



THE NUTRITIONAL VALUE OF GRASSHOPPERS AND LOCUSTS – A REVIEW

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Abstract

Alternative protein source discovery is one of the main objectives of all researchers in the nutrition field because the world population is increasing rapidly. Insects are currently on top of the list of alternative protein sources. Grasshopper and locust meals are from that category. Grasshoppers and locusts, commonly consumed in insect-eating communities, are among the most promising insects as food and feed. Therefore, this review aims to summarize available data on their nutritional composition including crude fiber (2.5–17.7%), chitin (4–11%), crude ash (1.8–6.7%), crude protein (16.6–77.3%), crude fat (2.6–54.9%), and energy (157–527 kcal/g) of grasshoppers varying between these ranges. The essential amino acids (AA) profile reflects methionine (0.9–3.9%), lysine (2.9–7.1%), threonine (1.6–5.3%), leucine (4.6–12.7%), tryptophan (0.4–3.2%), and valine (4.1–0.2%). The fatty acids (FA) profile is oleic acid (3.4–40.9%), linoleic acid (0.8–45.6%), linolenic acid (1.4–13.1%), and lauric acid (0.3–1.3%). The polyunsaturated FA (PUFA) (17.5–67.4%) and saturated FA (SFA) (22.1–56.8%) are present in the range quoted in brackets. The PUFA content richness is beneficial for human consumption. The huge diversity in the chemical composition of grasshoppers is mainly due to the substrate chemical composition on which grasshoppers propagate. Some allergic reactions have been reported in the literature, but the removal of wings, legs, and antennae overcame the allergenicity problem. In conclusion, this review summarizes the nutritional composition of grasshoppers and locusts in scientific literature.

Key words: caelifera, *Schistocerca gregaria*, *Locusta migratoria*, animal feed, alternative proteins

The overall population of the world is expected to reach 9 to 11 billion in 2050 (Tomiyama et al., 2020; Legendre and Baker, 2022). Consequently, the focus is increasing on food security and environmental challenges associated with the consumption and production of food. The World Health Organization (WHO) predicts that up to 870 million people may experience malnutrition due to food shortages (Baker et al., 2016; van Dijk et al., 2021). This information is more difficult to accept considering the forecasted decline of available land and rising protein demand. The absolute extent of land required to supply a certain raw resource, such as meat, is related to this problem. However, the problem incorporates not only the acreage necessary for foraging in free range or cultivated pastures but also the area necessary for fodder production. The demand for land usage and resources is now rising, eventually leading to their depletion (Alexander et al., 2015). Livestock production is the world's largest land consumer which constitutes around 30% of the total land area (Steinfeld et al., 2006). Deforestation induced by pasture and fodder crop increase is reported for 8% of total anthropogenic CO₂ emissions (Steinfeld et al., 2006). Because feed production is accountable for most of the consequences of greenhouse gases (GHG) emissions, insect farming is more effective in terms of land usage than conventional animal production and it is more

effective in terms of feed utilization. Livestock production is experiencing tremendous sustainability challenges worldwide, which are emerging in the European Union (EU) due to consumption issues, including the health and ecological implications of consuming meat and increasing public worries about animal care (Guyomard et al., 2021).

The Orthoptera order, which accounts for 13% of all edible insects and includes the widespread agricultural pest grasshopper *Locusta migratoria*, is frequently eaten in various parts of the world (Mishyna et al., 2019). Siddiqui et al. (2023) stated that there are at least 120 species of edible grasshoppers and locusts, which are eaten in large quantities in many African and Asian nations as well as in some areas of America and are a powerhouse of nutrients and antioxidants. Their protein content can reach up to 76%. They have a shorter life span and take 4 to 8 weeks to become adult as compared to grasshopper and a quick rearing rate of 10–16 folds in every cycle (Clarkson et al., 2018). The Old Testament records one of the first permissible consumptions of insects as sustenance, allowing the ingestion of “any kind of locust, any kind of bald locust, any kind of cricket, and any kind of grasshopper.” (Leviticus 11:22; (Evans et al., 2015)). Following Leviticus 11:20–22 of the Bible, Jewish tradition bans consuming all insects other than locusts, katy-

didids, crickets, and grasshoppers. Due to their technological operational features, such as water and oil absorption capacity, colloidal stability, and jellification capacity, they might be utilized as a consistent texture ingredient in food items (Gravel and Doyen, 2020). Food experts are encouraging researchers to investigate additional applications besides the most typical, a ready-to-eat fried form of grasshoppers (Cruz-López et al., 2022). They are insect species that have the greatest biomass and a huge population (Cerritos, 2011). Furthermore, because certain grasshoppers are found in swarms (locusts), they are easier to grow and harvest. Grasshoppers are gathered and sold in local marketplaces in regions (Africa, particularly Nigeria) where grasshoppers are regarded as both a traditional cuisine and a problem to agricultural crops (Haber et al., 2019). In 65 nations, primarily in Africa and Asia, locusts have been widely harvested during epidemics and consumed for centuries (Mitsuhashi, 2016; Van Huis, 2020). Paul et al. (2016) stated that their flavour has a neutral taste comparable to almonds and walnuts. Recently, Kulma et al. (2023) tested the sensory properties of *Locusta migratoria* and concluded that its taste resembles mushrooms, chicken, smoked mackerel and ham. Kelemu et al. (2015) divided *Locusta* into seven types: red (consumed in Kuwait, Mexico and Saudi Arabia (Mitsuhashi, 2016)), Bombay and migratory (Thailand, China, Japan, Philippines, Vietnam, India, Laos, Malaysia, and Myanmar from Asia, Mexico from South America along with United States, and Europe (Poma et al., 2017; Costa-Neto and Dunkel, 2016)), desert, brown, Sahelian, Australian plague (Australia), and South American (Colombia and Brazil). Younger ones are more prone than older men and women to practice entomophagy, while Chinese people are more likely than Germans to consume locusts (Sun-Waterhouse et al., 2016). Lim et al. (2022) conducted a trial in two areas of Malaysia and found that adults in the Klang Valley and Kuching still have a low acceptability of eating insects, with sensory factors, food safety concerns, and feelings of dislike serving as the primary obstacles. Contrarily, Kulma et al. (2020) conducted a trial in the Czech Republic and stated that age and gender substantially impacted the replies from a sociodemographic perspective; younger individuals and males expressed more favorable opinions about entomophagy than older persons and women. Crickets, katydids, and locusts were the most popular processed insects over whole insect consumption. Most respondents (77.7%) stated they would not object to eating meat products made from animals that were fed insects.

This review provides detailed insight into chemical composition of edible grasshoppers and locusts with emphasis on AA, FA, macro and micro minerals, and allergens.

Nutritional profile

Proximate composition and energy

The complete nutritional profile of locusts and grasshoppers is given in Table 1. The longhorn grass-

hopper (*Ruspolia differens*) is an important food source in the Lake Victoria Region of East Africa. Kinyuru et al. (2010) reported grasshopper's crude protein contents to be 37.1 % in green and 35.3% in brown forms. The moisture content of grasshopper and locust are as follows; fresh (55.0, 44.98%), sun dried (7.05, 2.35%), oven dried (4.0, 1.38%), which varies depending on species, freshness, meal and powder form (Wambui et al., 2022). The crude fiber is found between 1.0% (fat enriched grasshoppers) and 17.7% (dried powder) as fresh weight or as it is basis. The excessive fiber content of *L. migratoria* is analogous to that of *R. differens* and could therefore bestow more health benefits for humans and animals (Fombong et al., 2021). The exoskeleton of grasshoppers and locusts contains a considerable amount of chitin in it which varies from 4.71 to 11.84% of DM (Kaya et al., 2015). Next to cellulose, chitin is the second-most prevalent bioactive polysaccharide on the earth (Joseph et al., 2021). It is commonly recognized that dietary fiber may give animals nutritional value by supplying energy (Varel and Yen, 1997; Jamroz et al., 2002). Dietary fiber indirectly enhances immune system and gastrointestinal health (Jha and Leterme, 2012; Jha et al., 2010; Pieper et al., 2008). Enhancing the structure and functionality of the mucosa and boosting the quantity and variety of commensal bacteria in the gastrointestinal tract, it may aid in maintaining the health of the small and large intestines of poultry (Jha and Mishra, 2021). Chitin from edible insects is a great prebiotic that may have an impact on the gut flora. When ingested, the chitin from insects increases the variety of the fecal bacteria, which benefits the gut microbiome. The gut microbiota produces signals that have an impact on health, immune system, metabolism, and normal nutritional status (Kipkoech, 2023). The protein, fat, and energy contents of locusts are similar to those of meat, 18–29%, 1–32%, and 106–353 kcal/100 g, respectively (Arshad, 2018; Peng et al., 2020). Table 1 shows that energy ranges between 218 and 527.5 kcal per gram. Grasshopper meal includes antinutritional compounds such as oxalates, phytates, and tannins, which may reduce nutrient availability (Skotnicka et al., 2021). The grasshoppers contain higher protein content but lower carbohydrate content compared to conventional protein sources, whereas frying leads to more carbohydrate content (Kuntadi et al., 2018). Levels of carbohydrates in grasshoppers are between 39 and 49% (Porusia et al., 2020). Insects have minimal carbohydrate content and are categorized as low carbohydrate high protein entities. According to Siriamornpun and Thammapat (2008), the carbohydrate value of numerous species of insects in Thailand varies from 7 to 16%, equivalent to the carbohydrate content of insects in Nigeria, which varies from 7 to 20%. The chemical and energy composition make grasshoppers and locusts interesting alternatives for animal and human nutrition.

Table 1. The content of nutrients (% of dry matter) and energy value (MJ) of locusts and grasshoppers and their species

Parameter	Crude Protein	Crude Fat	Crude Fiber	Crude Ash	Energy (MJ)	Reference
Longhorn GH	39.95	56.25	0.1	1.84	ND	(Shabo et al., 2022)
SFGH	47.64	6.76	ND	3.48	ND	(Reyes-Herrera et al., 2022)
MFGH	51.45	6.45	ND	2.45	ND	
ML	54.16	30.52	9.19 ²	3.08	2.14	(Fombong et al., 2021)
SG	61.41	19.1	6.61 ²	2.7	1.98	
DL	46.3	32.3	4.8	6.7	1.88	(Kinyuru, 2021)
SG	52.3	12	NG	10.0	0.74	(Mariod et al., 2017)
GH (Fry)	27.67	11.25	2.61	4.93	ND	(Porusia et al., 2020)
GH (Roast)	39.08	9.78	3.38	5.28	ND	
ALF GH	60.07	14.86	ND	4.05	ND	(Ibarra-Herrera et al., 2020)
MGF GH	63.94	10.37	ND	4.08	ND	
WGHF	60.55	9.18	ND	2.27	1.59	(Dewi et al., 2020)
GHM	52.50	27.10	8.30	4.25	ND	(Amobi et al., 2020)
African GH	55.49	20.65	16.81	7.03	ND	(Nginya et al., 2019)
DL	54.43	21.92	17.64	6.41	ND	
Edible GH	53.83	22.15	18.32	5.69	ND	
SG	38.1	10.6	ND	4.0	ND	(Mishyna et al., 2019)
GH Powder	35.3	13.3	ND	3.9	ND	(Haber et al., 2019)
Defatted GH powder	39.1	18.0	ND	4.0	ND	
GHM (<i>Oxya hyla</i>)	64.67	2.58	9.23	4.59	ND	(Ghosh and Mandal, 2019)
SP	53.8	29.81	10.96	5.05	ND	(Khalil, 2013)
SP	52.74	10.51	ND	ND	ND	(Cuj-Laines et al., 2018)
ML	53.1	11.4	ND	3.3	ND	(Brogan, 2018)
ML	ND	7.7-11.7	ND	ND	ND	(Poma et al., 2017)
<i>Ruspolia</i> GH-FD	46.41	35.56	11.33	4.79	2.17	(Fombong et al., 2017)
<i>Ruspolia</i> GH-OD	48	35	13	5	2.19	
<i>Schistocerca</i> sp.	61	17	10	4.6	ND	(Paul et al., 2016)
<i>S. histrio</i> S	77.25	4.71	11.15	2.05	1.55	(Ruiz et al., 2015)
SP	75.87	6.02	7.08	2.52	1.64	
<i>Taeniopoda eques</i> B	71.05	5.85	10.56	2.95	1.57	
<i>Melanoplus femurrubrum</i> D	74.7	5.23	10.01	3.4	1.56	
<i>Schistocerca</i> spp.	62.5	16.0	10.05	4.5	1.76	
DL	78.73	13.53	2.58	3.41	1.80	(Zielińska et al., 2015)
DL	59.9	33.2	12.2	5.6	2.20	(Khalil, 2013)
SP	53.57	8.98	ND	ND	ND	(Van Huis et al., 2013)
VGM	61.50	6.87	8.5	4.30	0.91	(Alegbeye et al., 2012)
SP	71.50	7.75	ND	ND	ND	(Melo et al., 2011)
<i>Ruspolia</i> GH-brown	44	46	5	3	ND	(Kinyuru et al., 2010)
<i>Ruspolia</i> GH-green	43	48	4	3	ND	

GH = grasshopper; ND = not determined; SFGH = soy sprouts fed GH; MFGH = maize leaves fed GH; ML = migratory locust; ¹Processed; ²Chitin; SG = *Schistocerca gregaria*; DL = desert locust; BL = Bombay locust; VGM = variegated grasshopper meal; ALF = alfalfa; MGF = maize green fodder; WGHF = wood grasshopper flour; GHM = grasshopper meal; SP = *Sphenarium purpurascens*; FD = freeze dried; OD = oven dried.

Table 2. Essential amino acid (g/100 g of protein) contents of locusts and grasshoppers and their species

Species	SFG	MFG	ML	SG	MLP	WGH	LP	DL adult	ML	SH	SP	BF	MF
Unit	g/100 g												
Histidine	2.44	2.61	2.723	2.632	1.6	ND	1.03	3.0	1.4	1.9	2.2	2.4	2.31
Methionine	ND	ND	ND	ND	0.9	0.78	3.92	1.9	ND	2.0	2.5	1.8	2.98
Isoleucine	6.34	5.91	4.618	4.625	2.9	ND	2.38	5.1	2.5	5.3	4.2	4.7	2.64
Leucine	12.67	11.5	8.456	8.23	5.0	7.67	4.52	8.3	4.6	8.7	8.9	8.8	5.82
Lysine	6.57	6.06	4.784	4.569	3.6	3.94	7.11	6.6	2.9	5.7	5.7	5.5	6.17
Threonine	5.32	4.8	3.962	3.947	2.3	ND	1.58	3.0	1.9	4.0	3.1	4.4	3.70
Tryptophan	0.91	1.1	0.971	0.82	0.5	ND	3.21	ND	0.4	0.6	0.7	0.6	0.64
Valine	9.22	8.39	7.211	6.868	4.2	ND	4.16	7.8	4.1	5.1	5.7	5.7	4.09
Reference	(Ibarra-Herrera et al., 2020)	(Fombong et al., 2021)	(Brogan et al., 2021)	(Dewi et al., 2020)	(Cao et al., 2019)	(Mishyna et al., 2019)	(Purschke et al., 2018)	(Blásquez et al., 2012)					

GH = grasshopper; SFG = sprout fed GH; MFG = maize leaf fed GH; ML = migratory locust; SG = *Schistocerca gregaria*; WGH = wood grasshopper; DL = desert locust; SH = *Sphenarium histrio*; SP = *Sphenarium purpurascens*; BF = *Boopeton flaviventris*; MF = *Melanoplus femurrubrum*; MLP = migratory locust powder; LP = locust protein; ND = not determined.

Table 3. Fatty acid composition (% of total fatty acids) of locusts and grasshoppers and their species

Fatty Acids	(Kinyuru, 2021)	(Ibarra-Herrera et al., 2020)	(Fombong et al., 2021)	(Torruco-Uco et al., 2019)	(Paul et al., 2016)	(Sánchez-Muros et al., 2014)	(Raksakantong et al., 2010)
Species	DL	SFG	MFG	ML	SG	SP	SP
Caproic acid C6:0	ND	0.91	0.75	ND	ND	ND	ND
Caprylic acid C8:0	ND	1.15	2.40	ND	ND	ND	ND
Capric acid C10:0	ND	0.66	1.14	ND	ND	ND	ND
Lauric acid (C12:0)	0.32	0.72	1.13	1.30	0.41	ND	ND
Myristic acid (C14:0)	2.55	0.38	0.61	3.63	2.66	ND	ND
Palmitic acid (C16:0)	26.88	7.71	7.99	43.01	26.14	0.78–25.59	1.10–1.40
Stearic acid (C18:0)	3.81	3.44	3.58	6.31	7.02	1.55–12.42	9.20–10.30
Oleic acids (C18:1)	31.66	40.78	32.62	22.85	40.87	2.01–24.90	22.70–24.40
Linoleic acid (C18:2)	24.067	0.42	0.83	9.32	6.85	12.30–45.63	36.30–39.00
Linolenic acid (C18:3)	10.14	0.74	0.69	4.85	13.11	0.62–40.10	1.00–1.40
Total saturated fatty acids (TSFA)	33.56	22.1	29.6	56.85	36.95	0.59–38.90	34.60–35.60
Total unsaturated fatty acids (TUFA)	66.47	ND	ND	43.15	63.05	ND	ND
Polyunsaturated fatty acids (PUFA)	34.81	20.8	19.1	17.45	20.68	41.–62.40	37.30–40.40
n-6/n-3 ratio	2.4	0.28	0.42	1.63	0.54	ND	ND

GH = grasshopper; SFG = sprout fed GH; MFG = maize leaf fed GH; ML = migratory locust; SG = *Schistocerca gregaria*; DL = desert locust; SP = *Sphenarium purpurascens*; ND = not determined.

Table 4. Mineral composition (mg/100 g) of locusts and grasshoppers and their species

	(Fombong et al., 2021)		(Kinyuru, 2021)	(Ibarra-Herrera et al., 2020)		(Dewi et al., 2020)	(Nginya et al., 2019)			(Fombong et al., 2017)		(Kinyuru et al., 2010)	
	ML	SG	DL	ALF	MGF	WGH	AG	DL	EG	FD GH	OD GH	BRD	GRD
Macro minerals													
Potassium	796.01	1309.46	101.30	1028.80	1007.40	ND	344	310	250	816.4	779.19	259.7	370.6
Phosphorus	697.17	968.65	171.00	ND	ND	ND	153	160	142	685.9	652.31	121.0	140.9
Sodium	221.89	285.14	27.58	34.61	37.54	ND	ND	ND	ND	69.1	54.01	229.7	358.7
Calcium	129.79	80.48	208.36	200.95	235.15	ND	146	101	110	1034.7	895.67	24.5	27.4
Magnesium	86.01	128.29	40.18	123.93	131.33	ND	56.4	13.3	5.0	161.0	145.75	33.1	33.9
Ca/P	0.19	0.08	NG	NG	NG	ND	NG	NG	NG	NG	NG	NG	NG
Micro minerals													
Zinc	12.70	24.88	3.68	17.84	17.98	63.5	22.5	23.6	32.8	14.2	14.63	12.4	17.3
Manganese	0.40	1.26	3.57	1.71	1.74	ND	1.4	1.5	1.4	8.29	7.40	2.5	5.3
Iron	6.59	7.31	4.83	13.33	18.29	13	32.2	22.5	7	220.1	216.56	13.0	16.6
Copper	1.20	4.86	ND	2.98	3.02	ND	5.3	3.2	1.8	1.66	1.66	0.5	0.6

GH = grasshopper; ML = migratory locust; SG = *Schistocerca gregaria*; DL = desert locust; WGH = wood grasshopper flour; AG = African grasshopper; EG = edible grasshopper; FD = freeze dried; OD = oven dried; BRD = brown *Ruspolia differens*; GRD = green *Ruspolia differens*; ND = not determined; NG = not given.

Protein and amino acid content

Amino acids (AA) are integral part of protein and facilitate different functions of body like gene expression, immune response, milk production, hormones secretion, anti-inflammatory effect, anti-oxidative activity, neurotransmitter formation, pigmentation, digestion via enzymes, and regulation of ionic balance in body (Wu et al., 2014). Chemically or structurally identical AA can be antagonistic to one another, which results in lower food intake, strange behavior, and stunted animal growth (Wu, 2009).

The crude protein content of grasshoppers and locusts ranges between 16.6 and 77.25% depending upon the species and physical form of locusts and grasshoppers (Table 1). The protein to weight ratio per grasshopper (*S. purpurascens*) on a DM basis is 50% and remains consistent throughout its growth (Cerritos-Flores et al., 2015); It has already been stated that grasshoppers have greater protein levels than fish or beef steak (Akhtar and Isman, 2018). Protein concentration in dried powder grasshoppers may reach about 70–80% on a DM basis, with better digestibility (after processing and chitin extraction), and it includes essential AA like leucine and lysine (Blásquez et al., 2012; Rumpold and Schlüter, 2013 a). The crude protein content of edible insects is up to 77% of DM (in grasshoppers) (Belluco et al., 2013; Finke et al., 1989), whereas *Ruspolia differens* contains 47.7% crude protein in oven dried powder of DM (Fombong et al., 2017), the crude protein levels of all orthopterans range between 43.9 and 77.1% (Rumpold and Schlüter, 2013 a; FAO, 2019). Although locusts' crude protein contents are usually superior than the conventional protein sources, the existence of the chitin may hinder solubility, however, it may be reduced 6-fold at basic pH (Brogan, 2018) and by chitin separation for usage in food (Shahidi et al., 1999). Furthermore, the 6.25 conversion factor of nitrogen-to-protein, frequently used to calculate protein content of insect, has been reported to overestimate the protein concentration of migrating locusts and other insects by 17% because of their chitin concentration (Boulos et al., 2020). Later authors suggested a nitrogen-to-protein conversion ratio of 5.33 for an even more precise assessment of locust and other edible insect protein levels that are present in the chitin of the exoskeleton. All developmental stages of grasshoppers contain nine essential AA, whose content increases with the growth of exoskeleton structures along with enriched structural protein (Zamudio-Flores et al., 2019).

Reyes-Herrera et al. (2022) conducted a trial on grasshoppers by feeding them soy and corn leaves and compared the amino acid profile with egg as standard. They stated that histidine, isoleucine, and threonine were present in same amount as egg, but lysine and tryptophan were less compared to egg. Leucine and valine were higher than egg amino acid profile. In addition, grasshoppers are a particularly rich source of phenylalanine (22–117 milligram in each gram of protein on DM basis) (Paul et al., 2016), which is used for the creation of neu-

rotransmitters, thyroxine, and melanin for metabolic processes (Stargrove et al., 2008). Tryptophan is the essential AA in the structure of grasshoppers (*Oxya hyla*); it is missing at all stages of development and in fact, has only been discovered in minute amounts (0.51 g/kg of protein) in previous investigations (Das and Mandal, 2014). The processing of grasshoppers also influences their nutritional profile; for example, roasting retains more protein than frying, as seen by around 39% of DM protein in the roasted grasshoppers vs almost 28% of DM in the frying ones (Porusia et al., 2020). According to Kuntadi et al. (2018), dried Javanese grasshoppers (*Valanga nigricornis* Burn) contain 76.69% protein. They proposed that *V. nigricornis* is a suitable choice protein source because its protein content is higher than the maximum measured protein content of vegetable sources (35.8% soybean) (Rumpold and Schlüter, 2013 a). Therefore, it can be stated that *S. purpurascens* has more leucine, isoleucine, methionine, lysine, phenylalanine, cysteine, threonine, tyrosine, histidine, and valine, than egg and beef (Rodríguez-Miranda et al., 2019). The AA profile of different locusts and grasshoppers is summarized in Table 2. No clear trends can be seen in the amino acid data of insects, even among those which belong to same class.

Fatty acid composition

The right intake of fatty acids (FA) for overall maintenance is crucial since these FA are precursors to a vast variety of body compounds and are essential for the maintenance of cell membranes (Alagawany et al., 2022). Adipose tissue stiffness, oiliness, and oxidative stability are all influenced by FA content (Wood et al., 2008).

The lipid content of *R. differens* is 35.60% (Fombong et al., 2017) of DM, which can be correlated to their highly polyphagous nature and capability to save higher amounts of lipids in the early stages of life (Finke, 2002). This is significant since insect fat is an enriched source of unsaturated fatty acids (Akhtar and Isman, 2018). The high fat content described for orthopterans is a direct sign of energy, and the energy values documented in the study of Fombong et al. (2021) are within the range described in the literature for other species (400–500 kcal/g) (Rumpold and Schlüter, 2013 b). Locusts have polyunsaturated fatty acids (omega-3 and omega-6) vital for cardiovascular disease prevention (Brogan, 2018; Kinyuru, 2021). Locust (Bombay locust, *Acridium succinctum* L.), meat source (beef, pig, mutton), and offal (liver, kidney, brain) contain 66, 62–81, and 261–2200 mg/100-gram cholesterol, respectively (Yhoun-Aree, 2010). Furthermore, the desert locust contains phytosterols, which inhibit cholesterol absorption, reducing its balance in the bloodstream and promoting cardiovascular protection (Cheseto et al., 2015). Orthoptera (grasshoppers, crickets, locusts) have a fat percentage of 13%, but Coleoptera (beetles, grubs) have a fat level of 33% (Rumpold and Schlüter, 2013 a). Lehtovaara et al. (2017) found that changing the grasshoppers' feed (substrate) can modify their fatty acid composition. A higher concentration of linoleic and

α -linolenic acids, eicosapentaenoic acid, and docosahexaenoic acid in the grasshopper diet enhances the level of these fatty acids. Substrate composition leads to a higher n-6 and n-3 fatty acid ratio. The fatty acid composition of different grasshoppers and locusts is summarized in Table 3.

Mineral content

Every tissue and fluid in the body contains minerals, which are inorganic compounds that are required for the maintenance of specific physicochemical processes that are vital to life (Soetan et al., 2010).

The mineral content provided in the literature shows a significant amount of variance. Some of them meet the requirement of animals, whereas others need supplementation of minerals to obtain optimum outcomes. As shown in Table 4, grasshoppers are an inadequate source of calcium due to the absence of a crystalline skeleton, which provides minerals (Finke and Ooninex, 2014). Ademolu et al. (2010) examined the detailed mineral composition of *Zonocerus variegatus* during post embryonic development. They stated that the adult stage contains macro minerals phosphorus (218 mg/g), potassium (7.61 mg/g), and sodium (3.06 mg/g) and micro minerals iron (1.84 mg/g), magnesium (0.39 mg/g) and zinc (0.17 mg/g) on DM basis. Desert locusts contain equivalent or higher quantities of calcium than cattle, pig, and mutton, which have between 4 and 28 mg/100 g (Ahmad et al., 2018). Migratory locust has equivalent or greater levels of iron (8–20 mg/100 g of DM) and zinc (2.4–14.8 mg/100 g of DM) than mutton, beef, and pork (Ahmad et al., 2018; Sun-Waterhouse et al., 2016). Zinc levels in migrating locusts are equivalent to those found in mutton, beef, and pig, while heavy metal levels are within acceptable limits in other meals such as vegetables and fruits (Ahmad et al., 2018; Poma et al., 2017). In Fadipe et al. (2018) study, standard procedures were used to investigate the effect of sun drying and roasting on the mineral content of edible grasshoppers eaten in Niger State, Nigeria. The authors found that sundried grasshoppers had the highest Fe, Ca, and Mn contents, whereas fresh samples had the highest Cu content and least P, K, and Mn contents. The Zn, K, P, Na, and Mg content of roasted grasshoppers prepared in the laboratory was highest, while roasted grasshoppers purchased from the market contained the least P, Na, Fe, Zn and Mg contents. Ssepuuya et al. (2020) stated that roasting insect samples increased numerous minerals, including calcium and other trace minerals, which can be correlated with the tight linkage of these minerals with protein, especially chitin (Gilbert and Avenant-Oldewage, 2018). The mineral composition of different grasshoppers and locusts is summarized in Table 4.

Influence of substrate on nutritional profile of grasshoppers

Reyes-Herrera et al. (2022) stated that the crude protein content of the soy-fed grasshoppers (SFG) was 46.5% of DM, significantly lower than that of the maize-

fed grasshoppers (MFG; 51.2% of DM), showing that the diet may influence the protein levels. These figures are lesser as compared to previous ones, which were 65.2% of DM (Blásquez et al., 2012) and 75.9% of DM (Ruiz et al., 2015) for *Sphenarium purpurascens*. In these investigations, however, a conversion factor of 6.25 was applied, which overestimated the findings. Nonetheless, the protein level of the soy sprouts was higher (4.1%) than maize. In contrast, the protein concentration of the grasshoppers fed with it was reduced by 4.7%, which is due to the conversion factor difference. Specific conversion factors varied slightly amongst the three insect species, with mealworms (Noyens et al., 2023) (5.33), crickets (5.25), and locusts (5.33) scoring. When a 6.25 conversion factor was used, the protein content was overestimated by 17% on average. The calculated average of 5.33 is validated by published data and is recommended for general usage instead of 6.25 to estimate more precise insect protein levels. In the case of insect protein isolates, the protein conversion factor of 5.6 is suggested for usage (Boulos et al., 2020). This is consistent with a previous study on the effect of feed (substrate) on *S. purpurascens*. These maize green fodder and alfalfa diets provided 63.9% and 60% of the protein, respectively (while using the conversion factor of 5.6) (Van Huis et al., 2013; Ibarra-Herrera et al., 2020). These values are consistent with the findings of previous researchers who discovered that food is vital for the ultimate protein levels in insects, and the increase or reduction will rely on the protein composition of the diet (Adámková et al., 2020; Dreassi et al., 2017; Oonincx and Finke, 2021; Rutaro et al., 2018). The fat percentage of the fresh SFG was 6.6, whereas the MFG had a fat level of 6.3 on DM basis. The total digestible fiber was 32.2% DM in the SFG and 24.9% DM in the MFG, which was statistically different. The SFG has more than 29.3% DM insoluble dietary fiber (IDF) compared to 23.3% DM in the MFG. Soluble dietary fiber (SDF) level was greater in the SFG (3.8% DM) than in the MFG (1.5% DM). Furthermore, the soy sprout feed in grasshoppers has a favorable influence since it boosted SDF concentration, which would enhance human microbiota health, IDF, and the reduction in production of intestinal gas (Kalala et al., 2018). Reyes-Herrera et al. (2022) examined the AA profiles: the most abundant essential AA was leucine, which had values of 126.7 mg/g in soy sprout-fed and 115.0 mg/g protein in the maize leave-fed grasshoppers, which were greater than the 88.2 mg/g protein found in the egg. This is consistent with another investigation, in which leucine was shown to be the most abundant of the essential AA (8.1 mg/16 g N) in *S. purpurascens* (Virginia et al., 2015). The amounts of ten AA were shown to be substantially different, including four (leucine, lysine, threonine, and valine) essential AA and six (alanine, asparagine, proline, glycine, glutamic acid, and serine) non-essential AA. Except for asparagine and glycine, the SFG had larger amounts of these AA than the MFG in most circumstances. The researchers noted that diet change influenced AA profiles and that soy

sprout supplementation permitted the storage of essential AA. In both samples (SFG, MFG), oleic acid was the most prevalent monounsaturated fatty acid, accounting for 40.7% and 32.6%, respectively. The polyunsaturated fatty acid with the greatest content was α -linoleic acid, 14.5% in the SFG and 10.3% in the MFG, respectively. Oleic acid and α -linoleic acid are beneficial fatty acids because they are linked to a lower risk of cardiovascular disease and inflammation (Rutaro et al., 2018). The saturated and unsaturated fatty acids ratio of the substrate on which insects are grown greatly influences their nutritional profile (Lawal et al., 2021). The content of fatty acids varies greatly based on life stage, species, light, nutrition, and temperature, although unsaturated fatty acids are more abundant than saturated fatty acids (Ojha et al., 2021; Oonincx and Finke, 2021). According to Salama (2020), a diet high in carrots raises the fat and vitamin A content of farmed migratory locusts, instead the protein content is inversely proportional to the bran content in the diet.

Present status and future directions

Some insects can now be used as animal feed, according to animal feed rules such as the “Insect Industry Promotion and Support Act” and “Control of Livestock and Fish Feed Act” (MOAFRA, 2010; FAOLEX Database, 2019). For example, mealworm larvae, grasshoppers, crickets, mosquito larvae, and black soldier fly larvae, can all be utilized if raised properly. According to EU legal regulations [EU 2017/893, 2021/1372, Novel Food Regulation], the usage of compound feed containing processed animal protein obtained from insects is allowed for feeding fish in aquaculture, poultry, and pigs. An insect not recognized as a feed material may not be utilized lawfully (Kim, 2019). An increasing global population and resource depletion necessitate reconsidering eating patterns and practices, particularly those linked to meat intake, which also applies to pet owners.

As per plan of European Union for promoting agricultural farm goods in 2023, the Commission will set aside €185.9 million to support marketing initiatives for high-quality, sustainable EU agri-food products both inside the EU and internationally (European Commission, 2022). The 2023 promotion policy work program was established by the Commission, and it helps to realize the political goals of the European Commission for 2019–24, particularly the Farm to Fork strategy. The promotion initiatives that are chosen for 2023 are anticipated to favor and promote products that meet goals like promoting environmentally friendly methods in EU agriculture, improvement of animal welfare and encouraging the intake of healthy produce, healthy meals, and sustainable lifestyles. Above agenda shows that EU policy also supports promotion of insect farming and consumption.

According to Siddiqui et al. (2023) there are 43 brands of insect-based pet food products that are currently commercially available. In Europe, there are 35 brands of pet food made from insects, particularly from meal-

worms and black soldier fly larvae. Similarly, Ahmed et al. (2022) stated that numerous studies have been done utilizing insect meal as an alternative protein source in pet food for cats, dogs, reptiles, rabbits, birds, ornamental fishes, and sugar gliders.

Large-scale GHG emissions are allegedly caused by livestock production (Dorgbetor et al., 2022). A different important aspect to address the worldwide problem of GHG emissions is insects. When compared to other animals, insects emit the least amount of GHG (Ahmed and Inal, 2022). According to later authors, using insects for farming, feeding, and decomposing (recycling) dung can lower greenhouse gas emissions.

Conclusion

Investigating novel alternative protein sources to feed the world's increasing population leads to insect inclusion as a promising option. The enriched profile of grasshoppers and locusts makes them a suitable alternative of conventional protein sources used in animal feed, although the insect eating communities and tribes living in Africa and Sahara Desert consume them as their ample food. Grasshoppers and locusts are protein enriched (16–77%), high fat (2.5–54%), and polyunsaturated fatty acids (PUFA) augmented (17–67%) sources having beneficial influence on animal health. Grasshoppers and locusts also contain chitin, which can be studied as antimicrobial peptides.

Furthermore, lauric acid content of grasshoppers and locusts is higher (0.8–45%), which has beneficial influence on growth, immunity, and antimicrobial profile of intestine. Future studies are needed to define the optimal inclusion level of grasshoppers and locusts for ideal animal outputs.

Disclosure statement

The authors declare that no competing interests may be construed as a potential conflict of interest.

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