"Nutritional Value of German Cockroach Meal (*Blattela germanica*) as a SuperPRO Feed for Poultry in Kenya"

Abstract

Evaluating animal feedstuff is a crucial aspect of animal nutrition and formulation. It provides basic nutritional value information on the quality of conventional feedstuffs and enriches the database with novel feedstuffs. A study was conducted to evaluate the nutritional value of the German cockroach (*B. germanica*) and the parameters compared to the literature for anchovy fishmeal. Samples of adults and sub-adult *B. germanica* were analysed for dry matter content, crude protein, ether extracts, minerals, and crude fibre. Samples of sub-adult *B. germanica* were further analysed for profiles of amino acids and fatty acids and mineral composition. The chemical composition was compared to that documented for of anchovy-fishmeal by calculating parameters such as essential amino acid index, chemical score, and ideal amino acid ratios. The parameters were also compared to those recommended by NRC and GRRS. The dry matter, crude protein, crude fibre, and ash were 91.40, 56.64, 7.94, 6.05, 4.11 and 89.12, 58.28, 15.03, 5.21, 3.45 for adult and sub-adult, respectively. Whereas crude protein was similar, the crude fat (15.03 %) in nymphs was significantly different from adults ($p<0.05$). The crude protein level in german cockroaches was lower than that of anchovy fishmeal. Polyunsaturated fatty acid in nymph *B. germanica* accounted for 70 % of crude fat, dominated by oleic acid (35.90 %). All the essential amino acids were present, with leucine (3.14 mg/g) and methionine (0.65 mg/g) being the highest and lowest, respectively. The essential amino acid index of anchovy fishmeal (1.83) is better than cockroach meal (1.73). The level of essential amino acids in *B. germanica* exceeded the ideal amino acid ratios prescribed by NRC and GRRS for broiler chicken. Although the nutritional value of *B. germanica* is lower than of fishmeal, but is sufficient to as alternative chicken feed.

Introduction

The global feed production industry has expanded rapidly in the last decade attributed growth in livestock production. According to Alltech, (2021), compound feed production increased from 1.176 billion tons in 2019 to 1.187 billion tons in 2021, estimated at 1 per cent globally for the same period. Moreover, China, the USA, and Brazil lead in animal feed production. Poultry feeds account for the largest share of feed produced globally; the broiler feed production, which was 332.5 million tons in 2019, reached 334.5 million tons in 2020 with an increase of 1 per cent. Broiler feeds' share in global feed production is 28.2 per cent. As the demand for poultry products increases, there is a need for more feedstuffs for this rapid expansion.

In feed production, protein supplements are one of the most expensive and limiting feed ingredients. Dietary protein requirements of poultry are often met by incorporating 17–22% of plant protein supplements, 1–2% of animal protein supplements, and 0.2–0.5% of synthetic amino acids broadly classified as LowPRO feed (less than 15% of protein content), MiddlePRO feed (15–30% of protein content), HiPRO feed (30–50% of protein content) and SuperPRO feed (with over 50% protein content)(Parisi et al., 2020). Soybeans and fishmeal are the main feedstuffs that supply these proteins for poultry. There has been a challenge in the supply of these feedstuffs in developing countries including Kenya due to stiff competition for them as human food(Gasco et al., 2020; Kenya MarketTrust(KMT), 2016). Suitable alternatives such as insects are required to sustain the growth in poultry feed production.

Consumption of edible insects for human and animal nourishment has been practised for centuries, but it is now being promoted to ameliorate pangs of food insecurity globally (Govorushko, 2019). It is estimated that over 3000 million families consider edible insects as part of their diets. More than 2300 species of edible insects have been documented (Van Huis, 2020). Therefore the type of edible insects in a given place tends to vary depending on local prevailing climate and level of anthropogenic activities (Van Huis, 2013). Insect species within the order coleopteran dominate the global list of edible insects (Hanboonsong *et al.*, 2013). Other factors that determine the species of insects consumed are indigenous knowledge, skills of harvesting skills, processing methods and available (Kelemu et al., 2015; Raheem et al., 2018).

Globalisation and cultural interaction have transformed the trend and behaviour of consuming insects globally. For instance, there is a similarity in the consumption pattern of edible insects in places where diversity existed before; this is attributed to adopting new species of edible insects (Govorushko, 2019). Besides, the consumption of termites and grasshoppers was domiciled in Eastern Africa but has now spread to western Africa and Europe (Moreki & Tiroesele, 2012). Similarly, the consumption of cockroaches was a common practice in South America and the Far East (China) but has spread to South Korea and Eastern Africa. Despite being used as food and feed in Tanzania (unpublished), cockroaches are now being produced at Maishahai Farm on an industrial scale for export to Korea for biomedical exploration (Kulma *et al.*, 2016). Traditionally humans associated cockroaches with dirtiness, hindering their advancement as food and feed.

Wild harvesting is the main method of obtaining edible insects (Dao *et al.*, 2020; Govorushko, 2019). However, this method is not sustainable to cater for ever-increasing demand. Some edible insects, such as termites, are seasonal and only available during some part of the year (Dao *et al.*, 2020). Seasonable edible insects may be harvested during peak periods, processed, and preserved for later consumption. Method of processing may be in the form of drying, frying, milling, blanching or simple steaming (Mutungi *et al.*, 2019). It has also been noted that some processing may alter the quality of the products, while prolonged storage also affects the chemical composition and final nutritional value (Ekpo, 2011).

Insects as food and feed are rich in nutrients required by all animals, such as energy, protein, fat, vitamins, and minerals. Energy levels are similar to meat from other animal species except pork (Rumpold & Schlüter, 2013). Genetics, habitat, substrate, growth stage, age, processing method and preservation affect edible insects' chemical composition and nutritional value (Dobermann, Swift, & Field, 2017). The majority of insects have a crude protein 30-65% dry weight that is 77-98% digestible, comprising 46-96% of essential amino acids with a limited amount of lysine and tryptophan(Dobermann et al., 2017; Ramos-elorduy, 2010). Insects have a significant amount of fats that range from seven to 77 g/100 g of dry weight.

Insect larvae, subadults, and adult soft-bodied adults have more fats than other categories. Hard exoskeleton insects like crickets, grasshoppers, cockroaches, and locusts have lower fat content than termites (Bukkens, 1997). Insect fatty acid profile is similar to that of white meat. Still, it has more polyunsaturated fatty acids (PUFAs), mainly linoleic acid (C18:2) and occasionally linolenic acid (C18:3), that can be used to synthesise essential fatty acids such as eicosapentaenoic acid (EPA) (C20:5) and docosahexaenoic acid (DHA) (C22:6) (Dobermann et al., 2017). Insects are also reported to contain minerals such as calcium, iron, zinc and lots of vitamin A. Some Insects contain some toxins and anti-nutrient factors. Cryptotoxics contain toxic substances from either direct synthesis or accumulation from their diet. Phanerotoxics have specific organs that synthesise toxins (Belluco 2013). Other anti-nutrients found in negligible levels in edible insects are hydro-cyanide, oxalate, phytate, phenol and tannins (Dobermann et al., 2017).

Limited information is available on specific methods for analysing the chemical composition of insects. AOAC's official method of analysing conventional food and feed is applied to insect products. These include procedures such as proximate analysis, profiling for amino acids, fatty acid profiles, and mineral salts. The nutritional value of insects could be evaluated by expressing amino acid profiles as a percentage of lysine; calculating the essential amino acid index (EAAI), calculating the chemical score (Veldkamp & Bosch, 2015), and also calculating of ideal amino acid ratio (IAAR) (Wecke *et al*., 2016). The calculated values are then compared with other feedstuff documented in the literature. EAAI measures the adequacy between the concentration of all the essential amino acids in the dietary protein and the requirement of the target animal.In contrast, the lowest C.S. value is the first limiting amino acid. Lysine has been widely used as the reference amino acid in the calculation of IAAR because it has been demonstrated that chickens exhaustively utilise it during digestion. This concept is being advocated in modern nutritional studies to increase nitrogen absorption efficiency in chicken (Wecke *et al*., 2016). For protein-rich feedstuffs, the value can be compared with those of soybean and fishmeal. Using the parameters mentioned earlier, it is easier to establish the suitability of some novel feeds and add them to a database of potential feeds or conduct further *in vivo* studies (Wecke et al., 2016). This study evaluated the nutritional value of the German cockroach as a potential feed ingredient for broiler feed production in developing countries.

Materials and Methods

Study Site

The insects (*B. germanica*) for nutritional analysis were obtained by rearing them for six months at Kenya Agricultural and Livestock Research Organization –Non-Ruminant Institute, Kakamega, Kenya. The *B. germanica* were fed on a composite diet consisting of locally available organic wastes, including brewer's waste (40%), fishmeal (20%), and wheat bran (40%).

Optimisation of *B. germanica* Colony

The insects were reared in four 60-litres capacity containers in a dark room. They were provided with accessible water and feed throughout the research period. Stacked carton trays were used to provide a hiding place, while 6 inches from the brim of each container was laced with petroleum jelly to deter cockroaches from escaping.

Analysis of Samples for Chemical Composition

At the end of six months, samples of cockroaches from each container were harvested using an insect net. They were then sacrificed by cold shock by placing them in a refrigerator (-5 ^{o}C) for 24 hours before being removed, washed in water and strained to remove any impurities and then dried in an oven at 60^{o} C for 24 hours. Dry *B. germanica* were sorted into adults and nymphs; nymphs possess wings while adults do not, then milled to 1mm particle and stored under (-5 ^{o}C) for proximate analysis, amino acid profiling, fatty acid profiling and mineral content determination. The proximate analysis, amino acid profile and fatty acid profile were determined according to standard procedures and guidelines (Association Of Analytical Chemistry (AOAC), 1990).

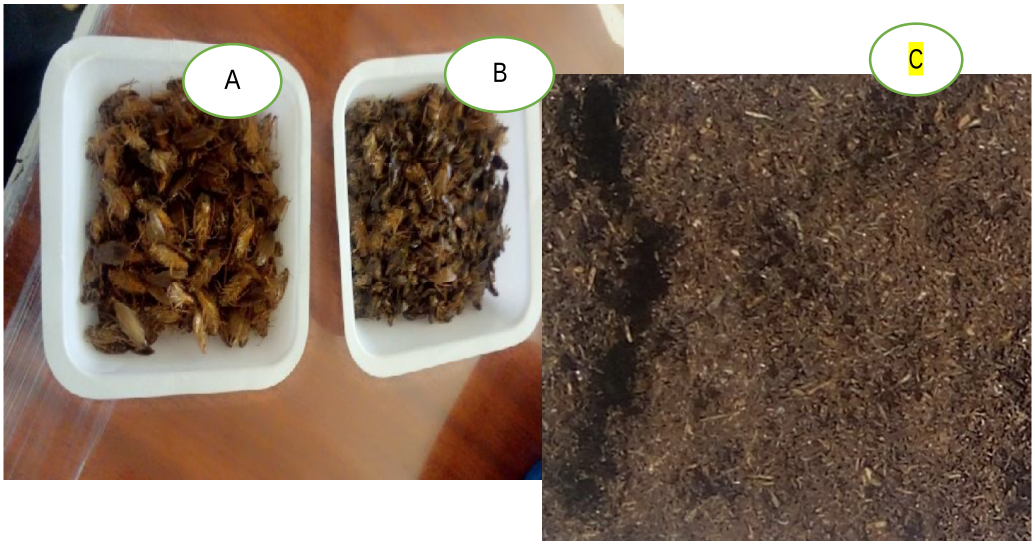

Figure 1. Nymph-B, adult-A, and ground sample-C of *B. germanica*
Source: Author

Determination of Dry Matter and Moisture Content

Dry Matter was determined using AOAC Method 0934.02. In principle, dry empty porcelain crucibles were dried overnight at 105 ^{0}C, placed in a desiccator to cool to room temperature, and weighed. 2g of sample was added (W_0) into the three crucibles and placed in an oven at 105^{0}C for 12 hours. The crucibles+samples were then placed in a desiccator and allowed to cool to room temperature (W_t). The moisture content and dry Matter were calculated using the following formulae:

(a) Moisture (%) = $((W_0 - W_t)/W_0)100)$
(b) Dry matter (%) = $((W_t/W_0)*100)$.

Determination of Ash

Total ash was determined by the AOAC method 0942.05. The samples were oven dried at 105^{0}C for 12 hours to get the dry matter. Into a dry, empty porcelain crucible (W_c), 2g of the dry matter was added (W_a). The dry matter samples were ignited overnight in a muffle furnace at 550 ^{0}C, then cooled in a desiccator to room temperature and weighed (W_b). The ash was calculated as follows;

Ash (%) = ((Wb-Wc)/Wa-Wc)*100

Determination of Organic Dry Matter

Organic Dry Matter (%) = 100- Ash (%)

Determination of Crude Protein

Crude protein was determined by the Kjeldahl Method, where 1g of sample was digested in sulfuric acid using K_4SO_4 as a catalyst, N was converted into NH_3 and then distilled in boric acid. The solution was titrated with 0.1142 N H_2S0_4 until the colour turned purple. (Zaklouta, Hilali, Nefzaoui, & Haylani, 2011). The following formula was used to calculate crude protein.

Calculations %N = [1.4007× (Vc–Vd) ×N]/W

Vc = volume of acid used for sample titration, Vd = volume of acid used for the blank N= Normality of acid while W= sample weight in grams, 1.4007: conversion factor milliequivalent weight of nitrogen and N percent

Calculation:

Crude protein (%) = % N*6.25.

Determination of Crude Fat

Ether Extracts were determined by adding 5g dry matter of ground *B. germanica* (W.F.) in petroleum ether and then filtering the mixture. Petroleum ether was then evaporated in the Southern Apparatus from Gerhardt GmbH to obtain the weight of crude fat as residue (W.P.) (Zaklouta *et al.*, 2011).

Calculation

Crude Fat (%) = $((W_P/W_F)*100)$

Determination of Crude Fibre

The organic residue left after sequential fat extraction with ether was used to determine the crude fibre using the following formulae.

$$Crude\ Fibre(\%) = \frac{(Dry\ weight\ of\ Fat - free\ sample)}{Dry\ Weight\ of\ sample\ with\ fat\ before\ Ashing} \times 100$$

Calculation of Metabolizable Energy

The metabolisable energy was estimated by calculation using the following formulae (Pauzenga, 1985)

$$ME\left(\frac{Kcal}{Kg}\right) = (g\ of\ crude\ protein \times 4) + (g\ of\ crude\ Fat \times 9) + (g\ of\ nitrogen - free\ extract\ \times 4)$$

Determination of Nitrogen free extract

Nitrogen Free Extract (NFE) was calculated by determining the difference according to the procedure of Pauzenga (1985) as;

$$Nitrogen\ Free\ Extract(\%) = (Dry\ Matter(\%) - (Crude\ Fibre + Crude\ Protein + Crude\ Fat + Ash)\%)$$

Determination of Macro and Trace Minerals

The concentrations concentration of specific minerals was determined using the method 0968.08 atomic absorption method; in principle, the ash was dissolved in 10% hydrochloric acid (HCL), and water was added up to 100 ml mark in a standard flask. Magnesium, Calcium, Iron, Phosphorus, Manganese, Zinc, and Copper were analysed by alpha 4 Atomic Absorption Spectrophotometer. Sodium and Potassium were determined by official method 0965.17, using Flame Photometer (Corning 405) (AOAC 1990).

Determination of Fatty Acid Profiles

A 10 grammes sample of the dry cockroach was used for crude fat extraction in fatty acid profiling as per the description Official method 996.06. Fats were extracted by hydrolytic method and then methylated into fatty acid methylated esters (FAMES) and subsequently quantitatively measured in gas chromatography and recorded (AOAC, 1990).

Determination of Amino Acid Profiles

Ten grammes of a dry sample of *Blattela germanica* was obtained to extract proteins for amino acid profiling as outlined in the AOAC 1990 Official Method 994.12; Performic Acid Oxidation with Acid Hydrolysis–Sodium Metabisulfite. In principle, acid oxidation was performed before hydrolysis to oxidise cysteine and methionine to cysteic acid and methionine sulfone, respectively. Sodium metabisulfite was added to decompose performic acid. Amino acids were liberated from protein by hydrolysis with 6M HCl. Hydrolysates were diluted with sodium citrate buffer, pH was adjusted to 2.20, and individual amino acid components were separated on ion-exchange chromatography.

Calculation of Essential Amino Acid Index (EAAI)

The following formula was used ……….(Veldkamp & Bosch, 2015)

$$EAAI = n\sqrt{\frac{aa_1}{AA_1} \times \frac{aa_2}{AA_2} \times \frac{\cdots}{\cdots} \times \frac{aa_n}{AA_n}}$$

Where EAAI= essential amino acid index, *aa* = amount of amino acid in protein source in per cent of crude protein, *A*.A. = the requirement of the target animal for amino acids in per cent of crude protein and *n* = the total of amino acids used in the calculation. This parameter considers the level of amino acids in the target species and those in the studied protein.

Calculation of Chemical Score (C.S.)

A chemical score (C.S.) was calculated for each amino acid in the studied protein. It was calculated by dividing the quantity of amino acid in *B. germanica* by the quantity in the target animal (broiler grower chicken) and multiplying by 100. Lowest C.S. represented the first limiting amino acid; subsequently, scores ranked the rest of the amino acids.

Calculation of Ideal Amino Acid Ratios (IAAR)

This value relates other essential amino acids to the lysine concentration in the protein under analysis; in this case, the sample was nymph *B. germanica*. It was calculated by dividing each quantity of essential amino acid by the quantity of lysine and multiplying by 100.

Data Analysis

Essential amino acid index (EAAI), chemical score (C.S.), and ideal amino acid ratios (IAAR) of *B. germanica* about the requirement of broiler growers were calculated and compared with that of fishmeal. Chi-square was used to compare the proximate composition of nymphs and adults.

Results and Discussion

Proximate Composition of *Blattela germanica* Meal (BGM)

Proximate results of *Blattela germanica* meal for adults and nymphs are as recorded in **Error! Reference source not found.**, where the percent dry matter was 91.40 ± 0.84 % and 89.12 ± 0.03% for adults and nymphs, respectively. There was no significant difference in dry matter composition between the adults, nymphs, and fishmeal. The percent dry matter composition is similar to that reported by Boate *et al.* (2020) for the American cockroach (*Periplaneta americana*).

The crude protein is 56.64±0.93 and 58.28±0.01 for adults and nymphs *B. germanica*, respectively. These figures are lower than documented literature value of 78% for this species (Zielińska *et al.*, 2019). Crude protein in fishmeal varies with species but generally ranges from 50-70%, for instance, omena-fishmeal (55%), which is lower than anchovy-fishmeal (64%). Crude protein in *B. germanica* is lower than that of *Blattodea* species (60.2- 67.8 %), as reported by Kulma *et al*. (2016). Insect in the order *Blattodea*, where all cockroach species belong) are documented to have an average crude protein of 53 % (Amza & Tamiru, (2017). Based on the finding of these results, it can be concluded cockroach meals can be an alternative complement or supplement to fishmeal in livestock diets (Karimi, 2006).

The research also recorded a crude fat content of 9.94 and 15.03 % for adult and nymph *Blattella germanica*, respectively. This implies that a nymph accumulates more crude fat than an adult does. The results are similar to those of Kulma *et al*. (2016), who reported a crude fat of 23.6 - 36.3% for subadults and 14.5-21.4% for adults in *Blattodea* species. Fats are requisite in broiler nutrition; they provide energy. The total ash is an indicator of minerals; in this study, the nymph and adult *Blattela germanica* had 3.87 and 4.5 %, respectively, as indicated in **Error! Reference source not found.**.

Table 1. Proximate composition of adult and nymph *Blattela germanica*

Proximate Component (%)	**Nymph *B.germanica***		**Fishmeal**	**Requirement in grower's diet**
	Adult	**Nymph**		
Dry Matter (%)	91.40±0.84	89.12±0.03	92	90
Organic Dry Matter	95.89	96.55	89	
Crude Protein	56.64±0.93	58.28±0.01	64.2	16
Crude Fat	7.94±0.11	15.03±0.25	9.2	<7
Crude Fibre	6.05±0.22	5.21±0.45	1	<8
Ash	4.11±0.03	3.45±0.03	11	
NFL	16.66	7.01	6.6	
ME(Kcal/Kg)	3639.56	3964.3	3420	2900
Reference			NRC,1994	NRC,1994

Mineral Profile of nymph *B. germanica*

The results of macro and trace elements are indicated in Table 2. Potassium was the highest (0.54), while magnesium (0.12) was the least macro mineral. Iron was the highest trace mineral, while copper was the least. Mineral content in cockroach meals was lower than that in fishmeal but is adequate to meet the minimum daily requirement for grower chicken. These trends in these results are similar to those reported in Sule *et al*., 2020 but contrary to those in (Boate *et al*., 2020), although both studied *P.americana*. Minerals are an important component of animal diets as they are utilised as structural components of organs and tissues, activators in enzyme and hormone systems, constituents of body fluids and tissues and as regulators of cell membrane activity, thus vital for animal health. Macronutrient elements are required in large quantities and can easily be supplied in diets from other feedstuffs, but trace mineral daily targets can easily be attained through daily diets.

Table 1. Composition of macro and micro minerals of nymph *Blattela germanica* nymph

Minerals			
Macro Mineral	Composition (%) *B.germanica*	Anchovy Fishmeal	Daily Requirement in broilers (%)
Calcium	0.23±0.02	3.73	0.80
Phosphorous	0.35±0.07	2.43	0.30
Magnesium	0.12±0.01	0.24	0.400
Potassium	0.54±0.02	0.69	0.25
Sodium	0.22±0.02	0.65	0.15
Trace Minerals	Composition(ppm)		
Iron	481.00±19	220	60
Zinc	156.00±9	103	35

Manganese	67.00±7	10	30
Copper	49.00±5	9	40

Ppm = parts per million

Essential Amino Acid Concentration of *B. germanica*

The quality of crude protein could be evaluated by the type and quantity of amino acid present. In this study, the highest percentage of amino acid was leucine (3.14±0.63), while the least was methionine (0.65 ± 0.01), as indicated in **Error! Reference source not found.**. More than 90% of essential amino acids were present. The trend in the composition of the protein is similar to those reported for American cockroaches (Sule *et al.*, (2020)

Table 2. Concentration and Chemical Score of amino acid in *B. germanica* in relation to literature for anchovy-fishmeal

Amino Acid(A.A.)	**Anchovy Fishmeal**	**AAC in Nymph *B. germanica*(g/100g C.P.)**	**Chemical Score – Anchovy Fishmeal (%)**	**Chemical Score-Nymph *B. germanica* (%)**
Leucine	7.74	3.14±0.63	832.26	337.63
Lysine	7.91	2.81±0.02	958.82	330.59
Arginine	5.70	2.46±0.08	570.00	246.00
Valine	5.43	2.23±0.03	775.71	318.57
Phenylalanine	4.12	1.95±0.21	735.71	348.21
Isoleucine	4.74	1.71±0.34	764.52	275.81
Threonine	4.37	1.67±0.04	642.65	245.81
Histidine	2.41	1.28±0.11	892.59	474.07
Methionine	3.02	0.65±0.01	943.75	203.13

AAC=amino acid composition

Essential Amino Acid Index (EAAI) of *B. germanica* meal

The Essential Amino Acid Index (EAAI) for nymph *B.germanica* meal (1.73) was lower than that of fishmeal (1.86). EAAI summarises the concentration and distribution of amino acids in a given feedstuff to the consuming animal; feedstuffs with higher EAAI tend to have better protein quality. It could be deduced protein quality in *B. germanica* meal is lower than fishmeal but better than that of *Blattodea* species (< 0.7), black soldier fly larvae (1.24), black soldier fly prepupae (1.43), housefly larvae (1.25), housefly prepupae (1.19) and to mealworm larvae 1.72 (Kulma et al., 2016; Veldkamp & Bosch, 2015). Insects, like other animals, synthesise protein depending on the available quantity of essential amino acids provided in their diets; their body does not have a mechanism for producing the amino mentioned above acids. When the distribution of essential amino acids is proportional in the diet, their utilisation will be efficient and beneficial. Based on these findings, the concentration and distribution of amino acids differ from that of German cockroach meals.

Chemical Score of *B. germanica* meal

The chemical score for nymph *B. germanica* was calculated and compared to those in literature for anchovy fishmeal, as shown in Table 3. Leucine and methionine had the highest and lowest chemical score at 337.63 and 203.13, respectively, as shown in **Error! Reference source not found.**3. For fishmeal, lysine (958.82) and phenylalanine (735.71) had the highest and lowest chemical scores, respectively. Therefore, leucine and phenylalanine was the first limiting amino acid in German cockroach meal and anchovy fishmeal, respectively.(Veldkamp & Bosch, 2015). Although the C.S. are lower than those of fishmeal, leucine and methionine are usually deficient in most plant proteins, thus necessitating the inclusion of animal proteins such as insects in the diets of chicken effective growth, production and reproduction(Bovera et al., 2016; Parisi et al., 2020).

Ideal Amino Acid Ratio

The ideal amino acid ratio to evaluate protein quality is adopted in modern poultry nutrition, as highlighted earlier in the literature review. The ideal amino acid ratio (IAAR) for various amino acid content in nymph *B. germanica* was determined and recorded, as shown in **Error! Reference source not found.**4. Leucine had the highest IAAR (144), while methionine (23) had the least score. Regarding IAAR for the broiler diet, as outlined in NRC (1994), only leucine, phenylalanine and histidine amino acids had ratios above the recommended values. The three amino acids translate to about 33 % of essential amino acids; the percentage is higher than that of fishmeal, which is 22%. In this case, a cockroach meal was better than fishmeal.

The regional difference has led to a slight variation in IAAR value in the USA and Europe, as indicated in Table 4. Further comparison was made for IAAR in nymph *B. germanica* concerning similar values as prescribed in German Recommended Ratios Standards (GRRS). It was realised that the percentage of amino acids with IAAR values above those prescribed by GRRS were 33% and 11% for *B. germanica* meal and fishmeal, respectively. For both comparisons, cockroach meal had a higher percentage and thus better than fishmeal.

Table 3. Calculated Ideal amino acid ratios (IAAR) related to lysine (Lys = 100) in nymph B. germanica compared with literature data (NRC, GRRS)

Type of Amino Acid	**IA (USA)**	**IAAR(Germany)**	**IAAR-Anchovy-Fishmeal**	**IAAR- *B. germanica***
Lysine	100	100	100	100
Leucine	109	112	81	144
Arginine	110	108	102	88
Valine	82	-	72	79
Phenylalanine	65	65	85	69
Isoleucine	73	69	47	61
Threonine	74	67	47	59
Histidine	32	32	25	46
Methionine	42	37	34	23
Average	**64**	**74**	**66**	**74**

NRC =National research council, GRRS= German recommended ratio standards

The concentration of non-essential amino acids in nymph *B. germanica* is recorded in Table 5. From the table, it can be noted that glutamine was highest while serine was the lowest.

Table 4. Non-Essential Amino Acid Profile of nymph *Blattela germanica*

Type of Amino Acid	**Composition (%)**	
	B. germanica	Anchovy Fishmeal
Glutamate	4.22±0.21	3.35±0.04
Aspartate	3.39±0.14	2.89±0.01
Alanine	2.52±0.09	1.76±0.02
Proline	2.22±0.06	0.99±0.01
Glycine	1.94±0.01	1.05±0.01
Serine	1.69±0.01	1.19±0.03

The quantity of non-essential amino acids in nymph *B. germanica* was higher than that of fishmeal. Kulma *et al*. (2016) and Sule *et al*. (2020) reported a similar trend for the nonessential amino acid. In practical feed formulation, these amino acids are given little attention because they can easily be synthesised from nitrogen by animals, including insects.

Fat content Fatty Acid profile nymph *Blattela germanica*

Adult and nymph cockroaches contained 7 and 15 % crude fat, respectively. There was a significant difference in fat content between the nymph and adult cockroaches; subadults are rich in fats compared to adults; this may be attributed to intense feeding habits and inactive sexual habits. The total fat composition and variation between adults and sub-adult are similar to that of Bukken (1997).

Fats extracted from the subadults were further profiled for fatty acids concentration. The proportion of polyunsaturated fatty acids (70.39%) was more than saturated fatty acids (28.16%). Generally, oleic acid (35.90±0.16) and lauric acid (0.67±0.02) were the highest and lowest fatty acid, respectively (Table 6), whereas oleic and palmitoleic were the highest and lowest unsaturated fatty acids. Stearic and lauric were the highest and lowest saturated fatty acids, respectively. The proportion of PUFA is similar to that of Doberman *et al*. (2017).

Table 5. Type of fatty acids and percent composition of nymph *Blattela germanica*

Type of Fatty Acid	**Fatty Acid Chain**	**Composition (%)**	**Fishmeal (%)**
SFA			
Lauric	12:0	0.67±0.02	0.079±0.002
Myristic	14:0	4.10±0.04	5.394±0.010
Palmitic	16:0	7.54±0.02	20.296±0.031
Stearic	18:0	11.81±0.05	4.211±0.026
Arachidic	20:0	1.66±0.04	0.147±0.002
Behenic	22:0	2.38±0.26	0.129±0.074
Sub Total		**28.16**	**30.256**
INFO			

Palmitoleic	16:1(n-7)	01.19±0.00	5.047±0.009
Oleic	18:1(n-9)	35.90±0.16	12.285±0.09
Myristoleic	14:1(n-7)	01.86±0.01	0.208±0.008
Linoleic	18:2(n-6)	11.51±0.07	1.710±0.011
Linolenic	18:3(n-3)	09.61±0.17	1.053±0.008
Gadoleic	20:1(n-11)	01.20±0.03	1.367±0.016
Arachidonic	20:4(n-6)	09.12±1.01	1.343±0.026
SubTotal		**70.39**	**23.013**

The trend in the composition of fatty acids is in tandem with those reported by (Kulma *et al.*, 2016), who studied *Blattodea* species. The percentage of saturated fatty acids (SFA) was almost similar at 28.16 % and 30.26% for nymph *B. germanica* and fishmeal, respectively. Variation was recorded in the percent proportion of unsaturated fatty acids; 70.39 % was recorded in fats from nymph *B. germanica* compared to 23.01 % from anchovy fishmeal. Based on the results from this study, german cockroach meals could have high levels of unsaturated fatty acids that may limit their shelf life. A similar challenge was experienced in the storage of termites that also have high-fat content. In nutrition studies, fats supplement the energy sources in feed, especially carbohydrates, are limited. During feed digestion and absorption, excess fats are stored as an abdominal fat pad in chicken. Higher deposition of abdominal fat pad negatively affects fertility in breeding hen and may alter the carcass quality and increase cooking loss.

For appropriate nutrition, chicken requires a daily supply of 1% linoleic fatty acid in their daily diet, but nymph *B. germanica* meal can provide 11%, sufficient to sustain a chicken. However, when exposed to air or other active compounds, unsaturated fatty acids have reactive points that can undergo oxidation and rancidification. A higher level of UNFA (70%) in cockroach meals may challenge the durability of compounded feeds unless appropriate antioxidants are added into feeds during formulation. Defatting could also be used to reduce fat and increase crude protein concentration.

Conclusion

German cockroach (*B.germanica*) meal is a SuperPRO feed with protein content that range from 56% to 58%. It could be used as a protein ingredient in to replace or complement fishmeal in broiler chicken diets. Further study *in vivo* studies are needed to validate this novel feedstuff.

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