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AUTORI:

M. De Marco[a*], S. Martínez[b*], F. Hernandez[b], J. Madrid[b], F. Gai[c], L. Rotolo[d], M. Belforti[d], D. Bergero[a], H. Katz[e], S. Dabbou[d], A. Kovitvadhi[d], I. Zoccarato[d], L. Gasco[c,d*], A. Schiavone[a*†]

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M. De Marco[a*], S. Martínez[b*], F. Hernandez[b], J. Madrid[b], F. Gai[c], L. Rotolo[d], M. Belforti[d], D. Bergero[a], H. Katz[e], S. Dabbou[d], A. Kovitvadhi[d], I. Zoccarato[d], L. Gasco[c,d*], A. Schiavone[a*†]

[a] Department of Veterinary Sciences, University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, Italy;

[b] Department of Animal Production, University of Murcia, Campus de Espinardo, 30071 Murcia, Spain;

[c] Institute of Science of Food Production, National Research Council, Largo Paolo Braccini 2, 10095 Grugliasco, Italy;

[d] Department of Agricultural, Forest and Food Sciences (DISAFA), University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, Italy;

[e] Hermetia Baruth GmbH, An der Birkenpfuhlheide 10, 15837 Baruth/Mark, Germany.

*contributed equally

[†]Corresponding author: Prof. Achille Schiavone, Department of Veterinary Sciences, University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, Italy. Tel. +39 011 6709208 - Fax: +39 011 2369208. E-mail: achille.schiavone@unito.it

Email addresses:
MDM: michele.demarco@unito.it
SMM: silviamm@um.es
FH: nutri@um.es
JM: alimen@um.es
FG: francesco.gai@ispa.cnr.it
LR: luca.rotolo@unito.it
MB: marco.belforti@unito.it
DB: domenico.bergero@unito.it
HK: h.katz@hermetia.de
SD: sihem.dabbou@yahoo.fr
AK: attawitthai@hotmail.com
IZ: ivo.zoccarato@unito.it
LG: laura.gasco@unito.it
AS: achille.schiavone@unito.it

Abstract

The aim of this study was to determine the apparent digestibility coefficients of the total tract (CTTAD) of nutrients and the apparent metabolisable energy (AME and AMEn) of two insect larval meals (*Tenebrio molitor* and *Hermetia illucens*) for broiler chickens. The amino acid (AA) apparent ileal digestibility coefficients (AIDC) was also determined. The experimental diets were: a basal diet and two diets prepared by substituting 250 g/kg (w/w) of the basal diet with *Tenebrio molitor* meal (TM) or *Hermetia illucens* meal (HI). No statistical difference was found between the two insect larval meals for the CTTAD of the nutrients, except for the CTTAD for ether extract ($P<0.001$) where the HI meal proved to be more digestible than the TM meal (0.99 and 0.88, respectively). The CTTAD for DM was 0.60 and 0.53; 0.66 and 0.66 for OM; 0.60 and 0.51 for CP, whereas it was 0.64 and 0.69 for GE, for TM and HI, respectively. No difference was observed between TM and HI ($P>0.05$) for AME or AMEn (AME = 16.86 and 17.38 MJ/kg DM, respectively; AMEn = 16.02 and 16.60 MJ/kg DM, respectively). The average AIDC of the 17 analyzed AAs was higher ($P<0.001$) in TM than in HI (0.86 and 0.68, respectively) because the AIDC of isoluecine, lysine, methionine, phenylalanine, valine, alanine, aspartic acid, glycine, glutamic acid and tyrosine was higher ($P<0.05$) in TM than in HI. Overall, the present results have shown that TM and HI meals are excellent sources of AME for broilers and a valuable source of digestible AA, particularly as far as TM meal is concerned.

Keywords: Insect larval meal; Amino acid; Metabolisable energy; Apparent digestibility; Broiler chicken.

1. Introduction

Soybean meal is the most frequently used protein source in diet formulations for broiler chickens. However, in recent years, the increasing price of this raw material has become a critical aspect for the economic sustainability of the poultry meat industry, particularly in some developing countries (Chadd, 2007). The evaluation of alternative ingredients that are affordable and locally available as substitutes for conventional protein meals is therefore required.

The use of insects as an alternative source of protein in animal feeds is becoming more globally appealing. Invertebrates constitute a raw material that is included in the European Union Feed Material Register, and although they are currently authorized only for fish and pets, insect-derived feeds could also represent a suitable ingredient for feed manufacturing for pigs and poultry in the near future. This aspect could be a first step towards combating the severe challenges of the global capacity to supply sufficient food. In this context, insects have captured the interest as a complementary source of protein, AA, fat, carbohydrates, vitamins and trace elements (Chen et al., 2009). Number of authors have reported interesting results about the suitability of different types of insect meal as diet ingredients for livestock animals (pigs, poultry, different fish species), (Veldkamp et al., 2012; Van Huis, 2013; Makkar et al., 2014; Henry et al., 2015).

Among the different insect species, Black soldier fly (*Hermetica illucens,* HI) and Yellow mealworm (*Tenebrio molitor*, TM) show interesting characteristics, because they can valorize organic waste producing proteins, fats and energy, which are exploitable for feed (Zheng et al., 2013). These two insects have the potential to recycle lost nutrients by incorporating the residual AA and fatty acids of manure and organic wastes into their biomass. This resulting biomass is usually high in protein and fat, which makes it interesting for incorporation into animal feeds (Makkar et al., 2014; Henry et al., 2015). The meal derived from HI larvae is a high-value feed source that is rich in protein and fat. It has been reported that the crude protein content ranges between 350 and 570 g/kg (Veldkamp et al., 2012). The amount of fat is extremely variable and depends on the type of diet: values of 150-250 g/kg have been reported for larvae fed on poultry manure, 280 g/kg for those fed on swine manure, 350 g/kg for cattle manure and 420–490 g/kg for oil-rich food waste (Makkar et al., 2014). As a component of a complete diet, HI larvae have been found to improve the growth rate of chickens (Hale, 1973; Oluokun, 2000), swine (Newton et al., 1977), and several commercial fish species (Newton et al., 2005; St-Hilaire et al., 2007). The larvae of TM are easy to breed, and they grow easily on dried and cooked waste materials from fruit, vegetables and cereals in various combinations. For this reason, they are already produced industrially as feeds for pets and zoo animals, including birds, reptiles, small mammals, amphibians and fish (Makkar et al., 2014). The meal derived from TM larvae has a high content of crude protein, which ranges between 440 and 690 g/kg, and a fat content that varies between 230 and 470 g/kg (Veldkamp et al., 2012). In livestock, TM has been shown to be an acceptable protein source for African catfish (Ng et al., 2001) and for broiler chickens (Ramos-Elorduy et al., 2002).

The potential of insects for use as livestock feeds may also have a positive environmental impact: in fact, their production involves less energy, land area utilization and environmental footprints (Pimentel et al., 1975; Makkar et al., 2014). All this evidence indicates that the use of insects in feed formulations could be an opportunity to make the broiler chicken supply-chain more sustainable than it currently is. Moreover, it is also important to emphasize that insects are a part of the natural diet of poultry. Nevertheless, at present, information about insect digestibility in poultry is scarce, and this limits the design of adequate insect-based diets for broilers.

For this reason, this study was undertaken to evaluate the apparent nutrient digestibility, the apparent ileal AA digestibility and the apparent metabolisable energy of HI and TM meals fed to broiler chickens.

2. Materials and methods

The study was performed at the poultry facility of the Department of Veterinary Sciences of the University of Turin (Italy). The experimental protocol was designed according to the guidelines of the current European and Italian laws on the care and use of experimental animals (European directive 86 609/EEC, put into law in Italy with D.L. 116/92).

2.1 Ingredients

Two insect larval meals, namely, TM meal and HI meal, were studied. The TM meal was obtained from Gaobeidian Shannong Biology Co. Ltd., Gaobeidian, Hebei province (China), while the HI meal was obtained from Hermetia Futtermittel GbR, Baruth/Mark (Germany). The TM and HI are omnivorous and were fed cereal by-products. The larvae weight at collection ranged between 150 and 220 mg. The collected larvae were dried for 20 h in an oven at low temperature (60 °C) and grinded to a meal. Both insect larval meals were full-fat and produced from the larval stage of insects. Before the digestibility trial, representative samples of the two insect larval meals were analyzed, in triplicate, for dry matter (DM), crude protein (CP), ether extract (EE), ash, gross energy (GE) and AA composition.

2.2 Pre-experimental period

One-day-old male broiler chickens (Ross 708) were raised in a floor pen till d 19 and fed a commercial broiler starter diet (227 g/kg of CP; 13.4 MJ/kg metabolisable energy). All the birds were vaccinated at hatching against Newcastle disease, Marek disease, infectious bronchitis and coccidiosis. At d 19, ninety birds of uniform body weight were chosen and homogeneously distributed over thirty cages (3 birds *per* cage). The cages (60 × 60 cm) were placed in an insulated room with devices to control the temperature, light and humidity. Each cage had a linear feeder at the front and a nipple drinker at the back. Health status and mortality were monitored daily throughout the whole experimental period. The birds were fed a commercial finisher broiler diet (190 g/kg of CP; 13.6 MJ/kg metabolisable energy) until the assay diets were introduced on d 26. The feeds and water were provided *ad libitum*.

2.3 Digestibility trial

On day 26, the cages were randomly assigned to three assay diets (10 replicates *per* diet). A basal diet, based on corn and soybean meal, was formulated (Table 1), and two experimental diets were subsequently formulated by substituting 250 g/kg (w/w) of the basal diet with two insect larval meals. Celite® (Celite Corp., Lompoc, CA, USA), was added to each diet at 20 g/kg as an acid-insoluble ash (AIA) digestibility marker in order to calculate the digestibility of the AAs. The diet adaptation period lasted 6 d. Total tract digestibility was evaluated *per* cage, through the total collection of excreta method, from day 32 for four consecutive days. Fresh feeds and water were available *ad libitum*. Feed intake *per* cage was measured throughout the experiment and the excreta was sampled daily during the test period. The total fresh excreta *per* cage was weighed daily, frozen at −20°C and lyophilized. 4 days excreta *per* cage was pooled for further analysis.

On day 35, all the birds were euthanized by the intravenous injection of sodium pentobarbital, and the content of the lower half of the ileum was collected, according to the procedures described by Ravindran et al. (2005). The ileum was defined as that portion of small intestine extending from Meckel's diverticulum to a point 40 mm proximal to the ileo-cecal junction. The ileal content for each cage was pooled, lyophilized, ground to pass through a 0.5-mm sieve, and stored at −20°C in airtight containers until laboratory analyses were conducted.

2.4 Chemical analysis

Both the dried excreta and diet samples were subsequently ground to pass through a 0.5-mm sieve and stored in airtight plastic containers for DM, ash, CP (AOAC, 2005; procedure numbers of 930.15, 924.05, 984.13, respectively), EE (Folch et al., 1957), GE (IKA C7000, Staufen, Germany) and AIA (Vogtmann et al., 1975) analyses. The uric acid (UA) content in the excreta samples was determined spectrophotometrically according to the Terpstra and De Hart (1974) method. The CP amount of excreta was calculated as follows: CP = (total nitrogen – UA-nitrogen) × 6.25.

The apparent digestibility trial was performed, using the total excreta collection method, to determine the apparent digestibility coefficients of the total tract (CTTAD) for DM, organic matter (OM), CP, EE, GE, and the apparent metabolisable energy (AME).

Ileal content samples from each cage were analyzed for DM, AIA concentration and AA. In order to perform the AA determination, samples of the diets, ileal digesta and insect larval meals were prepared using a 22 h hydrolysis step in 6 HCl at 112ºC under a nitrogen atmosphere. Performic acid oxidation occurred prior to acid hydrolysis for methionine and cystine. The AA in hydrolysate was determined by means of HPLC after postcolumn derivatization, according to the procedure described by Madrid et al. (2013). Tryptophan was not determined.

2.5 Calculations

Two different methods were used for the TM meal and the HI meal to calculate the CTTAD of the dietary nutrients, AME and the apparent ileal digestibility coefficient (AIDC) of the AAs (Ravindran et al., 2005; Nalle et al., 2012).

The CTTAD of the dietary nutrients of the insect larval meals were calculated as follows:

$$\text{CTTAD X}_{\text{diet}} = [(\text{total X ingested} - \text{total X excreted})/\text{total X ingested}]$$

$$\text{CTTAD X}_{\text{insect larval meal}} = [\text{CTTAD X of insect larval meal diet} - (\text{CTTAD X of basal diet} \times 0.75] / 0.25$$

where X represents DM, OM, CP, EE and GE.

The AME values of the insect larval meals were calculated using the following formula with appropriate corrections made according to the differences in the DM content:

$$\text{AME}_{\text{diet}}\ (\text{MJ/kg}) = [(\text{feed intake} \times \text{GE diet}) - (\text{excreta output} \times \text{GE excreta})] / \text{Feed intake}$$

$$\text{AME}_{\text{insect larval meal}}\ (\text{MJ/kg}) = [\text{AME of insect larval meal diet} - (\text{AME basal diet} \times 0.75)] / 0.25$$

Correction for zero nitrogen (N) retention was made using a factor of 36.54 kJ *per* gram N retained in the body in order to estimate the N-corrected apparent metabolisable energy (AMEn) (Hill and Anderson, 1958). N retention was calculated using the following formula:

$$N_{\text{retention}} = [(\text{feed intake} \times \text{N diet}) - (\text{excreta output} \times \text{N excreta})]/\text{feed intake (kg)}$$

The AIDC of the AA of the insect larval meals was calculated, using AIA as the indigestible marker, as follows:

$$\text{AIDC of AAX}_{\text{diet}} = (\text{AAX/AIA})\text{d} - (\text{AAX/AIA})\text{i} / (\text{AAX/AIA})\text{d}$$

$$\text{The AIDC of AAX}_{\text{insect larval meal}} = [(\text{AIDC AAX of the insect larval meal diet} \times \text{AAX of the insect larval meal diet}) - (\text{AIDC AAX of the basal diet} \times \text{AAX of the basal diet} \times 0.75)] / (\text{AAX of the insect larval meal diet} \times 0.25).$$

where:

(AA/AIA)d = ratio of the AA and AIA concentrations in the diet;

(AA/AIA)i = ratio of the AA and AIA concentrations in the ileal digesta;

AAX : represents each AA evaluated.

2.6 Statistical analyses

The statistical analysis of the total tract digestibility coefficients, apparent metabolisable energy and apparent ileal digestibility coefficients was performed with SPSS 17 for Windows (SPSS, Inc., Chicago, IL, USA). The experimental unit was the cage. Data concerning total tract digestibility coefficients, apparent metabolisable energy and apparent ileal digestibility coefficients of the TM meal and HI meal were analyzed using Student's t-test for independent samples. Before testing for group differences, normality of the data distribution and homogeneity of variances were assessed using the Shapiro-Wilk test and the Levene test, respectively. Differences were considered to be significant at $P \leq 0.05$.

3. Results

The proximate composition and GE of the three assay diets and of the two insect larval meals are summarized in Table 2. The TM meal resulted to have a higher CP content than the HI meal (524 and 369 g/kg DM, respectively). On the contrary, the EE content of the HI meal was higher than that of the TM meal (343 and 280 g/kg DM, respectively). The GE contents of the TM and HI meals were similar (24.4 and 23.8 MJ/kg DM, respectively).

The AA compositions of the three assay diets and of the two insect larval meals are presented in Table 3. Lysine was the most abundant indispensable AA in the TM meal, whereas glutamic acid was the most abundant dispensable one. The most represented indispensable AAs in the HI meal were leucine and lysine. As in TM meal, glutamic acid was the most abundant of the dispensable AAs. Both insect larval meals were also good sources of methionine and threonine. The TM meal showed higher lysine, methionine and threonine contents than the HI meal.

The CTTAD of the nutrients, as well as the AME and AMEn of the TM and HI meals are reported in Table 4. No statistical differences were found between the tested insect larval meals for any of the CTTAD of the nutrients, except for EE ($P<0.001$), which was higher for the HI meal than the TM meal (0.99 and 0.88, respectively). The CTTAD for DM was 0.60 and 0.53; 0.66 and 0.66 for OM; 0.60 and 0.51 for CP, whereas it was 0.64 and 0.69 for GE, for TM and HI, respectively.

No difference was observed between TM and HI ($P>0.05$) for AME or AMEn. In particular, HI showed mean AME and AMEn values of 17.38 and 16.60 MJ/kg DM, respectively, while for TM, AME and AMEn they were 16.86 and 16.02 MJ/kg DM, respectively.

The determined values for the AIDC of the AAs are presented in Table 5. The AIDC of the AAs in TM ranged from 0.80 to 0.93, while in HI it ranged from 0.42 to 0.89. Overall, the AIDC of 17 AA was higher ($P<0.001$) in TM (0.86) than in HI (0.68). This reflects the significantly higher ($P<0.05$) AIDC levels of isoleucine, lysine, methionine, phenylalanine, valine, alanine, aspartic acid, glycine, glutamic acid and tyrosine in TM than in HI. Among the indispensable AAs, lysine and methionine were the AAs that showed the greatest difference between the two insect larval meals (AIDC for lysine: 0.85 and 0.46 in TM and HI, respectively, and AIDC for methionine: 0.80 and 0.42 in TM and HI, respectively).

4. Discussion

The compositional data have shown that the two insect larval meals are good sources of protein and fat. In particular, the TM meal has shown a higher CP content than soybean meal which is close to that of meat meal, however it has a higher fat content. This result indicates how this insect larval meal could be used as both a protein and an energy ingredient for feeds (Sauvant et al., 2004). The HI meal has shown a similar CP content to some plant protein sources, such as sunflower meal, lupins or faba beans, but also a higher fat content (Sauvant et al., 2004). The CP and EE determined for the TM meal was within the range reported by other researchers (Bernard et al., 1997; Ramos-Elorduy et al., 2006; Barroso et al., 2014; Sánchez-Muros et al., 2014). The fat content reported in the HI meal was consistent with previous findings, while the protein content was slightly lower (Newton et al., 1977; Sheppard et al., 2007; Sánchez-Muros et al., 2014). This may be due to the substrate where the larvae were raised, which can influence variability in the amount of CP, EE and fatty acids composition (Makkar et al., 2014).

The AA profiles of the TM and HI meals were within the ranges reported by other authors (Ramos-Elorduy et al., 2002; St-Hilaire et al., 2007; Barroso et al., 2014; Makkar et al., 2014; Henry et al 2015). Both meals are a good source of AA as they are both rich in methionine and lysine, which content is higher than the common plant protein ingredients used in poultry feeds (Ravindran et al., 1999; 2005; Nalle et al., 2012; Barroso et al., 2014). The methionine and lysine contents in the TM meal are slightly lower than those in fish meal, but higher than those in meat meal (Ravindran et al., 1999; Sauvant et al., 2004). The methionine and lysine contents in the HI meal are in line with or slightly below those of meat meal (Ravindran et al., 1999).

In this study, no differences have been found between the TM meal and the HI meal in the CTTAD for DM, OM, CP and GE. Nevertheless, differences have been found for CTTAD of EE, where the HI meal has resulted more digestible than the TM meal. Overall, the CTTAD of the nutrients were not very high for either of the insect larval meals, except for EE. Little information is available about the CTTAD of insects in chickens, and to the best of the authors' knowledge, no studies have dealt with CTTAD for TM meal or HI meal. Consequently, a direct comparison between results is not possible. Only two studies concerning insect digestibility have been found, and both were carried out using dried housefly meal. Hwangbo et al. (2009) fed 4-week old broilers a diet with 300 g/kg dried housefly larva meal or soybean meal for 7 days and reported a very high AD coefficient of CP for housefly larvae (0.98). Pretorius (2011) tested dried housefly larva meal fed to 3-week old broiler chickens by substituting 500 g/kg (w/w) of a maize meal-based diet with insect larval meal and found a CP digestibility of 0.69. The CTTAD of nutrients found in the present digestibility trial are lower than the two above-mentioned studies, mainly with respect to those found by Hwangbo et al. (2009). It can be speculated that the chitin contained in the exoskeleton of the TM and HI larvae can negatively affect CTTAD of nutrients. In this context, Ravindran and Blair (1993) pointed out that the chitin contained in the hard outer shell of insects is difficult to digest by domestic poultry, although the high chitin content of insect meals does not appear to have detrimental effects on poultry performance.

The AME and AMEn values of the TM meal and HI meal are comparable to such high-energy vegetable ingredients as sunflower seed (Sauvant et al., 2004). The AME and AMEn values found in the present study, as well as the CTTAD of the nutrients, are not at the moment comparable with other insect larval meals, because no similar studies have been found in literature. However, the high CP and EE contents of the TM meal and HI meal make these two ingredients have high metabolisable energy values. In fact, with the exception of pure fat ingredients, such as vegetable oils and animal fats, the values of AME obtained in this study are higher than all the ingredients normally used in poultry feeds (Sauvant et al., 2004). This aspect could make these two insect larval meals attractive and functional for poultry feed formulation. As confirmation of this thesis, other studies reported how these two meals can be used to feed poultry. Hale (1973) pointed out that chickens fed a diet containing HI larva meal, as a substitute of soybean meal, showed lower feed conversion ratio than the control group.

Ramos-Elorduy et al. (2002) showed, with regards to TM meal, how dried yellow mealworms included in quantities of up to 100 g/kg in a broiler starter diet based on sorghum and soybean meal could be used without any negative effects on either the performances or palatability. In another study, it was noted that TM could replace fishmeal in laying hen diets and a 2.4% higher egg-laying ratio than that obtained with good quality feed could be obtained (Wang et al., 1996).

In the present study, differences in the AIDC of the AAs have been found between the TM and HI meal. The AIDC of 17 AA in the TM meal was higher and showed fewer variations than in the HI meal. Threonine (0.80) and methionine (0.80) for

TM, and methionine (0.42) and isoleucine (0.45) for HI were the least digested indispensable AAs, while the most digestible indispensable AAs were phenylalanine (0.91) and arginine (0.90) in the TM meal, and arginine (0.83) and histidine (0.81) in the HI meal. Moreover, it should be noted that the AIDC of all the indispensable AAs in TM was greater than 0.80. It is surprising low digestibility shown in HM for some indispensable amino acids as methionine and isoleucine, which may be inherent to the raw material or due to technical processing for obtain this meal, which is unknown to us. To the authors’ knowledge, no studies on the AIDC of AAs in TM or HI meal in broilers have been conducted. For this reason, it is not possible to make a comparison of the values obtained in the present study with published data. However, it has been postulated that insect larval meals could be used in poultry feeding to replace protein sources such as soybean meal (Ramos-Elorduy et al., 2002; Veldkamp et al., 2012; Makkar et al., 2014). In this sense, the average AIDC of the indispensable AAs in TM coincides with the findings of Valencia et al. (2009), Ravindran et al. (2005) and Huang et al. (2006) in 21, 42 and 49 day old broilers, respectively. It is worth noting that both the concentration and the AIDC of lysine in the TM meal were similar to that of the soybean meal analyzed in the above studies (Ravindran et al., 2005; Huang et al., 2006, 2007), although the AIDC for methionine was lower in the TM meal than in the soybean meal. However, the concentration of methionine in the TM meal was higher than that of soybean meal, and TM has therefore resulted to be a good source of this AA. Moreover, when the AIDC of the indispensable AAs in TM was compared with other plant protein sources (pea protein concentrate, full-fat soya bean and sunflower meal), it was interesting to observe that the AIDCs were higher in the TM meal than in the above-reported protein sources for most of the AAs (Ravindran et al., 2005; Valencia et al., 2009). As far as animal protein sources are concerned, it was noted that AIDC was similar or slightly higher in the TM meal than in the fish meal for most of the AAs (Ravindran et al., 2005), although the AA content was lower in TM. The average AIDC of the dispensable AAs calculated in TM was higher than in the soybean meal and the other protein sources analyzed in the above studies (Ravindran et al., 2005; Huang et al., 2006; 2007; Valencia et al., 2009). In general, the AIDC of AAs results of the TM meal can be considered interesting. Consequently, it is reasonable to consider TM meal as an appealing protein source for broiler feeds. As far as HI meal is concerned, the average results of AIDC for the indispensable and dispensable AAs were lower than those obtained for the soybean meal and other protein sources examined by the previous authors (Ravindran et al., 2005; Huang et al., 2006, 2007; Valencia et al., 2009).

5. Conclusion

Many authors have pointed out how there is a need for the evaluation of the nutrient digestibility of processed insects as a feed ingredient. Our study have shown that TM and HI meals are valuable sources of AME and digestible AA. This study has provided updated and never before determined nutritional values of TM meal and HI meal, which could be two potential future ingredients for use in the formulation of broiler feeds. The acquired knowledge of AME and AMEn will be useful for nutritionists and feed companies to obtain better formulate innovative poultry feeds. Looking to the future, the next foremost gamble will be to evaluate the point of view of the European consumers in respect of the use of insects as a livestock feed. Nowadays, little is known on the insects food safety side and this can be of critical importance to meet society's approval, especially if people are not accustomed to eating insects, also indirectly. Legislative issues will also have to be discussed and resolved.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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Table 1

Composition (g/kg as fed) of the basal diet.

Ingredients	
Maize meal	580.0
Soybean meal	343.7
Soybean oil	45.0
Dicalcium phosphate	12.4
Calcium carbonate	11.2
Sodium chloride	2.2
Sodium bicarbonate	1.5
Trace mineral-vitamin premix[1]	4.0
Calculated analysis	
AME, MJ kg^{-1}	12.2
Crude Protein	201
Methionine	4.0
Lysine	10.9
Methionine + Cysteine	6.1
Threonine	7.8
Calcium	8.7
Phosphorous	5.7

[1] Mineral-vitamin premix (Final B Prisma, IZA SRL), given values are supplied per kg diet: 2.500.000 IU of vitamin A; 1.000.000 IU of vitamin D3; 7.000 IU of vitamin E; 700 mg of vitamin K; 400 mg of vitamin B1; 800 mg of vitamin B2; 400 mg of vitamin B6; 4 mg of vitamin B12; 30 mg of biotin; 3.111 mg of Ca pantothenate acid; 100 mg of folic acid; 15.000 mg of vitamin C; 5.600 mg of vitamin B3; 10.500 mg of Zn, 10.920 mg of Fe; 9.960 mg of Mn; 3.850 mg of Cu; 137 mg of I; 70 mg of Se.

Table 2

Analyzed chemical composition of the three experimental diets and of the two insect larval meals.

	Basal diet	*Tenebrio molitor* diet	*Hermetia illucens* diet	*Tenebrio molitor* (TM)	*Hermetia illucens* (HI)
Dry matter (g/kg diet)	903	914	917	948	957
Organic matter (g/kg DM)	830	850	833	912	827
Crude protein (g/kg DM)	198	270	235	524	369
Ether extract (g/kg DM)	65.7	107	121	280	343
Gross Energy (MJ/kg DM)	17.0	18.8	18.6	24.4	23.8

Table 3

Amino acid concentration (g/kg DM) of the three experimental diets and of the two insect larval meals.

	Basal diet	*Tenebrio molitor* diet	*Hermetia illucens* diet	*Tenebrio molitor* (TM)	*Hermetia illucens* (HI)
Indispensable amino acids					
Arginine	16.6	19.3	18.2	28.0	19.4
Histidine	7.69	9.92	9.09	16.8	11.3
Isoleucine	9.74	12.4	10.4	22.1	17.2
Leucine	17.8	20.4	19.4	31.5	24.0
Lysine	9.84	15.5	11.2	35.9	22.3
Methionine	4.86	6.24	5.48	10.1	9.05
Phenylalanine	14.0	15.3	14.1	18.8	14.4
Threonine	9.54	11.6	11.3	18.5	15.2
Valine	9.80	13.7	12.0	28.2	22.0
Dispensable amino acids					
Alanine	7.01	14.8	13.0	38.9	30.3
Aspartic acid	17.2	23.2	19.7	43.7	32.2
Cysteine	4.56	6.83	6.98	12.5	13.8
Glycine	10.8	13.8	12.9	22.1	19.1
Glutamic acid	30.7	37.4	34.4	62.9	38.5
Proline	13.4	18.1	20.0	34.3	37.3
Serine	11.9	14.7	14.1	22.7	18.4
Tyrosine	9.71	15.0	10.8	32.8	21.6

Table 4

Apparent digestibility coefficients of the total tract (CTTAD) of the nutrients, AME and AMEn of insect larval meals for broilers[1].

	Tenebrio molitor (TM)	*Hermetia illucens* (HI)	SEM	P
DM	0.60	0.53	0.02	0.20
OM	0.66	0.66	0.02	0.87
CP	0.60	0.51	0.03	0.23
EE	0.88	0.99	0.02	0.00
GE	0.64	0.69	0.02	0.23
AME (MJ/kg DM)	16.86	17.38	0.47	0.59
AMEn (MJ/kg DM)	16.02	16.60	0.46	0.54

DM = dry matter; OM = organic matter; CP = crude protein; EE = ether extract; GE = gross energy; AME = apparent metabolisable energy; AMEn = nitrogen-corrected apparent metabolisable.

[1] Each value represents the mean of ten replicates (three birds *per* replicate).

Table 5

Apparent ileal digestibility coefficients (AIDC) of amino acid of the two insect larval meals for broilers[1].

	Tenebrio molitor (TM)	*Hermetia illucens* (HI)	SEM	P
Indispensable amino acids				
Arginine	0.90	0.83	0.03	0.23
Histidine	0.85	0.81	0.02	0.44
Isoleucine	0.82	0.45	0.05	0.00
Leucine	0.82	0.76	0.03	0.24
Lysine	0.85	0.46	0.05	0.00
Methionine	0.80	0.42	0.05	0.00
Phenylalanine	0.91	0.63	0.04	0.00
Threonine	0.80	0.75	0.03	0.46
Valine	0.82	0.62	0.03	0.00
Mean	0.84	0.64	0.03	0.00
Dispensable amino acids				
Alanine	0.93	0.86	0.02	0.04
Aspartic acid	0.89	0.61	0.04	0.00
Cysteine	0.84	0.82	0.02	0.52
Glycine	0.89	0.67	0.04	0.00
Glutamic acid	0.88	0.74	0.03	0.00
Proline	0.84	0.89	0.01	0.06
Serine	0.89	0.82	0.03	0.21
Tyrosine	0.83	0.43	0.05	0.00
Mean	0.87	0.73	0.02	0.00
Overall mean[2]	0.86	0.68	0.03	0.00

[1] Each value represents the mean of ten replicates (three birds *per* replicate).

[2] Average digestibility of 17 amino acids.