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Sustainable Protein Alternatives: Exploring The Viability of Edible Insects in Crisis Settings

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ABSTRACT
Edible insects are garnering attention as sustainable protein alternatives to address the nutritional challenges in crises. These scenarios, characterized by severe food insecurity and malnutrition, are frequently exacerbated by conflicts, natural disasters, and the COVID-19 pandemic, affecting vulnerable populations. This analysis examines the potential of edible insects, which are rich in protein, essential amino acids, and micronutrients, to address these issues. More than 2,000 insect species are considered edible, with the most frequently consumed being beetles, caterpillars, bees, wasps, ants, grasshoppers, locusts, and crickets. In East Africa, insect farming is expanding, with a focus on crickets, black soldier flies, and other species. However, the industry faces challenges related to feed expenses, pathogen and pest risks, and insufficient research. Enhancing the acceptability and nutritional quality of these foods can be achieved through value addition via processing techniques and incorporation into various food products. High-quality insect protein isolates for food applications can be obtained through protein extraction methods such as alkaline extraction and enzymatic hydrolysis. Promising avenues for increasing edible insect consumption include developing insect-based meat alternatives and fortifying baked goods with insect flour. Nevertheless, consumer acceptance remains a significant obstacle, necessitating additional research on the sensory properties and safety of insect-based foods. Overcoming these challenges requires increased funding, capacity building, and stakeholder coordination to expand the production and utilization of edible insects as a sustainable solution to nutrition challenges in crisis settings.

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INTRODUCTION

Global crises like war and pandemics have forced millions to flee, creating an urgent need for studies on nutrition challenges in crisis settings. People in crisis situations are those forced to leave their homes due to violent conflict, political pressure, and oppression. These groups include those in conflict zones, those crossing borders, and those settled in other nations. Despite these distinctions, people in crises share common vulnerabilities (Pelletier et al., 2024). Loss of life, displacement, hunger, and disease outbreaks significantly impact people in crisis (Zaman et al., 2020).

Food security faces challenges from increasing population, rising consumption, and potential food supply crises. Agricultural output has levelled off, causing widespread hunger in developing countries. Food insecurity stems from climate change, energy crisis, declining soil fertility, pests, plant diseases, increased prices and inequitable distribution (Bao and Song, 2022; Dopelt, Radon, and Davidovitch, 2019). With global population expected to exceed 9.8 billion by 2050 (Mafu et al. 2022), nutritional security is threatened. Dependence on wheat, rice, and maize cannot meet future food demand. Despite increased production, over 820 million people face food insecurity and 2 billion face nutrition insecurity (Jha et al., 2024). Global meat consumption is projected to increase by 75%, reaching 465 million tons annually by 2050 (Sakadevan and Nguyen 2017, Imathiu 2020). The meat industry threatens the environment through greenhouse gas emissions, deforestation, biodiversity loss, and water pollution (Dopelt, Radon, and Davidovitch 2019, Huis and Oonincx 2017). New technologies like genetically modified crops, pest-resistant genotypes, and integrated plant management may take time to become feasible and eco-friendly. Therefore, identifying alternative food protein sources is crucial for sustainable food supply. The Food and Agriculture Organization (FAO) proposed a program to promote alternative sources, including insects (Naseem et al. 2021).

Nutrition Challenges in Crisis Settings

Food Insecurity

The interaction of political, social, and economic factors influencing global food security is increasingly threatened by climate change. These threats include floods, hurricanes, cyclones, droughts, wildfires, heatwaves, rising sea levels, and sea ice pattern changes. Weather-related disasters now occur five times more frequently than fifty years ago, with extreme weather leading to droughts and floods. Such events damage infrastructure, disrupt services and economies, pose health risks, and impact food systems. Data from 15 nations showed households experiencing climate shocks were more susceptible to food insecurity (Hadley et al., 2023). After climate-related disasters, disadvantaged communities face the highest food insecurity risk in both low and high-income countries. Following Hurricane Katrina in 2006, segregated communities in New Orleans experienced prolonged food insecurity. Climate change also interacts with trends like population growth, dietary changes, and urbanization, affecting food security in complex ways.

Price Shocks

Vulnerable populations face challenges accessing affordable food due to inflation and scarcity. Research shows individuals in low-income, food-importing nations struggle to afford nutritious meals as food costs rise. The Sahel region faces hunger and food insecurity challenges, driven by agricultural land pressure from population growth and climate change. Droughts worsen price fluctuations, impacting household welfare (Hodjo et al., 2024). A 2010 World Food Programme report found that during price surges, at-risk households experience reduced food accessibility and nutritional deficiencies. In 2021 and 2022, global food and fertilizer costs increased sharply as economies recovered from COVID-19 amid supply disruptions. The Russia-Ukraine conflict, involving major food producers, added another shock. Rising fertilizer prices raise concerns about reduced fertilizer usage, potentially affecting crop yields and food security. While challenges persist, international food prices remain above historical norms (Vos et al., 2025). A Nigerian study analyzed how food price changes affect household welfare. Results showed rising cereal prices negatively impact household food consumption and caloric intake. Studies found Nigerian households cope with price increases by reducing meal frequency and size. Research evaluated the 2008 food crisis's impact on Nigerian welfare indicators, noting gaps between recommended and actual nutrition intake. Studies also explored food prices' relationship with obesity and weight issues among Nigerian women. Nigerian farmers experienced inefficiencies with the Commodity Board, leading to reduced output. The government dismantled marketing boards in 1986 for market-driven pricing (Akerele et al., 2024). Later governments implemented agricultural input subsidies, moving toward incentive-based pricing strategies.

Dependence on Food Aid

Communities affected by crises depend heavily on humanitarian food aid, which is often inadequate. International efforts typically include food aid initiatives in response to national crises. These initiatives originated in post-World War II Western Europe as part of the Marshall Plan. The United States adapted this model for developing countries in the late 1950s through Public Law 480, the Agricultural Trade Development and Assistance Act of 1954. The United States remains the leading provider of food aid, contributing over half of global food donations (Tigistu et al., 2023). Ethiopia has been one of the largest recipients of food aid worldwide and the largest in Africa. During emergencies, food aid forms the primary component of humanitarian assistance. An emergency is a situation causing significant harm that threatens lives and exceeds communities' capacity to manage. Factors like disasters and low agricultural productivity contribute to Ethiopia's need for external aid, creating dependency. Ethiopia's fragile food security is evident in its increasing reliance on foreign food aid. Between 2022 and 2023, Ethiopia faced unprecedented food aid needs due to drought and food insecurity. As food insecurity remains a global challenge, the UN 2030 Agenda for Sustainable Development urges vulnerable countries to address "Ending poverty" (Goal 1); "Ending hunger and achieving food security" (Goal 2); and "Taking urgent action to combat climate change" (Goal 13) (Tofu et al., 2023).

Malnutrition

Acute Malnutrition (Wasting)

Acute malnutrition, a form of undernutrition, is marked by bilateral pitting edema, wasting, or decreased mid-upper arm circumference (MUAC) or weight-for-height/length (WFH/L). It includes severe acute malnutrition (SAM) and moderate acute malnutrition (MAM). SAM is diagnosed in children with MUAC below 11.5 cm or WFH/L Z-score below -3, while MAM is identified in children with MUAC between 11.5–12.5 cm or WFH/L Z-score below -2. Wasting often results from inadequate food intake or infectious diseases, particularly diarrhea. In 2020, 45.4 million children under five were affected by wasting, with 13.6 million severe cases (Muse et al., 2025). MAM accounts for over half of acute malnutrition cases. Children with malnutrition have weakened immune systems and increased mortality risks. Crisis settings in Africa show high wasting prevalence, with 14 million children under five affected. The 2016 National Nutrition Survey showed 7.6% of children under five in Burkina Faso were undernourished, with 1.4% severely malnourished. Sudan reports high levels of acute malnutrition. In the Nigerian cohort, the median age was 8.2 years, compared to 10 years (range 4.9-13.8) in high-income countries. Males constituted 49.6% and 51.3% of the groups. The mean BMI in the Nigerian cohort was lower than in high-income countries (13.7 vs. 16.9 kg/m^2, $p<0.001$). Among 803 Nigerian children, 34.2% were underweight, 36% had height-for-age below -2, and 42.6% had BMI-for-age Z-score below -2. Severe acute malnutrition affected 20% of the Nigerian cohort, versus 0.7% in high-income countries ($p<0.001$) (Ghafuri, 2017).

A comprehensive study monitored children recovered from severe acute malnutrition alongside healthy peers over six months across Mali (nine locations), South Sudan (six locations), and Somalia (one location). Monthly assessments evaluated children's nutritional status to determine relapse rates and compared acute malnutrition risk between exposed and non-exposed children. The study examined exposed children aged 6-47 months discharged from community-based malnutrition management programs. Non-exposed children without acute malnutrition history were matched by age, sex, and community. Acute malnutrition was defined by mid-upper arm circumference below 125 mm, weight-for-height Z score less than -2, or nutritional edema. The study aimed to determine cumulative acute malnutrition incidence after six months in both groups (King et al., 2024).

Chronic Malnutrition (Stunting)

Globally, one-third of children with severe wasting receive treatment. About 149.2 million children under five experience stunted growth, 45.4 million are wasted, and 38.9 million are overweight. In Kaduna, northwestern Nigeria, stunting and underweight rates among children under five are 47.9% and 35.5%. Despite a US$2,169,000 investment by the state government and UNICEF in 2016 to combat severe acute malnutrition (SAM), Kaduna shows 2.4% prevalence by mid-upper arm circumference (MUAC). SAM management has shifted from inpatient care to community-based outpatient therapeutic programs (OTP) due to limited beds. The OTP treats children aged 6-59 months with SAM using Ready-to-use therapeutic foods (RUTF) and medical protocols, with weekly monitoring until improvement (Kudan et al., 2023). Prolonged food insecurity leads to stunted growth and developmental delays. Most internally displaced people (IDPs) live in basic structures near schools and missions. Their vulnerability increases due to poverty and poor nutrition. Given widespread malnutrition in IDP camps, it contributes to diseases, with malnutrition rates reaching 52% among children (Okoro et al., 2024).

Micronutrient Deficiencies

Micronutrient deficiencies, including calcium, iron, vitamin A, folate, zinc, riboflavin, and vitamin B-12, can cause malnutrition. Food fortification effectively reduces these deficiencies in low-income areas. In Nigeria, 2018 data show 37% of children are stunted, 7% wasted, and 23% underweight, with anemia affecting 58% of women and 68% of children. An accurate food composition database is vital; Nigeria's first, from 2017, lacks data on common soups and dishes. Over two billion people globally suffer from chronic micronutrient deficiencies, linked to diets low in these nutrients. Nigerian soups, containing plant and animal ingredients with minimal protein, palm oil, and vegetables, offer micronutrients but also antinutrients that hinder absorption (Adams et al., 2025; Akinbule et al., 2022). Limited dietary diversity leads to deficiencies in iron, vitamin A, zinc, and other nutrients.

Role of Protein in Nutrition

Proteins are vital for health, providing nitrogen, functioning as hormones, and facilitating tissue building and enzyme activity (An et al., 2025). People mainly obtain protein from animals, supplying complete proteins with all amino acids. However, animal proteins are costly, require extensive land (Liu et al., 2025), contribute to emissions, and excessive intake can cause health issues. Identifying safe protein alternatives is crucial. As populations grow, alternative protein sources are essential. Edible insects offer reduced carbon and water footprints and can utilize food waste, aligning with circular economy principles. Yet, research is needed to scale up insect production (Niemira et al., 2024). With the population expected to exceed ten billion by 2050, sustainable food supply is vital. Entomophagy, or insect consumption, is emerging as a viable solution (Psarianos et al., 2025). This ancient practice, evidenced by chitin remnants, has fluctuated due to cultural preferences. Food security concerns have renewed interest, with studies introducing modern culinary techniques to overcome stigmas.

While crop and livestock farming are emphasized, insect cultivation is an underutilized yet promising food source. Research is shifting perceptions, encouraging adoption. Compared to traditional agriculture, insect farming offers a cost-effective option for sustainable livelihoods (Sokame et al., 2024). Edible insects are increasingly seen as a solution to sustainable food production challenges, offering advantages over conventional livestock, such as better feed conversion efficiency, lower emissions, and reduced water usage.

Currently, 113 countries practice entomophagy, mainly in Asia, Africa, and Latin America, where 2 billion people eat insects. Scientists are improving processing techniques and shelf life of insect products through protein and lipid extraction (Pastrana-Pastrana et al., 2025). Over 2,300 insect species are edible, containing proteins, amino acids, fatty acids, and micronutrients, varying by diet and life stage.

Edible insects provide nutritional, environmental, and food security benefits, while containing biologically active molecules that combat diseases. Using insects as ingredients in unrecognizable forms could increase acceptance in North America and Europe. Enzymatic hydrolysis is proposed to enhance insect protein functionality and health benefits.

Global Context of Edible Insects

Entomophagy

Entomophagy, the practice of consuming insects, dates back 400 million years, with insects making up 80% of the animal kingdom. Over two billion people include them in their diets. Researchers have identified 1,900 edible insect species in 113 countries (Bernard and Womeni 2017). The edible insects market is projected to reach 1.2 billion by 2023 (Liceaga, 2021). The world population is expected to grow by 2.4 billion between 2015 and 2050, with 1.3 billion in Africa, mainly Nigeria (United Nations 2021). By 2050, Nigeria's population may reach 300 million. Nigerians consume only 7-10 grams of protein daily, below the FAO's recommended 35 grams (Ebenebe et al., 2017), worsening malnutrition and highlighting the need for alternative proteins. Edible insects have been processed into flour and oil. Insect flour is used in bread, cakes, biscuits, and soups (Ebenebe et al., 2020). Fortifying mealworm and grasshopper flour with erişte, Turkish egg, wheat flour, lentils, and white kidney beans enhances nutrition (Çabuk and Yilmaz, 2020). Edible insects contain essential amino acids missing in Nigerian protein sources. Ekpo (2011) found that African palm weevil, coconut palm rhinoceros beetle, caterpillar, and termite are rich in lysine and methionine, lacking in cereal, soybean, and lentil proteins. Insect protein content ranges from 21% to 75% of body mass (Elhassan et al., 2019).

Insect Species

Insects constitute one of the most diverse animal groups on Earth, occupying nearly all ecosystems and comprising roughly half of the total animal biomass (Gonz´alez Hern´andez et al., 2019). Approximately 2,000 insect species are considered edible, and this number is increasing. Among these edible species, beetles and caterpillars dominate at 49%, while others include bees, wasps, and ants (14%); grasshoppers, locusts, and crickets (13%); Hemipterans (10%); dragonflies (3%); termites (3%); and flies (2%) (Pr´osper Ortega, 2020). Insects can be consumed as eggs, larvae, pupae (chrysalis, puparia), or adults, though not all insects are edible at every developmental stage, varying among taxa. Edible species are collected from the environment and processed through baking or roasting, though some species can be eaten raw (de Carvalho et al., 2019). In gastronomy, they can be fried, stewed, cooked, steamed, boiled, or roasted, with heat treatment and seasoning. Once prepared, they can be eaten as snacks, like nuts or vegetable chips, and used as ingredients in various dishes, such as salads or pizzas.

Nutritional Profile of Edible Insects

Among the roughly 2,000 identified edible insect species, few have been thoroughly examined for nutritional content. Insects provide rich protein and mono- and polyunsaturated fatty acids, along with vitamins like riboflavin, pantothenic acid, biotin, and folic acid, and minerals including copper, iron, magnesium, manganese, phosphorus, selenium, and zinc. These nutrients align with WHO and FAO recommended daily intake guidelines (Bessa et al., 2017; Guzmán-Mendoza et al., 2016). For insects lacking certain nutrients, combining them with other foods creates nutritionally complete meals (Nowak et al., 2016). Nutrient levels vary by species, diet, rearing conditions, and developmental stage (Meyer-Rochow and Jung, 2020). Caloric content ranges from 293 to 776 kilocalories (kcal) per 100 g of dry matter. The thousand-headed snake worm (Latebraria amphipyrioides) provides 349 kcal per 100 g, while the Mexican moth (Phassus triangularis) delivers 761 kcal per 100 g. Insects contain 38% to 77% protein by total dry weight, with Orthoptera order insects showing higher concentrations. Although insects are consumed worldwide (Halloran et al., 2016), Western cultural influences have relegated entomophagy to a survival strategy or diet associated with poverty. These perceptions impede entomophagy promotion as a sustainable dietary option (Motoki et al., 2020). Research on house and two-spotted crickets showed 60% to 70% protein content (DWB), essential amino acids, 10% to 23%

lipids, omega-3 and omega-6 fatty acids, and minerals including sodium, calcium, and phosphorus, indicating their potential as an alternative nutritional source.

Field crickets analyzed using spectroscopic methods contained 55.6% crude protein and 11.8% fat, with notable levels of palmitic, oleic, and linoleic acids. A study on armored crickets showed energy content of 454.3 kcal/100g, with compositions of carbohydrate (1.20%), protein (69.2%), fat (16.8%), ash (8.6%), and chitin (4.2%). The insects provided 11.48 mg iron, 491 mg phosphorus, and 4.37 mg zinc per 100g. Major essential amino acids included leucine (60.7 mg/g protein), phenylalanine/tyrosine (59.3 mg/g protein), valine (48.4 mg/g protein), and lysine (46.7 mg/g protein). Predominant fatty acids were palmitic and stearic (2005.3 mg/100g and 2034.5 mg/100g), with monounsaturated fatty acids including palmitoleic and oleic acids, and polyunsaturated fatty acids comprising linolenic acid and EPA. Analysis of Morio worm and Jamaican crickets showed the worm contained 46.80% protein and 43.64% lipid, while crickets had 65.52% protein and 21.80% lipid. A study on harvesting timing showed 13-week crickets contained 36-60g/100g crude protein and 12-25g/100g lipids. Cricket powders from Thailand and Canada contained 42.0-45.8% protein and 23.6-29.1% fat, with significant mineral content. Analysis of cricket, silkworm, and locust powders revealed protein content exceeding 70g/100g in cricket and locust, and 50g/100g in silkworm, with essential amino acids surpassing FAO/WHO/UNU guidelines for adults (Hassan et al., 2024).

Edible Insects Crisis Settings

Opportunities

One of the most compelling benefits of using edible insects as a sustainable protein source is their short life cycles and rapid production rates. These characteristics make them particularly well-suited for addressing nutritional challenges in crisis settings, where timely and scalable solutions are essential. Edible insects, such as crickets, mealworms, and black soldier flies, have significantly shorter life cycles compared to traditional livestock like cattle, pigs, or chickens.

Crickets (Acheta domesticus)

Insects are nutritious and suitable for human consumption. The house cricket (Acheta domesticus, AD), from Southwest Asia, is now widespread across multiple continents and was recently recognized as a novel food by the EU (EU 2022/188). This cricket is consumed for its palatability and high nutritional value, containing proteins, lipids, and essential nutrients. The lipid content ranges from 8.9 to 43.9 g/100 g dry matter (DM). Crickets contain more unsaturated fatty acids (UFA) (61–64%) than saturated fatty acids (SFA) (32–39%). These SFAs are linked to increased LDL-cholesterol and inflammation, contributing to cardiovascular disease. Crickets lack omega-3 long-chain polyunsaturated fatty acids (n–3 LC-PUFAs) and show an unbalanced n–6/n–3 ratio (17–29). High UFA levels in diet reduce chronic ailments, while increased n–3 LC-PUFA consumption improves cognitive function. Research shows these fatty acids can be increased through marine-derived biomass in their diet (Ajdini et al., 2025). Protein enhancement requires removing indigestible components like chitin. Defatted insect powder is used for protein extraction through traditional or advanced methods, with alkaline extraction being most common (Palcu et al., 2025). Several Tenebrio molitor products have been approved as novel foods in Europe under Regulation (EU) 2015/2283. Tenebrio molitor contains high-quality proteins (47.0% to 60.2%) and lipids (19.1% to 36.7%), with essential omega 3 (46.1–47.3 g/100 g) and omega 6 (31.1–31.6 g/100 g) fatty acids, plus iron, zinc, and vitamin B12 (0.47 µg per 100 g) (Oonincx et al., 2015).

Refugee Camps in East Africa

In Kenya and Uganda, pilot projects have introduced cricket farming to supply protein to refugees (Munke-Svendsen et al., 2020). A study explored buns made with cricket flour (CFC). Most consumed insect species are beetle larvae (Coleoptera), caterpillars (Lepidoptera), grasshoppers and crickets (Orthoptera), and ants, bees, and wasps (Hymenoptera). Most species are harvested from the wild. Western interest surged after the 2013 FAO report "Edible Insects: Future Prospects for Food and Feed Security." Companies rearing insects for pet food began producing insects for human consumption and animal feed. Species farmed for human food include house crickets (Acheta domestica), migratory locusts (Locusta migratoria), yellow mealworms (Tenebrio molitor), lesser mealworms (Alphitobius diaperinus), and silkworm pupae (Bombyx mori). A review of over 1,100 documents listed silkworms, bees, beetles, mealworms, crickets, and cicadas as main edible groups. The predominant technology uses protein isolates as ingredients. Insect species should be recommended based on nutritional value (Van Huis & Rumpold 2023).

Disaster Relief in Southeast Asia

Thailand and Lao PDR have a longstanding tradition of entomophagy, enhancing food security and nutrition. While insects were traditionally collected for personal consumption, there is now an increasing trend of selling them in local markets as income sources. Though household consumption remains common, patterns are evolving with growing demand for insects as snacks in urban areas. Production methods now include both wild collection and insect farming. Marketing strategies are adapting to changing consumer preferences, especially in urban populations. The production, processing, and marketing of edible insects generate income and employment opportunities throughout Thailand and Lao PDR, with niche markets offering expanding prospects. In Thailand, black soldier fly larvae have been utilized to convert organic waste into protein-rich feed for livestock (Chia et al., 2019).

Challenges and Considerations

While the rapid production of edible insects offers significant benefits, several challenges must be addressed:

Cultural Acceptance

In certain regions, insects are not part of the traditional diet, requiring cultural barriers to be overcome (van Huis, 2020). Research by Palcu et al. (2025) suggests that individuals curious about trying insects might benefit from emotion regulation strategies. These strategies include cognitive distraction techniques, such as imagining coffee smells or showers, and activities like music or social media. Engaging in these activities while sampling insect-based foods may enhance the experience and could promote environmental benefits. Previous research has focused on marketing insect-based foods as sustainable and nutritious or emphasizing personal benefits, despite emotional resistance to trying them. Limited research addresses the negative emotions associated with consuming insects. A study confirms that humor effectively overcomes reluctance to consume insects, demonstrated by the slogan "Eat them before they eat you." Brands targeting consumers might incorporate guides for consuming insects on packaging, integrating emotion regulation strategies. Research indicates that positive reappraisal enhances the desire for alternative proteins, including insects. Although these findings may seem contradictory, they differ in methodology concerning reappraisal manipulation, measures, and sample. Further research is needed to understand how situational factors influence reappraisal success.

Infrastructure

Insect farming requires initial investment in training, equipment, and supply chains (Halloran et al., 2018). Technical constraints present significant challenges. While automation and vertical farming technologies have advanced in developed countries, such progress remains limited in developing regions. A major concern is electricity availability, crucial for large-scale insect production systems. In rural areas, unreliable electricity supply hinders the adoption of modern farming technologies and optimal insect growth conditions. It is essential to develop efficient rearing systems, feed formulations, and waste management processes tailored to local conditions and rural community challenges (Ibitoye et al., 2025).

Regulatory Frameworks

Establishing guidelines is crucial for ensuring insect-based product safety and quality (FAO, 2013). Stakeholders must work with policymakers to develop science-based regulations. Industry standards ensure food safety and promote growth. Cooperation among industry, research institutions, and government is vital for regulation. Education initiatives are needed to address public perception. Highlighting sustainability and nutritional benefits of insect farming can influence public attitudes. Marketing strategies focusing on environmental benefits can enhance acceptance. Research and innovation can address technical challenges. Investments in renewable energy can tackle electricity shortages in farming. Collaboration among institutions and technology providers can drive progress. Interdisciplinary research integrating multiple sciences can solve technical challenges. Urban insect farming has potential for sustainable agriculture, but overcoming regulatory and technical challenges is crucial. By establishing regulations and investing in innovation, urban insect farming can contribute to sustainable food systems. Traditional livestock like cattle require 18–24 months to reach slaughter weight, while chickens take 5–7 weeks (FAO, 2013). This rapid growth allows insects to be farmed multiple times annually (Ibitoye et al., 2025).

Case Studies and Pilot Projects

Food security in Kenya faces challenges from high input costs, dysfunctional markets, poor land management, and post-harvest spoilage. In 2015, the Global Acute Malnutrition (GAM) and Severe Acute Malnutrition (SAM) rates at Kakuma refugee camp were 20.5% and 11.1%, up from 7.9% GAM in 2013 due to South Sudanese asylum-seekers. Anaemia affects two-thirds of children, while the local Turkana population has a 28.7% GAM rate. At the camp, crude mortality and underage mortality rates were 0.2/10,000/day and 0.07/10,000/day in 2016. Employment opportunities are limited, with women working in food services and cleaning, while men engage in small businesses and trades. Educational enrollment rates are 25% for pre-schools, 65% for elementary, and 2% for secondary schools. Agriculture and animal husbandry are not feasible due to climate and restrictions. Regular droughts impact Turkana County, where 90% live below the poverty line. Cricket farming was introduced in refugee camps as a protein and income source. In Kakuma, a cricket colony at DanChurchAid supplied eggs to trained households from seven nationalities. Households received starter kits with supplies and harvested 0.5-3.0 kg of crickets per cycle, using them as food (55.65%) or feed (44.35%). Processing methods included sun drying, blanching, or frying, with sun drying and frying being most common (52.17%). A significant correlation ($P < 0.001$) existed between cricket use and processing methods. The harvested crickets could provide over 30% of recommended daily protein intake for women and children, though strengthening the cricket value chain remains necessary.

Innovative Approaches to Scaling Edible Insect Solutions

Insects Farming

For large-scale production, insect species must exhibit rapid growth, dietary adaptability, low chitin content, and efficient feed bioconversion (Galecki et al., 2021; Bakula and Galecki, 2021). Species should consume various materials while remaining resilient to microclimate changes (Galecki et al., 2021; Cadinu et al., 2021). Key factors include feed availability, rearing conditions, and safety procedures (Kok, 2021). Understanding biological and chemical residues is crucial. H. illucens can accumulate heavy metals, though Purschke et al. found no pesticides in larvae (Purschke et al., 2017). Products may become contaminated through harmful substances. Limited knowledge exists about insect metabolic pathways (Lievens et al., 2021). Insects can serve as pathogen reservoirs (Doi et al., 2021; Galecki and Sockol, 2019; Grenda et al., 2021), including COVID-19 transmission (Doi et al., 2021). Sustainable farming requires infrastructure and personnel (Dossey et al., 2016; Specht et al., 2019). Farms need protection from pollution and pests, with management systems including HACCP (Fraqueza et al., 2017).

Farm buildings must comply with hygiene and biosecurity standards (Higgins et al., 2018). Premises must be contamination-free and cleanable. Breeding facilities should prevent cross-contamination from other production sites. Farms require clean and dirty zones, air filters, and adequate space (Krystyna et al., 2022). Regular monitoring for contamination and pests is necessary. Pest control systems should prevent external threats and insect escape. Common pests include insects, spiders, birds, and rodents (Drummond et al., 2019; Savary et al., 2019). Facilities require proper maintenance with prompt waste removal (Krystyna et al., 2022).

The Status of Insect Farming Enterprises

In East Africa, there is considerable potential for farming edible insects, such as Acheta domesticus, Scapsipedus icipe, Gryllus bimaculatus, Schistocerca gregaria, Ruspolia differens, Hermetia illucens, Tenebrio molitor, and Rhynchophorus phoenicis (Magara et al., 2021; Egonyu et al., 2020). Despite this potential, the growing industry has received limited research attention. Insect farming is developing into a rapidly expanding agribusiness (Zewdu et al., 2020), following global trends (Govorushko, 2019; Darrien and Boccuni, 2018). Companies have emerged in Kenya, Tanzania, and Uganda, with over 95% operating as microenterprises, presenting opportunities to transition into automated systems as the market grows.

Farming insects for food

Cricket farming is growing in Kenya (378 farmers) and Uganda (140 farmers) due to entomophagy traditions. Commonly farmed species include S. icipe, A. domesticus, and G. bimaculatus. SMEs produce over 30 tons of cricket powder annually (Magara et al., 2021). InsectiPro Ltd. in Kenya produces one ton monthly at 30-32°C and 55-75% humidity. Rearing technology for locusts, grasshoppers, palm weevils, flies, mealworms, and African fruit beetles requires optimization. High feed costs are the primary expense (Oloo et al., 2021), requiring research into alternative diets (Mmari et al., 2017). Farming adoption depends on awareness, mobile phone ownership, risk aversion (Cheseto et al., 2020), and sales. Dried cricket products cost US $10.9-18.2/kg, exceeding prices of wild-caught grasshoppers in Tanzania (US $4.2-4.5/kg) and Uganda (US $2.8-3/kg) (Chia et al., 2019). Both farmed and wild-caught insect prices surpass fishmeal prices in Europe (Madau et al., 2020). Mass production and circular economy adoption are expected to reduce prices to compete with livestock at US $4-5/kg (Chia et al., 2019). Data on insect farming costs in Africa remains limited.

Value addition of insects for food and feed

Edible insects are mainly used in the form of dried whole or ground meals, which can be added as an ingredient in baked goods and serve as a protein source in animal feed (Chia et al., 2020; Sumbule et al., 2021; Mary et al., 2020; Kinguru et al., 2021). Common food products enriched with insect meal include crackers, buns, cupcakes, samosas, chapatis, biscuits, bread, cookies, and cereal-based porridge, among others, to enhance their nutritional value and boost consumer acceptance (Megido et al., 2018; Vogel et al., 2018). Various processing techniques, such as oven baking, boiling, smoking, roasting, pan-frying, vacuum cooking, and extrusion, have been employed to significantly enhance nutritional properties, reduce microbial contamination, improve palatability, and increase consumer acceptance. Consequently, advanced processing technologies must be aligned to develop a new generation of products with extended shelf life and improved safety quality. Additional value-added products include nutraceutical compounds, biodiesel, chitin, chitosan, and oils derived from diverse African edible insects.

Protein Extraction of Edible Insects

Insect protein is extracted using conventional methods (aqua-based, salt, solvent, detergent, alkali) and non-conventional green methods (enzyme, ultrasound, microwave, pulsed electric field-assisted) (Kumar et al., 2021). Alkaline extraction is most common, with proteins solubilizing at alkaline pH to yield 70% crude protein. Proteins precipitate at pH 4–5 after removing undesirable components (Brogan et al., 2021). Protein solubility increases with pH due to amino acid ionization (Deleu et al., 2019), though cricket protein extractability using ascorbic acid at pH 2-3 exceeded that using sodium hydroxide at pH 13 (Amarender et al., 2020). Mintah et al. (Mintah et al., 2020) achieved 64.44% extraction for Hermetia illucens using alkali extraction. Protein content was measured using Kjeldahl method with nitrogen conversion factor (6.25), though Janssen et al. (Janssen et al., 2017) determined factors of 4.76 for whole larvae and 5.60 for water-soluble protein extracts.

Ionic liquids offer more effective protein isolation than traditional solvents. Choline hydroxide ionic liquid increased silkworm pupa protein content by 12.14% versus conventional methods (Zeng et al., 2021). Salting-assisted extraction enhances alkaline solubility-acid precipitation (AEAP) efficiency. Jiang et al. (Jiang et al., 2021) found protein yields increased from 22.26% to 39.5% with combined salting treatments. Conventional methods can yield lower protein extraction due to degradation affected by extraction conditions. Green technologies now focus on enhancing extractability and reducing degradation. Physical extraction methods like ultrasound, microwave, and pulsed electric field can significantly enhance protein extraction efficiency (Psarianos et al., 2022; Mishyna et al., 2019). Ultrasound offers easy operation and reduced solvent use (Yusoff et al., 2022). Microwave technology provides green advantages but can degrade bioactive compounds (Segatto et al., 2022; Munoz-Almagro et al., 2021). Psarianos et al. (2022) found cricket protein yield increased 32.47% after 15 minutes using pulsed electric field (4.90 kJ/kg), while 24.53 kJ/kg and 49.10 kJ/kg treatments yielded 30.47% and 39.55% higher than control (Meijer et al., 2025).

Food Products and Edible Insects

Meat Products and Meat Analogs with Edible Insects

Recent scientific investigations into the integration of insects into meat products have been expanding. The primary technological characteristics of edible insect proteins include emulsifying capacity, gel formation, water and oil retention, and solubility (Kim et al., 2020; Scholliers et al., 2019). Research efforts focus on substituting meat protein with insect protein, using either whole or defatted flour. The mealworm (Tenebrio molitor) has been extensively studied due to its high nutritional content, comprising 53.10% proteins, 36.7% lipids, and 5.1% fibers (EFSA NDA Panel et al., 2021). Insect proteins have been shown to enhance the stability of meat emulsions, although textural challenges remain. Scholliers et al. (2019) observed that increasing insect content diminishes the textural qualities of cooked-meat sausages. Conversely, Choi et al. (2017) reported reduced firmness in mealworm frankfurters, while Kim et al. (2016; 2017) noted contrary effects. These discrepancies may arise from differences in incorporation methods and reformulation strategies. Research indicates that samples containing 100% insect protein exhibit greater heat stability compared to jerky analogs (Kim et al., 2022). Kiiru et al. (2020) found that extrusion temperature and the quantity of cricket flour influence the tensile strength of meat substitutes. Kim et al. (2022) identified that optimal texture is achieved with a composition of 40% insect and 60% vegetable protein. The incorporation of edible insects encounters challenges due to food neophobia and altered sensory profiles (Megido et al., 2016; Villasenor VM et al., 2021; Ardon R and Prinyawiwatkul W, 2021). Cho and Ryu (2022) found that increased mealworm content improved acceptance scores despite lower texture ratings. Choi et al. (2017) demonstrated that frankfurters with 10% yellow mealworm maintained acceptance levels comparable to controls. While advancements have been made in developing insect-containing meat products, further research is necessary to fully understand their properties. Studies indicate that incorporating more than 10% insects results in undesirable changes, necessitating innovative strategies to include higher proportions without compromising quality.

Bakery products with edible insects

Edible insects have been incorporated into bakery products to enhance protein and fiber levels, support gluten-free products (Skendi et al., 2021), and provide unique sensory characteristics (Mancini et al., 2022). Insect flours have gained attention for inclusion in bread, cookies, muffins, cakes, and snacks. Insect flour enhances nutrition through high protein, fiber, unsaturated lipids, and minerals (Soare et al., 2019). Smarzyński et al. (2021) found increased protein and minerals in cookies with 2% cricket powder. Insect proteins provide low lipid content and high essential amino acids. Luna et al. (2021) created cricket protein hydrolysates with 70% crude protein for tortillas, containing essential amino acids. Recent research focuses on improving product quality as consumer acceptance increases (Gurdian et al., 2022; Gurdian et al., 2021). Due to consumer aversion, bakery companies incorporate insects as powder (Mancini et al., 2022). The main limitations are sensory attributes and neophobia (Yazici and Ozer, 2021). Insect flours result in darker color and distinct smell, affecting acceptability. Lacking gluten, insect flour impacts texture, decreasing hardness and cohesiveness (Kowalski et al., 2022; Çabuk, 2021). Kowalski et al. (2022) found that supplementing wheat bread with insect flours is acceptable up to 10% replacement. For biscuits and cookies, 5-25% cereal flour substitution is possible (Yazici and Ozer, 2021). Researchers have explored using isolated insect proteins instead of whole flour (Luna et al., 2021). Protein extraction methods include enzymatic proteolysis, lipid extraction, and fermentation (Liceaga, 2021).

Technological Innovations

Fermentation is a processing technology that enhances food properties, particularly in creating high-quality products from edible insects. Research indicates that fermenting cricket flour boosts its amino acid and mineral content, thereby enriching insect-based sourdough products. This process releases specific peptides with biological functions from insect proteins. Studies have demonstrated that fermented insect flours exhibit increased antioxidant and anti-hypertensive activities due to protein degradation, which releases bioactive peptides. Fermented field crickets have shown superior anti-diabetic, anti-cholesterol, and antioxidant activities compared to their non-fermented counterparts, with these bioactivities being influenced by the fermenting microorganisms (Dhakal et al., 2025).

Integration with Existing Nutrition Programs

Meyer-Rochow and Jung (2022) creatively propose that "Mealworms and spaghetti is food that makes you happy!" and "Forget about the fork and put a cricket on your fork!" (Lisboa et al., 2024). These engaging expressions encapsulate the concept of integrating edible insects into daily meals, emphasizing their potential to enhance both enjoyment and health benefits in dining experiences. By adopting such innovative and positive messaging, the appeal of edible insects can be increased, thereby promoting their acceptance on a global scale. The incorporation of edible insect flours from crickets and locusts into an extruded rice product has demonstrated success, exhibiting acceptable shelf stability and sensory characteristics. Nutritionally, the developed insect rice products are energy-dense (high in fat content) and serve as an excellent source of protein, while also containing significant amounts of dietary fiber and iron. Sensory evaluations involving 120 untrained panelists indicated that cricket formulations were more favorably received compared to locust formulations. There is a positive outlook on the overall acceptance of entomophagy, even in developed countries. As a staple food providing 20% of the world's dietary energy and consumed by over 1 billion people, rice serves as an ideal vehicle for delivering nutrients carried by edible insects. The incorporation of insect flours in processed foods such as extruded rice products can significantly enhance consumer acceptance by mitigating the 'yuck' factor associated with intact insects (Tao et al., 2018).

Policy and Advocacy

Legal frameworks are essential for insect farming and marketing of insect-derived foods. Commission Regulation (EU) 2017/893, which modifies Annexes of Regulation (EC) No. 999/2001 and Commission Regulation (EU) No. 142/2011, specifies insect species meeting safety criteria for feed production. These species include H. illucens, M. domestica, T. molitor, A. diaperinus, G. sigillatus, A. domesticus, and G. assimilis. They are designated as novel foods in the EU following risk evaluations and EFSA's scientific opinion dated 8 October 2015. The species are non-pathogenic, non-invasive, and do not cause harm. According to EFSA's opinion on 13 January 2021, yellow mealworm larvae are safe for human consumption. Novel food products have a simpler registration process, and insect-based products can be marketed in the EU. Several African nations have frameworks for collecting wild edible insects (Gałęcki et al., 2022). When farmed, insects must comply with substrate and legal requirements for food and feed. EU regulatory limits ensure free movement of goods and consumer protection. Due to limited research, specific regulatory limits for insects are largely absent. Regulation (EC) No 178/2002 principles apply to ethical requirements and safety criteria. While Directive 98/58/EC excludes invertebrates from livestock welfare, national laws may apply. The Netherlands' 'Wet dieren' law ensures insect welfare through basic freedoms. Though insect sentience remains uncertain, a precautionary welfare approach is advised. While Regulation (EU) 2017/893 removed slaughterhouse requirements for insect PAPs, no EU welfare regulations exist for killing. IPIFF has issued a non-binding factsheet for standardizing insect welfare practices (Meijer et al., 2025).

Pathogen and pest risks associated with insect farming systems

No major disease outbreaks have been reported in BSF farming systems due to their antimicrobial peptides (AMPs) that reduce bacterial loads in substrates (Gerrard et al., 2019). Though studies on fungal infections are limited, BSF larvae are susceptible to Metarhizium anisopliae and Beauveria bassiana (Tanga et al. in preparation). Lecocq et al. (Khamis et al., 2020) reported B. bassiana pathogenicity to adult BSF in laboratory trials. Key natural enemies include the pupal parasitoid, Eniacomorpha herme-tiae Delvare, causing over 70% parasitism (Tanga et al., 2020), mite Macrocheles muscaedomesticae (Scopoli), pests (Tribolium castaneum Herbst and Necro-bia rufipes DeGeer), pathogenic bacteria (Campylo- bacter, Morganella, Wohlfahrtiimonas, and Providencia) and fungi (Cyberlindnera sp. and Trichosporon sp.) (Maciel-Vergora et al., 2021). Adult crickets infected with M. anisopliae and B. bassiana show advanced mycosis (Tanga et al. in prepa-ration). Lethal pathogen Rickettsiella grylli affects adult crickets in Kenya and Uganda (Merciel-Vergora and Ros, 2017). Cricket paralysis virus (AdDNV) remains absent but requires monitoring given its incurable nature (Merciel-Vergora and Ros, 2017). This necessitates monitoring and prevention measures to minimize pathogen impact in farmed insects.

CONCLUSION

Edible insects are recognized as sustainable protein sources for addressing nutritional challenges in crisis situations. With over 2,000 edible insect species, commonly consumed ones include beetles, caterpillars, bees, wasps, ants, grasshoppers, locusts, and crickets. Insect farming is growing in East Africa, focusing on crickets and black soldier flies, yet faces challenges of feed costs, pathogen risks, and limited research. The acceptability and nutritional quality of insect-based foods can be improved through processing techniques and incorporation into food products. Protein extraction methods can produce high-quality insect protein isolates for food applications. Developing insect-based meat alternatives and fortifying baked goods with insect flour are strategies to increase consumption. Consumer acceptance remains a challenge, requiring research on sensory properties and safety. Addressing these issues needs funding, capacity building, and stakeholder coordination to expand edible insect use in crisis settings.

Vision for the Future

With global population rising and pressure on food systems mounting, edible insects are emerging as a sustainable, nutritious food source. In crises where food supply chains are disrupted, insects offer an alternative to meet nutritional needs. Insects like crickets, mealworms, and locusts provide complete proteins with essential amino acids, comparable to meat and fish. They contain iron, zinc, calcium, magnesium, and B vitamins, often lacking in emergency supplies. Many edible insects contain healthy unsaturated fats, including omega-3 and omega-6. In crises, insect-based foods can prevent malnutrition among vulnerable groups. Insects require less land, water, and feed than livestock, with crickets needing 12 times less feed than cattle for equivalent protein. They reproduce rapidly, enabling swift food production. Insect farming generates fewer emissions and can be established locally in crisis-affected areas. Insects can be integrated into food aid programs as protein-rich powders or bars. In regions where insect consumption is traditional, these products can enhance feeding programs. Small-scale insect farming provides income and promotes self-reliance, involving women, youth, and marginalized groups. As agriculture becomes vulnerable to climate change, insect farming offers resilience by reducing dependence on staple crops. With population reaching 9.7 billion by 2050, insects provide a scalable protein source.

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