead to inconsistent densities when larvae are moved into grow-out trays at a lower density. Inconsistencies at this stage affect harvest timing, cause cohorts to develop unevenly, and ultimately disrupt steady-state production.

Another important metric in insect farming is feed conversion into insect biomass, which can be expressed in several ways. Any deviation from expected values signals opportunities or issues that must be addressed, whether in environmental conditions, larval density, or feedstock quality.

These data also establish the minimum cost of production. For instance, using the wheat bran prices noted above and a feed conversion rate of six, the resulting cost is approximately 9,000 UGX (≈ $2.50) per kilogram of dried mealworms – before accounting for additional expenses such as the broodstock required to sustain the grow-out population.

The cost of an egg therefore becomes a critical calculation for farms operating across the full lifecycle. In hybrid models, where broodstock are maintained at a centralised facility and middle-aged larvae are supplied to grow-out farms, the true cost of larvae can only be determined by aggregating all expenses incurred at the centralised site, and dividing it by the quantity of eggs.

The challenge in monitoring is not whether to collect data, but how much and how often. Every measurement requires labour, and in resource-constrained settings the cost of monitoring can quickly outweigh its benefits.

After an initial phase of establishing baseline metrics for each life stage – ideally during an extended training period – a useful principle is to distinguish between routine indicators and diagnostic indicators.

Routine indicators, such as egg-to-larva survival, larval growth rate, adult egg-laying rates, and feed conversion, should be tracked consistently because they provide the clearest picture of colony performance.

Diagnostic indicators, by contrast, can be measured only when a problem arises, allowing staff to concentrate their effort where it is most needed. Ideally, these data are relayed to a technical expert with deep knowledge of mealworm biology, who can recommend corrective actions and targeted diagnostic tests. Over time, an onsite leader can gradually develop the capacity to troubleshoot independently and assume full ownership of the farm, though this progression requires patience and experience.

In contexts such as refugee settlements, where staff may have limited technical training, monitoring systems should be designed for simplicity and reliability. This means following these recommendations:

- **Focus on a few key indicators:** focus on four to five core indicators that matter most for productivity, and make sure these data are acted on.

- **Use visual tools:** use wall charts, pictograms, or colour-coded records to reduce reliance on technical language.

- **Build habits:** schedule tasks on the same day every week the same so monitoring becomes routine. For example, pupae are separated on Monday and Friday, eggs are collected on Tuesday, harvests occur on Wednesday, etc.

- **Trigger deeper checks only when thresholds are crossed:** for example, if survival of eggs to middle-aged larvae is below 20%, then check for diagnostic indicators, such as survival of eggs versus survival of hatchlings to middle-aged larvae, and also investigate temperature, humidity, and feedstock.

- **Train through demonstration:** hands-on practice and peer-to-peer learning are often more effective than written manuals even if the latter are a good reference.

By keeping systems lightweight yet targeted, farms can generate actionable data without overwhelming staff or creating unnecessary complexity. This approach ensures that operational insights remain practical and directly tied to decision-making.

Operations that rely on memory and intuition alone struggle to troubleshoot or improve systematically. Even a simple notebook tracking a few core metrics is a meaningful start, but farms should build toward structured, evidence-based reporting over time. Insect farming is a relatively new vocation and, unlike traditional agricultural practices, it does not benefit from generational knowledge passed down through experience. As such, structured data collection and evidence-based reporting are essential to validate competence, troubleshoot effectively, and build credibility with stakeholders.

A woman in Kyaka II refugee settlement tending to her household mealworm production. With proper training households can manage the entire mealworm life cycle in their homes.

11. Conclusions

In conclusion, mealworm production promises a new source of high-quality protein that can be produced locally with relatively limited capital investments. The RefIPro project has demonstrated both the feasibility of producing mealworm in a refugee setting, and the value of adding mealworm protein to school meals.

However, new projects should recognise the technical know-how needed to establish production of a novel type of livestock, with no established ecosystem of expertise to support farmers. It should not be assumed that sustainable mealworm production can be established in a short time.

Projects must begin with a rigorous business and feasibility assessment that highlights the two largest cost drivers: labour and feedstock.

For large-scale, professional production facilities, labour costs are likely to dominate overall expenses, making it essential to define realistic assumptions about workforce requirements and efficiency.

Feedstock costs are equally critical, as the viability of mealworm production depends on the availability and affordability of local inputs. The financial model therefore turns in large part on how well the mealworm fits the local context: whether it can be reared productively within the region's climate and space constraints, whether it is culturally acceptable as food, and whether its feed requirements can be met affordably from locally available inputs.

Comparative analysis should weigh these costs against alternative protein sources, including conventional livestock such as chickens, and consider whether insect products offer unique health benefits that justify their expense relative to imports.

Once this foundation is secured, projects should prioritise achieving steady-state production – even at smaller scales – to clarify operational realities such as broodstock allocation, farm management capacity, and labour efficiency at larger scales.

Ultimately, the lessons learned emphasise that business viability – anchored by labour and feedstock economics, and by the mealworm's suitability to local conditions – must lead the way, with technical and operational factors integrated into a broader strategy for sustainable and scalable insect farming.

Mothers Against Malnutrition And Hunger

FOR HEALTHIER AND PRODUCTIVE COMMUNITIES

RAISE Research and Action for **Income Security**

info@raise.dk • Skæringvej 88 • 8520 Lystrup • CVR: 39 69 98 69