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THE POTENTIAL OF MEALWORM (*Tenebrio molitor*) AND FIELD CRICKET (*Gryllus assimilis*) AS ALTERNATIVE NUTRIENT SOURCES IN RUMINANT FEED PRODUCTION

Husna Fasihah[1], Hamdan Ahmad[1], Ibrahim Shehu Kura[1,3], Intan Haslina Ishak[1] & Hasber Salim[1,2*]
[1]School of Biological Sciences,
Universiti Sains Malaysia,
11800 Minden, Malaysia
[2]Vector Control Research Unit,
Universiti Sains Malaysia,
11800 Minden, Malaysia
[3]Department of Biology,
College of Education,
PMB 39, Niger, Nigeria
*Corresponding author: *hasbersalim@usm.my*

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ABSTRACT

Since the world population reaches nine billion by 2050, both humans and animals may experience further malnourishment and starvation. It is crucial to comprehend the current state of food waste and reuse. The food wastes were used in this study as media in rearing process of two type of insects (mealworm and cricket). The study was carried out to evaluate the potential of mealworm (*Tenebrio molitor*) and field cricket (*Gryllus assimilis*) as a supplement diet to produce high-quality feed for ruminant animals in Malaysia. Rearing procedures were carried out using two different media viz; conventional basic diet (CBD) and alternative feed (AF) as insects feed. The nutritional elements (i.e., dry matter, crude protein, metabolizable energy, ether extract, crude fibre, acid detergent fibre, organic matter digestibility and total digestible nutrient) in four insect stages (larvae and pupae of mealworm, nymphs and adults of cricket) were assessed proximately using standard techniques which is the Kjeldhal method for protein, Soxhlet apparatus for crude fat analysis, crude fibre, and van soest acid detergent fibre procedures. The results revealed that, nutritional elements in the insect stages of development in two different diets were very significant and proved mealworm that consume alternative feed from food waste is the best feed. Mealworm is the best group because of the high main nutritional element was observed in CP and EE (42.90±1.17 and 32.96±0.84, respectively). While, the low in indigestible nutrient i.e., CF and ADF with values of 4.14±0.31 and 18.32±0.56. However, these values significantly differed (P<0.05) from most of the groups. Therefore, the findings suggested that these insects contain a promising level of the required nutrient compositions particularly mealworm which highly demonstrated potential ingredients to be formulated in high quality animal feed.

Keywords: Insects, cricket, mealworm, ruminant feed, Conventional Basic Diet (CBD), Alternative Feed (AF), proximate analysis.

ABSTRAK

Disebabkan populasi dunia yang mencecah sembilan billion pada 2050, manusia dan haiwan kedua-duanya akan mengalami kekurangan nutrisi dan kebuluran. Ianya amat penting untuk ditelusuri keadaan sisa dan penggunaan semula bahan makanan pada masa sekarang. Sisa makanan digunakan di dalam kajian ini sebagai bahan media untuk menternak dua jenis serangga iaitu (larva kumbang dan cengkerik). Kajian ini dijalankan bagi mengenalpasti potensi larva Kumbang Beras (*Tenebrio molitor*) dan Cengkerik Padang (*Gryllus assimilis*) sebagai diet tambahan untuk menghasilkan makanan yang berkualiti tinggi bagi ruminan di Malaysia. Kaedah penternakan dijalankan dengan menggunakan dua jenis media iaitu; makanan asas kovensional (CBD) dan makanan alternatif (AF) sebagai makanan bagi serangga. Elemen nutrisi (bahan kering, protein kasar, tenaga boleh metabolisme, lemak kasar, serat kasar, serat asid detergen, bahan organik keterhadaman dan jumlah nutrien boleh cerna) di dalam empat peringkat serangga (larva dan pupa bagi ulat kumbang beras, nimfa dan cengkerik dewasa) dinilai menggunakan teknik piawai iaitu kaedah Kjeldhal untuk protein, kaedah Soxhlet untuk analisis lemak kasar, serat kasar dan prosedur fiber asid detergen van soest. Hasil kajian menunjukkan elemen makanan bagi peringkat serangga yang berlainan peringkat tumbesaran di dalam dua diet yang berbeza adalah sangat signifikan dan menunjukkan ulat kumbang beras yang memakan makanan alternatif dari sisa makanan adalah sangat bagus. Ulat kumbang beras adalah kumpulan yang terbaik kerana elemen makanan asas penting yang paling tinggi dilihat pada CP dan EE (42.90±1.17 and 32.96±0.84 setiap satu). Manakala, yang paling rendah direkodkan bagi nutrien kurang hadam, CF and ADF pada nilai 4.14±0.31 and 18.32±0.56. Nilai-nilai ini adalah signifikan (P<0.05) dari kebanyakkan kumpulan lain. Oleh itu, cadangan hasil kajian adalah serangga khususnya ulat kumbang beras mengandungi tahap komposisi nutrien yang berpotensi sebagai bahan yang dapat diformulasikan kepada makanan haiwan yang berkualiti.

Kata kunci: Serangga, cengkerik, ulat kumbang beras, makanan ruminan, Makanan Asas Konvensional (CBD), Makanan Alternatif (AF), analisis proksimat.

INTRODUCTION

The effect of insect production is attaining an extensive amount of impact as a novel way to provide protein for animal feeding (Huis 2020). Despite the fact insects are rich in protein levels nonetheless, other analyses of nutritional elements such as fat, fibre, energy and acid detergent fibre should be done to complete feed investigation (Syamsuddin et al. 2020). Insects are animals that exist in great populations around the world and countless insect species offer nutritional content for nutritive value (Huis & Oaonincx 2017). Mealworms and cricket are the species that are potentially discovered as animal feed ingredients and there are more than a few studies that compared these two species in terms of nutrient contents (Zielińska et al. 2015). The research works by Siemianowska et al. (2013), Zielińska et al. (2015), Alexandra et al. (2020), Gabriella et al. (2022), had reported about the resemblances between this two species and compare between both types in their research. Furthermore, there are reports that discovered both of these insect species may have potential dietary values (ESFA 2015; Gabriella et al. 2022; Nowak et al. 2016). The dietary profiles of different stages between adult crickets and mealworm larvae are stable in terms of amino acids, fatty acids, and other trace elements (Zielińska et al. 2015). Hence, it is directly suggested that different phases, such as the nymph stage for crickets and pupae stage for mealworms are also possibly advantageous to be applied as well. Moreover, the other resemblances between these two species is, that they have similar structural characteristics. Irrespective of the insect species and treatments, the water binding capacity, foaming, and gelation characteristics of these two species did not alter after enzymatic hydrolysis (Alexandra et al. 2020). Siemianowska et al. (2013) also testified that the nutritive value of both species can also adjust a new result of animal diet. As a result, different diets provided to mealworms and crickets will affect in finished insect meal products with different nutritional values.

According to Payne et al. (2016), insects generally can offer a high nutrition content. Henceforth, insects are a proper source of ruminant feed. Research has shown that insects have higher palatability which may support the advance effect of performance in ruminant (Manuela et al. 2023). Insect-based feed production could hypothetically increase economic development (Fabio et al. 2020). Therefore, it is proven that insect meal is right to be supplied to ruminants as a source of protein (Jayanegara et al. 2017). Insects are highly capable of converting feed into body weight and growth (Harinder 2014). The insect also can be reared in great density in a small space to aid in the recycling of food waste into high-quality products (Ibrahim & Hadura 2021). They are rich in ether extract and can supply essential fatty acid requirements for ruminants as well (Ghani 2017). On the other hand, exploitation of residual biomasses as animal feed is a brilliant alternative to the environment and economy (Fairuz et al. 2023). Thus, insects may potentially contribute in ruminant feed industry afterwards to solve the issue of malnutrition and provide sufficient food and diet to ruminant animals. The objective of this study is to determine the proximate composition, ADF, ME, OMD and TDN of mealworms and crickets reared in different media for production of ruminant feed.

MATERIALS AND METHODS

Rearing Process

The rearing process was conducted indoors at room temperature at 30^{o}C and 65 % humidity on about five to six weeks of mealworm larvae and cricket nymphs, whereas, seven to eight weeks of mealworm pupae and adult cricket were considered and samples collected after the second generation.

Rearing and Production of Mealworms

One kg of mealworms bought from a pet shop at Jelutong, Penang, Malaysia was separated into two groups (A and B) based on the distinct feed source (1 g/day). If the feed supply was almost run down as indicated by changes in colour and particle size, the feed media was subjected to confirm ad libitum feeding as described by (Oonincx et al. 2015). Group A was an organic source of food waste (i.e., 71% chicken meat+29% peel turnip as an alternative feed) (Changqi et al. 2020) while group B was a conventional basic diet of 50% turnip and 50 % lettuce. Vegetables and fruits are recognised as suggesting rearing substances for insects diet according to the EU regulation (Costanza et al. 2017).

One hundred g in five replicates (R1, R2, R3, R4, and R5) of the mealworms provided with oats as bedding in each group and kept in plastic box each plastic box (17 x 9 x 6 cm) and enclosed with a net material to avoid external insects from impending into set up of the experiment and permitted the mealworm to grow under normal surroundings for the speeding of pupation. Each number of the pupae that grew was separated and moved into other plastic boxes labeled according to the groups and replicates (A and B) and systematic observing of pupae metamorphosis was done (Melis et al. 2019).

The adult beetles were then transferred into a separate plastic box and supplied with extra oats meal with the same setup as the larvae of the mealworm to allow for more nesting room. Oat as bedding was given *ad libitum* and been substituted after it changed to dust. These boxes were supervised regularly for the presence of eggs that hatched between 4 - 9 days depending on the temperature which when hatched found at the lowest of the box. Eggs were not removed as they acted as an indicator that determined the number of larvae (mealworms). Upon hatching, the mealworm larvae were transferred out from the adult beetle and monitoring was done daily or weekly for cleanliness and maintenance of the container (i.e., experimental setup). All groups were subjected to proximate analysis to determine their nutrient level.

Rearing and Production of Crickets

One kg of cricket population bought from a pet shop at Parit Buntar, Perak, Malaysia was grouped into two (A and B) based on the different feed sources (1 g/day). If the feed given was almost short, as indicated by changes in colour and particle size the feed media was added up to confirm *ad libitum* feeding as described by (Oonincx et al. 2015). Group A contained an organic source of food waste of combination (71% chicken meat+29% peel turnip as an alternative feed) (Changqi et al. 2020), while group B, was a conventional basic diet of 50% turnip and 50 % lettuce. Vegetables and fruits are known as promising rearing substrates for insects produced for this purpose according to the EU regulation (Costanza et al. 2017).

Modified plastic boxes each measuring (35 x 23 x 22 cm), were constructed, with a hole of (20 cm long and 3 cm diameter) and enclosed with small mesh size netting materials to allow airing and inhibit the crickets escaping from the box. Each container had 100g with five replications of the crickets that were supplied with oats as bedding *ad libitum* replaced after it changed to dust and the set up was watered to keep the cricket alive. The moist loose soil was provided on the bottom of the containers to allow the hatching of the eggs as described by (Yupa 2020). The preparation was observed for two weeks for the crickets to breed and lay eggs. The hatched eggs in the soil were removed and incubated into other containers for development (metamorphosis). All groups were subjected to proximate analysis to determine their nutrient level.

Proximate Analysis of Nutrient Elements

A total of 20 g of each insect from each replicate were collected and subjected to proximate analysis. This analysis was conducted following standard procedures to identify the elements of the nutrient content in both mealworms and cricket at the feed technology laboratory, technology industry USM. The nutrient elements such as dry matter (DM), crude proteins (CP), metabolizable energy (ME), ether extract (EE), crude fibre (CF), acid detergent fibre (ADF), organic matter digestibility (OMD) and total digestible nutrient (TDN) were subjected in proximate analysis from AOAC (2016).

Analysis to Investigate Dry Matter (DM)

The initial weight of about 5 g of feed sample was weighed and transferred to a drying oven at 105°C for at least 12 hours. The sample was allowed to cool in a dryer then weighed again and finally broken down into small pieces with a grinder. The procedure of this experiment was repeated three times to reduce errors and allow the generation of accurate data and the identification was conducted by referring to the method by AOAC (2016).

Calculation:

$$\text{Moisture content (\%)} = \frac{(c-b)x100}{(b-a)}$$

$$\text{Dry matter (\%)} = 100\% - \text{Moisture content (\%)}$$

a = weight of empty crucible
b = weight of crucible+sample before drying process
c = weight of crucible+sample after drying process

Analysis to Investigate Crude Protein (CP)

Crude protein identification was conducted by following the method adopted by AOAC (2016). Three main processes in crude protein investigation include digestion, distillation and titration. The procedure of this experiment was repeated three times to reduce errors and allow the generation of accurate data.

Digestion Process

The feed was digested using Kjeldahl's (Velp - scientifica, Heating Digester) because it can evaluate the total nitrogen content of the sample after it has been digested in sulphuric acid with a catalyst. 0.5 g feed samples were weighed and transferred into a Kjeldahl flask and 1 tablet of catalyst was poured into the flask, followed by the additional of 10ml concentrated sulphuric acid (H_2SO_4) solution. 3 ml hydrogen peroxide (H_2O_2) solution was added to the preparation in the flask. The samples were let to digest until the content became clear colour. The samples were allowed to stand for 3 - 10 hours to thorough the process, then heated at low temperature for complete reaction in the flask and finally allowed to cool.

Distillation Process

25 ml of 4% H_3BO_3 boric acid and 35 ml of 35% NaOH sodium hydroxide solutions were transferred into a distillation tube that was connected to a distillation machine (Protein Distillation Unit Velp Scientifica, UDK 127, ID 141395). The distillation process took about 3 to 5 minutes until colour changed to blue (endpoint) after being reacted with ammonia gas (i.e., boric acid solution turned blue due to reaction with ammonia gas).

Titration Process

The distilled solution obtained was titrated with 0.01 M sulphuric acid (H_2SO_4) solution up until colour changed from blue to red as an endpoint. The calculation for crude protein is using the formula below after the titration process.

$$\text{Crude protein (\%)} = \frac{(P\ x\ M\ x\ L\ x\ Fc\ x\ Fp\ x\ 100)}{(W\ x\ \%DM)}$$

W= Feed sample (g)
P= g Nitrogen equivalence to 1ml acid 1M sulphuric (0.028)
M= Molarity for standard acid use for titration (0.01M)

L= ml titration after minus the control sample titration
Fc= Dilution factor (250/5)
Fp= Nitrogen changing factor to crude protein (6.25)
DM (%) = Dry matter at Analysis to investigate dry matter (DM)

Crude Lipids/ Ether Extracts (EE) Investigation

For the Ether extract experiment, 3 g feed samples were approximately weighed in a pre-weighed extraction thimble. The thimble was transferred into the Soxhlet apparatus (M-Top Soxhlet Extraction Mantles 6 Racess, Model MS-EAM Series (with temperature controller), MTOPs-KOREA). 200 ml petroleum ether extract was then poured into a round bottom flask of the Soxhlet, and the condenser was allowed to run water as cooling effects in the fume chamber (Labline General Purpose Fume cupboard), which was heated at a low temperature of about 40 - 60^{o}C for 8 - 10 hours. The round bottom flask was then detached from the Soxhlet apparatus to drain out the solvent. The moist ether extract in the round bottom flask was placed in the oven (Memmert), and dried at 100°C for 24 hours, it was then allowed to cool in the desiccator, and weighed as described by AOAC (2016). The procedure of this experiment was repeated three times to reduce errors and allow the generation of accurate data. The calculations are using the formula below.

$$\text{Ether extract (\%)} = \frac{(d-c)x100}{((b-a)x\,\%DM)}$$

a = weight of empty thimble
b = weight of thimble+sample
c = weight of empty round bottom flask
d = weight of round bottom flask+extracted lipid (after drying)
DM (%) = Dry matter at Analysis to investigate dry matter (DM)

Analysis to Investigate Crude Fibre (CF)

For the crude fibre, nutrient investigation, 2.0 g of dried and defatted sample was weighed and transferred into a round bottom flask, 150 ml (5%) sulphuric acid (H_2SO_4) solution was then added and boiled for 30 minutes (initially at low temperature and later increased to boiling point 40 – 60°C) by using extractor M-Top Extraction Mantles 6 Racess, Model MS-EAM Series (with temperature controller) MTOPs-KOREA, 5 ml of NaOH was transferred and the excess acids were neutralized by using 40% NaOH (Litmus blue paper) as an indicator. 10 ml 25% of NaOH was put by the addition of 2 drops of antiform was added and refluxed for 30 minutes. The hot mixture was filtered, and the precipitate was rinsed away by using 1% HCL followed by hot water to remove the acids. Phenolphthalein was applied as an indicator to identify the endpoint. The residual samples on the filter paper were rinsed with methyl spirit, positioned inside a crucible, and dried in an oven at 105°C until constant weight was obtained (overnight). The dried filter paper was then moved inside the desiccator to cool down and weighed. The crucible was placed to ash in a muffle furnace (Thermolyne SYBRON, Type 6000 Furnace), and heated at 450°C until the black spot vanished. The crucible was left to cool and the final weight was noted down. The procedure of this experiment was repeated three times to reduce errors and allow the generation of accurate data. The calculations are using the formula below.

$$\text{Crude fibre (\%)} = \frac{(c-d)x100}{(a\,x\,\%DM)}$$

a = weight of feed sample
b = weight of crucible
c = weight of crucible+filtered residue (after drying)
d = weight of crucible+ash
DM (%) = Dry matter at Analysis to investigate dry matter (DM)

Acid Detergent Fibre (ADF) Investigation

Acid detergent fibre nutrient investigation was conducted with 1 g of sample weighed and transferred into round bottom flask. 100 ml acid detergent solution was transferred into the flask and then heated to boil for 60 minutes. The sample was then filtered and weighed and allowed to dry by using a vacuum pump (Pump Vacuum GAST, Model DOA-P504-BN, ID 0410603709, Mich, USA). The precipitate was washed away with hot distilled water and wetted with acetone, and allowed the crucible to dry out in the oven at 105°C for 24 hours and the final weight was recorded. The procedure of this experiment was repeated three times to reduce errors and allow the generation of accurate data. The calculations are using the formula below.

$$\text{Acid detergent fibre (\%)} = \frac{(c-b)x100}{a}$$

a = weight of feed sample
b = weight of crucible
c = weight of crucible+filtered residue (after drying)

Calculation of Metabolizable Energy (ME)

Metabolizable energy calculation was performed following the method of Zainal et al. (2011). The calculations are using the formula below.

$$\text{Organic matter digestability (\%)} = 99.41 - (1.17\%ADF)$$

$$\text{Metabolizable energy } \left(\frac{\text{MJ}}{\text{Kg}}\right) = 0.16\,x\,Organic\,matter\,digestibility\,(\%)$$

$$\text{Total digestible nutrient (\%)} = 96.35 - (\%ADF\,x\,1.15)$$

ADF (%) = Acid detergent fibre at previous analysis.

Statistical Analysis

Detailed data were evaluated using SPSS Statistic (Ver. 17 for Windows, SPSS Inc. Chicago, IL). To test significant differences, prior to analyses, all data were examined with the Shapiro Wilk test for normal distribution. P-values is more than 0.05, thus it rejected the alternative hypothesis and determined that the data comes from a normal distribution. A one-way analysis of variance was carried out to compare data recorded on different species, stages, and feed media. Where significant differences occurred, Tukey–Kramer's Honestly

Significant Difference multiple comparisons test was applied for mean separation (*P*<0.05) between samples test.

RESULTS

Chemical Compositions of Nutrient Elements of Mealworm (*Tenebrio molitor*)

The result of the analysis of the chemical compositions of nutritional elements (i.e., dry matter, crude proteins, metabolizable energy, ether extract, crude fibre, acid detergent fibre, organic matter digestibility, and total digestible nutrients) of the mealworms is presented in (Table 1). For the dry matter (DM), the highest DM was recorded for the AF with a value 40.95±0.58%, this value was not substantially difference (*P*>0.05) from the recorded values of the rest of the groups. The highest crude protein (CP) in mealworms was recorded for AF of the larvae (42.90±1.17%). This value had no significant difference (*P*>0.05) from CBD crude protein. However, differed significantly (*P*<0.05) from the CBD and AF of the pupae of the same insect with the lowest value recorded for the CBD of the pupae (35.89±0.86%). The highest metabolizable energy (ME) was obtained from AF media groups for both larvae and pupae (15.88±0.00 and 15.88±0.02% respectively). Whereas the lowest ME were from CBD media groups for both stages as well with a value of 15.87±0.01%. However, these values were insignificant (*P*>0.05) from one another. For ether extract (EE), the highest was recorded for AF pupae with a value of 39.19±0.90%, and the least was for CBD larvae 28.21±0.59%. However, the highest value significantly differed (*P*<0.05) from the values obtained for the rest of the groups in the same insects. The significant highest of CF in mealworms was obtained in AF of pupae with a value 17.27±0.32% and the lowest value was recorded for CBD of the larvae with a value of 2.57±0.31%. The highest value significantly differed (*P*<0.05) from the recorded value of CF for the rest of the groups. The highest and the lowest ADF elements of the same insects (mealworm) were recorded for the AF group in pupae and CBD group in larvae with the values 19.54±0.89% and 13.30±0.09% respectively. However, this highest value was insignificant from the value of AF of the larvae, similarly the lowest value recorded was insignificant from the value recorded for CBD of the pupae.

Table 1. Mean Chemical composition of nutrient elements in mealworm

	Mealworm			
	Larvae		**Pupae**	
	CBD	**AF**	**CBD**	**AF**
DM	40.73±0.23ab	40.95±0.58ab	38.79±0.37a	40.94±0.18ab
CP	42.66±0.18b	42.90±1.17b	35.89±0.86a	37.03±0.94a
ME	15.87±0.01a	15.88±0.00a	15.87±0.01a	15.88±0.02a
EE	28.21±0.59a	32.96±0.84b	35.44±0.36c	39.19±0.90d
CF	2.57±0.31a	4.14±0.31a	11.12±1.53b	17.27±0.32c
ADF	13.3±0.09a	18.32±0.56b	14.91±0.98a	19.54±0.89b
OMD	99.19±0.01a	99.26±0.03a	99.18±0.01a	99.23±0.01a
TDN	75.28±0.65a	40.95±0.58ab	73.88±1.02a	79.20±1.13b

Values are Means±SE of Mean replicates. Values followed by the same superscript(s) along the row are significantly different at (*P*<0.05). CBD, conventional basic diet; AF, alternative feed; DM, dry matter (%); CP, crude protein (%); ME, metabolizable energy

(MJ/Kg); EE, ether extract (%); CF, crude fibre (%); ADF, acid detergent fibre (%); OMD, organic matter digestibility (%); TDN, total digestible nutrient (%).

Chemical Composition of Nutrient Elements in Crickets (*Gryllus assimilis*)

The result of the chemical compositions of nutrient elements viz; dry matter, crude proteins, metabolizable energy, ether extract, crude fibre, acid detergent fibre, organic matter digestibility, and total digestible nutrients, of the crickets are presented in (Table 2). For the dry matter (DM), the highest DM was recorded for the AF media for adult cricket (69.29±0.11%). This value was insignificant (P>0.05) from the CBD of the adult. However, differed considerably (P<0.05) from the AF and CBD values of the nymphs (44.71±0.60 and 33.61±1.03%) of the same insect. The highest value of crude protein (CP) in crickets was recorded for AF with a value of 56.95±0.93%. This value had significant difference (P<0.05) from the rest of the groups. The ME obtained for all groups was the same at 15.85%. For the ether extract, (EE), the highest was recorded for AF for nymph and the lowest for CBD of adult cricket with the values 10.32±0.10% and 5.80±0.04%, respectively. These values differed significantly (P<0.05) between both different stages. The significant highest of crude fibre (CF) in crickets was recorded for AF of the nymphs with a value of 20.08±0.49% and the lowest value was recorded for CBD of the same stage with a value of 10.80±0.03%. All values were significantly differed (P<0.05) from one another. The highest value of ADF element was recorded for AF of the nymph 30.88±1.81%. This highest value significantly differed (P<0.05) from the recorded values of the same element in the same insects.

Table 2. Maen Chemical composition of nutrient elements in crickets

	Crickets			
	Larvae		**Pupae**	
	CBD	**AF**	**CBD**	**AF**
DM	33.61±1.03a	44.71±0.6b	69.28±0.08c	69.29±0.11c
CP	51.80±1.53a	55.47±1.39b	54.37±0.71b	56.96±0.93c
ME	15.85±0.00a	15.85±0.04a	15.85±0.01a	15.85±0.01a
EE	9.03±0.12b	10.32±0.10b	5.80±0.04a	6.77±0.99a
CF	10.80±0.03a	20.08±0.49d	12.26±0.62b	17.69±0.93c
ADF	28.48±0.20a	30.88±1.81b	27.47±0.62a	27.48±0.27a
OMD	99.05±0.02a	99.08±0.03a	99.09±0.03a	99.09±0.01a
TDN	60.84±2.07a	63.60±0.23b	64.75±0.30b	64.75±0.71b

Values are Means±SE of Mean replicates. Values followed by the same superscript(s) along the row are significantly different at (P<0.05). CBD, conventional basic diet; AF, alternative feed; DM, dry matter (%); CP, crude protein (%); ME, metabolizable energy (MJ/Kg); EE, ether extract (%); CF, crude fibre (%); ADF, acid detergent fibre (%); OMD, organic matter digestibility (%); TDN, total digestible nutrient (%).

DISCUSSION

Ruminants demand vital nutrients to develop body mass rich in proteins and fats for their growth (Denis et al. 2021; Harinder 2014). Providing animals with insects will be a factor in the growth and development because insects have a higher prospective as ruminant feed supply. The result obtained in this current study is quite significant because it correlated with a finding of authors on a nutrient diet or supplement for ruminant animals. Dry matter in insects was fairly high more than 40% for adults as reported by Alexandra et al. (2020) in their research works. It was testified that the dry weight of the chitin from adult insects was comparatively higher than that from too young chitin and the difference was observed at cricket groups (Alyani et al. 2020). This report was corroborated by the current result of this study which revealed utmost dry matter was in the range of 40 – 69% of DM. Dry matter (DM), is a preliminary element indicator of the measure of nutrients in an exact feed given to animals. These dry matter standards were necessary to determine because it is directly connected to the variations assessment of other nutritional elements such as ether extract, crude fibre and crude protein (Alexandra et al. 2020).

Protein measures in insects were relatively high as indicated by Belluco et al. (2013), agreeing with Harinder (2014), who found mealworms with a high amount of CP at 47 - 60%, which their findings were a little higher than this current research which at 35 – 43%. High crude protein levels in crickets in this current research (range of 52 - 57%), were defended by the preceding research of Bovera et al. (2015); Cullere et al. (2016); and Taufek et al. (2016), which revealed high measure of crude proteins which more than 50 % in crickets than other insects. Conversely, Finke (2013), and Xiaoyu et al. (2021) in their study had also emphasized the fact that an extensive level of nitrogen from insects probably was caused by the chitin and would approximately using nitrogen up to 6.25 times, which could result to an overestimation on insect's true protein level. The high crude proteins (CP) in the insects most particularly the crickets are because of the nitrogen comprised inside the chitin compared to mealworms. However, a higher chitin level will cause of lower digestibility rate in animals due to the structural difference between cellulose and chitin. The cuticle of insects includes chitin in a medium with cuticular proteins, lipids, and other compounds (Anna et al. 2018; Nation 2002). This is the factor that contributes to higher CP content. Therefore, this current research signifies further study to compare with the CF value to acquire in the selection process to make a better decision in choosing the best insect and type of feed. According to Yusoff (2010), plant cellulose is similar to chitin in animal and is best to be provided in the diet instead of the animal chitin for ruminant as it is not good for digestion. Thus, cellulose should be complemented in the animal feeds for palatability and growth and development status.

In this study, crude fibre (CF) and acid detergent fibre (ADF) were demonstrated to be higher in crickets 11 - 20% (CF) and 27 - 31% (ADF) than mealworm insects 3 - 17% (CF) and 13 - 20% (ADF). Consequently, due to the existence of high chitin in the crickets causing the crickets not really digestible for animals, while mealworms are suggested in this current study. Besides, soft bodied insects like larvae of mealworms contain less chitin and are more digestible than other commonly used feeder insects (Jinsu et al. 2020). Moreover, Finke (2002) and Ibitoye et al. (2018) specified that chitin values in the crickets may cause to consist of high nitrogen content then leads to unfulfilled indication of the true proteins. This cohort with the statements by Yusoff et al. (2007); Yusoff (2010); Zainal et al. (2011), and Rofiq (2021) reported, feeds that have high acid detergent fibre (ADF) had less being digested while the feeds that have low ADF had a good digestibility.

Elements such as total digestible nutrient (TDN), organic matter digestibility (OMD) and metabolizable energy (ME) were set up to be correlated among each other. Based on the body physiology, the ruminant animals do not really have the ability to accurately digest crickets in their stomach chambers compared to mealworms due to high CF and ADF values in insects as (Harinder 2014). In this current research, it is brought into the observation that element like total digestible nutrient (TDN) is higher in the mealworms 74 - 81% than in the crickets 61 - 65%. Hence, based on this current discovery, mealworms are the best insects to be fed to ruminant animals. Equally, Aguilar-Miranda et al. (2002); Hardouin & Mahoux, (2003), discovered that nutrient elements such as metabolizable energy and total digestible nutrients were higher in mealworms around 15 - 16 MJ/Kg (ME) and more than 70% (TDN) compared to other insects. In addition, mealworms are easy to breed, feed, rear and have a valuable protein profile and hypothetically can be used for animal diets (Al-Arif et al. 2017; Veldkamp et al. 2012). Moreover, mealworms also comprise of high fat level which is an important energy source in animal feed (Harinder 2014). In the current study, it has been detected that both insects displayed almost similar energy values of about 15 MJ/ Kg of metabolizable energy (ME) even though considerably high in mealworms. This level of metabolizable energy is perfect for ingesting by ruminant animals. This is in agreement with the work of Yusoff et al. (2007); Yusoff (2010) who stated that the energy requirement with range values 5.00 - 12.84 MJ/Kg is for ordinary goat in Malaysia such as Katjang goat has a weight range of 20 - 70 kg cause the growth and development of approximately 50g/ day. Besides that, energy requirement of the range values about 7.20 - 17.36 MJ/Kg is for feedlot goats that have a weight of 10 - 70kg and grow around at a rate of 150 g/ day. A report from Yusoff (2010) revealed that feedlot goats weighing 10 - 60 kg need about 7.20 - 15.94 MJ/Kg of energy in which values can attained by both insects as reported in the findings of current research for ME were more than 15 MJ/Kg. Therefore, from the previous finding it can be deduced that insects could offer of the required amounts of an optimal level of energy for goat consumption. Conversely, research by of Luo et al. (2004), revealed that ME necessity for weight was 23.1 MJ/Kg average daily gain weight for meat and dairy goats and 19.8 MJ/Kg average daily gain for indigenous goats, which is higher than our findings. Energy shortages will cause to the incidence of metabolic disease, declined production and deprived reproduction productivity (Butler 2000; Qingbiao et al. 2021). Therefore, fat is the element that can help to provide additional energy for the animal. Making use of mealworms as an energy source is a perfect and most feasible option to achieve nutritional requirements in ruminant feed. The ether extract is a vital supplement as high energy concentration offers more energy. Sheep, goats and beef cattle will get value from fat which offer a highly concentrated form of energy mostly required during lactation or the finishing beef phase (Edward et al. 2021). This nutrient can provide vital fatty acid supplies for ruminant animals (Ghani 2017). This nutrient was identified to be high in mealworms 28 - 39% than crickets 6 - 10% in this current study. This cohort with the finding of Harinder (2014), who discovered that mealworms contain a great amount of fat at 31 - 43%, which is a little higher from our current data. Contrarily, Harinder (2014), also reported fatty acid composition of mealworms is also almost similar to crickets. According to Joaquín et al. (2014), grain rich bases of energy such as concentrate type of feed will upsurges acid production which can cause low rumen pH and acidosis. Contrariwise, ether extract is not fermented in the rumen and allows energy improvement without build-up of acid in the rumen. Starch and sugar supports are fermented at opposing rates in the rumen and ultimately form acid, meanwhile fat is not fermented in the rumen and does not lead to production of acid (Edward et al. 2021), thus, that is the purpose of ether extract analysis.

Besides that, one of the main problems the ruminant animals is a lack of ability to avoid pollution of methane gas during digestion of the defecated waste, since 12% of feed energy ingesting is discrete as methane gas (Hyeok et al. 2019). This gas is produced in the rumen as a result of feed fermentation. However, ether extract is not fermented and a higher fat ratio can reduce methane accumulation, donating to improved feed efficiency and decreasing harmful environmental releases (Rasmussen & Harrison 2011; Williams et al. 2020). Ingestion and conversion of feedstuff in energy provide heat in the animal body, which may cause heat stress in hot weather environments. To stabilize this problem, ether extract produces considerably less heat than all other energy bases and is frequently supplemented to diets as a practicable substitute to reduce heat stress. Additionally, fat is also acknowledged as a cooling agent (Hyeok et al. 2019), nevertheless, it is not common knowledge that fat is a cooling ingredient for animals. As many know, the digestion process and adaptation of feedstuff to energy will bring warmth to the body of a ruminant. Fat turns out expressively lower heat than other energy sources and is commonly added to feed in warm temperatures as a beneficial technique for reducing heat stress. In Malaysia, farmers normally use forage and concentrate-based regimes which moderately contain low fat concentration, around 3% of the diet. In this current study, it has been revealed that insects can be applied to enhance the concentration of the fat greater than 3% because insects such as mealworms have higher concentration of ether extract. Thus, this current study were using insects as a substitute.

Ether extract offers energy up to 2.25 times the density of the energy source (Jefferson et al. 2013), and can be fed at whatever time but is mainly valued where the energy demand is high (Williams et al. 2020) it also delivers fertility in ruminant animals, which is important to encourage conception and pregnancy frequency (Rodney et al. 2015; Westwood et al. 2000). As a final point, for insects diet and its consumption can only be identified when researchers control the variables by using alternative diets (Behmer 2009). By altering the nutrient constituents of alternative diet, whether qualitatively or quantitatively can frequently run to a diet that is acceptable to the target species (Jaana et al. 2019). The conventional basic diet (CBD) media was found to be less effective in this present study. As a result of nutritional values in insects that consume alternative feed (AF) media were better to the common basic diet. Furthermore, the alternative feed also can support in rearing process as good as the conventional practice. This is due to the presence of excess human food which is high in protein content (Hina et al. 2021). This is in agreement with the work of Thompson & Redak (2000); Wilkinson et al. (2001); Simpson et al. (2004), who stated that a lack of necessary nutrient elements such as crude proteins can cause uncertainty and malnourishment in insect leading improper growth and development. Additionally, it has been described that protein is more highly vital in animals like herbivores and omnivores as compared to carbohydrates, hence the huge effects on the animals when there is a protein deficiency (Denis et al. 2021; Simpson & Raubenheimer 2005).

CONCLUSIONS

Based on these studies, it proved that insects such as mealworms can be utilised as potential sources of protein and other nutrients in ruminant feed production. It satisfies that among the two different media, AF derived from human waste food can be heavily considered in the production of these insects as these insects preferably mealworms provide high standard nutrients which is high in crude protein, metabolizable energy and ether extract. In addition, mealworm is essentially lower in crude fibre content than cricket. Crude fibre is not good for animal digestibility. Insect rearing is also highly cost-effective and environmentally friendly. Therefore, waste feed is recommended for use as an alternative in the production of animal feed, owing to its cost-effectiveness and reduced environmental waste pollution. Malaysians can consider mealworms and crickets as animal feeds for ruminant animals emphasizing mealworms insects.

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Conflict of Interest
The authors declare that they have no conflict of interest.

Ethics Declarations
No ethical issue is required for this research

Data Availability Statement
This is a Doctor of Philosophy Project and the data are currently in Ph.D thesis entitled "Mealworms and Crickets as Protein Sources in Complete Rations Formulated with Kenaf, Yeast and Cereal Grains for Growing Ruminants in Malaysia" (2023).

Authors' Contributions
Hamdan Ahmad and Husna Fasihah conceptualized this research and designed experiments; Husna Fasihah and Hasber Salim, Intan Haslina Ishak participated in the design and interpretation of the data; Husna Fasihah, wrote the paper and Ibrahim Shehu Kura participated in the revisions of it. All authors read and approved the manuscript.

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