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Chemical composition of Migratory Locust (*Locusta migratoria*) across different metamorphic stages

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Abstract
Locusts are often considered as humans' nuisances and crop pests, despite evidence that they are high in protein and maybe consumed by animals. They have generally been overlooked. However, the current increase in entomophagy has been partly attributed to the nutritional value of insects, which is important, especially when considering the global scarcity of dietary sources. At the same time, locusts are rich in nutrients and can be mass-produced sustainably. Purpose of this study was to determine the chemical composition, nutritional and mineral content (macro and micro), and the heavy metal elements of migratory locusts (*Locusta migratoria* (L.), *Orthoptera*: *Acrididae*) at various metamorphic stages in newly emerged nymphs of the 4th and 5th instars, as well as immature adults (IA) and mature adults (MA). Crude protein (CP), ether extract (EE), total carbohydrates (TC), crude fiber (CF), ash, energy, dry matter (DM), and moisture were all measured as percentages. The macro and micro minerals content were determined, macro-mineral as (calcium (Ca) g/100g, phosphorus (P) g/100g, magnesium (Mg) g/100g, potassium (K) g/100g, and sodium (Na g/100g), micro minerals as (iron (Fe) g/100g, copper (Cu) mg/kg, manganese (Mn) mg/kg, Zinc (Zn) g/100g, boron (B) mg/kg, and cobalt (Co) mg/kg, nickel (Ni) and chromium (Cr) were measured. Selenium (Se), lead (Pb), mercury (Hg), arsenic (As), and cadmium (Cd) were all undetectable in samples.

Keywords: Edible insect, crude proteins, total carbohydrate, minerals (macro and micro), heavy metal elements

Introduction

Due to climate change and other urgent environmental problems such as pollution, ecological degradation, and resource depletion, the search for sustainable protein sources to feed the growing population and cattle is needed worldwide (Hassoun *et al.*, 2022) [31]. Also, the growing global population, limited agricultural resources, and pollution necessitate finding sustainable alternatives to meat production. *Locusta migratoria* considers a sustainable solution due to lower cultivation costs, minimal environmental impact, including reduced greenhouse gas emissions and waste generation, and high nutritional value (Šerifović *et al.*, 2022) [52].

Among the many feasible options, insect farming appears to be the most appealing because it produces affordable and high-quality protein substitutes for human consumption while having a lower carbon footprint and requiring fewer environmental inputs (*e.g.*, water and land) than the current livestock farming systems (Meshulam *et al.*, 2022, and Baiano, 2020) [7, 39].

The European Union has approved *L. migratoria* as a novel source of safe food for human consumption, addressing Western consumer skepticism and ensuring quality and safety in commercialization. This is a significant step in addressing global food production challenges and promoting sustainable diets (Šerifović *et al.*, 2022) [52].

Currently, scientists are attracted to the potential of insects as a source of food and feed, especially locust species with high reproductive and growth rates and easy mass rearing potential, which are a promising source of nutritional value. According to projections by the Food and Agriculture Organization (FAO, 2017) [24], the world population will reach ten billion by 2050, resulting in a 50% increase in global food supply compared to food demand in 2012. Traditional protein sources will not be sufficient to feed the world's population, necessitating the use of other options such as insects. Harvesting pest insects can help reduce pesticide use and provide a food source (DeFoliart, 1997) [16]. *Schistocerca* spp. have been used in traditional medicine to treat intestinal disorders and as a nutritional supplement to address malnutrition (Ramos-Elorduy and Moreno, 1988) [49].

According to Egonyu *et al.* (2021) [20], data on dry-matter-based nutrient composition and nutritional value for migratory locusts, desert locusts, Bombay locusts, and two locust species from the genus *Schistocerca* are highly variable due to inconsistencies in the analysis methods used, interspecific differences, environmental conditions, life stages, diet, processing methods, and whether the insects were reared or wild collected.

Generally, insect rearing may be grown vertically, so minimal space is needed for mass-rearing. Insect rearing is more environmentally friendly than livestock due to lower greenhouse gas emissions, water pollution, and land use. Additionally, insects exhibit higher feed conversion efficiency (the ratio of feed input to body weight gain) compared to mammalian livestock (Van Huis *et al.*, 2013) [55].

Numerous studies have shown that edible insects contain significant amounts of nutrients such as proteins, fiber, fats, vitamins, and minerals, especially iron and zinc (Longvah *et al.*, 2011) [36]. Edible migrating locust contains about the same amount of crude protein, fat, and calories as beef, fish, lamb, chicken, milk, and eggs (Mohamed *et al.*, 2010) [40]. FAO (2010 a, b) [22, 23] strongly recommends using insects as human food and animal feed as a method to alleviate poverty.

Seasons, food abundance, and populations of the same species within the same broad area can all affect an insect's mineral composition (Mohamed *et al*. 2010) [40]. Locusts have nutritional value equal to or greater than meat. Locusts are high in calcium, iron, and zinc, and they contain safe amounts of heavy metals. Locusts were tested as additives in fish feed with promising results (Egonyu *et al*., 2021) [20].

However, locusts, like other insects, can cause significant crop and pasture damage, negatively impacting the food security of farmers and pastoralists (Makkar *et al*., 2022) [37]. For example, locust swarms devastated East Africa, including Ethiopia, Kenya, Eritrea, Uganda, South Sudan, Somalia, Djibouti, and Sudan. In June 2019, locust infestations in East Africa destroyed crops and pastureland, causing substantial damage. According to FAO (2020) [25], there was a 356,000-tonne loss in cereal crops and a 40% decline in pasture.

Despite their destructive potential, locusts also offer a potential solution: their high protein content (50–65% in dry matter) makes them a valuable alternative to conventional protein-rich feed resources like soybean meal and fishmeal for poultry and fish diets (Makkar *et al*., 2022) [37]. Clarkson *et al*., (2018) [12] highlights the potential of locusts as a meat or protein alternative for a growing population, as their content is comparable to traditional meat sources. Currently, only a few commercial insect-based products are available in the Western market, including ground insect flour, which is sold on its own or as an ingredient in various bars, chips, cookies or pasta. Migratory locust *L. migratoria* meal can be used as feed for fish in aquaculture, captive insectivores, and even humans (Finke, 2013) [26]. The growing aquaculture industry in Africa and Asia, coupled with the search for alternative protein sources, has led to feeding trials of locusts and grasshoppers for catfish and tilapia (Van Huis and Tran, 2022) [54]. The Netherlands is the top EU country for grasshopper cultivation, with an average selling price of 9.99 euros for 35 grams; consequently, over 2000 insect species are consumed globally, with grasshoppers accounting for 13%. The EU produced 500 tons of insect food in 2019, and by 2030, around 1 million tons of edible insects will be produced, processed into 260,000 tons of insect-based food, reaching 390 million consumers and generating a market value of around two billion euros (Gołaszewska *et al.*, 2022) [30].

While the nutritional value of edible insects varies widely among species (Agbidye, 2009; Longvah *et al*., 2011) [36] and within the same group at different metamorphic stages during the development, habitat, and diet (Cookman *et al*., 1984) [13], the large number and variability of insect species, coupled with factors like metamorphosis stage, origin, and diet, contribute to significant variation in their nutritional value (Finke and Oonincx, 2014) [27], research has shown that the diet of migratory locusts can be manipulated to alter their chemical composition (Oonincx *et al*., 2011) [44].

Currently, pesticide sprays are widely used to manage locusts and other significant insect pests because they are more effective and kill pests faster than other pest-control approaches. Convincing policymakers to develop legal frameworks that permit the harvesting of locusts for beneficial applications requires solid evidence that the approach, like insecticides, can efficiently lower locust populations to less harmful levels in a timely manner. This study assesses the potential of harnessing migratory locusts, *L. migratoria*, for beneficial purposes as a more sustainable management strategy. It highlights their nutritional value and establishes a foundation for their use as human food and, livestock and fish feed.

Material and Methods

Mass rearing of insects

The *L. migratoria* were obtained from a stock culture maintained at the Locust and Grasshopper Research Department, Plant Protection Research Institute, Agricultural Research Centre, Dokki, Giza, Egypt. This stock culture had been established through multiple generations. In the laboratory, the insects were reared in cages following the methods described by Robert *et al*. (2002) [50]. They were fed a diet of Maize leaves (*Zea mays L.*) (Poales: Poaceae) during the summer and Wheat (*Triticum aestivum L.*) (Poales: Poaceae) during the winter. The migratory locusts were reared at a temperature of 30±2°C and a relative humidity of 30–50%. The insects of *L. migratoria* used for examination were newly emerged nymphs of the 4^{th} and 5^{th} instars, as well as both immature and mature adults. The study was conducted, and the locust samples were taken in the winter season.

Samples preparation

All samples were dried in an oven at 58–60°C for 48 – 72hrs. After drying, the legs and wings were removed, then crushed and powdered using an electric grinder. The powdered samples were stored in plastic bags in the refrigerator until use (Abd-El Wahed and Ahmad 2019) [1].

Biochemical analysis

Proximate chemical analysis such as, crude protein (CP), ether extract (EE), crude fiber (CF), and ash were determined following the methods described in the Association of Official Analytical Chemists (AOAC, 2023). Moisture determination was by drying method. Total carbohydrates (TC) were determined in dried samples; according to the method of Dubois *et al*., 1956 [17]. All assays were performed in triplicate.

The estimation of minerals contents

Calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium (Na), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), cobalt (Co), selenium (Se), nickel (Ni), chromium (Cr), lead (Pb), mercury (Hg), arsenic (As), and cadmium (Cd) concentrations were determined in dried samples; using Optima 2000 DV inductively coupled plasma spectrometer, (PerkinElmer). Concentrations were recorded based on calibration curves developed using inductively coupled plasma (ICP) (merk) standard in reference to AOAC (2023). All assays were performed in triplicate.

The energy values

According to Fox and Cameroon (1989) [28], the energy values were computed using factors four for protein and total carbohydrates and nine for fat.

Statistical analysis

Data were analyzed by ANOVA, significant differences between means were compared using Duncan's multiple range test at a significance level of $P < 0.05$ with SAS statistical software (Duncan 1951) [18]

Results

The chemical composition of *L. migratoria* in newly emerged nymphs of the 4th and 5th instars, besides immature and mature adults, were determined by investigating the nutritional value, macro and micro mineral components, and heavy metal content of migrating locusts and suggesting their use as feed and food.

Nutritional content

Chemical composition

The data indicate significant differences in the nutritional composition in various metamorphic stages of *L. migratoria* (Table 1) as follows:

Table 1: Chemical analysis and energy in the total body homogenate of 4th, 5th nymphal instars, immature and mature adults of migratory locust *L. migratoria* based on dry matter (g/100g of dry matter)

Parameters	4th	5th	IA	MA
Crude protein (CP) %	74.38a	70.38b	64.33c	65.77c
Ether Extract (EE) %	21.77d	12.66c	23.9b	30.01a
Total Carbohydrate (TC) %	13.68a	11.27b	10.06b	13.8a
Crude fiber (CF) %	8.67a	9.75a	6.42b	8.32a
Ash (%)	25.19d	29.29c	35.28a	33.71b
Energy (kcal)	548.09b	440.64d	512.58c	588.37a
Dry Matter (DM) %	24.85c	24.74c	27.38b	31.52a
Moisture (%)	75.15a	75.27a	72.63b	68.49c
EE:CP	0.295c	0.18d	0.37b	0.465a
TC:CP	0.185b	0.16c	0.155c	0.215a
TC:CF	0.63b	0.895a	0.415d	0.465c

4th nymphal instar, 5th nymphal instar, Immature Adult (IA), Mature Adult (MA). Means with different letter within row are significantly different ($P < 0.05$), based on dry matter.

The crude protein (CP) content was significantly higher in the 4th nymphal instar (74.38%), while the lowest values, with no significant differences, were found in IA and MA (64.33 and 65.77%), respectively.

The ether extract (EE) content in the MA was significantly higher (30.01%) compared to the others, particularly the 5th nymphal instar, which had the lowest fat content at (12.66%).

The total carbohydrates (TC) content in the 4th nymphal instar stand out with a significantly higher, showing no significant difference from the MA, which were 13.68 and 13.8%, respectively, compared to the content in IA and 5th nymphal instar, which were 10.06 and 11.27%, respectively, showing no significant difference from both.

The crude fiber (CF) content was significantly higher and relatively similar in the MA, the 4th and 5th nymphal instars; the values were 8.32, 8.67, and 9.75%, respectively; there was a significant difference compared to the IA, which was the lowest value 6.42%.

The ash contents varied significantly; the value was 35.28% in the IA, which was significantly higher compared to the lower value of 25.19% in the 4th nymphal instar.

The difference in energy (kcal) from the MA was significant, providing significantly higher energy 588.37 kcal compared to the 5th nymphal instar 440.64 kcal which had the lowest significant content.

The dry matter (DM) and moisture in the MA were significantly higher in dry matter content and lower in moisture, with values of 31.52 and 68.49%, respectively. Conversely, the 4th and 5th nymphal instars showed significant differences, with the highest moisture content at 75.15 and 75.27%, respectively; and the lowest dry matter at 24.85 and 24.74%, respectively.

Based on data in Table (1) the ether extract (EE) to crude protein (CP) ratio is significantly different among the various metamorphic stages of *L. migratoria*, the MA has the highest ratio at 0.465, while the 5th nymphal instar has a significantly lower ratio than the others at 0.18.

The total carbohydrates (TC) to crude protein (CP) ratio also show significant differences. The MA has the highest ratio at 0.215, while the 5th nymphal instar and the IA had similar lower ratios of 0.16 and 0.155, respectively. The 4th nymphal instar had a ratio of 0.185, which is significantly higher than both the 5th nymphal instar and the IA but lower than the MA.

The total carbohydrates (TC) to ether extract (EE) ratio of relative indicate significant differences as well. The 5th nymphal instar had the highest ratio at 0.895, while the IA has a significantly lower ratio of 0.415.

Data in Table (2) indicate significant differences in the content values of the analysis in various metamorphic stages of *L. migratoria* as follows:

Table 2: Macro minerals content in the total body homogenate of 4th, 5th nymphal instars, immature and mature adult of migratory locust *L. migratoria* based on dry matter

Macro mineral (g/100g)	4th	5th	IA	MA
Calcium (Ca)	0.21a	0.20a	0.12c	0.15b
Phosphorus (P)	0.75a	0.68b	0.66c	0.57d
Magnesium (Mg)	0.201a	0.209a	0.2055a	0.143b
Potassium (K)	1.32a	1.26a	1.12a	0.86a
Sodium (Na)	0.21a	0.20a	0.14c	0.17b

4th nymphal instar, 5th nymphal instar, Adult immature (IA), Adult mature (MA). Means with different letter within row are significantly different ($P < 0.05$), based on dry matter.

Calcium levels are significantly higher in the 4th and 5th nymphal instars, at 0.21 and 0.20 g/100g, respectively, compared to the adult immature stage (IA), which is significantly lower at 0.12 g/100g.

Phosphorus content is significantly higher in the 4th nymphal instar at 0.75 g/100g and decreases in the subsequent stages, with the 5th nymphal instar, IA, and MA showing levels of 0.68, 0.66, and 0.57 g/100g, respectively.

Magnesium levels are relatively consistent in the 4th, 5th, and adult immature stages, with values of 0.201, 0.209, and 0.2055 g/100g, respectively, showing no significant differences among them. However, the mature locusts (MA) show significantly lower magnesium content at 0.143 g/100g.

Potassium content remains high across all stages, with no significant differences observed among the 4th, 5th, IA, and MA stages, which have values of 1.32, 1.26, 1.12, and 0.86 g/100g, respectively.

Sodium levels are significantly higher in the 4th, and 5th nymphal instars at 0.21 and 0.20 g/100g, respectively, compared to the adult immature stage (IA), which is significantly lower at 0.14 g/100g.

Data in Table (3) indicate significant differences in the content values of the analysis in various metamorphic stages of *L. migratoria* as follows:

Table 3: Micro minerals content in the total body homogenate of 4th, 5th nymphal instars, immature and mature adult of migratory locust *L. migratoria* based on dry matter.

Micro Mineral	4th	5th	IA	MA
Iron (Fe) g/100g	0.049a	0.055a	0.038b	0.055a
Copper (Cu) mg/kg	84.6c	58.9d	148.25a	89.25b
Manganese (Mn) mg/kg	11.93ab	12.545a	10.31b	5.4c
Zinc (Zn) g/100g	0.026a	0.024a	0.022a	0.013a
Boron (B) mg/kg	27	ND	ND	ND
Cobalt (Co) mg/kg	0.43ab	0.55ab	1.3a	0.12b
Selenium (Se)	ND	ND	ND	ND

ND=Not detected, 4th nymphal instar, 5th nymphal instar, Adult immature IA, Adult mature MA.
Means with different letter within row are significantly different ($P < 0.05$), based on dry matter.

The iron content shows a significant difference, with the 4th and 5th nymphal instars and MA having the highest concentrations and higher significance at 0.049, 0.055, and 0.055 g/100g, respectively. In contrast, the concentration in IA (0.038 g/100g) is significantly lower than in others.
The copper levels vary significantly, with the 5th nymphal instar showing the lowest concentration 58.9 mg/kg, while the IA is the highest 148.25 mg/kg.
The manganese content is significantly higher in the 5th immature locusts (12.545 mg/kg) compared to the others, while the MA shows a significant decrease (5.4 mg/kg).
The zinc levels are relatively consistent across all groups, with no significant differences observed. All groups have similar concentrations in the 4th, 5th nymphal instars, IA, and MA at 0.026, 0.024, 0.022, and 0.013 g/100g, respectively.
The boron content is reported only for the 4th nymphal instars (27 mg/kg), while the other groups are not detected (ND).
The cobalt levels show significant differences, with the IA (1.3 mg/kg) being much higher, while the MA (0.12 mg/kg) have a significantly lower concentration.
All groups show no detectable levels of selenium, indicating that this mineral is absent in the analyzed locusts.
Data in Table (4) indicate significant differences in the content values of the analysis in various metamorphic stages of *L. migratoria* as follows:

Table 4: Heavy metal elements content in the total body homogenate of 4th, 5th nymphal instars, immature and mature adult of migratory locust *L. migratoria* based on dry matter.

Heavy metal elements (ppm)	4th	5th	IA	MA
Nickel (Ni)	11.26b	9.94b	33.41a	9.8b
Chromium (Cr)	14.08c	10.3d	42.63a	25.42b
lead (Pb)	ND	ND	ND	ND
Mercury (Hg)	ND	ND	ND	ND
Arsenic (As)	ND	ND	ND	ND
Cadmium (Cd)	ND	ND	ND	ND

ND=Not detected, 4th nymphal instar, 5th nymphal instar, Adult immature IA, Adult mature MA.
Means with different letter within row are significantly different ($P < 0.05$), based on dry matter.

The highly significant concentration levels of nickel (Ni) and chromium (Cr) in the (IA) were 33.41 and 42.63 ppm, respectively. In contrast, the levels of nickel in the 4th and 5th nymphal instars and the (MA) were significantly lower, with values of 11.26, 9.94, and 9.8 ppm, respectively. The chromium content was significantly lower with the 5th nymphal instars with values of 10.3 ppm, (MA) presented a chromium level of 25.42 ppm, which is still lower than that of the (IA) but higher than that of the 5th nymphal instars. It has been found that lead, mercury, arsenic, and cadmium throughout all life stages were not detected.

Discussion

According to Yakti *et al*. (2025) [58], the *L. migratoria* has a lot of promise because of its high nutritional content and appropriateness for large-scale production for food and feed uses. The EU has approved the migrating locust for human consumption (Wildbacher *et al*., 2025; Nachtigall *et al*., 2025) [41]. Cyprial (2014) [15, 57] found that the impact of the seasons on locust protein, a non-conventional animal protein was 18.3% during the hot dry season and 96.7% during the rainy season. Kouřimská and Adámková (2016) [34] found that insects' protein and fat content vary based on their type and development stage, and these differences are significant depending on the insect's nutritional status. The results of previous research may differ because locust species develop differently in different instars and because samples were taken at other times of the year. Kinyuru (2021) [33] found that the nutritional content of insects is influenced by developmental stages, types of food, and the geographical conditions of the areas where they grow.
In addition, the flying activity in a swarm could impact the balance of specific nutrients such as protein, fats, and carbohydrates, as these nutrients might have been used to produce energy for flight. There is only a slight difference between these values and those of egg protein (83%) or beef (85%) and even a little difference between these values and those of most plant proteins such as soybean (81%) (Ochiai *et al*., 2020) [43].
Poma *et al*. (2017) [48] in Belgium found the proximate composition of migratory locust on dry matter and fat were 27 and 7.7–11.7%, which in agreement with our findings.
According to Lampová *et al.* (2024) [35] investigation, the protein quality of the migrating locust, *Locusta migratoria*, ranges from good to excellent. Abd-El Wahed and Ahmad (2019) [1] found that the chemical analysis of desert locusts, (*Schistocerca gregaria* Forskål, 1775) (*Orthoptera*: *Acrididae*) nymphs had the largest amounts of crude protein, total carbohydrate, ash, and moisture content (65.92, 4.59, 6.42, and 67.54 %, respectively); while adults had the lowest amounts (56.79, 2.98, 3.51, and 57.66 %). However, the opposite is true for ether extract content and dry matter, with adults having the highest percentages of 28.82 and 42.34%, respectively, while nymphs had the lowest percentages of 15.15 and 32.46%, respectively. Additionally, adults had a higher energy contribution than nymphs (498.45 and 418.37 Kcal, respectively), while fiber content was 7.9 in both. These findings matched our results for crude protein and moisture in nymphs and fat and dry matter in adults, but our results contradict this study at total carbohydrate, ash, energy, and fiber content.
Our findings do not align with that of Elagba (2015) [21], who reported that the proximate analysis of *L. migratoria* showed the following values /100g of dry matter: crude protein, Ether Extract, carbs, crude fiber, ash, moisture, and calories were 96.19, 50.42, 19.62, 4.78, 15.65, 6.24, 3.81, and 490.4 kcal/100g, respectively. The Ether Extract to crude protein ratio (EE:CP) was 0.39, the carbohydrate to

crude protein ratio (CH:CP) was 0.09, and the carbohydrate to Ether Extract ratio (EE:CF) was 0.24. In contrast to Brogan (2018) [10], who reported that the dry matter, fat, and ash content in Thailand were 95.3, 11.4, and 3.3%, respectively, *L. migratoria* had minimal levels of ash due to the absence of an internal calcified skeleton found in vertebrates. Soft-bodied insects produce less fiber than hard exoskeleton insects, while the protein content was partially stable at 71.2%. Although our data are more divergent than the previous study by Virginia *et al*. (2015) [56] in Mexico, which found five different types of grasshoppers, *Sphenarium histrio* (Gerstaecker), *Sphenarium purpurascen s* (Charpentier), *Taeniopoda eques* (Burmeister), *Melanoplu s femurrubrum* (DeGeer), and *Schistocerca* spp, the moisture, dry matter, fiber, and total carbohydrates ranged from 35.29–43.19, 56.81–64.71, 7.08–11.15 and 6.66–9.59, respectively. The four species had low total fat ranging from 4.71–6.2%, except for *Schistocerca*. spp., which had a concentration of 16.0%.

Our results indicate that the determined protein content ranged from 64.33–74.38%, which is almost in agreement with Makkar *et al*. (2014) [38] for grasshoppers, which was quite high, ranging from 62.5–77.25%. In fish feed, migratory and desert locusts can substitute 25% of the protein.

Adult female of (*Zonocerus variegatus* L., 1758) (*Orthoptera*: Pyrgomorphidae) had a higher proximate composition in crude protein, dry matter, fat, ash, crude fiber, and carbohydrate that males; it was 17.28 & 14.96, 38.35 & 33.04, 1.18 & 1, 1.05 & 0.90, 1.14 & 1.03, and 17.73 & 15.14 g/100g, respectively (Ademolu *et al*., 2017) [32]. Alegbeleye *et al*. (2011) [5] demonstrate that they used varied amounts of *Zonocerus* adults to replace fish meal in the diets of (*Clarias gariepinus* Burchell, 1822) (Siluriformes: Clariidae). They found that *Zonocerus* could substitute up to 25% of the fish diet without causing any negative effects.

Oonincx *et al*. (2011) [44] found that a grass + wheat bran and carrot diet increased lipid levels and β-carotene concentration in the *L. migratoria*. This diet significantly altered the chemical composition of the insects, resulting in higher lipid levels and β-carotene concentration in their bodies. Salama (2020) [51] stated that high carrot content in farmed *L. migratoria* food appears to increase its fat and vitamin A content, whereas its protein content decreases as the percentage of wheat bran in the diet increases.

Our findings are somewhat consistent with Rumpold and Schlüter (2015) [9], who reported that *Orthoptera* (grasshoppers, locusts, and crickets) have protein, fat, fiber, ash, and energy levels of 61.32, 13.41, 9.55, 3.8 %, and 426.25 kcal/100g, respectively.

The results of the current study are partially consistent with Van Huis *et al*. (2013) [55], who revealed that the adult of *L. migratoria*, has a calorie value of 179 kcal/100g of dry matter. Bednářová (2013) [8] found that the energy value of edible insects is influenced by their fat and protein contents. Larvae and pupae contain more protein and less fat, whereas species with high protein content have lower energy values. The *Locusta migratoria* nymphs had fat and protein dry matter content of 13 and 62.2%, respectively; in addition to edible insects being significant source of fiber, the nymphs had the highest fiber content, reaching 27% in dry matter.

According to Pérez-Ramírez *et al*. (2019) [47], the Central American locust, *Schistocerca piceifrons piceifrons* (Walker), is a serious agricultural pest in Mexico and Central America. The *S. p. piceifrons* adults had moisture, dry matter, protein, fat, ash, and fiber contents of 65.84, 34.15, 80.26, 6.21, 3.35, and 12.56%, respectively g/100g of dry weight. Its high protein level, fiber content, and low fat content make potentially useful for developing healthier food alternatives in general. According to Ahmad *et al*. (2018) [4] and Peng *et al*. (2020) [46], locusts have equal or higher protein, fat, and calorie levels to meat (18–29%, 1–32%, and 106–353 kcal/100g, respectively).

Minerals are essential for many biological activities. Many developing countries suffer from micronutrient deficiencies, which cause serious health issues. These deficiencies can stunt growth, weaken the immune system, and negatively impact both mental and physical development. Insects, such as the *S. gregaria*, are often ignored as potential sources of essential minerals. Notably, they have much higher levels of iron (Fe), zinc (Zn), and calcium (Ca) than traditional meat sources such as beef and poultry. For example, while beef has six mg/100 g dry weight of iron and poultry 1.2 mg/100 g, the *S. gregaria* contains an impressive 8.38 mg/100 g. Similarly, in terms of calcium, beef averages 4–27 mg/100 g dry weight, poultry 5–14 mg/100 g, and *S. gregaria* has a remarkable 70 mg/100g. Moreover, insects are generally recognized as excellent sources of zinc. Beef has an average of 12.5 mg/100 g dry weight, which falls short of the *S. gregaria*'s 18.6 mg/100 g. It is noteworthy that insects often have low sodium levels, much below the recommended daily intake of 1500 mg. *Schistocerca gregaria* contains copper (Cu) (6.32 mg/100 g), sodium (Na) (173 mg/100 g), potassium (K) (749 mg/100 g), and magnesium (Mg) (82 mg/100 g) (Oonincx *et al*., 2010; Sirimungkararat *et al*., 2010; Zielińska *et al*., 2015) [45, 53, 61]. Edible insects are high in mineral elements including calcium, phosphorus, iron, and zinc, which our bodies need as supplements (Yin *et al*. 2017) [59].

The minerals content in *L. migratoria* was extremely low, with the exception of phosphorus (P) (29.6 ppm). The other minerals were zinc (Zn) 0.9, iron (Fe) 0.6, boron (B) 0.3, cobalt Co (0.1), and manganese (Mn) 0.04 ppm (Elagba, 2015) [21].

Adult female of *Z. variegatus* had significantly higher sodium (Na) and iron (Fe) concentrations in their body samples than males (21.68 & 21.61 and 2.36 & 2.17 mg/100g), respectively. Conversely, adult males, on the other hand, had significantly higher calcium (Ca) and magnesium (Mg) concentrations (72.46 & 78.30 and 9.87 & 10.36 mg/100g), respectively (Ademolu *et al*., 2017) [32]. Grasshoppers are low in calcium because their skeletons are not mineralized (Finke and Oonincx, 2014) [27]. Grasshopper species contain enough zinc to meet daily needs. Zinc is essential for immunity and enzyme function, but magnesium is important for calcium metabolism and other vital chemical reactions in the body (Challem, 2003) [11].

Some edible insects have high levels of minerals such as potassium, sodium, calcium, copper, iron, zinc, manganese, and phosphorus. However, their mineral content varies depending on the season and the insects' diet (Kouřimská and Adámková, 2016) [34].

Desert locust has calcium, iron, and zinc micronutrient levels that are comparable to or higher than those of mutton, beef, and pork (Ahmad *et al*., 2018) [4]. According to Poma *et al*. (2017) [48], the dry matter-based mineral composition of migratory locusts in Belgium is zinc (3.7–3.8), copper (0.5–0.9) and cobalt (<0.003).

Our results showed that lead (Pb), mercury (Hg), arsenic (As), and cadmium (Cd) were undetected in the total body homogenate of 4th, 5th nymphal instars, adult immature, and mature of *L. migratoria* based on dry matter, while nickel (Ni) and chromium (Cr) were trace amounts. This findings almost agrees with that of Elagba (2015) [21], who found that the migrating locust has trace amounts of elements such as lead (Pb) and chromium (Cr) (0.2 and 0.1 ppm), respectively. In Belgium, Poma *et al*. (2017) [48] reported that mineral content in migratory locust was chromium 0.01–0.02, lead <0.003, nickel 0.02, arsenic <0.003, and cadmium ≤0.003 (mg/100g).

The current study partial in agreement with those of Ademolu *et al*. (2017) [32] who found heavy metals (Pb, Zn, Cu, Cd, and Ni) in the bodies of adult female and male of *Z. variegatus*. However, the concentrations of these heavy metals were very low: 1.10 & 1.00, 1.26 & 1.07, 0.88 & 0.86, 0.34 & 0.29, and 0.12 & 0.11 mg/100g, respectively. Crawford *et al*. (1996) [14] and Zhang *et al*. (2009) [60] observed a slight accumulation of cadmium in farmed migratory locusts, but no copper, mercury, or lead accumulation was detected.

Our study confirmed, as others have shown, that parameters such as sex, life stage, and environmental conditions (temperature, day length, humidity, light intensity) can influence the chemical composition of insects (Finke and Oonincx, 2014) [27].

A recent study of frozen and dried food products made from farmed migratory locusts aimed at the European food market found that the concentrations of arsenic, mercury, lead, and cadmium in the samples were similar to the limits established for other food items, indicating that they are safe for consumption (EFSA Scientific Committee, 2021) [19]. The heavy metal levels in migratory locust, like those in fruits and vegetables, are within acceptable limits (Ahmad *et al*., 2018) [4].

There are few reports of heavy metal contamination of wild locusts, thus further research is needed. However, farmed migratory locusts have been found to have a minor buildup of cadmium but not copper, mercury, or lead from their diet (Crawford *et al*., 1996; Zhang *et al*., 2009) [14, 60], which matches the findings of our study.

A recent analysis of frozen and dried formulations of farmed migratory locust food products made by Fair Insects BV in the Netherlands and marketed to the European food market found that the samples' levels of arsenic, mercury, lead, and cadmium were safe to eat because they were comparable to those found in other foods (EFSA Scientific Committee, 2021) [19].

According to Anand *et al*. (2008) [6], acridids offer continuous and consistent feed supply for animal nutrition. In accordance to Ghosh and Mandal (2019) [29], the growth of *Labeo rohita* (Hamilton, 1822) (Cypriniformes: Cyprinidae) fingerlings was unaffected when grasshopper meal (*Oxya hyla hyla*) was substituted for fish meal; with 64.67% protein by dry matter, the grasshopper maybe a novel protein-rich ingredient in the aqua-feed formulation. Also Adeyemo *et al*. (2008) [2] found that broilers fed *S. gregaria* food matured normally. Additionally, grasshoppers, *Ruspolia nitidula* (Scopoli, 1786) (*Orthoptera*: Tettigoniidae), often known as "nsenene," desert locusts *S. gregaria*, and African grasshoppers *Acanthacris ruficornis* could be substituted in chicken diets (Nginya *et al*., 2019) [42].

Conclusion

The results indicated that the chemical composition of migratory locusts, *L. migratoria* in various metamorphic stages could be considered a promising source of feed and food. This study presented the nutritional potential of *L. migratoria*, demonstrating that both 4th and 5th nymphal instars, adult immature, and mature migratory locusts have high nutritional value. The findings indicate that this locust is rich in protein, fat, and energy, making it a viable food and feed source for humans and livestock (fish in aquaculture, captive insectivores, and poultry). Entomophagy is an important sustainable agricultural practice that reduce reliance on pesticides while enhances profitability by using locusts as a food or feed source. Furthermore, this study reveals that differences between nymphs and adults have a significant impact on mineral concentrations. The locusts also contain essential minerals at healthy nutritional levels, as well as heavy metal elements in amounts considerably below hazardous levels. Further investigation is necessary to explore amino acids, fatty acids, and particularly vitamins, as current data on these nutrients is limited to migratory locusts.

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