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Effects of diet on the nutritional composition of the desert locust *Schistocerca gregaria* (Orthoptera: Acrididae)

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ABSTRACT

The desert locusts, *Schistocerca gregaria* have a great history of being used as food. They are rich in proteins, minerals, fibre, and fats. An experiment was conducted to determine the effects of diet on the nutritional composition of desert locusts. They received a diet of wheatgrass, sorghum grass, and green gram leaves respectively. Proximate and mineral composition of mature locusts and feed plants was done using standard methods. The data were subjected to analysis of variance (ANOVA) using a general linear model procedure. Moisture content was significantly higher in locusts reared on the sorghum diet (35.1%) and lowest in the green grams diet (12.9%). Locust reared on green gram diet recorded high protein, fat, and fibre compared to sorghum and wheat diet. Locusts reared on a wheatgrass diet recorded a significantly high amount of carbohydrate (14.3%) and ash (3.20%) compared to sorghum and green gram diet. The highest calculated energy was in locust reared on the green gram diet (2184.95KJ/g) while locust reared on the sorghum diet recorded the least energy 1391KJ/g. Magnesium and Calcium minerals were higher in all the locusts reared on the three diets. The mean values for Phosphorus were significantly lower followed by Copper in all the tested locusts. Locust reared on sorghum leaves recorded a significantly high amount of Potassium. The findings revealed that locusts are highly nutritive and can be reared on locally available feeds and can therefore play a major role in the food and nutritional security of people

Keywords: Edible insects, nutritive value, alternative protein, food security, feed plants, desert locust.

RÉSUMÉ

Effets de diète sur la composition nutritionnelle du criquet pèlerin *Schistocerca gregaria* (Orthoptera : Acrididae)

Les criquets pèlerins, *Schistocerca gregaria*, ont une longue histoire d'être utilisés comme nourriture. Ils sont riches en protéines, minéraux, fibres et graisses. Une expérience a été menée pour déterminer les effets du régime alimentaire sur la composition nutritionnelle des criquets pèlerins. Ils ont reçu une diète composée respectivement d'herbe de blé, d'herbe de sorgho et de feuilles de haricot doré vert. La composition proximale et minérale des criquets matures et des plantes fourragères a été réalisée à l'aide de méthodes standard. Les données ont été soumises à une analyse de variance (ANOVA) en utilisant une procédure de modèle linéaire général. La teneur en eau était significativement plus élevée chez les criquets élevés avec la diète à base de sorgho (35,1%) et la plus faible avec la diète à base de haricots dorés verts (12,9%). Les criquets élevés avec une diète à base de haricots dorés verts ont enregistré des taux élevés de protéines, de graisses et de fibres par rapport aux régimes à base de sorgho et de blé ($p<0.001$). Les criquets élevés sous une diète à base d'herbe de blé ont enregistré une quantité significativement élevée de glucides (14,3%, $p<0.001$) et de cendres (3,20%, $p<0.001$) par rapport à la diète à base de sorgho et de graines vertes. L'énergie calculée la plus élevée a été enregistrée par les criquets élevés avec la diète à base de haricots dorés verts (2184,95 KJ/g), tandis que les criquets élevés avec la diète à base de sorgho ont enregistré la plus faible énergie (1391 KJ/g). Les minéraux magnésium et calcium étaient plus élevés chez tous les criquets élevés avec les trois diètes. Les valeurs moyennes du phosphore étaient significativement plus faibles, suivies par celles du cuivre, pour tous les criquets testés. Le Criquet élevé sur des feuilles de sorgho a enregistré une quantité significativement élevée de Potassium ($p<0.001$). Les résultats ont révélé que les criquets sont hautement nutritifs et peuvent être élevés avec des aliments disponibles localement et peuvent donc jouer un rôle majeur dans la sécurité alimentaire et nutritionnelle des populations.

Mots-clés : Insectes comestibles, valeur nutritive, protéine alternative, sécurité alimentaire, plantes fourragères, criquet pèlerin.

INTRODUCTION

Edible insects have played a major role in the history of human nutrition, especially in the tropics (Holloran et al., 2018; Oonincx & Finke, 2021). Most edible insects are rich in proteins, fats, and minerals which is quite comparable to that of vertebrate meat (Clarkson et al., 2018; Ebenebe et al., 2020; Egonyu et al. 2021; FAO, 2021; Veldkamp et al., 2022), hence a good alternative protein source for human diet (Hlongwane et al., 2021). The consumption of insects has been decreasing in many societies around the globe (Rumpold et al., (2014), however, recently, there has been an increasing interest in the utilization of insects as a sustainable protein source and a way of tackling undernutrition, especially in developing nations (Clarkson et al., 2018). The communities that still consume edible insects mostly harvest them from the wild which is not sustainable since they are seasonal (Arena et al., 2020). At the same time, insects harvested from the wild could be contaminated by toxic pesticides used in agricultural farms (Aman et al., 2016) hence not safe for consumption. There is therefore a need to domesticate them for safe human consumption.

The desert locusts, *Schistocerca gregaria* (Orthoptera: Acrididae), historically have been associated with insect pests that destroy crops across the world (Cheseto et al., 2015; Clarkson et al., 2018). However, they also have a great history of being used as human food in Africa, Asia, and the Southern USA (Kietzka et al., 2021). They are rich in nutrients such as proteins, minerals, fibre, and fats (Mariod et al., 2017; Clarkson et al., 2018), which is comparable to conventional proteins such as eggs, meat, fish, and soy (Ssepuuya et al., 2018). Apart from their nutritional composition, they have phytosterols which when ingested are metabolized into derivatives that provide good health benefits to humans (Kietzka et al., 2021). *S. gregaria* also has the potential to contribute to livelihood and employment opportunities. Locusts have therefore been recently viewed as having a great potential of being reared under controlled conditions for food and feed (Mariod et al., 2017; Ssepuuya et al., 2018). This is because, locusts have high reproductive potential since their numbers can increase 10 to 16 folds between each generation (Clarkson et al., 2018), and have a shorter life cycle where adults can be reached between four to eight weeks depending on the rearing conditions and hence high biomass production (Gosh et al., 2014; Clarkson et al., 2018). Besides insect rearing is environmentally safe since less water and land are required and lower greenhouse gas emissions are emitted (Kelemu et al., 2015; Van Huis & Oonincx, 2017).

To have enough safe desert locusts for human consumption, the ability to mass rear them is an important factor. This will ensure that insects are available throughout for food. Besides the suitable environmental factors required for rearing locusts, plants fed to insects while rearing them can influence their nutritional composition and tissue formation (Ssepuya et al., 2018; Idowu et al., 2019). Unfortunately, the basic biological know-how on the nutritional composition of desert locusts reared under laboratory conditions on locally available feeds in the Western region of Kenya is scant, which poses a constraint on the development of sustainable small-scale rearing as an alternative protein for food and feed.

Since the nutritional composition of insects is greatly influenced by their diet, the aim of the current study sought to evaluate the proximate composition and mineral composition of the desert locust (*S. gregaria*), reared under laboratory conditions and fed on the three different local feed plants; green gram (*Vigna radiate*), wheat (*Triticum aestivum*), and sorghum (*Sorghum bicolor*). The feed plants' proximate composition and mineral composition were also evaluated to find out how they correlate with the nutrient composition of the processed mature desert locust.

MATERIALS AND METHODS

Study area

The study was carried out under laboratory conditions at the University of Eldoret, Kenya (latitude 0.571065°, longitude 35.303885°). The area receives a mean annual rainfall of 1124 mm with temperatures ranging between 17 and 26^{O}C. The study was carried out from August to December 2021.

Rearing of locust

At the University of Eldoret, desert locusts (*S. gregaria*) in the gregarious phase were raised in the insectary rearing room chamber measuring 4.5 × 4.5 m. The chamber for rearing insects was kept at 27± 5 °C, 40–50 % RH, and a photoperiod of 12H:12H Light: Dark. The chamber was adequately aerated and equipped with a duct system to maintain negative pressure. The locusts' eggs were kept in the incubator at 27 °C and upon hatching, 200 nymphs were randomly selected and transferred into wooden rearing cages each measuring (50 x 50 x 50 cm) (Cheseto et al., 2015). Each of the three cages had 200 nymphs at the start of the experiment. The insects in each cage were raised on three different feed plants; wheatgrass, sorghum grass, and green grams seedlings respectively. Fresh feed plants were provided every morning till when they matured at 8 weeks.

Plate 1&2. Desert locusts from left to right (nymphs and mature) raised in the gregarious phase under laboratory conditions. © Mmbone Sylvia, 2021

Feed plants materials

At the University of Eldoret in Kenya, green gram (*Vigna radiate*), wheat (*Triticum aestivum*), and sorghum (*Sorghum bicolor*) were cultivated in the greenhouse in 2 L plastic pots (17 cm diameter) filled with red soil, compost, and sand (3:2:1, v/v/v). After three weeks of germination, the leaves of the seedlings were harvested and fed to desert locust nymphs separately immediately after hatching.

Harvesting and processing of desert locusts for proximate analysis

At eight weeks, the locusts were harvested, starved for twenty-four hours, frozen, and dried under the oven at 80 ^{o}C for 8 hours. After drying, the appendages (legs and wings) were removed before grinding the mature locusts into powder form using a blender. Proximate analysis was determined using the standard methods recommended by the Association of Official Analytical Chemists (AOAC, 1999). Crude protein, crude fat, crude fibre, ash and nitrogen-free extract (NFE) were estimated. Moisture percentage was calculated by drying the sample in an oven at 100 °C for 2 hours. The dried sample was put into a desiccator, allowed to cool, and then reweighed. The process was repeated until a constant weight was obtained. Crude protein was determined by the Kjeldahl method and total protein content was calculated as the amount of total N determined multiplied by nitrogen to-protein conversion factor of 6.25. Fat percentage was calculated by drying fats after extraction in a Soxhlet using Diethyl ether. Ash content was calculated by combusting the samples in a silica crucible placed in a muffle furnace. The percentage of carbohydrates was determined by subtracting all of the components (crude protein, crude lipid, fat, and ash) from 100.

Mineral analysis of mature locust

Mineral elements (Ca, Mn, Mg, Fe, Cu, K, Zn and Na) were determined from digested samples using an Atomic Absorption Spectrophotometer (AAS Buck 210VGP System). Na and K concentrations were determined using Corning 410 Flame Photometer (Bamidele et al., 2016). The machines were first calibrated using the machine standards for each of the mineral elements. After the calibration for each of the mineral elements, the digested samples were individually passed through the machines for the calibrated element. Levels of each of the elements were displayed on the monitor screen of the machines and were printed at the end of the elemental reading (Idowu et al., 2019)

Proximate and mineral analyses of wheat, sorghum and green gram leaves

Green gram leaves, sorghum, and wheat grass were first cleaned with clean water before the commencement of the experiment. Proximate composition analysis of the samples was carried out according to the methods recommended by the AOAC, (1999). All determinations were carried out thrice. Moisture content was determined by drying 5 g of fresh leaves of each sample to a constant weight at 105 °C in an air oven. Nitrogen was determined by the micro Kjeldahl method. The value obtained for total nitrogen was multiplied by the conversion factor of 6.25 to calculate the level of crude protein. Crude fats were determined by extracting a 5 g sample with petroleum ether for 6 h using a Soxhlet apparatus (Akwaowo et al., 2000). The crude fibre was determined using 5 g of the dried defatted sample according to the method of Abara et al., (2009). The level of ash was determined by incinerating a 5 g sample in a muffle furnace at 550 °C for 5 h (Abara et al., 2009).

Mineral elements (Microwave-assisted digestion) of the sample were accomplished in the presence of concentrated HNO_3 and 30 % H_2O_2. Iron, manganese, zinc, copper, calcium and magnesium, were determined using atomic absorption spectrophotometer (Varian AA 240 FS) and sodium and potassium were determined using a Jenway PFP7 flame photometer (Abara et al., 2009). Phosphorus was determined colometrically using the molybdovanadate method (AOAC, 1999).

Statistical analysis

Data obtained were subjected to statistical analyses using the Statistical Package for Social Sciences (SPSS) version 21.0. and Excel. Data were presented as mean ± standard error of the mean (SEM). Analysis of Variance (ANOVA) was conducted to determine the significant difference in the proximate, and minerals compositions between the plant feed treatments. All statistical analyses were considered significant when the *p*-value was less than 0.05 ($p < 0.05$).

RESULTS

Proximate composition of green gram leaves, sorghum and Wheatgrass

Table 1 shows the proximate composition of the three plants fed to desert locusts. The highest percentage (%) moisture content was recorded in sorghum grass and significantly low ($F_{0.05\ (2,\ 6)}$ =16.62, p<0.05) in green gram leaves and Wheatgrass. For ash content, Wheatgrass had the highest % followed by green gram leaves then sorghum grass at the lowest level with a significant difference ($F_{0.05\ (2,\ 6)}$ =866.96, p=0.001). Green gram had the highest % fat content in comparison to sorghum and Wheatgrass. Similarly, Proteins and Crude fibre contents were in high % in green gram leaves followed by wheat grass. Sorghum grass had the least amount of crude fibre compared to wheatgrass and green gram leaves.

Table1. Proximate analysis of green gram leaves, sorghum and Wheatgrass

Proximate	Green gram	Sorghum	Wheatgrass	F-Ratio	*p-value*
Moisture (%)	0.04±0.00^a	0.06±0.00^b	0.04±0.00^a	16.62	0.0036
Ash (%)	13.27±0.29^a	11.87±0.21^b	19.40±0.20^c	866.96	<0.0001
Fat (%)	6.11±0.17^a	2.62±0.08^b	2.42±0.03^b	1119.98	<0.0001
Proteins (%)	17.23±0.15^a	9.47±0.42^b	13.75±0.28^c	490.94	<0.0001
Crude fibre (%)	11.40±0.53^a	2.00±0.20^b	10.33±0.61^c	343.87	<0.0001
Carbohydrate	51.95±5.51^a	73.98±8.20^b	54.44±4.28^c	25036.04	<0.0001
Energy[1] (kJ/g 100g)	1387.87±100.00	1495.28±100.00	1232.36±100.00	7.82	0.0213

[abc] Mean values (±S.E) in the same row having the same superscripts are not significantly different at $p < 0.05$, N = 3

Mineral composition analysis of mature green gram leaves, sorghum and Wheatgrass

Green gram leaves had the highest P, Ca, Fe, K, and Na level significantly different (p<0.05) from sorghum and wheat grass. Sorghum grass on the other hand had the highest significant (p<0.05) percentage content of Zn, Mg, and Cu while wheatgrass had the highest Mn levels though not significant with levels in sorghum as illustrated in Table 2.

Table 2. Mineral composition analysis of mature green gram leaves, sorghum and Wheatgrass

Minerals	Green gram	Sorghum	Wheatgrass	F-Ratio	*p-value*
P (%)	0.45 ± 0.01^{a}	0.31 ± 0.01^{b}	0.38 ± 0.01^{c}	163.62	<0.0001
Ca (Mg/100g)	12.87 ± 0.22^{a}	3.90 ± 0.07^{b}	4.31 ± 0.17^{c}	2782.74	<0.0001
Zn (Mg/100g)	0.35 ± 0.01^{c}	0.43 ± 0.01^{a}	0.40 ± 0.02^{b}	27.02	0.0001
Mg (Mg/100g)	21.17 ± 0.04^{a}	26.15 ± 0.80^{b}	13.44 ± 0.14^{c}	556.45	<0.0001
Fe (Mg/100g)	0.97 ± 0.03^{a}	0.49 ± 0.03^{b}	0.17 ± 0.02^{c}	639.1	<0.0001
Mn (Mg/100g)	0.20 ± 0.01^{a}	0.22 ± 0.01^{ab}	0.23 ± 0.01^{b}	8.84	0.0162
Cu (Mg/100g)	0.21 ± 0.01^{a}	0.27 ± 0.01^{b}	0.06 ± 0.01^{c}	200.36	<0.0001
K (%)	155.55 ± 3.66^{a}	62.98 ± 1.93^{b}	42.57 ± 4.31^{c}	915.73	<0.0001
Na (%)	5.68 ± 0.43^{a}	3.32 ± 0.26^{b}	1.91 ± 0.10^{c}	125.11	<0.0001

^{abc} *Mean values (±S.E) in the same row having the same superscripts are not significantly different at p < 0.05, N = 3*

Proximate composition of the desert locust (*S. gregaria*)

The proximate composition of desert locusts evaluated on three feed plants in the current study is shown in Table 3. Moisture content was observed to be significantly higher in locusts reared on a sorghum diet. This was followed by the wheat and green gram leaves diet respectively. On the other hand, locust reared on green gram leaves diet recorded significantly high protein, fat and crude fibre content compared to sorghum and wheat diets. However, locusts reared on a wheatgrass diet recorded a significantly high amount of carbohydrate and ash content compared to sorghum and green gram leaves diet. The highest calculated energy was seen in locusts reared on the green gram diet, while the sorghum diet recorded the least energy.

Table 3. Proximate composition (%) of the processed mature desert locust (*S. gregaria)*

Components	Green gram diet	Sorghum diet	Wheat diet
Moisture	12.99 ± 0.2^{c}	35.10 ± 0.2^{a}	25.02 ± 0.1^{b}
Protein (N×6.25)	48.14 ± 0.6^{a}	41.86 ± 0.5^{c}	45.38 ± 0.3^{b}
Fat	36.08 ± 0.2^{a}	16.42 ± 0.2^{b}	12.03 ± 0.2^{c}
Ash	1.62 ± 0.1^{c}	2.30 ± 0.3^{b}	3.20 ± 0.2^{a}
Crude fiber	12.89 ± 0.6^{a}	10.45 ± 0.3^{b}	9.40 ± 0.0^{c}
Carbohydrate	1.23 ± 0.6^{c}	4.32 ± 1.0^{b}	14.37 ± 0.5^{a}
Energy[1] (kJ/g 100g)	2184.95^{a}	1391^{c}	1453^{b}

^{abc} *Mean values (±S.E) in the same row having the same superscripts are not significantly different at p < 0.05, N = 3.*
[1]Calcualted by multiplying with Atwater's factor (FAO, 2003) where energy (kJ) = (% carbohydrates×16.736 kJ/g) + (% protein×16.736 kJ/g)+ (% oil×37.656 kJ/g)

Mineral composition of the *S. gregaria* reared on three diets

Magnesium (Mg) and Calcium (Ca) were observed to be higher in all the desert locusts reared on the three diets respectively than other minerals tested (Table 4). This was followed by zinc (Zn) and iron (Fe) respectively. The mean values for phosphorus (P) were significantly lower which was followed by copper (Cu) in all the locusts reared on the three diets respectively. Locust reared on sorghum leaves recorded a significantly high amount of potassium (K) and the least amount of sodium compared to locust reared on other feed treatments.

Correlation between plants fed to locusts and the nutrients in mature processed locusts

A correlation was carried out to assess if the nutrients and elements in the plants fed to locusts influenced the nutrients in the locust (Table 5). There was a positive significant correlation between the % Phosphorus (P) in all three feed plants (green grams, sorghum, and wheat) and the % Phosphorus in mature locust meal (r=1.0000, p<0.0001).

Table 4. Mineral composition (mg/g) of the mature desert locust (*S. gregaria*)

Mineral	Green grams treatment	Sorghum treatment	Wheat treatment	F-Ratio	*p-value*
P (%)	0.45±0.01[a]	0.31±0.01[c]	0.38±0.01[b]	163.62	<0.0001
Ca (Mg/100g)	26.91±0.41[c]	38.42±0.20[a]	32.85±0.46[b]	714.07	<0.0001
Zn (Mg/100g)	16.08±0.88[c]	19.68±0.47[a]	18.26±0.24[b]	28.07	0.0009
Mg (Mg/100g)	37.80±0.11[c]	53.08±0.12[a]	42.83±0.09[b]	15036.04	<0.0001
Fe (Mg/100g)	12.84±0.21[c]	15.56±0.07[a]	14.55±0.18[b]	210.64	<0.0001
Mn (Mg/100g)	1.56±0.08[c]	2.10±0.07[b]	3.13±0.07[a]	356.06	<0.0001
Cu (Mg/100g)	1.07±0.04[a]	0.69±0.03[c]	0.91±0.00[b]	166.90	<0.0001
K (%)	7.08±0.50[c]	15.47±1.20[a]	9.09±0.48[b]	89.39	<0.0001
Na (%)	2.17±0.15[a]	1.35±0.08[b]	0.92±0.04[c]	120.42	<0.0001

[abc] Mean values (±S.E) in the same row having the same superscripts are not significantly different at p < 0.05, N = 3

Moreover, the % Ash (r=0.9177, p=0.2601), % Crude Fibre (r=0.7639, p=0.4466), Ca (r=0.9967, p=0.0514), Zn (r=0.9945, p=0.0666), Mg (r=0.4009, p=0.7374), Fe (r=0.9859, p=0.1070), Cu (r=0.3892, p=0.7455) and % Na (r=0.9508, p= 0.2005) in green gram and locust were positively correlated but not significant. The other nutrients in feeds plants and locusts meal were negatively non-significant correlated.

Protein in sorghum plant feeds was positively and significantly correlated with protein in the locust meal (r=0.9983, p=0.037). However, % Moisture (r=0.9608, p=0.1789), % Fat (r=0.336, p=0.7818), Mg (r=0.3252, p=0.7892), Fe (r=0.5542, p=0.626), Mn (r=0.8596, p=0.3414), Cu (r=0.9899, p=0.0907) and % K (r=0.7046, p=0.5022) were positively not significantly correlated between sorghum feed plants and locusts meal.

For wheatgrass plant feeds, % Ash (r=-1.0000, p<0.0001), Mg (r=-1.0000, p=0.0014) and % K (r=-1.0000, p<0.0001) were negatively but significantly correlated with locust meal. While % moisture, Protein, % Crude Fibre, Ca, Fe and Cu were positively non-significant correlated between wheat grass and locust meal.

Table 5. Correlation between three different plants fed to locusts and processed mature locusts

Nutrients and mineral	Green gram	Sorghum	Wheatgrass
% Moisture	-0.8122	0.9608	0.9177
% Ash	0.9177	-0.9608	-1.0000*
% Fat	-0.7271	0.3360	-0.4590
Protein	-0.3041	0.9983*	0.4911
% Crude Fibre	0.7639	-0.3518	0.9955
% P	1.0000*	1.0000*	1.0000*
Ca(Mg/100g)	0.9967	-0.9826	0.0857
Zn(Mg/100g)	0.9945	-0.9687	-0.9690
Mg(Mg/100g)	0.4009	0.3252	-1.0000*
Fe(Mg/100g)	0.9859	0.5542	0.8131
Mn(Mg/100g)	-0.6178	0.8596	-0.8680
Cu(Mg/100g)	0.3892	0.9899	0.4449
% K	-0.6256	0.7046	-1.0000*
% Na	0.9508	-0.5960	0.1555

*Correlation (r) figures with * are significant at p<0.05*

DISCUSSION

Locusts are edible insects that are beneficial in terms of nutrients and can be mass-produced and thus sustainable. Mass production of locusts for food is significantly advantageous to livestock production since less land, water, and feeds are required (Clarkson et al., 2018). The nutritional composition of any insect greatly varies due to habitat and food consumption as well as the stage of sampling (nymphs/adults) (Mariod et al., 2017, Ssepuuya et al., 2018).

Protein is essential for the development and repair of body tissues of animals, therefore, the protein content of locusts evaluated in this study can adequately supply the essential protein to the growing population of people since it is comparable to or higher than the conventional protein. The protein content of locusts was greatly influenced by the plant feeds reared on to maturity. The protein content of locust reared on green grams was higher (48.14%) followed by that reared on wheat (45.38%) and these were higher than that of beef (40.5%) as stated by Gosh et al., (2017). The high protein in locusts studied could be attributed to the high protein content in feed plants which was recorded in green gram leaves (17.23%), followed by wheat grass (13.75%). The protein content of locust meal in this study was lower than that reported by Mariod et al., (2017) at 52.3% and Clarkson et al., (2018) who had 50.79%. However, Egonyu et al., (2021), analyzed the protein content of locusts caught in the wild in Kenya and found it to be 46.3% which was not significantly different from the current study result.

The protein content in analyzed locusts in the current study is therefore comparable to or higher than the most commonly consumed conventional proteins. For example, in the current study, the locust crude protein ranged between 41.86%- 48.14% which is higher than raw pork chop protein and chicken breast which averaged at 18.1% and 24.2% respectively (Ahmad et al., 2018). The variations in the protein content from different studies in the locust meal could therefore be attributed to the type of feed materials available for the insects' consumption, inconsistencies in the methods of analysis used and the period of sampling (Egonyu et al., 2021). The protein content of green gram leaves as well was lower than the values reported by previous studies (Preethi et al., 2021). The differences may be due to ecological zone location, and the type of soil nutrients applied during germination.

In human diets, fat is crucial because it enhances the flavor of food by absorbing and holding their tastes besides increasing the palatability of food (Idowu et al., 2019). They are also vital in the structural and biological functioning of the cells and help in the transport of nutritionally essential fat-soluble vitamins (Siulapwa et al., 2014). The fat content in locust meals significantly correlated with the fat content of plant materials consumed. The locusts raised on green gram leaves had the highest amount of crude fat (36.08%), while wheat-fed locusts registered the least (12.03%). The difference is attributed to the plant's feeds given to the insect as green grams fat content was high at (6.11%) while wheatgrass was (2.42%). The fat content in the current study on locusts fed on green grams was considerably higher compared to the study done by Clarkson et al., (2018) whose fat content was 34.9% in *L. migratoria.* Egonyu et al., (2021), analyzed the wild locust in Kenya, and the fat content was 29.8% which was higher than the locust fed on wheatgrass. Lower numbers of fat content (18.6% to 29.6%) was also observed by Oonincx & van der Poel (2011) although these numbers are higher compared to the locust fed on sorghum and wheatgrass in the current study. However, the composition of fat in locust meals studied by Mariod et al., (2017) was considered the lowest at 12.0%. The differences in the fat content could be attributed to the habitat and type of feed locusts consumed in their development stage. The results of fat content observed in the locusts in this study demonstrate that locusts can offer a good amount of fat content for the human diet. In their study, Cheseto et al., (2020), found out that the oil extracted from locusts is also rich in omega 3-fatty acids, vitamin E, and flavonoids than most commonly used plant oils hence locust meal is essential, especially in young developing children and the old age.

Carbohydrate is an important requirement in the human diet hence the main energy source. The carbohydrate content recorded in the current study indicates that locusts raised on wheat grass had the highest carbohydrate content which was comparable to that recorded by Clarkson et al., (2018) at 13.46% in *L. migratoria*. However, this was slightly lower compared to the observation made by Mariod et al., (2017), whose locust carbohydrate content was found to be 19.0%. The locusts raised on sorghum and green gram leaves had the lowest amount of carbohydrates. Egonyu et al., (2021) also recorded low amounts of carbohydrates in locusts harvested from the wild at 9.9%. Mohamed (2015) also reported low amounts of carbohydrates in *L. migratoria* at 4% and 14%. According to Clarkson et al., (2018), carbohydrate content in orthopteran species is generally low. The differences in the carbohydrate content could also be attributed to the type of feeds the locusts consumed, and the breeding environments of the locusts. An adult human requires about 400-500 g of carbohydrate intake as starch (Siulapwa et al., 2014). However, the carbohydrates recorded in the current study may not be able to meet the human requirement unless supplemented by other foods that have higher carbohydrates.

The analysis of ash content indicated an ash value for the Desert locust fed with Sorghum and Wheatgrass to be higher than the values indicated in green gram leaves fed locust. The ash content of locust raised on green gram was consistent with the value obtained by Clarkson et al., (2018) who obtained ash content on *L. migratoria* at 2.42%. However, the ash content observed by Mariod et al., (2017) and Egonyu et al., (2021) in locusts was higher at 10.0% and 9.9% respectively. The Ash content of a given sample according to consensus among researchers correlates with the mineral contents of the sample (Siulapwa et al., 2014). The mineral content of *S. gregaria* studied indicates that it had a fair source of mineral elements. *S.gregaria* treated with sorghum grass meal had the greatest significant percentages of Calcium, Zinc, Magnesium, iron, and potassium and this was closely followed by locusts fed on green grams which had a higher amount of Phosphorus, Copper, and sodium compared to other treatments. Locusts fed on wheat had only Manganese whose content was higher than the other treatments in the locust meal. The percentages of most mineral contents in plants consumed by the locusts correlated with the mineral composition in mature locust meal. For example, the amount of Phosphorus in feed plants was highly correlated with phosphorus in the locust meal. However, Calcium, iron, potassium and Copper amounts in plants did not correlate with the amount in the locust meal. Green grams leaves for example had the greatest amount of K (Potassium) (155.55%), which was followed at a distance by sorghum (62.98%) among the three feed treatments. However, this did not translate into a high amount of K in the locust fed on the said plants instead locust fed on sorghum had the highest amount of K (15.47%) while the green gram-fed locust was (7.08%).

Minerals are known to play important metabolic and physiologic roles in the living system. As cofactors for antioxidant enzymes, iron, zinc, copper, and manganese enhance the immune system (Kinyuru & Ndung'u, 2020; Nyangena et al., 2020). On the other hand, magnesium and zinc prevent, bleeding disorders, muscle degeneration, impaired spermatogenesis growth retardation, immunological dysfunction, and cardiomyopathy (Siulapwa et al., 2014). Calcium in the human body is very important in building strong bones and teeth, blood clotting (Ghosh et al., 2017; Idowu et al., 2019) oocyte activation, muscle contraction, fluid balance within cells, and regulation of heartbeat (Idowu et al., 2019). The fair levels of minerals present in *S. gregaria*, therefore, indicate that they are a good source of minerals for human food, especially among children, pregnant women, and lactating mothers. The cereal-based diets for infants could therefore receive a boost with the addition of locust meals.

The three tested feed plants fed to locusts, that is, green gram (*Vigna radiate*), wheat (*Triticum aestivum*), and sorghum (*Sorghum bicolor*) resulted in considerable amounts of proteins and other nutrients in the mature locusts' meal which was comparable or higher than the most commonly consumed proteins. Green gram plant feeds resulted in higher protein content in locusts followed by wheat feed diet hence both plants look promising in feeding locusts for mass production for food and feed.

CONCLUSION

From the study, it may be concluded that *S. gregaria* can be raised on a wide variety of foods, however, this will have an effect on the protein content of the insect. Therefore feeding locusts with green gram leaves according to our study amounted to *S.gregaria* having a significant amount of proteins followed closely with the *S.gregaria* raised on a wheatgrass diet. The protein content of *S.gregaria* raised on these two diets is comparable to commonly consumed vertebrate proteins. The study, therefore, recommends these two diets in raising and breeding locusts as alternative proteins for food and feed. Locust protein if well promoted can help control malnutrition among children, especially in developing countries. Since feed plants influence the nutrient composition as well as subsequent growth and development of the insect, there is a need for further research to optimize these conditions for optimal growth and survival rate of *S.gregaria.*Therefore, the rearing of locusts for food and feed can increase their availability and safe consumption and thus contribute to sustainable food production. We recommend the experiment and analysis of other locally available feed plants that can be used for locust rearing.

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Conflict of interest

The authors declared that they have no conflict of interest.

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