Nutritional Value of Insects in Pet Food

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Due to the increasing global population, the world cannot currently support the well-known techniques of food production due to their harmful effects on land use, water consumption, and greenhouse gas emissions. The key answer is a solution based on the use of edible insects. They have always been present in the diet of animals. They are characterized by a very good nutritional value (e.g., high protein content and contents of essential amino acids and fatty acids, including lauric acid), and products with them receive positive results in palatability tests.

Keywords: companion animal nutrition ; edible insects ; pet food production

1. Protein and Amino Acids

When considering new sources of protein, it is important to determine the quality of the protein. Protein of animal origin is considered the benchmark in terms of nutritional value. Nutritional quality is defined as the ability of a protein to meet basic amino acid requirements and is usually based on the composition of the amino acid proteins and their digestibility. In recent years, new sources of protein have emerged that make it possible to shift to more sustainable food production.

Protein is the most expensive of all nutrients in both economic and ecological terms [1]. Protein provides essential amino acids and chemicals necessary in the processes of amino acid synthesis, gluconeogenesis, and energy transformation.

Importantly, the protein content is usually calculated from the total nitrogen using the nitrogen to protein conversion factor (Kp) of 6.25. This factor overestimates the protein content due to the presence of non-protein nitrogen in insects. In a study [2], the specific Kp of 4.75 was calculated for the *Hermetia illucens*, and a Kp of 4.67 was calculated for *Tenebrio molitor*, while Homska et al. [3] obtained a Kp of 5.12 for *Hermetia illucens* larvae meal and a Kp of 4.91 for *Tenebrio molitor* larvae meal. When using insects as an alternative protein source, care should be taken to avoid overestimating the protein content due to the presence of non-protein nitrogen. To avoid overestimating the protein content of insects, the authors of these studies proposed to use the above-mentioned Kp [2][3]. What is more, the protein content of an ingredient should be calculated from the sum of individual amino acids [4][5].

Table 1 presents the contents of macronutrients and energy values in selected forms of insects.

Table 1. The content of nutrients (% of dry matter—DM) and energy value (MJ) in selected forms of insects.

Species	Life Stage	Crude Protein	Crude Fat	Crude Fiber	Crude Ash	Gross Energy
Black soldier fly [6]	Larvae	42.35	24.90	7.00	21.50	22.10
Mealworm [7]	Larvae	53.75	37.10	-	2.75	26.85
	Imago	65.30	14.88	20.20	3.30	1.60
Banded cricket [8]	Imago	70.00	18.23	3.65	4.74	1.90
House cricket [9]	Nymph	67.25	14.41	15.72	4.80	17.32
	Imago	67.57	20.68	-	4.33	19.10
Field cricket [10]	Imago	56.40	28.80	7.00	6.40	21.50

The contents of nutrients in insects may vary depending on the species as well as the environment in which they live and what they were fed [11]. Insects are rich in protein with high nutritional quality In a study conducted by Udomsil et al. [12] the essential amino acids contents of crickets were comparable to those of egg, chicken, pork, and beef, which are considered the main protein sources of the dog diet.

Different diets, especially those with different protein contents, can affect the growth and nutritional value of crickets. In the studies by Bawa et al. [13], an assessment was made of the effect of commercial diets and other formulated diets on the nutritional composition and growth parameters of domestic crickets. It was shown that crickets can be effectively produced on a 22% protein diet to improve their nutritional value [13].

Nowadays, one of the most promising sources of protein is black soldier fly larvae (BSFL). The literature data indicate that BSFL consist, on average, of 40–44% crude protein [14]. In the research of Huang et al. [14], it was shown that the crude protein contents in BSF, *Tenebrio molitor* larvae, and cricket are 42.0%, 38.3%, and 32.6% DM, respectively. **Table 2** shows a comparison of the contents of essential amino acids (EAA) in insects compared to conventional protein sources in feed and raw pet food materials.

Table 2. Essential amino acid (g/100 g of protein) contents in insect species and pork, beef, chicken, soybean meal, and fishmeal.

Item	Mealworm Larvae [15]	Black Soldier Fly Larvae [16]	House Cricket Imago [16]	Pork (*longissimus dorsi muscle*) [17]	Beef (Chuck) [18]	Chicken (Breast) [19]	Soybean Meal [20]	Fish Meal (*Peruvian anchovy*) [21]
Protein (g/100 g DM)	52.23	45.2	67.4	19.09	68.00	21.3	45.97	68.77
Arg	3.61	4.78	6.19	2.72	7.04	8.83	5.67	5.21
Val	3.62	9.03	9.36	3.67	6.59	4.79	4.33	5.38
Leu	4.22	7.23	8.00	4.27	9.09	7.09	8.04	7.66
Ile	2.51	4.73	4.91	2.39	5.65	3.90	4.00	4.00
Phe	2.51	4.38	3.77	3.1	4.54	3.71	5.99	3.36
Phe + tyr	6.62	10.58	11.77	4.82	8.53	6.81	9.21	6.28
Met	1.15	1.53	1.68	2.61	3.49	4.98	1.11	3.14
Met + Cys	3.42	2.79	2.76	2.81	4.97	6.01	2.05	4.19
Lys	3.03	7.43	6.41	3.96	9.79	9.95	5.44	7.63
His	1.60	3.21	2.63	2.6	4.32	3.47	3.00	2.08
Trp	0.57	1.46	1.04	0.23	1.37	2.07	1.65	0.99
Thr	2.42	4.18	3.90	3.05	5.04	4.93	4.81	4.14
Sum EAA	31.62	55.42	59.96	38.15	62.40	57.84	48.20	47.56

The high lysine and threonine contents in both *A. domesticus* (4.49 and 2.30 g/100 g of protein, respectively) and *G. bimaculatus* (4.76 and 2.75 g/100 g of protein, respectively) [12] could help supplement cereal-based diets, which are generally low in these essential amino acids [22]. In most edible insects, lysine and tryptophan have been reported to be low. However, the low or limiting amino acids vary according to insect species and their diets [23]. The results of a study [12] demonstrated that both *A. domesticus* and *G. bimaculatus* could be used as dietary amino acid supplements that provide gratifying amounts of the essential amino acids for human health. In terms of EAA content, insects can be a valuable alternative to the fish meals and soybean meals commonly used in pet food production.

2. Fat and Fatty Acids

Insects are a very good source of fat with a high nutritional quality. The crude fat levels range from 14.41 to 37.1% and are usually higher in larvae than in imago, as is the case with mealworms. Mealworm larvae consist of 37.10% fat, while imago consist of 14.88% fat (**Table 1**). BSF contain about 35–40% lipids [14][24]. Interestingly, due to their high fat content, BSF larvae were used as biodiesel [25][26]. At the same time, BSF provided the highest amount of crude fat 36.2% DM. These results partially overlap with the information presented in **Table 1**. BSF can be considered a type of “energy” insect, rich in both proteins and lipids [14].

The fatty acid contents of insects may vary depending on the environment in which they live and the species as well as what they were fed [11]. The fatty acid profiles found in insects most likely reflect the fatty acid composition of the feed they were fed [27]. It has been shown that the fatty acid profile of crickets depends on their age [28]. Saturated fatty acids (SFA) are primarily a source of energy for the body. In insects, SFA levels range from 28.20 to 49.60% fatty acids and are comparable to the SFA contents of conventional protein sources, such as chicken breast (43.14% of fatty acids). The fatty acid content depends on what the insects are fed, e.g., in the studies by Ewald et al. [29], most of the BSFLs contained a high percentage of SFA (up to 76% of total fatty acids), which is higher than the value they obtained from Matin et al. [16].

Important acids are C10:0 and C12:0, which are easily digestible. Until now, the most common dietary source of C12:0 was coconut oil. The high content of lauric acid (C12:0) can be considered as a factor increasing the immune response of animals. This compound also shows antimicrobial activity against pathogenic bacteria such as *E. coli*, *Salmonella* sp., and *Clostridium perfingens* [30]. BSF larvae is particularly rich in C12:0 acid, in which it constitutes 28.6% of the total fatty acids. Lauric acid (C12:0) has been shown to account for approximately 40% of the total fatty acids in BSF larvae [31]. This value is much higher than what can be found in conventional protein sources, such as chicken (1.80% of fatty acids), beef (0.07% of fatty acids) and pork (0.13% of fatty acids). Research conducted, among other reasons, in order to determine the effect of nutrition on the fatty acid composition of abdominal fat in poultry showed that dietary BSFL oil significantly increased the amount of branched-chain fatty acids in broilers. The fatty acid composition of abdominal fat was influenced by dietary fat sources. In particular, chickens fed diets containing BSFL oil were characterized by a higher content of SFA, especially lauric acid, compared to chickens fed with corn oil [32].

The research of Jayanegara et al. [33] showed that mealworm oil and cricket oil were similar in terms of the main fatty acid profiles. These findings suggest that the oils from these insects are particularly rich in monounsaturated fatty acids (MUFA). Insects are especially rich in oleic acid (C18:1 n-9), and its best source is domestic cricket (44.60% of fatty acids), which contains twice as much of this acid as, e.g., pork (23.65% of fatty acids) (**Table 3**). An adequate supply of this acid is important because it determines the oxidative stability of a given fat.

There are two different groups of polyunsaturated fatty acids (PUFAs): the ‘n-3-fatty acids‘ and ‘n-6-fatty acids’. Both are considered as essential fatty acids (EFA) because they cannot be synthesized by monogastric animals/humans and therefore must be obtained from the diet or supplementation. They have the greatest impact on the nutritional value of fat, mainly due to linoleic acid (LA, C18:2 n-6) and α-linolenic acid (ALA, C18:3 n-3), which form the essential fatty acids (EFA). The proportions of polyunsaturated fatty acids (PUFA) are high in mealworm larvae (25.10% of fatty acids) and house crickets (29.50% of fatty acids).

It is worth remembering that an adequate supply of antioxidants, including vitamin E, is important in the diet of animals, the demand for which increases with the supply of PUFAs. The results of the studies by Cheseto et al. [34] found that insect oils are richer in fatty acids, flavonoids, and vitamin E than vegetable oils. The results also suggest that the presence of fatty acids and higher levels of flavonoids and vitamin E in insects in greater amounts than in vegetable oils could serve as potential suitable biomarkers for their nutritional value for use as food ingredients. Of the n-6 fatty acids, the concentrations of linoleic acid (LA) determined in all the oils in that study were higher than those found in conventional meat products such as fish, beef, and chicken [35].

All insect oils are generally low in n-3 fatty acids [33]. In the body, ALA, as a result of successive desaturation and elongation processes, is metabolized into long-chain polyunsaturated derivatives of eicosapentaenoic acid (EPA; C20:5 n-3) and docosahexaenoic acid (DHA; C22:6 n-3). They play an important role in preventing or alleviating lesions, including inflammatory diseases. The main source of the EPA and DHA in the diet are algae and fish that feed on algae. Among insects, BSF larvae are the most significant source of EPA (1.70% of fatty acids) and DHA (0.70% of fatty acids).

Interestingly, research by Seo et al. [36] shows that food with BSFL can be successfully used in the nutrition of older dogs. Moreover, feeding with BSFL for 12 weeks lowered the serum cholesterol levels of the dogs at the end of the experiment.

As shown in **Table 3**, insects have comparable fatty acid contents to conventional animal sources, which proves that they can also be a good alternative in terms of their fatty acid content.

Table 3. Fatty acid composition (% of total fatty acids) in selected insect species and conventional protein sources.

Fatty Acids	Mealworm Larvae [37]	House Cricket Imago [12]	Black Soldier Fly Larvae [29]	Chicken (Breast) [38]	Beef (Intercostal Muscle) [39]	Pork (*Longissimus dorsi muscle*) [17]
C10:0	0.02	0.03	<0.5	0.73	0.05	0.16
C12:0	0.37	0.18	28.6	1.80	0.07	0.13
C14:0	3.13	0.86	6.1	3.62	3.15	1.67
C16:0	19.50	31.20	12.6	23.99	30.39	26.22
C18:1, n-9	44.60	25.80	25.10	31.81	41.02	23.65
C18:2, n-6	24.00	27.90	12.50	16.62	2.51	23.43
C18:3, n-3	0.91	1.39	3.40	0.89	0.23	0.45
C20:5, n-3	0.13	0.12	1.70	0.17	0.05	0.21
C22:6, n-3	0.07	0.00	0.70	0.00	0.05	0.44
SFA	28.20	42.30	49.60	43.14	49.92	39.95
UFA	71.60	56.30	50.50	57.16	50.08	60.04
MUFA	46.50	26.80	31.80	36.96	46.10	24.49
PUFA	25.10	29.50	18.70	20.27	3.98	35.55

3. Minerals

Insects, apart from being rich in protein and fat, are also an important source of minerals. The insects' internal soft tissues are covered with a hard protective layer known as the exoskeleton. It performs several functions in the bodies of insects, acts as a protective shell, and is designed to facilitate metamorphosis. The exoskeleton is rich in chitin and is excreted from the body during metamorphosis. Insects have a protein-rich exoskeleton rather than a calcified skeleton, so the mineral content of most insects is relatively low [40]. While the availability of phosphorus in plant sources is low, nearly 100% of phosphorus is found in insects. Mostly, insects are good sources of trace elements, including iron, zinc, copper, manganese, and selenium. Finke [40] found, however, that the mineral composition is mainly a reflection of the material that insects were fed. Common animal protein sources have an excess of phosphorus over calcium.

While the exoskeleton of most insects is primarily composed of protein and chitin, black solder fly larvae [41] have a calcified exoskeleton in which calcium and other minerals are incorporated into the cuticle. Therefore, they can contain high levels of calcium [42]. As reported by Liu et al. [43] the content of calcium reaches up to 2900 mg/100 g in mature larvae, while the content of calcium in the DM can be significantly higher in the E-prepupa stage (3000 mg/100 g) than in the mature larval stage. In the same studies, the phosphorus content in the E-prepupa stage (620 mg/100 g) almost doubled that in mature larvae (350 mg/100 g), and the calcium-to-phosphorus ratio was 4.84–8.28:1, respectively.

As reported by Udomsil et al. [12], in cricket the calcium content can reach up to 149 mg/100 g, while the phosphorus content can reach up to 899 mg/100 g. The mineral composition in general probably largely reflects the food sources for insects, both those that are present in the gastrointestinal tract and those that are incorporated into the insect's body as a result of the food it consumed. For example, the calcium contents of wax worms, house crickets, mealworms, and silkworms can all be increased 5- to 20-fold when fed a high-calcium diet. This increase in calcium appears to be solely due to the residual food in the gastrointestinal tract, with little of the calcium being incorporated into the insect's body [44].

Table 4 shows mineral composition of selected insect species in comparison with common livestock species.

Table 4. Mineral composition (mg/100 g) in selected insect species and common livestock species.

Item	Black Soldier Fly (Larvae) [41][43]	House Cricket (Adult) [12]	Mealworm (Larvae) [45][46]	Duck (Breast) [47][48]	Pork (Semimembranosus Muscle) [49]	Chicken (Muscle) [50]	Lamb (Lean Lamb) [51]	Beef (Intercostal Muscles) [51]
				Macroelements				
Ca	2900	140.3	43.5	8.2	11.8	11.1	16.1	6.1
P	350	842.4	706	205.7	225	134.4	195	182
Ca:P	8:1	1:6	1:16	1:25	1:19	1:12	1:12	1:29
K	57	365.3	947.9	227.2	280	206.4	303	266
Mg	24.5	127.9	202.7	21.4	26.6	17.9	23.5	21.2
Na	100	95	364.5	101.4	59.8	78.3	68.3	39.8
				Microelements				
Zn	61.4	18.4	10.4	1.2	2.7	1.1	4.2	5.2
Fe	200	8.2	6.7	3.3	1.4	1.4	1.8	2.6
Mn	2	4.1	0.5	0.4	0.02	0.01	10.7	11.9
Cu	0.1	4.6	1.3	0.2	0.3	0.06	0.1	0.1

Insects are a good source of Ca and P, which are important in the growth of young animals, and as shown in **Table 4**, the meat species have an unfavorable Ca to P ratio, i.e., an excess of P in relation to Ca. Excess P is a factor limiting Ca absorption, which leads to kidney disease. The meat diet for dogs has a precise tendency to risk this nutritional imbalance.

4. Chitin

Chitin is contained in the procuticle, the innermost layer of the epidermis, which in turn is the outermost layer of the insect exoskeleton [52].

The results of research by Henriques et al. [53] show that the chitin content in insects can vary largely in a range of 8–4600 micrograms of chitin per insect, depending on species, sex, and instar. The chitin content increases with the development of the larvae into further stages [54].

Chitin in insects is a problem due to its indigestion in humans and animals due to the lack of chitinase. Therefore, it is recommended to at least partially remove the chitin present in insects in order to increase their nutritional value. However, the removed chitin can provide an advantage when used in a low concentration as a feed additive, as the substance has antimicrobial properties against a wide range of microbial species. Its biological activity can be further enhanced by converting it into chitosan in a deacetylation procedure [55]. About half of the crude fiber analyte may be chitin, but the N-acetylglucosamine polymer contributes little to the crude protein value.

Future research should investigate whether this problem can be solved by consuming insects along with fruits such as *Bromeliaceae* and *Caricaceae*, which contain enzymes with chitinase-like activity [56].

5. Health Properties

In addition, insects are a source of antimicrobial peptides (AMPs) and lauric acid, which may be factors that improve the immune response and have a positive effect on the breakdown of the digestive tract microbiome [57][58][59][60].

Protein derivatives from BSF larvae (proteins and protein hydrolysates) contain a significant amount of low-molecular-weight peptides with antioxidant potential. The Mouithys-Mickalad et al. [61] study investigated the in vitro antioxidant potential of commercial BSF proteins and protein hydrolysates for radical scavenging activity, the modulation of myeloperoxidase activity, and the modulation of the neutrophil response. It has been found that BSF protein derivatives can effectively protect against the cell damage resulting from neutrophil and myeloperoxidase activity. The results of this study indicate that BSF protein derivatives can potentially be included in pet food formulas as health-promoting ingredients [61]. Edible insects and invertebrates are a potential source of antioxidant components, the effectiveness of which depends on their taxonomy and eating habits. More evidence is needed to understand whether the practice of eating insects and invertebrates may contribute to modulating oxidative stress in humans. The results show that the water-soluble extracts of grasshoppers, silkworms, and crickets show high antioxidant capacity (Trolox equivalent antioxidant capacity, TEAC) values, five times higher than fresh orange juice [62].

There is a low probability of a dog's allergy to insect protein in food because insect protein is not very common in the nutrition of dogs. Insects, even when they are present in pet food, still have a small percentage due to the high protein content. Therefore, insect-based foods are increasingly used in the nutrition of dogs suffering from food allergies to conventional protein sources, such as poultry or beef. In case of dogs with food allergies, it is necessary to provide adequate food to minimize clinical symptoms. A risk of commercial pet food is possible contamination with foreign protein. Therefore, food containing hydrolyzed protein is not always suitable. For example, some dogs with a food intolerance to chicken protein will still react to hydrolyzed chicken liver, depending on the strength and type of the immune response. Therefore, for dogs with food allergies, it is worth introducing insect pet food into their diet [63].

However, with insects being used more extensively in the future as a protein source in companion animal food, further research into their allergenic and cross-reaction potential is required [64].

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