Feedipedia
www.feedipedia.org
Broadening Horizons
February 2023 #55

Locusts and grasshoppers: nutritional value, harvesting and applications

By Harinder P. S. Makkar[1], Valérie Heuzé[2], and Gilles Tran[2]

[1]International Consultant and Adjunct Professor, University of Hohenheim, Stuttgart, Germany

[2]Project officers, Association française de zootechnie, Paris, France

Corresponding author: H. P. S. Makkar

e-mail address: hpsmakkar@outlook.com

Introduction

Insects and in particular locusts are often considered a nuisance to human beings and mere pests for crops. It may be true in situations such as East Africa where locusts have recently caused a huge loss to crops in Ethiopia, Kenya, Eritrea, Uganda, South Sudan, Somalia, Djibouti and Sudan. Lately, this infestation of desert locusts arrived in East Africa in June 2019, feeding on hundreds of thousands of hectares of crops and pastureland and devastating huge crop and grazing biomasses. For example, an FAO study reports a loss of 356,000 tonnes in cereal crops and pasture reduction of about 40%; and in Kenya locusts destroyed at least 30% of the pastureland. This has adversely affected food security in these countries. Other countries, e.g., India, Pakistan, China, Tanzania, Saudi Arabia, Oman and Iran have also encountered locust-mediated enormous crop losses in the recent

Figure 1. Desert locust swarm in South-Morocco, in 2004.

Photo credit: Magnus Ullman, Wikimedia Commons, CC BY-SA 3.0

past.

In recent times, due to increasing demand of protein for both animals and humans, the use of insects as food and feed has attracted the attention of scientists, feed industry, development workers, and regulatory and safety authorities. Locusts are rich in protein and can be fed to animals a point that has largely been ignored in the locust infested countries. There is a severe deficiency of good quality animal feed, which is one of the major constraints for increasing livestock production in most of the countries affected by locusts. It may also be noted that the environment footprint of locusts is low.

The greenhouse emission (g/kg mass gain) for locusts is about 100 versus 1100 and 2800 for pig and beef respectively.

Locusts and grasshoppers, like most insects, are rich in protein and energy. Fresh insects contain about 25 –35% dry matter. The crude protein content is high, usually in the range of 50–65% (dry matter basis), though lower values and higher values are reported. The fat content is quite variable and ranges from relatively low values (< 10%) to high ones (> 30%) (Table 1a and Table 1b).

The crude fibre is in the 8-15% range and corresponds to some extent to chitin, a polysaccharide found in the exoskeleton of insects. The presence of chitin, being a non-protein nitrogen polysaccharide, can cause an overestimation of the protein content when estimated from the mineral nitrogen measured by the usual Kjeldhal or Dumas method and multiplied by 6.25. Protein content may be overestimated by 17% due to presence of chitin.

Composition

Type	Species	DM	CP	CF	Fat	Ash	Ref.
Locusts	*Locusta migratoria*	26.8	61.7		17.9	4.3	1
	Locusta migratoria	31.0	64.9		18.6	4.0	1
	Locusta migratoria	28.8	58.2		23.5	3.9	1
	Locusta migratoria	34.4	58.3		22.7	3.8	1
	Locusta migratoria	29.1	55.5		24.7	3.7	1
	Locusta migratoria	34.3	55.5		29.6	3.3	1
	Locusta migratoria		50.8		34.9	2.4	2
	Locusta migratoria	97.6	46.8		35.3	2.3	3
	Locusta migratoria	92.2	53.7		19.4	3.7	3
	Nomadacris septemfasciata	92.0	63.5	13.5	14.1	8.7	4
	Schistocerca gregaria	94.0	52.3		12.0	10.0	5
	Schistocerca gregaria	89.5	51.6	14.0	10.9		6
	Schistocerca gregaria (commercial)	21.6	60.5	19.9	16.2	0.7	15
	Schistocerca gregaria (1 day, female)		63.3				7
	Schistocerca gregaria (1 day, male)		52.0				7
	Schistocerca gregaria (10 days, fe-male)		57.8				7
	Schistocerca gregaria (10 days, male)		52.5				7
	Schistocerca gregaria (20 days, fe-male)		40.6				7
	Schistocerca gregaria (20 days, male)		47.3				7

Table 1a. Proximal composition of locusts (expressed in % DM)

DM: dry matter, CP: crude protein (N x 6.25), CF: crude fibre

Type	Species	DM	CP	CF	Fat	Ash	Ref.
Grasshoppers	*Acrida exaltata*		64.5	7.7	7.1	5.0	8
	Acanthacris ruficornis	88.4	66.0		10.2	11.4	14
	*Grasshopper mix**	90.1	77.9	9.9	7.4	4.7	9
	Hieroglyphus banian		63.6	7.2	7.2	4.9	8
	Kraussaria angulifera	91.0	71.1		12.9	8.3	14
	Oxya fuscovittata		64.0	7.5	6.5	5.0	8
	Spathosternum prasiniferum		65.9	7.0	8.1	5.1	8
	Zonocerus variegatus		61.5		6.9	4.3	10
	Zonocerus variegatus		58.0	12.4	15.5	2.9	11
	Zonocerus variegatus				9.1		12
Katydids	*Anabrus simplex*	93.8	60.0	9.8	12.9	6.9	13
	Anabrus simplex	93.7	56.0	8.2	19.9	5.4	13
	Anabrus simplex	94.0	57.7	7.6	12.4	9.0	13

Table 1b. Proximal composition of grasshoppers (expressed in % DM)

Grasshopper mix* = *Acrida lata*, *Atractomorpha bedeli*, *Oxya japonica*, *Gampsocleis buergeri*

DM: dry matter, CP: crude protein (N x 6.25), CF: crude fibre

The essential amino acid composition of locusts and grasshoppers is reasonably good, but generally inferior to that of traditional protein-rich ingredients such as soybean meal and fish meal (Table 2). This is notably the case for lysine and sulphur amino acids. Tryptophan content seems relatively high. However, information is lacking on the variability of the amino acid profile of acridid protein, so conclusions are difficult to draw.

Insects contain relatively little ash compared to other animal products such as fish meal, so their content in individual minerals is low, particularly in calcium and magnesium, while sodium content is much higher than in plant-based feeds.

As animal feed

Despite their good nutritional value and long-time use as human food, there is limited information about feeding locusts and grasshoppers to animals, and only for pigs, poultry, and fish. Generally, these insects can replace part of the protein sources in monogastric species, but performance decreases when the inclusion rate increases. This is likely caused by the lower quality of their protein, which itself can be overestimated due to the presence of chitin.

Figure 2. Desert locust close-up. Photo credit: Michael Linnenbach, Wikimedia Commons, CC BY-SA 4.0

Pigs

In Eastern Africa, dried red locusts (*Nomadacris septemfasciata*) fed to pigs in a mixed diet (20% protein) resulted in a satisfactory growth rate, but the fresh meat and bacon had a definite fishy taint. Removal of the locust meal from the diet three weeks prior to slaughter reduced the taint but did not completely eliminate it.

Type	Locusts		Grasshoppers				Katydids	Soybean meal	Fish meal
Species	*Schistocerca gregaria*	*Schistocerca gregaria*	*Grasshop-per mix*	*Zonocerus variegatus*	*Zonocerus variegatus*	*Zonocerus variegatus*	*Anabrus simplex*		
Reference	1	2	3	4	5	6	7	8	8
Lysine	5.9	4.3	3.8	5.7	4.8	3.4	6.2	6.2	7.5
Threonine	4.0	4.8	2.4	4.0	3.1	2.9	4.8	3.8	4.1
Methionine	2.3	1.0	1.0	2.0	1.9	2.3	1.3	1.4	2.7
Cystine	1.7	0.5	0.5	1.6	0.7	0.5	0.1	1.6	0.9
Tryptophan				1.8		0.8	0.5	1.4	1.0
Isoleucine	4.1	3.6	2.9	4.2	3.7	3.9	5.3	4.6	4.1
Valine	3.8	7.4	4.4	3.4	3.5	4.3	6.0	4.8	5.0
Leucine	5.9	6.8	5.6	5.1	5.1	5.6	8.6	7.6	7.2
Phenylalanine	4.5	2.9	2.3	4.5	3.1	2.3	2.8	5.1	3.9
Tyrosine	3.1	6.9	3.9	2.9	2.5	3.6	6.2	3.5	3.0
Histidine	4.2	2.2	1.6	4.2	3.9	1.9	3.3	2.7	2.5
Arginine	7.4	4.7	3.7	7.3	6.1	3.7	4.5	7.3	6.2
Alanine	5.1	11.6	9.1	5.2	3.7	4.1		4.4	6.3
Aspartic acid	9.4	6.6	5.1	9.2	8.2			11.3	9.1
Glutamic acid	15.4	10.0	7.0	15.3	13.4			17.8	12.6
Glycine	4.8	6.8	4.7	4.7	4.5	4.7		4.2	6.7
Serine	5.0	4.0	2.7	5.2	4.7			4.7	3.9
Proline	3.8		2.1	3.9	4.3	2.1		5.0	4.3

Table 2. Amino acids in locusts and grasshoppers (expressed in g/16 g N)

Poultry

Direct predation. Birds are natural predators for locusts and grasshoppers. A chicken can eat up to 70 insects per day and a duck can eat up to 200. In China, large bands of chickens or ducks, nicknamed “armies” in the medias where such flocks are shown marching from one area to another, are used to prevent or control outbreaks. In the Philippines, free-range chickens fed on grasshoppers were found to taste better and had a higher market price than those fed on conventional commercial feed. In the Tibetan Plateau, free-range chickens reared on grassland containing a large population of grasshoppers had lower live weights, breast, wing, thigh and drum weights, and higher dressing percentage and breast percentage, compared with chickens fed a soybean meal-maize diet. The meat from free-range grasshopper-fed broilers had less cholesterol and higher concentrations of total lipid and phospholipids as well as more antioxidative potential and a longer shelf life.

Broilers. Workers have tried to replace part of fish meal with locust and grasshopper meal and found that such partial substitution is generally suitable. In Nigeria, broilers (1-28 days old) given desert locust meal (Schistocerca gregaria) to replace 50% of the protein from fish meal (1.7% of the total diet) gave better body weight gain, feed intake and feed conversion ration. In China, meal from the grasshopper Acrida cinerea replaced 20% and 40% fish meal in broiler diets with similar growth rates and feed consumption as the control diet. In Nigeria, grasshopper meal included at 2.5 to 7.5% in broiler (1-49 days old) diets depressed weight gain and feed efficiency, though it increased the protein content of the carcass. In another study, grasshopper meal included at 2.5% of the diet was found to be a suitable and cheap substitute for imported fish meal.

Japanese quail. In India, Japanese quails (Coturnix japonica japonica) were fed with various diets in which grasshopper meal (Oxya hyla) gradually replaced fish meal. The best results were obtained with the diet in which 50% of the fish meal was replaced with Oxya meal. Fecundity was significantly higher, compared with the control treatment.

Fish

Catfish. Desert locust meal (Schistocerca gregaria) was used to substitute up to 25% of the dietary protein in African catfish Clarias gariepinus juveniles without a significant reduction in growth. Excess chitin may have contributed to reducing performance and feed efficiency when higher substitution rates were used. Meal of variegated grasshopper (Zonocerus variegatus) replaced up to 25% fish meal in the diets of Clarias gariepinus without any effect on growth and nutrient utilization. Higher inclusion rates decreased digestibility and performance.

Nile tilapia. Migratory locust meal (Locusta migratoria) replaced fish meal up to 25% in the diets of Nile tilapia fingerlings (Oreochromis niloticus) without any adverse effect on the nutrient digestibility, growth performance and haematological parameters.

Potential constraints as animal feed

Pesticides and contaminants. Due to their status as agricultural pests, locusts and grasshoppers may be sprayed with insecticides in governmental control programmes or by farmers, resulting in significant amounts of residues in consumed insects. These risks are of major concern in the traditional practices of harvesting and consuming insects in the wild, where the control of chemical applications is difficult. In Kuwait, after the outbreak of 1988/89, high concentrations of residues of organophosphorus pesticides were detected in locusts collected for food. Similar such examples have been reported from Korea and Mali.

Bioaccumulation of lead in chapulines grasshoppers (*Sphenarium*) from the tailings of Mexican silver mines is suspected to have caused an outbreak of lead poisoning in 2000 in California after people consumed the insects. Accumulation of cadmium could also take place from biomass used by locusts.

In a study in Russia, the locusts produced were dried using a system called “extruder vector” that dried locust bodies by heat and pressure and destroyed all harmful bacteria. Heat and pressure treatment could eliminate the risk of microbial contamination. As for any nutrient-rich feed or food resources, improper storage of locusts postharvest, for example in contaminated containers and/or in moist conditions may lead to fungal growth and risk of mycotoxins.

Spines. The presence of large spines on the tibia of locusts and grasshoppers may cause intestinal

Figure 3. Woman catching 'chapulines' with a basket in Mexico

Photo credit : Joaquín Murguía-González, CC BY-NC 4.0 international.

constipation, which has been shown to be fatal in monkeys in the wild, and this has occasionally required surgery in humans. Grinding or removing the legs and wings is therefore recommended prior to consumption.

Harvesting

Harvesting locusts and grasshoppers as food or feed is a biological control method that may help reducing the use of pesticides and thus environmental pollution. In Mexico, hand-picking *chapulines* grasshoppers (*Sphenarium* spp.) that infest alfalfa fields decreased environmental damage, while generating an extra source of nutrition and income from the consumption and sale of grasshoppers. In Thailand, the outbreak of patanga locust (*Patanga succincta*) in maize in the late 1970s led to a campaign to promote the eating of this locust, which is now farmed for food purposes.

In addition to direct predation by domestic birds described in the poultry section, three types of methods are used to harvest locusts and grasshoppers: manual catching, statics traps, and mobile traps. Harvesting is generally done at dusk, at night or at dawn when the insects are less mobile or fly more slowly or close to the ground. Locusts and grasshoppers are particularly vulnerable in the early morning when they are still numbed by the cold. It is important to note that collecting these insects for food and feed should never be done when pesticides are used. Pesticide-contaminated locusts and grasshoppers, when harvested, should only be used in composting. Other non-chemical control methods are frightening and preventing the insects from landing. Details on harvesting methods can be obtained from our review listed at the end.

Figure 4. Static catching device in Uganda. Photo credit: Atuhaire, P., BBC, Copyright (2018), reproduced with permission.

Other uses

Locusts sprayed with pesticides could be used for composting, which could be used as a fertilizer after ensuring that the composted product is free of pesticides. During compositing pesticides would get degraded to innocuous products. Locusts are rich in chitin, which can be used as a probiotics. Chitin is also known to bind dietary lipids including triglycerides and can be exploited for treatment of hyper-cholesterol in blood. Furthermore, locust oil is rich in omega-3 fatty acids, suggesting their potential use for preventing coronary heart diseases. Locusts could have a number of industrial uses including production of bioplastics and bioactive proteins and peptides.

Conclusion and way forward

Locusts and grasshoppers are crop and pasture destroyers. However, their use as animal feed could be one of the strategies to convert this species of '*mass destruction*' to a '*resource*'. The crude protein content of locusts and grasshoppers is high, usually in the range of 50–65% in dry matter basis, with reasonably good essential amino acid composition. Those insects can replace approximately 25% of the conventional protein sources (e.g., soymeal and fish meal) in the diets of poultry, pigs and fish. Addition of locusts that replaces 50% and beyond of conventional protein sources is also possible, especially in commercial production system, if supplemented with synthetic essential amino acids which are easily available at a low cost these days. This is expected to decrease cost of feed production and increase profit to farmers, in addition to decreasing carbon footprint of animal source foods.

For making locusts and grasshoppers as a mainstream feed resource, rearing approaches need upscaling, and the harvesting techniques need adaptation to specific conditions. The locust infestations do not take place every year and not last long, implying that availability of locusts is irregular and for a short duration. Another option would be harvesting of grasshoppers that have stable population levels and can be supplied in substantial amounts at a regular interval. Nevertheless, smallholder farmers can use ground locusts as a feed supplement to the diets they normally feed to their livestock, which is deficient in protein in most of the cases. This would lead to increase in livestock production and productivity. The grinding of the locusts or grasshoppers using a locally made simple grinding machine may be possible at a cooperative or farmers' group level in a village. Capacity building activities on safe feeding of locusts and grasshoppers need promotion.

Currently, use of insecticides is considered to be an efficient approach for controlling the locusts, but use of pesticides has been shown to cause severe damage to the environment and inhabiting biological life including animals, humans, aquatic system and other insects including the beneficial ones. An integrated control approach (along with use of insecticides) wherein harvesting of locusts for use as food or feed also becomes an important strategy, would decrease use of pesticides and their associated negative effects. In such an integrated approach, the identification of the pesticide status of wild insects would be necessary to ensure the safety of their consumption. The will and participation of stakeholders (NGOs and departments that deal with emergencies) involved in controlling locusts using insecticides is required to make the best use of locusts as livestock feed. The people should be educated on collection of only live locusts for use as animal feed, and the dead ones could be used for composting. Capacity building of farmers and provision of information on the adverse effects of dead locusts after insecticide spray to animals and humans would help in the safe use of locusts. Also local people can be informed by the concerned department if the locusts in their areas have been sprayed with insecticides or not. Insecticide-free locusts and grasshoppers could be used as animal feed or human food, while insects sprayed with pesticides may be used for compost making. Institutional and policy support would be required to achieve this. Capacity building and advance preparation of the locust control emergency units towards use of the integrated approach that also considers use of locusts as animal feed would be a triple-win for the smallholder farmers, the environment, and human and animal health.
A concern has also been raised that people actively collecting the locusts during the night (when locust settle) puts them at risk either from wildlife or from other rural population. A community-based approach and communication of the advantages of locust harvesting to the community: crop and pasture

protection, and prevention of animal and human health deterioration as a result of insecticide spray would help in overcoming resistance by the rural population. Locust harvesting if takes place by using light and sound would deter wild animal from coming near to the people collecting the locusts. Alternatively, collection can be done in the mornings when the locusts are numb.

The information provided here in brief along with that available in our detailed review (reference given below) would help the countries in preparedness to make the best use of a resource generated due to arrival of 'uninvited guests', to enhance food security and create business opportunities.

References

1. Makkar HPS, Tran G, Heuzé V, Ankers P. State-of-the-art on use of insects as animal feed. Animal Feed Science and Technology 2014;197:1–33.

2. EFSA. Risk profile related to production and consumption of insects as food and feed. EFSA Journal 2015;13(10):4257.

3. Raheem D, Carrascosa C, Oluwole OB, Nieuwland M, Saraiva A, Millán R, et al. Traditional consumption of and rearing edible insects in Africa, Asia and Europe. Critical Reviews in Food Science and Nutrition 2019;59(14):2169–88.

4. BfR, NRL-AP, Garino C, Zagon J, Braeuning A. Insects in food and feed—Allergenicity risk assessment and analytical detection. EFSA Journal 2019;17(S2):e170907.

5. MoA, NDRMC, Save the children, FEWSNET, FAO, WFP. Impact of desert locust infestation on household livelihoods and food security in Ethiopia: joint assessment findings [Internet]. 2020. Available from: https://ec.europa.eu/knowledge4policy/publication/impact-desert-locust-i...

6. Wadekar N. Two new generations of locusts are set to descend on East Africa again—400 times stronger. Quartz Africa 2020. Available from: https://qz.com/africa/1836159/locusts-set-to-hit-kenya-east-africa-again...

7. van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, et al. Edible insects—Future prospects for food and feed security [Internet]. Roma, Italy: FAO; 2013. 188 p. (Forestry Paper; vol. 171). Available from: https://www.fao.org/3/i3253e/i3253e.pdf

8. Makkar HPS, Opio P, Matere J, Angerer J, Innocente L, Kinyanjui W, et al. National feed security system: What it entails and making it operational in East Africa. Broadening Horizons 2020;(53). Available from: https://www.feedipedia.org/content/national-feed-security-system-what-it...

9. Balehegn M, Mekuriaw Z, Miller L, Mckune S, Adesogan AT. Animal-sourced foods for improved cognitive development. Animal Frontiers 2019;9(4):50–7.

10. FAO. Frequently Asked Questions (FAQs) about locusts [Internet]. Locust Watch—Desert locust. 2020. Available from: http://www.fao.org/ag/locusts/en/info/info/faq/index.html

11. Arthurs S. Grasshoppers and locusts as agricultural pests. In: Encyclopedia of entomology. Springer Science & Business Media; 2008. p. 1690–4.

12. Lecoq M. The migratory locust in Africa and in Madagascar. Québec, Canada: Orthopterists' Society; 1991. 32 p. (The Orthopterists' Society series of field guides).

13. Launois-Luong MH, Lecoq M. Reference manual of WMO codes for transmission of pest locust data. 1993. 64 p. Available from: https://www.researchgate.net/publication/255718093_Reference_manual_of_WMO_codes_for_transmission_of_pest_locust_data

14. Sword GA. Gregarious behavior in insects. In: Encyclopedia of entomology. Dordrecht: Springer Science & Business Media; 2008. p. 1733–40.

15. Oonincx DGAB, van der Poel AFB. Effects of diet on the chemical composition of migratory locusts (locusta migratoria). Zoo Biology 2011;30(1):9–16.

16. Clarkson C, Mirosa M, Birch J. Potential of extracted locusta migratoria protein fractions as value-added ingredients. Insects 2018;9(1):20.

17. Osimani A, Garofalo C, Milanović V, Taccari M, Cardinali F, Aquilanti L, et al. Insight into the proximate composition and microbial diversity of edible insects marketed in the European Union. European Food Research and Technology 2017;243(7):1157–71.

18. Hemsted WRT. Locusts as a protein supplement for pigs. The East African Agricultural Journal 1947;12 (14):225–6.

19. Adeyemo GO, Longe OG, Lawal HA. Effects of feeding desert locust meal (Schistocerca gregaria) on performance and haematology of broilers. In: Tropentag 2008 [Internet]. Hohenheim, Stuttgart, Germany; 2008. Available from: https://www.tropentag.de/2008/abstracts/full/623.pdf

20. Göhl B. Locusts. In: Tropical Feeds: Feed Information Summaries and Nutritive Values [Internet]. Roma, Italy: Food and Agriculture Organization of the United Nations; 1975. p. 435. Available from: https://books.google.fr/books/about/Tropical_Feeds.html?id=AsJCaQ6j0McC&...

21. Grabowski NT, Nowak B, Klein G. Proximate chemical composition of long-horned and short-horned grasshoppers (Acheta domesticus, Schistocerca gregaria and Phymateus saxosus) available commercially in Germany. Archiv für Lebensmittelhygiene 2008;59(6):204–8.

22. Touber F. Evolution de la composition corporelle en azote et en acides aminés du criquet pèlerin Schistocerca gregaria [Orthopt. Acrididae] au cours de son développement. Annales de la Société entomologique de France 1981;17(1):125–30.

23. Anand H, Ganguly A, Haldar P. Potential value of acridids as high protein supplement for poultry feed. International Journal of Poultry Science 2008;7(7):722–5.

24. Badanaro F, Bilabina I, Awaga KL, Sanbena Bassan B, Amevoin K, Amouzou K. Identification et composition nutritionnelle de quelques espèces d'orthoptères consommées au Togo. Revue CAMES 2015;3(1):14–20.

25. Sugimura K, Hori E, Kurihara Y, Itoh S. Nutritional value of earthworms and grasshoppers as poultry feed. Japanese Poultry Science 1984;21(1):1–7.

26. Alegbeleye WO, Obasa SO, Olude OO, Otubu K, Jimoh W. Preliminary evaluation of the nutritive value of the variegated grasshopper (Zonocerus variegatus L.) for African catfish Clarias gariepinus (Burchell. 1822) fingerlings. Aquaculture Research 2012;43 (3):412–20.

27. Ladeji O, Solomon M, Maduka H. Proximate chemical analysis of Zonocerus variegatus (Giant grasshopper). Nigerian Journal of Biotechnology 2003;14(1):42–5.

28. Womeni HM, Linder M, Tiencheu B, Mbiapo FT, Villeneuve P, Fanni J, et al. Oils of insects and larvae consumed in Africa: Potential sources of polyunsaturated fatty acids. OCL 2009;16(4–6):230–5.

29. Jonas-Levi A, Martinez J-JI. The high level of protein content reported in insects for food and feed is overestimated. Journal of Food Composition and Analysis 2017;62:184–8.

30. Boulos S, Tännler A, Nyström L. Nitrogen-to-protein conversion factors for edible insects on the Swiss market: T. molitor, A. domesticus, and L. migratoria. Frontiers in Nutrition. 2020;7:89.

31. Cheu SP. Changes in the fat and protein content of the African migratory locust, Locusta migratoria migratorioides (R. & F.). Bulletin of Entomological Research 1952;43(1):101–9.

32. Sauvant D, Perez J-M, Tran G. Tables INRA-AFZ de composition et de valeur nutritive des matières premières destinées aux animaux d'élevage. 2e édition. Versailles: INRA Editions; 2004.

33. Balogun BI. Growth performance and feed utilization of Clarias gariepinus (Teugels) fed different dietary levels of soaked Bauhinia monandra (Linn.) seed meal and sun-dried locust meal (Schistocerca gregaria) [Internet] [Thesis]. 2011. Available from: https://kubanni-backend.abu.edu.ng/server/api/core/bitstreams/e6120e0c-c...

34. Adeyeye EI. Amino acid composition of variegated grasshopper, Zonocerus variegatus, Tropical Science 2005;45(4):141–3.

35. DeFoliart GR, Finke MD, Sunde ML. Potential value of the Mormon cricket (Orthoptera: Tettigoniidae) harvested as a high-protein feed for poultry. Journal of Economic Entomology 1982;75 (5):848–52.

36. INRAE, CIRAD, AFZ. FeedTables.com [Internet]. 2022. Available from: https://www.feedtables.com/content/soybean-meal-oil-5-48-protein-oil; https://www.feedtables.com/content/fish-meal-protein-65

37. Ojewola GS, Udom SF. Chemical evaluation of the nutrient composition of some unconventional animal protein sources. International Journal of Poultry Science 2005;4(10):745–7.

38. Mohamed EHA. Fatty acids contents of the edible migratory locust Locusta migratoria, Linnaeus, 1758 (Orthoptera: Acrididae). International Journal of Advances in Pharmacy, Biology and Chemistry

2015;4(4):746–50.

39. Wu KJ. Is a duck army coming for Pakistan's locusts? Not so fast. Smithsonian Magazine. 2020. Available from: https://www.smithsonianmag.com/smart-news/duck-army-coming-pakistans-loc...

40. Khusro M, Andrew NR, Nicholas A. Insects as poultry feed: A scoping study for poultry production systems in Australia. World's Poultry Science Journal 2012;68(3):435–46.

41. Sun T, Long RJ, Liu ZY. The effect of a diet containing grasshoppers and access to free-range on carcase and meat physicochemical and sensory characteristics in broilers. British Poultry Science 2013;54(1):130–7.

42. Sun T, Liu Z, Qin L, Long R. Meat fatty acid and cholesterol level of free-range broilers fed on grasshoppers on alpine rangeland in the Tibetan Plateau. Journal of the Science of Food and Agriculture 2012;92(11):2239–43.

43. Sun T, Long RJ, Liu ZY, Ding WR, Zhang Y. Aspects of lipid oxidation of meat from free-range broilers consuming a diet containing grasshoppers on alpine steppe of the Tibetan Plateau. Poultry Science 2012;91(1):224–31.

44. Fronda FM. Notes on locust meal as a poultry feed. Philippine Agriculturist 1935;24(5):425–7.

45. Liu CM, Lian ZM. Influence of Acrida cinerea replacing Peru fish meal on growth performance of broiler chickens. Journal of Economic Animal 2003;7(1):48–51.

46. Ojewola GS, Eburuaja AS, Okoye FC, Lawal AS, Akinmutimi AH. Effect of inclusion of grasshopper meal on performance, nutrient utilization and organ of broiler chicken. Journal of Sustainable Agriculture and the Environment 2003;5(1):19–25.

47. Ojewola GS, Okoye FC, Ukoha OA. Comparative utilization of three animal protein sources by broiler chickens. International Journal of Poultry Science 2005;4(7):462–7.

48. Haldar P. Evaluation of nutritional value of short-horn grasshoppers (acridids) and their farm-based mass production as a possible alternative protein source for human and livestock. In: Expert Consultation Meeting on Assessing the Potential of Insects as Food and Feed in assuring Food Security, 23–26 January. Roma: FAO; 2012.

49. Johri R, Singh R, Johri PK. Effect of different formulated plant and animal diet on hematology of Clarias batrachus Linn. under laboratory conditions. Biochemical and Cellular Archives 2010;10(2):283–91.

50. Johri R, Singh R, Johri PK. Studies on ovarian activity in formulated feed treated Clarias batrachus Linn. Journal of Experimental Zoology, India 2011;14(1):111–5.

51. Johri R, Singh R, Johri PK. Histopathological examination of the gill, liver, kidney, stomach, intestine, testis and ovary of Clarias batrachus Linn. during the feeding on different formulated feeds. Journal of Experimental Zoology, India 2011;14(1):77–9.

52. Abanikannda MF. Nutrient digestibility and haematology of Nile tilapia (Oreochromis niloticus) fed with varying levels of locust (Locusta migratoria) meal [Bachelor of Aquaculture and Fisheries Management]. Abeokuta, Ogun State: Federal University of Agriculture; 2012.

53. Emehinaiye PA. Growth performance of Oreochromis niloticus fingerlings fed with varying levels of migratory locust (Locusta migratoria) meal [Bachelor of Aquaculture and Fisheries Management]. Abeokuta, Ogun State: Federal University of Agriculture; 2012.

54. Saeed T, Dagga F, Saraf M. Analysis of residual pesticides present in edible locusts captured in Kuwait. Arabian Gulf Journal of Scientific Research 1993 Jan 1;11:1–5.

55. Gibril S, Idris AA. Utilization of locust meal in poultry diets [Sudan]. Journal of Natural Resources and Environmental Studies (Sudan) 1997;1(1):19–23.

56. Handley MA, Hall C, Sanford E, Diaz E, Gonzalez-Mendez E, Drace K, et al. Globalization, binational communities, and imported food risks: Results of an outbreak investigation of lead poisoning in Monterey County, California, American Journal of Public Health 2007;97(5):900–6.

57. Zhang Z-S, Lu X-G, Wang Q-C, Zheng D-M. Mercury, cadmium and Lead biogeochemistry in the soil–plant–insect system in Huludao City. Bulletin of Environmental Contamination and Toxicology 2009;83(2):255.

58. Vorotnikov V. Russia: Processing locusts for compound feed [internet]. AllAboutFeed 2015. Available from: https://www.allaboutfeed.net/RawMaterials/Articles/2015/4/ Russia-Processing-locusts-into-

compound-feed-1742408W/

59. Cerritos R, Cano-Santana Z. Harvesting grasshoppers Sphenarium purpurascens in Mexico for human consumption: A comparison with insecticidal control for managing pest outbreaks. Crop Protection 2008;27(3):473–80.

60. DeFoliart GR. Chapter 102 - Food, Insects as. In: Resh VH, Cardé RT, editors. Encyclopedia of insects [Internet]. 2nd ed. San Diego: Academic Press; 2009. p. 376–81. Available from: http://www.sciencedirect.com/science/article/pii/B9780123741448001119

61. Cong D. Grasshopper catching season. Báo ảnh Việt Nam 2017. Available from: https://vietnam.vnanet.vn/english/grasshopper-catchingseason/265881.html

62. Payne CLR. Collecting grasshoppers among polycultural fields [Internet]. LibertyRuth 2015. Available from: http://www.libertyruth.com/blog/collecting-grasshoppers-among-polycultur...

63. Ramos-Elorduy J, Landero-Torres I, Murguía-González J, Pino MJM. Biodiversidad antropoentomofágica de la región de Zongolica, Veracruz, México, Revista de Biología Tropical 2006;56(1):303–16.

64. Hanboonsong Y, Jamjanya T, Durst PB. Six-legged livestock: Edible insect farming, collection and marketing in Thailand [Internet]. Bangkok:

Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific; 2013. 57 p. Available from: http://www.fao.org/3/i3246e/i3246e00.htm

65. Atuhaire P. The Ugandan love of grasshoppers - and how to harvest them. BBC News 2018. Available from: https://www.bbc.com/news/world-africa-46357020

66. Xu R, Zhou Q, Wang S. Technical development on mechanized control of locust. Transactions of The Chinese Society of Agricultural Machinery 2005;36(11):165–7.

67. Zhao J. Multi-functional locust trapping apparatus [Internet]. CN205284735U, 2016. Available from: https://patents.google.com/patent/CN205284735U/en

68.Wang L, Niu H, Zhou Q. Locust induced trapping experiment based on coupling effect of air disturbance stimulation and spectrum light source. Transactions of the Chinese Society of Agricultural Engineering 2014;30(5):108–15.

69. Lysakov A, Grinchenko V, Molchanov A, Devederkin I. Effect of ultra-bright led light for locust plague control. In: 18th international scientific conference engineering for rural development. Jelgava, Latvia; 2019. p. 630–4.

70. Olshansky OV, Beloglazov IV. Device for trapping locusts [Internet]. RU2520277C2. 2014. Available from: https://patents.google.com/patent/RU2520277C2/en

71. Gong H, Zhu G, Yu X. Locust catching and killing method [Internet]. CN104521919A. 2015. Available from: https://patents.google.com/patent/CN104521919A/en

72. United States Entomological Commission. The Rocky Mountain locust, or grasshopper of the West. In: Report of the Commissioner of Agriculture for the year 1877 [Internet]. Washington: Government Printing Office; 1878. p. 264–333. Available from: http://archive.org/details/CAT30951786015

73. Kang C, Luo T, Wang X. Vehicle mounted pneumatic locust catching machine [Internet]. CN101124899B. 2010. Available from: https://patents.google.com/patent/CN101124899B/

74. Krasyuk DV. Locust collecting apparatus [Internet]. EA029388B1. 2018. Available from: https://patents.google.com/patent/EA029388B1/en

75. Lebedev AT, Ochinsky VV, Pavlyuk RV, Zubenko EV, Zakharin AV, Lebedev PA, et al. Method of locust extermination and device for its implementation [Internet]. RU2676145C1. 2018. Available from: https://patents.google.com/patent/RU2676145C1/en

76. Li Z, Chen J, Guo X, Pang J, Song Y, Nuerlan H, et al. A kind of locust catching device [Internet]. CN207444092U. 2018. Available from: https://patents.google.com/patent/CN207444092U/en

77. Xu G. Locust trap [Internet]. CN201854617U. 2011. Available from: https://patents.google.com/patent/CN201854617U/en/enCN201854617U

78. Hinks CF, Erlandson MA. Rearing grasshoppers and locusts: Review, rationale and update. Journal of Orthoptera Research 1994;(3):1–10.

79. Azizi N, El Ghadraoui L, Petit D, Fadil F, Mohim A. A simple diet for the rearing success of the Desert Locust, Schistocerca gregaria (Forskål,1775) (Orthoptera, Acrididae). Bulletin de la Société entomologique de France 2010;115(4):445–50.

80. Straub P, Tanga CM, Osuga I, Windisch W, Subramanian S. Experimental feeding studies with crickets and locusts on the use of feed mixtures composed of storable feed materials commonly used in livestock production. Animal Feed Science and Technology 2019;255:114215.

81. Bernays EA, Woodhead S. The need for high levels of phenylalanine in the diet of Schistocerca gregaria nymphs. Journal of Insect Physiology1984;30(6):489–93.

82. Mehrotra KN, Rao PJ, Farooqi TNA. The consumption, digestion and utilization of food by locusts. Entomologia Experimentalis et Applicata1972;15(1):90–6.

83. Mordue (Luntz) AJ, Hill L. The utilisation of food by the adult female desert locust, Schistocerca gregaria. Entomologia Experimentalis et Applicata 1970;13(3):352–8.

84. Rao PJ, Subrahmanyam B. Azadirachtin induced changes in development, food utilization and haemolymph constituents of Schistocerca gregaria Forskal. Journal of Applied Entomology 1986;102(1–5):217–24.

85. Driver E. How insects can revolutionize our food systems [Internet]. Fix. 2021. Available from: https://grist.org/fix/from-plague-to-promise-howinsects-can-revolutioniz...

86. Samejo AA, Sultana R, Kumar S, Soomro S. Could entomophagy be an effective mitigation measure in desert locust management? Agronomy 2021;11(3):455.

87. Stull VJ, Finer E, Bergmans RS, Febvre HP, Longhurst C, Manter DK, et al. Impact of edible cricket consumption on gut microbiota in healthy adults, a double-blind, randomized crossover trial. Scientific Reports 2018;8(1):10762.

88. Egonyu JP, Subramanian S, Tanga CM, Dubois T, Ekesi S, Kelemu S. Global overview of locusts as food, feed and other uses. Global Food Security 2021;31:100574.