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REVIEW

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Prospects of rearing selected southern African swarming insects for animal feed: a review on insect farming and the economic value of edible insects

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Abstract

The potential of insects as animal feed is currently under doubtful spotlight due to the limited number of reared insect species and fewer farm or biotechnological companies producing insects on a large scale for animal feed worldwide. Again, the costs of incorporating reared insects in animal diets as an alternative replacement for expensive conventional protein sources (CPS), mainly fishmeal and soybean meal, remain uncertain due to gradual increase in the sales prices of farmed insects. To date, black soldier fly, yellow mealworm and cricket are the only insect species dominating in the insect farming industry at limited supply. This triggers the need to expand insect farming through the introduction of additional insect species while monitoring the costs of insect-based diets. The commercial rearing of swarming edible insects with a good nutritional profile, such as termites alates (*Macrotermes spp.*), migratory locusts (*Locusta migratoria*) and mopane worms (*Imbresia belina*) found in Southern Africa could potentially become an alternative solution to expand insect farming in addition to the commonly reared insect species. However, there is limited information available on the reproductive ability and economic value of swarming insects as animal feed. Therefore, this paper will provide an overview of the possible rearing of selected swarming insects as well as the profitability of using insect-based diets. It will also give clarity on whether the mass production of edible insects will be cost-effective or not by discussing and comparing recent sales prices of various edible insect as compared to that of CPS in animal diets.

Keywords Edible insects, Insect farming, Termites, Locusts, Mopane worms, Economic sustainability, Cost – benefit analysis

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Introduction

With the mounting human population, agriculture through intense farming in combination with biotechnology to produce alternative feed is a key strategy to address worldwide poverty, hunger and food insecurity, which is one of the Sustainable Development Goals by United Nations [1, 2]. However, the livestock production industry is facing a significant challenge in continuous rise in prices of feed ingredients, especially protein sources, such as fishmeal and soybean meal due environmental factors such as climate change including prolonged drought [3], greenhouse gas emissions, water and land pollution as well as high global demand for protein [4, 5]. Hence, fish and soyabean production are widely documented as the main contributor to high total feed costs in poultry, fish, pigs and pets diets [6, 7]. The European Union (EU) in 2017 promoted insects as food and feed to increase protein supply for both humans and animals, which stimulated more interest in insect farming [8–11]. However, due to health regulations, only limited number of 'conventional insect' species namely, domestic cricket *(Acheta domesticus),* black soldier fly *(Hermetia illucens)*, common housefly (*Musca domestica*) and yellow mealworm (*Tenebrio molitor*) were permitted to be bred and reared on a large scale. These insects are grown mainly on food substrates, such as mixed organic waste, food waste from shops and markets, industrial food waste and commercial animal feed [12]. Moreover, black soldier fly larvae is considered as the topmost farmed and studied insect for use as animal feed, mainly for poultry, fish and pets [9–11, 13–19].

However, for the sector to grow and expand sustainably for animal feed purposes, there is a need to increase the number of reared insect species through mass production of other edible insects including highly reproductive, seasonal swarming insects from Southern Africa. This includes edible insects such as termites alates (*Macrotermes spp.*), migratory locusts (*Locusta migratoria*) and mopane worms (*Imbresia belina*). These edible insects could be considered for farming on a large scale since they are environmentally friendly, have a good nutritional profile [20, 21]. Moreover, they are adapted to feeding on readily available specific tree leaves and grasses, however, they could also be reared on food substrates utilised by conventional insects [22]. Their incorporation in animal diets has been widely reported to provide nutritional, economic, environmental and health benefits [9, 23–28]. Most previous insects studies focused more on the nutritional value, processing, storage and safe consumption [29–32] and less on their profitability and price differentials [9, 33, 34]. Thus, are insects and insect-based diets cost effective and economically beneficial as compared to conventional protein sources?

This review, therefore, intends to provide valuable information on the potential rearing of selected swarming insects on a large scale as well as answers on the cost-effectiveness of incorporating insects and insect meals for animal feeding. Thus, the potential farming of termites, locusts and mopane worms based on their reproductive ability was discussed, different food substrates required by reared insects as well as recent reports on the inclusion of insect meals in animal diets, and lastly the economic efficiency of utilising insect-based animal diets and the costs of producing insects on a large scale were discussed.

Potential farming of termites, locusts and mopane worms

Edible insects could be acquired through harvesting, semi-domestication and indoor farming [10, 32]. Because insect harvesting is considered unsustainable as it tampers with the ecological food chain and biodiversity [32]. The indoor farming has been reported to provide quicker breeding cycles and a better return on investment. It also requires less space with limited barriers to enter the insect market [35, 36]. However, for successful rearing of insects, proper growth and a high reproductive potential play a significant role in identifying the type of edible insects suitable rearing on a large scale [37]. For instance, yellow mealworm and black soldier fly are the most popularly farmed insects since they can be easily multiplied rapidly and produced in large quantities [33]. The maggots from black soldier fly are available throughout the year and could be harvested after two to four weeks on a commercial scale [1, 17, 18, 22]. Again, they could turn food substrates, including organic by-products into high quality protein [38]. However, the larvae from commercially farmed insects are highly sensitive to the type of food substrates they consume and other factors, such as temperature, light and humidity, which significantly influences the successful rearing of edible insects in terms of growth and performance [39]. For instance, Johnsen et al. [33], observed that relative humidity below 48% could result in a high mortality rate of maggots just before the harvesting phase when reared on a large scale.

Hence, the recent research studies are closely monitoring the possibility of utilising swarming insects such as termite alates, locusts and mopane worms. These seasonal edible insects are endemic to Southern African soils. They have been shown to thrive well in a warm environment which enables them to grow and multiply rapidly, resulting in outbreaks [40]. As shown in Fig. 1, a small colony could produce large quantities of eggs that will yield more insects at the harvesting phase. Hence, they could potentially be explored as additional insect species to conventional insects reared or farmed on a large scale. The commercial rearing of these insects as feed ingredient could also play an important role in helping to reduce feed costs. However, it is critical to take into consideration factors including infrastructure, processing method, storage, marketing and distribution, laws and regulations as well as operational costs including food substrates, electricity and labour when rearing insects from egg to harvesting stage [17, 32, 34, 37, 41, 42, 66].

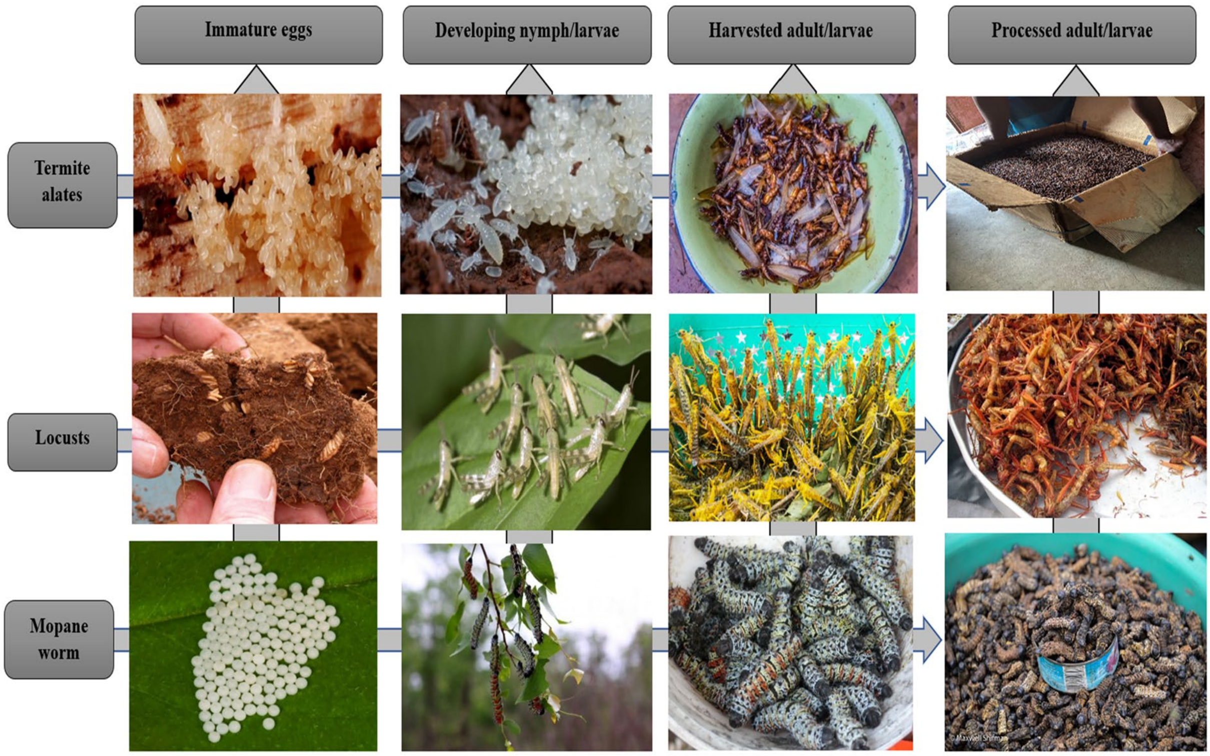

Fig. 1 Reproductive potential of selected insect species (Source: Microsoft bing: https://www.bing.com/images/search?)

Food substrates for edible insects

According to Rumbos et al. [11], the type of food substrates used to farm insects highly influences their reproductive ability and nutritional composition. Subsequently, affecting their colour, taste and palatability as animal feed. In general, farmed insect species at different stages of development require different feed substrates in varying quantities until the harvesting phase [17]. As shown in Fig. 2, the common edible insects are harvested at different growth stages, in which the earliest and latest harvest could be made in just 14 and 82 days, respectively. Their survival rate highly depends on the type of

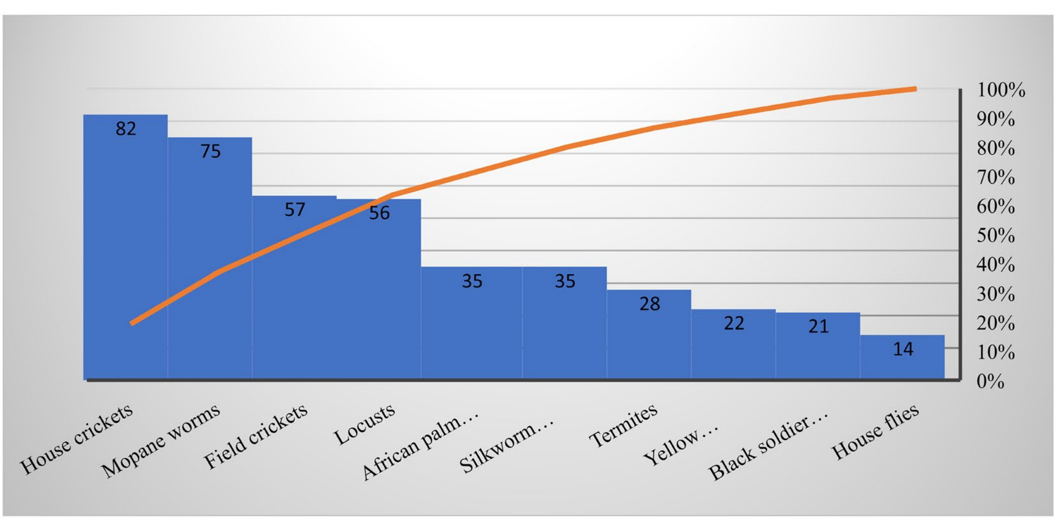

Fig. 2 Growth period of common edible insects until harvesting phase. [Source: [12, 42]]

food substrate they consume [42]. For instance, it takes only two weeks to harvest palm weevil larvae when fed fruit waste of banana and pineapple and millet waste [43]. However, fly maggots could be reared on organic waste materials, livestock manure and other feed substrates, such as fermented palm kernel meal, subsequently converting the substrates into high quality nutrients [43]. Yellow mealworms, on the other hand, require dried and cooked waste materials from fruits, vegetables, and cereals. Moreover, they could also be fed wheat bran or flour supplemented with soybean flour, skimmed milk powder and yeast [40, 44]. Again, crickets reared under an adult production system consume a mixed diet of vegetables and grains [28]. The waste materials excreted by farmed insects could be used as a biofertilizer to help boost the fertility of arable soils since the waste is mainly rich in nitrogen, phosphorus and potassium [45].

As shown in Table 1, winged termites, locusts and mopane worms could potentially be reared on similar substrates similar to commercially farmed insects, with the exception of livestock manure. However, mopane worms strictly require plant residues, especially mopane leaves as their main food source [22]. It has been reported that the consumption of unwanted food substrates could significantly influence nutrient availability in edible insects since not all feed substrates are suitable or permitted to be consumed by reared insects [46]. It is, therefore, not advisable to feed insects undesirable food substrates or even commercial diets or livestock feed ingredients since it will initiate competition of food between insects and livestock. Hence, knowledge about the various substrates required by each insect species is highly required [17]. Factors such as stage of development, mating season, and processing methods, and environmental factors like temperature, light, and humidity indirectly affects food substrates utilisation by farmed insects [19, 39].

Supplementation of selected insects in animal diets

Although there is little or no information on commercial farming of selected swarming insects (termites, locusts and mopane worms), Table 2 shows recent literature reported on partial or complete inclusion these swarming insects in livestock diets as a replacement for fishmeal or soybean meal. Based on the reported findings, both conventional insects and swarming insects as potential alternatives appears to produce similar results when included in animal diets, especially poultry species in particular. Thus, the selected swarming insects could successfully be included in diets to replace CPS at different levels without any adverse effect on their production parameters. Kenis et al. [1] also observed a nonsignificant difference in the growth and survival of chicks when utilising termite meal in comparison with conventional feedstuffs. Similar to commercially reared insects, their nutritional value has also been reported to be comparable to that of CPS [1, 20, 48]. In addition, Selaledi et al. [38] further reported that edible insects, including termites, locusts and mopane worms contain high quality protein, fats and essential minerals required for the proper growth and health of livestock. Hence, they could be potentially reared in large quantities for animal feeding. However, it has been reported that excess inclusion levels could significantly reduce performance due to an accumulation of fats and antinutritional factors such as chitin found in exoskeletons of insects [39]. Nevertheless, various processing methods including oil extraction, drying, boiling and degutting could aid in improving nutrient quality and availability of selected swarming insects when farmed in large quantities. Hence, there is a need for the commercial production of termites, locusts and mopane on a large scale. In addition, more studies and experimental trials in various countries are still required to support the available literature.

Economic cost–benefit analysis of common edible insects

From an economic perspective, the utilisation of insects and insect meals continue to expand and become more popular in the animal feed industry. As shown in Table 3, insect-based diets are considered to have a higher benefit − cost ratio with better return on investment when substituting CPS of up to 100% replacement level. Similarly, Roffeis et al. [49], Sumbule et al. [13] and Zewdu et al. [45] reported that insect-based diets could be economically beneficial when replacing fishmeal and soybean meal in animal diets since they could be included

Table 1 Food substrates suitable for termites, locusts and mopane worms

Insect name	Feed material/substrate	Harvesting phase	References
Winged termites (adult)	Fibrous and humidified waste or crop residues	After 3–4 weeks	[1]
Desert locusts (adult)	Kales, wheat sprouts and wheat pollard	After 6–8 weeks	[20, 47]
Mopane worms (caterpillar)	Mopane tree leaves and some other tree leaves around mopane woodland	After 4–6 weeks	[32]

Table 2 Comparison between commonly farmed and other selected insects used for livestock and aquaculture feed based on the processing techniques inclusion levels, and performance

Insect type	Processing methods	Animal type	Inclusion level	Findings	Country	References
Conventional insects						
Black soldier flies (*Hermetia illucens*)	Live, chopped, or dried and ground forms	Fish	30% replacement of fishmeal and soybean meal	Produced considerably faster growth rates in tilapia fish species	Guinea	[44]
Yellow mealworms (*Tenebrio molitor*)	Oven, freeze and infrared-drying, defatting/lipid extraction	Broiler chickens	Up to 100%	Did not affect the FI, BW, and BWG in male broilers aged 30–62 days	Turkey and Italy	[23, 26, 27]
Crickets (*Gryllus bimaculatus*)	Ground into powder	Ruminant species (unspecified)	Up to 20%	Could be used as an alternative high-quality feed in ruminant diets without adverse effects on nutrient digestibility with increased ammonia–nitrogen. However, their high fat content should be taken into consideration	Japan	[28]
Palm weevil larvae (*Rhynchophorus phoenicis*)	Freeze and oven-drying, defatting	Fish	100% replacement of fishmeal	Improved weight gain in Clarias gariepinus juvenile	Nigeria	[24]
Selected swarming insects						
Winged termites (*Macrotermes subhyalinus*)	Oven-drying	Fish and broiler chicks	50% replacement of fishmeal	Improved growth rate of catfish when replacing fishmeal in diets. *Macrotermes* could replace fishmeal in chick diets without any effect on daily weight gain and the feed conversion ratio	Nigeria and Burkina Faso	[1]
Locust/ grasshopper meal	Boiling and sun-drying	Indigenous chickens	Up to 100%	Reduced feed intake but tended to improve FCR and sensory attributes with no effect on carcass characteristics	Kenya	[20]
Mopane worms (*Imbresia belina)*	Degutting, roasting, sun-drying and grinding	Quails	Up to 150 g/kg replacement of soybean meal	Could be included in diets without adverse effect on performance, health and meat quality	South Africa	[48]

Table 3 Economic efficiency of insect meals as feed for animals

Insect type (dry)	Animal type	Insect meal inclusion	Conclusions	References
Black soldier fly pupae	Broilers	42% replacement of fishmeal and soybean meal	Resulted in a higher benefit – cost ratio with better return on investment compared to CPS	[56]
Yellow mealworms	Broilers	4–12% supplementation	The incremental levels of insect meal resulted in increased costs of poultry diets with reduced gross margins	[57]
Black soldier fly larvae	Layers	25 and 100%	Resulted in a positive benefit – cost ratio and return on investment. Hence, the inclusion levels were most suitable and cost-effective	[13]
Full fat black soldier fly larvae	Fish	10.50% inclusion	The inclusion level had the highest index of economic profitability	[14]
Defatted black soldier fly larvae	Fish	Up to 100% replacement of fishmeal	Increased economic efficiency	[58]
Black soldier fly larvae	Fish	75% replacement of fishmeal	Significantly reduced feed costs and resulted in higher economic returns	[59]
Black soldier fly larvae	Pigs	Up to 100% replacement of fishmeal	Insect meal inclusion had the same benefit – cost ratio and return on investment compared to fishmeal as a CPS in pig diets	[60]
Black soldier fly larvae	–	5 to 50% replacement of fish meal and soybean meal	Increased economic benefits	[29]

in less quantities and still provide more digestible protein as compared to CPS [48]. Black soldier fly is currently the most popular farmed insect produced in large quantities as a protein source for fish, poultry, pets and other livestock species (Fig. 3). Hence, there is a need to expand the insect farming industry to increase supply for animal feed through the introduction of other rapidly growing insects to meet insect demand, increase profitability and minimise the costs of insect-based diets [41]. However, the production capacity of farmed insects still limited by high production costs and increased market prices (Fig. 4), which consequently threatens the sustainability utilising commercial edible insects mainly black soldier fly and yellow mealworm in animal diets [15]. Edible insects prices are expected to become even more competitive in the next coming years due to a high insect demand with limited supplies because of fewer insect-producing farmers [12]. Similar to CPS, as high protein demand and human-to-animal competition continues to elevate their prices [9]. According to Roffeis et al. [49], the factors driving the economic performance of insect-based diets are costs mainly associated with labour and food substrates required for insect farming. In addition, the rearing systems used by insect biotechnology

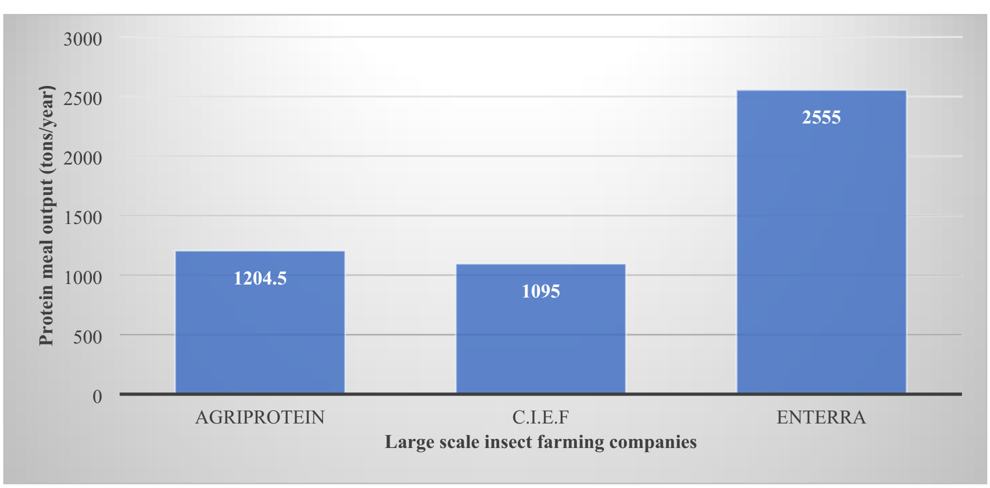

Fig. 3 Protein meal production output for black soldier fly in 2019 [Source: [12]]

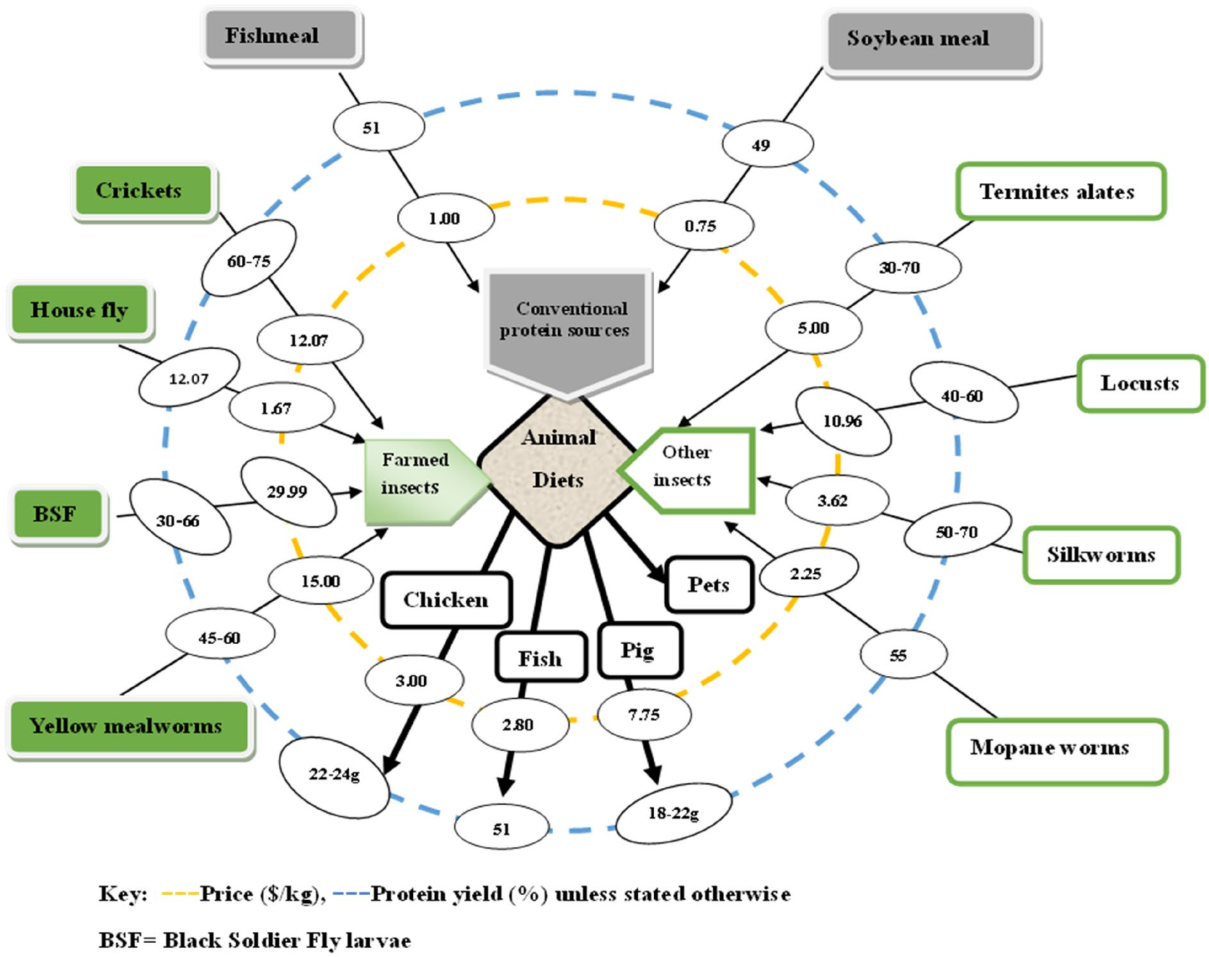

Fig. 4 Prices and protein yield of edible insects and conventional protein sources. (Sources: [12, 32, 50, 54, 61–65])

companies or farms require expensive equipment such as oil extraction machines, incubators, proper storage, and special diets for successful rearing [17, 37].

Therefore, knowledge about the protein yield (benefit) and sales prices (costs) are crucial in determining the cost-effectiveness of various edible insects compared to CPS [50]. The high costs of CPS, mainly fishmeal and soybean meal, and their negative impact on the environment has been widely documented [6, 51–54]. Based on recent data as shown in Fig. 4, edible insects appears to contain higher protein content than CPS in terms of protein yield, indicating that less quantity of insects could substitute higher amount of CPS in livestock diets. For instance, 1 kg of fish meal in diets could be substituted by 0.76, 0.81, 0.85, 0.91 and 0.95 kg of crickets (75% CP), termites/silkworms (70% CP), BSFs (66% CP), locusts/yellow mealworms (60% CP) and mopane worms (56% CP) whereas, 0.74, 0.79, 0.83, 0.89 and 0.93 kg of the same insect species, respectively, could be used to replace 1 kg of soybean meal (49%CP) in animal diets. Thus, insects-based diets would be more beneficial for animal producing farmers in terms of protein yield. Nonetheless, edible insects have remarkably higher prices ($ per kg) than traditional diets with CPS (Fig. 4), however, insect prices vary from one country to another depending on the demand and availability [12]. This recent gradual increase in prices may be due to a global increase in demand for edible insects with less supplies and limited insect producers as food and feed [4, 5, 8, 10, 11]. Moreover, the rise in import and export of edible insects between neighbouring countries, particularly in Africa, may also be the cause of elevated insect demand [55].

According to Fig. 1, black soldier fly larvae are currently the most expensive insects in $ per kg although they are currently the most preferred insects as feed for animals [14]. This may have a significant influence on the total costs of incorporating various insect meals in animal diets regardless of their nutritional and environmental benefits. Although all edible insects reported in Fig. 1 contained almost similar protein content, other potential alternatives including termites, locusts and mopane worms have lower prices per kg than conventionally farmed insects, especially black soldier fly and yellow mealworm. Similar to CPS and conventional insects, the protein content from swarming insects could be effectively utilised by livestock, mainly poultry, pigs and fish, to yield protein-rich meat for human consumption. Hence, the information on price differentials could prove to be very useful to livestock farmers when estimating the profitability of incorporating any type of edible insect species in animal diets to avoid operating at a loss [34].

Conclusion

The need for sustainable production of insects as animal feed to gradually substitute CPS is one of the main priorities of the insect farming industry since CPS production have negative impact on the environment and are responsible for a large proportion of the costs of feeds for livestock and aquaculture. Although the current prices of conventional edible insects and still high compared to CPS, expanding the insect farming industry through the addition of swarming insects with strategic breeding and better processing techniques will increase the quantity supply and improve affordability of edible insects in the market. This is because their sales prices per kilograms are more reasonable compared with high protein yield compared to conventional insects such as black soldier flies and yellow mealworms. In conclusion, breeding and mass production of swarming edible insects such as winged termites, migratory locusts and mopane worms could, therefore, improve the sustainability of insect farming and reduce total costs of utilising insect meals in animal diets. This could be highly beneficial to farmers, biotechnological and animal feed companies interested in insect rearing and production of insect-based diets to maximize production at reduced costs. However, further research is recommended on total operational costs and suitable food substrates required for optimal production of swarming insects as food and feed. Again, thorough research on comparison of insect based diets and other commercial diets in terms of cost benefits analysis is also recommended to make proper conclusions on farming and utilisation of edible insects in animal production industry.

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Author contributions
SD; conceptualization and was a major contributor in writing the manuscript. MM; was involved in reviewing and editing. TG, E and NA; were involved in critical revision and searching of relevant articles suitable for writing the manuscript. All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare that they have no competing interests.

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