Review Article

Sekobane D. Kolobe, Tlou G. Manyelo, Nthabiseng A. Sebola, Emmanuel Malematja, Mabelebele Monnye*

A transformative poultry feed system: The impact of insects as an alternative and transformative poultry-based diet in sub-Saharan Africa

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Abstract: There is growing interest in the transformation of costly, unsustainable feed systems to help address malnutrition and food insecurity in sub-Saharan Africa (SSA). In the poultry production industry, dietary insect meals were identified as a possible solution to aid in transforming poultry feeds by replacing expensive and environmentally threatening protein feed ingredients including soyabean and fish meal. Hence, playing an important role in helping to feed the ever-growing human population size through the production of more poultry meat and meat products. The potential of edible insects as highly nutritious, cost-effective, and biofriendly alternative protein feed ingredient in poultry diets is currently one of the most trending topics in animal nutrition worldwide. This review will provide a recent overview of the utilisation of insect-based diets by poultry-producing farmers in SSA, to improve poultry production at low costs with little effect on climate change. Therefore, the perspectives of various farmers towards using insect-based diets in poultry production; recent findings on the effect of insect-based diets on poultry production and performance; benefits of insect-based poultry meat; adoption and awareness of insect farming; and opportunities and constrains of rearing insects for animal feeding in SSA were discussed. Hence, there is still a need to improve insect farming infrastructure, educating and training insect and poultry-producing farmers on insect rearing and marketing, enforcing laws and policies on insect farming operation, investing and conducting more research on local insects in poultry diets, as well as conserving wild insects and the environment in general.

Keywords: insect meal, poultry production, insect farming, entomophagy, sub-Saharan Africa

1 Introduction

The production of adequate and sustainable food to curb global food insecurity by 2030 is some of the targets that falls under 17 Sustainable Development Goals set by the United Nations [1]. These targets are also reflected in the Agenda 2063 “Africa we want” and the National Development Plan of South African which also focus on improving nutrition and complete eradication of poverty and hunger in African countries. However, it is nearing 2030 and most targets are still far from being achieved [2,3]. The poultry industry, particularly chicken production, is one of the main meat protein sources produced in large quantity compared to meat from other livestock and, hence, contributes more to the Gross Domestic Product of African countries [4,5]. However, the continent, especially countries in sub-Saharan Africa (SSA), is experiencing a decline in poultry farming, particularly chicken production due to high feed costs, mainly protein sources such as fish meal and soyabean meal as shown in Figure 2 [6,7]. For instance, according to Vernooij et al. [8] and Abro et al. [9], the total poultry protein feed demand by the entire poultry sector (broilers, layers, and indigenous chickens) in Africa is approximately 1,306,004 tonnes. Hence, poultry-producing farmers tend to provide their flock with low-quality feeds which consequently leads to low production and performance. As such, most countries in the Sub-Saharan regions rely on imports of chicken meat from countries such as Brazil and the United States. Recently, there is an increased interest in the transformation of unsustainable animal feed [10]. This is because the production of soya and

* Corresponding author: Mabelebele Monnye, Department of Agriculture and Animal Health, University of South Africa, College of Agriculture and Environmental Sciences, Florida, 1710, South Africa, e-mail: mabelm@unisa.ac.za, tel: +27 114 713 983
Sekobane D. Kolobe, Tlou G. Manyelo, Nthabiseng A. Sebola, Emmanuel Malematja: Department of Agriculture and Animal Health, University of South Africa, College of Agriculture and Environmental Sciences, Florida, 1710, South Africa

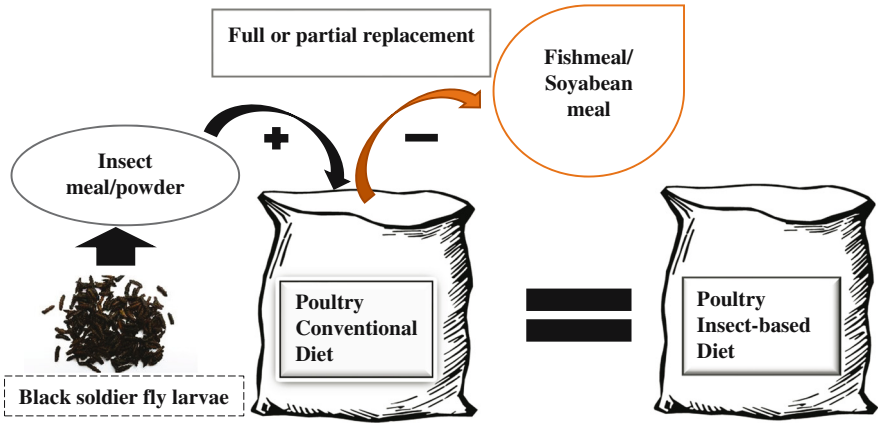

Figure 1: The transformation of poultry diets through inclusion of dried insect meals.

fishmeal as feed for livestock has been reported to cause adverse effects on the environment and contribute to climate change through: damage of marine ecosystem, soil contamination, air and water pollution, and large land utilisation, resulting in biodiversity loss [11–13]. Hence, the determination of novel solution to meet the animal protein requirement balancing of production animals is key to the development of animal industry in future trends [14].

Alternatively, insect meals have been widely documented as a potential protein feed ingredient to replace the main conventional feedstuffs in poultry diets [7,15–17]. Furthermore, they have long been known to be consumed by poultry species, especially free-range and indigenous chickens in rural areas [18]. There are about 500–1,500 edible insect species discovered in Africa [1,19–21]. This includes beetles, grasshoppers, locusts, crickets, termites, and stinkbugs [20]. Although the poultry sector contributes about 11% of total greenhouse gases in livestock production [11], insect production is considered environmentally friendly since it emits less ammonia and greenhouse gases while requiring limited space of land and water for rearing, hence, reducing climate change [14,20–22]. However, edible insects such as termites, locusts, and grasshoppers are highly recognised as important agricultural pests known to destroy homes and agricultural lands in SSA [23]. Despite vast literature reported on the nutritional status and performance of various insects as a potential protein source in the diets of animals such as fish, pig, rabbit, and poultry [24], there are limited reports on the current state utilising insect-based diets for poultry production in SSA. This is because insects as poultry feeds in the African commercial sector have not been fully explored [22,25].

Therefore, this review aims to discuss the recent updates and progress on the transformation of African poultry feed systems by using insect meals as an alternative protein ingredient in poultry feeds. Thus, discussing the perspectives of various farmers towards using insect-based diets in poultry production; recent findings on the effect of insect-based diets on poultry production and performance; benefits of insect-based poultry meat; adoption and awareness of insect farming; and opportunities and constrains of rearing insects for animal feeding in SSA will aid in concluding whether there is a positive progress in farming and utilisation of insects for poultry production in Africa.

2 Literature research strategy

This study uses data from pre-revised and published articles conducted on the adoption and awareness of insect farming, perspectives of various farmers towards using insect-based diets in poultry production, recent findings on the effect of insect-based diets on poultry production and performance, benefits of insect-based poultry meat, and governments action towards improving insect farming in SSA from electronic database such as Google scholar, Research gate, Directory of Open Access Journals, Science direct, and JURN. First, the electronic database was searched by using key words and other terms relevant for this topic such as insect meal, insect farming, poultry production, and SSA. The second step was to select relevant articles for the transformation of African poultry feed systems using insect-based diets. Third, the identified articles were further evaluated, sorted, and screened by their abstracts for relevancy. If the abstract passed the evaluation and screening phase, full articles were retrieved and read to be included as part of the manuscript.

3 Discussion

3.1 Adoption of insect farming practice in SSA

The consumption and rearing of edible insects for commercial production are rapidly gaining more attraction across Africa, particularly sub-Saharan countries due to increased demand for animal feeding including poultry species [5,7,20,26–28], with more youth and women entering the insect farming business [10,18]. The insect sector helps harvesters and small-scale producers generate more income in the market in countries such as Nigeria, Kenya, and South Africa [2]. Furthermore, insect markets in SSA also involve imports and exports of harvested insects between neighbouring countries such as Mozambique and Zimbabwe when there are high demands [29]. Although this creates competition between consumers and farmers who harvest insects to incorporate into poultry diets, the market size for insects is determined by the demand for consumption of insects and insect-based products [16].

Generally, insects farming on a large scale are reported to be economically beneficial in that it reduces feed costs when replacing conventional protein feedstuffs in animal diets [30]. Based on Table 1 and Figure 2, insects as a feed source are proving to be reasonable compared to the ever-increasing prices of conventional feed sources, specifically fishmeal and soyabean meal over past recent years. Furthermore, crickets and black soldier flies are proving to be the most dominant insect species farmed for animal feeding in SSA. Hence, Kenya and Uganda specialise in the mass production of black soldier flies for poultry feeding. They are the only SSA countries reported to contain higher number of insects producing farmers than the rest of the continent [4,31]. This is because in previous years, insect rearing as well as research studies on insect incorporation in poultry diets is limited in most African countries [25,32]. However, recently, there has been a steady increase in the utilisation of edible insects as feed in most parts of the continent [8,26,32].

3.2 Opportunities of rearing insects for animal feeding in SSA

3.2.1 Farming with commonly reared insects

In general, edible insects are globally recognised food and feed [33]. They could be easily reared on rearing mediums such as manure, and organic waste, especially at the larvae stage [20,34]. The utilisation of Agro by-products and weeds to feed reared insects could help clean the environment worldwide including SSA [35]. Insects despite being entomophagous, their environmental benefits include the ability to perform vital functions such as soil fertilisation, bioturbation and soil formation, decomposition of organic matter, and vegetation growth and diversity [10,36]. Furthermore, their wastes can be effectively utilised as a source of organic fertiliser that could be beneficial for plant-producing farmers in the continent [37]. Below are the opportunities of farming with commonly reared insects that are already available in the market and potential insects originating in the continent.

Commercial breeding of insects is considered sustainable, cost-effective, and profitable due to fast growth, high reproductive efficiency, and ability of reared insects to convert waste into valuable protein [38–42]. Thus, the approval of insects as feed (United Nations, September 2021) has stimulated more interest in using insect-based diets countries for poultry production worldwide including SSA countries [28]. Chia et al. [43] reported that about 70% of poultry farmers in Kenya have familiarised themselves with the incorporation of insects in diets. Most of them have accepted and are willing to purchase insect-based feeds from insect-rearing traders. Moreover, SSA countries in collaboration with international insect investors have established private companies including Agriprotein (South Africa), FasoPro (Burkina Faso), Ghana Aspire (Ghana), InsectiPro (Kenya), and Bioduu (Tanzania) which mainly focus on the mass production of insect species such as black soldier flies, yellow mealworms, and palm weevil larvae, hence, playing a significant role in many communities in

Table 1: Insect distribution, prices, and insect farmers producing insects as feed in Africa

Insect type	Country	Insect prices (US$/kg)	No. of insect-producing farmers
Black soldier fly (*Hermetia illucens*)	Egypt, Ghana, Kenya, Tanzania, Uganda	1.29	14
Crickets (*Acheta domesticus*)	Kenya, Rwanda, Uganda, Zimbabwe	12.07	48
Silkworms (*Periplaneta americana*)	Tanzania	3.62	1

Source: Verner et al. [18].

terms of research and creating more job opportunities to curb unemployment rate and food insecurity [4,18,21].

Hence, commercialisation and processing of insects on a large scale remain one of the priorities targeted by most African governments [21,22]. For that, Verner et al. [18] recently reported about 850 insect-producing farmers for food and feed in Africa. However, only 63 farmers reported to produce insects for animal feeding (Table 1). In addition, the INFEED, an internationally funded project in partnership with Cultivate Africa's Future Fund (CultiAF), conducted different feeding trials which aimed at utilising insect-based diets in sub-Saharan regions, specifically Kenya and Uganda to monitor the progress of insect farming. Hence, the project has proven to be beneficial in helping small- and medium-scale insect farmers of all genders including adults and youth to generate income, thus, improving the livelihoods of many communities, particularly in rural areas in terms of nutrition [7,21,31,44]. Moreover, various stakeholders engaging in insect farming for animal feeding in Africa include international agencies, policymakers, research organisations, private sectors, NGOs, and research organisations [18].

3.2.2 Potential farming with local African edible insects

Most poultry farmers using insect based diets in sub Saharan region rely on harvesting local insects in the wild than rearing than purchasing farmed insects in the market [41]. However, the harvesting method is considered unsustainable as it disturbs the ecosystem and also leads to overharvesting, which consequently result in the depletion of wild edible insects [38]. Hence, educating farmers about the benefits of insect utilisation and market opportunities will stimulate more consumers and farmers' interest and acceptability in insect rearing and consumption [22,43]. Moreover, there is a need to train and recruit more emerging insect-producing farmers around the continent to help promote insect farming and marketing for animal feeding [7]. It has been reported that farming of local insects could also be considered for poultry feeding since endemic insects pose no environmental harm to the area they originate from [18]. The most common edible insects used as food and feed in SSA include locusts, grasshoppers, termites, palm weevil larvae, stinkbugs, and mopane worms [45,46]. As shown in Table 2, the feeding trials of the potential inclusion of the above-mentioned local insects in poultry diets have already been documented.

Furthermore, research studies are closely monitoring the possibility of farming with swarming insects such as locusts and grasshoppers in fish and poultry diets [47–51]. This is because insect swarming of insects has been widely reported to be a serious concern to plant-producing farmers in SSA countries such as Botswana, Madagascar, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. Their outbreaks damage crops and also play a role in modifying ecological processes such as food chain, consequently, resulting in soil erosion, runoff, and lower yields [1,52,53]. In addition, South African farmers, particularly in the East and Western Cape have been adversely affected by seasonal swarming of locust species in recent years. It is alerted that the swarming will further continue in the next coming seasons; hence, it is advisable for farmers to always be on the lookout in those regions [54]. Therefore, poultry farmers could also consider swarming seasons as an opportunity to harvest insects for rearing and animal feeding purposes since it is cost-effective, and tons of insects could be easily collected. Furthermore, the utilisation of swarming insects in poultry diets could play an important role in helping to prevent damages made by insects while preventing the use of harmful pesticides to control insect outbreaks.

3.3 Potential of insect-based diets in poultry production

Edible insects have been widely documented as a possible alternative feed ingredient in poultry diets [14,23,39]. More so, it has been reported that there is huge recognisable competition between human, fish, and terrestrial animal industries for ingredients, particularly commercial protein sources such as soyabean and fish meal [40]. Hence, it is important to find ways of transforming poultry diets using novel feeds such as insect meals [39]. Figure 1 shows the transformation of poultry diets through incorporation of insects as a protein source to fully or partially replace conventional protein feed ingredients whereas, the recent literature reported in Africa on the effect of insect-based diets on poultry production and performance are indicated in Table 2. Based on the findings, the inclusion of various edible insects from different countries could improve the growth performance and meat quality parameters of poultry species.

However, insects have been reported to contain harmful and toxic elements such as heavy metals which could adversely affect the performance of animals consuming them; hence, their accumulation in large quantities indirectly threatens the health of humans [55]. In addition, the high chitin has also been observed to limit the utilisation of insects in poultry diets [14]. This is because chitin levels are considered the main anti-nutritional factor that is highly associated with adverse

Table 2: Recent findings on the effect of insect-based diets on poultry growth and performance in Africa

Study location (country)	Poultry type	Insect type (dry)	Insect meal replacement level	Findings	References
Egypt	Japanese Quail	Egyptian cotton leafworm (*Spodoptera littoralis*) larvae	Up to 100% of bone meal	Improved body weight gain and Feed conversion ratio without any effect on performance, carcass characteristics, haematological and serum biochemical indices	[56]
Kenya	Broiler chickens	Black soldier fly (*Hermetia illucens*) larvae	Up to 75% of fishmeal	Could be included in diets without compromising performance	[57]
Kenya	Broiler chickens	Black soldier fly (*Hermetia illucens*) pre-pupae	At 150 g/kg of soyabean meal	Could be included in diets without any effect on performance and meat quality	[6]
Kenya	—	Black soldier fly (*Hermetia illucens*) larvae	From 5 to 50% of fishmeal and soyabean meal	Economic benefits	[5]
Kenya	Indigenous chicken	Grasshopper meal (*Ruspolia nitidula*, *Acanthacris ruficornis*, *Schistocerca gregaria*)	Up to 100% fishmeal	Improved feed conversion ratio, crude protein digestibility, and sensory attributes. Reduced feed intake and did not affect weight gain	[48]
Niger	Indigenous chickens	House fly (*Musca domestica*) larvae	Up to 50% of fishmeal	Improved growth rate and feed consumption without any effect on body weight, feed conversion ratio, and carcass traits	[58]
Nigeria	Broiler chickens	African palm larva (*Rhynchophorus phoenicis*) and termite (*Macrotermes bellicosus*)	Up to 100% of fishmeal	Improved all growth performance parameters	[59]
Nigeria	Broiler chickens	Grasshopper meal	Up to 100% of fishmeal	Improved growth performance parameters	[49]
South Africa	Jambo Quails	Mopane worm (*Imbrasia belina*)	At 150 g/kg of soyabean meal	Could be included without any adverse effect on performance, health and meat quality	[60]
South Africa	Broiler chickens	Mopane worm (*Imbrasia belina*)	Up to 12% of soyabean meal of	Positively affected growth performance, meat quality, and sensory attributes	[61]
South Africa	Broiler chickens	Black soldier fly (*Hermetia illucens*) pre-pupae	Up to 15 of fishmeal%	Could be included without any effect on carcass, sensory or meat quality characteristics	[62]
South Africa	Jumbo Quails	Black soldier fly (*Hermetia illucens*) larvae	At 54 g/kg of soyabean meal	Improved gut morphology without any adverse effect on weight gain and meat quality	[63]

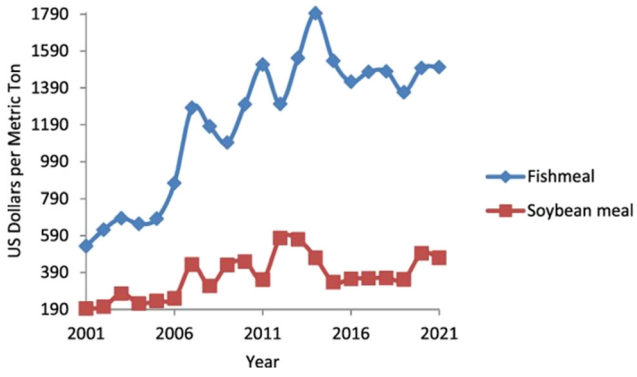

Figure 2: Prices of conventional protein sources (fishmeal and soyabean meal) from 2001 to 2021. Source: Nagappan et al. [71].

reduction in intake, absorption, digestibility, meat quality, and performance [14,34,40]. However, chitin content in insects could be reduced by removing their exoskeletons [64]. It has been also observed that chitin can be digested efficiently using enzyme chitinase [35]. Hence, knowledge and understanding of chitin as a limiting antinutritional factor as well as the optimal inclusion levels of insect meals in animal diets for better utilisation is vital [40]. This includes knowing the type of substrates including mixed organic wastes, food wastes plant materials and animal feeds fed to farmed insects since they influence the nutritional and health status of insects as well as animal-fed insect diets [18].

3.4 Benefits of insects in diets and poultry meat

3.4.1 Insect-based diets

Most edible insects are heavily documented to be rich in protein, lipids, vitamins, amino acids, and minerals required by livestock [16,32,65]. They outperform common meat such as beef, pork, fish, and chicken in terms of nutritional value [2,20,66]. Furthermore, their palatability and taste make them a suitable feed ingredient for poultry species during feed shortages [21,22]. Moreover, the processing techniques such as drying and grinding could also help improve insect utilisation as poultry feed [21]. Hence, there is a need for sustainable production and processing of insects as feedstuff for poultry species in SSA [25]. Although insects have nutritional, medicinal, economic, and environmental benefits when utilised as feed [20,22,32], they indirectly contribute to human diets when used as feeds for poultry [31]. For instance, the chitin present in insects' exoskeleton could possess anti-oxidative, anti-inflammatory, anti-microbial, and immunostimulatory activities, which could improve immunity and health status poultry species when incorporated in diets [2,16], subsequently, helping to prevent chronic diseases such as diabetes type in humans who consumed insect-based poultry meat [2]. They could, thus, influence the willingness of consumers to purchase insect-based products [22]. This is because there are different perspectives towards the acceptability of insect-based meat and meat products by consumers from various countries. For instance, most people especially in Western countries reject the consumption of insect-containing meat and by-products [22,33,67].

3.4.2 Insect-based meat

Although there is a continuous increase in costs of main protein feed ingredients as shown in Figures 2 and 3, the demand for protein from poultry meat, especially meat from broiler chickens in most African countries, continues to increase due to high population growth in the continent. Hence, the introduction of insect-based diets could serve as a sustainable solution to poultry production industry. For that, Mtolo et al. [32] conducted a study in South Africa on students' views towards consuming meat from chickens fed insect-based diets. It was concluded that above 50% of students from different universities are fully aware of insect inclusion in poultry diets and are willingness to consume insect-fed chicken meat with less concerns about the health risks associated with insects. However, the nutritional value along with the safe consumption of insects and insect-based poultry meat must always be taken into consideration when including insect meals along with other ingredients in animal diets to meet their nutrient requirements while maximising production and good health status [40].

3.5 Constraints of farming insects in SSA

In SSA, there is a lack of legislations and regulatory constraints involving feeding, welfare, harvesting, breeding, processing, and marketing [33,68–70]. Insects are only mentioned under food law, wildlife resources, and pest management [3]. However, according to the recent reports, countries including Kenya, Uganda, and Rwanda, have developed regulation standards, which focus on the use of dried insects such as cricket and termites as a protein source in animal feeds. The regulations strictly require wildlife permits for production and transportation on a large scale [18]. Moreover, other countries such as Botswana are still in the early stage of drafting and

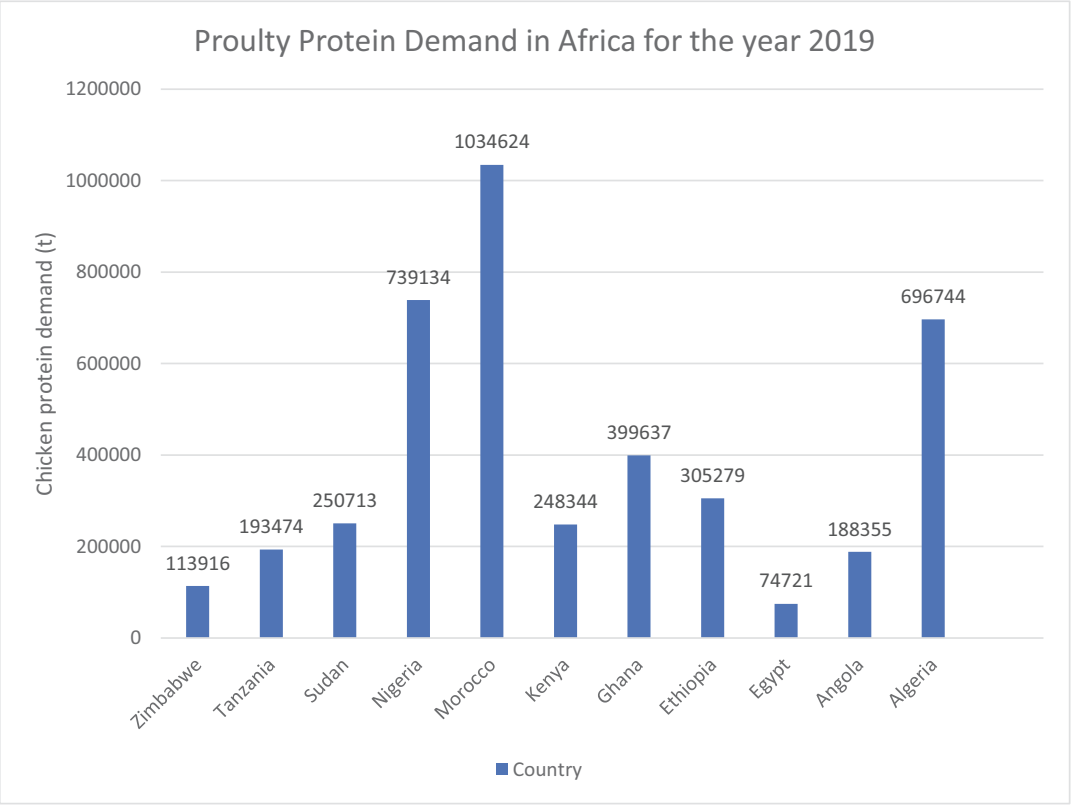

Figure 3: Poultry protein demand per ton (t) from chicken meat in Africa for the year 2019. Source: Verner et al. [18].

implementing laws and policies that will restrict insect utilisation to avoid overharvesting and prevent unauthorised hunting, harvesting, and farming of insects [3]. This could be done through successful approaches and procedures used by countries such as Thailand in Asia [18].

Although the legislations on insect hygiene and safe consumption are highly recommended [3], there is a lack of regulations on the safe utilisation of insects as feed in SSA [13,21,31], unlike in Europe where insects such as yellow mealworm and migratory locust novel food have been recently authorised as safe to consume by human and animals [18]. The ignorance of the safe consumption of insects could be that insects have long been utilised without any consideration of the health risks they pose to animal-fed insects [32]. However, the unsafe consumption of insects has been heavily reported to threaten animal health due to the possibility of insects containing disease pathogens, contaminants, allergens, toxins, and pesticide residues [3,33,55,68].

Nonetheless, in general, there is a lack of financial support for insect-rearing farmers to sustain the production and marketing of insects [10]. Although insect-based meals have been highly documented to be cost-effective feed than commercially produced diets for animal production [3,30]. In terms of substrate availability, labour, fuel, transport, and housing costs, the current insect farming systems for large-scale production have been observed to be more expensive than the production of traditional poultry feeds [18,24,72] (Figure 3). They could also report the increasing prices over time for conventional protein feed sources, animal products, and insect feed. Other challenges faced by already existing small- and medium-scale insect farmers in SSA include poor infrastructure and lack of advanced technologies for efficient production [1,32]. Moreover, they are constrained by insufficient knowledge and skills in various production systems including cage system, pens for large-scale production, open farming system, and captive production system to rear insects on a large scale for animal feeding [4,22,31]. According to Conti et al. [73], finding a suitable production system to produce novel animal feeds will promote sustainable agriculture with increased output and less harm to the environment.

4 Conclusion

The utilisation of inset-based diets could sustainably play a critical role in maximising poultry production at a

reasonable feed cost to help address food insecurity in SSA. The insect-farming industry could be highly beneficial to many communities through income generation and creation of more jobs, thus improving the livelihood of Africans as a whole. Although there are concerns about the safe consumption of meat from poultry reared on insect-based diets, people in SSA accept the idea of consuming insect-based products including poultry meat. However, the lack of finance, knowledge and skills, and marketing and production systems to breed and process sufficient insects on a large scale for poultry feeding is still a serious concern for emerging and small-scale insect-producing farmers, which, consequently, discourages most people not to consider entering insect farming business in SSA. Hence, the governing bodies and different stakeholders involved should employ more strategic plans aimed at promoting insect farming for livestock feed in Africa. This could be achieved by providing financial support to insects and poultry-producing farmers through funding projects and research trials, finding ways to encourage and educate more farmers on sustainable insect farming and enforcing proper laws and policies that will help maximise insect production and minimise harm to the environment.

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