MEALWORMS AND CRICKETS AS PROTEIN SOURCES IN COMPLETE RATIONS FORMULATED WITH KENAF, YEAST AND CEREAL GRAINS FOR RUMINANTS IN MALAYSIA

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CBD	Conventional basic diet
AF	Alternative feed
DM	Dry matter
CP	Crude protein
CF	Crude fibre
CL	Crude lipid
EE	Ether extract
ME	Metabolizable energy
ADF	Acid detergent fibre
OMD	Organic matter digestibility
DME	Dry malt extract
PKE	Palm kernel expeller

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ULAT KUMBANG BERAS DAN CENGKERIK SEBAGAI SUMBER PROTEIN DALAM RANSUM KOMPLIT YANG DIFORMULASI BERSAMA KENAF, RAGI DAN BIJIRIN UNTUK RUMINAN DI MALAYSIA

ABSTRAK

Ulat kumbang beras (*Tenebrio molitor*) dan cengkerik padang (*Gryllus assimilis*) telah dinilai sebagai sumber protein bagi menghasilkan makanan ruminan yang berkualiti tinggi di Malaysia. Penilaian makanan juga telah dijalankan bagi sumber serat, iaitu kenaf. Manakala molases, jagung dan bijirin gandum adalah sebagai sumber tenaga. Penilaian makanan dalam penghasilan makanan ruminan tidak seharusnya berfokus hanya kepada protein semata-mata, tetapi juga perlu kepada tenaga yang boleh dimetabolismekan, serat kasar dan lipid kasar. Bahan-bahan makanan yang dinilai di dalam kajian ini telah menunjukkan bahawa ia berpotensi tinggi pada protein dan tenaga. Kedua-dua kumbang beras dan cengkerik telah dikenal pasti mempunyai protein yang tinggi, manakala jagung dan gandum mengandungi tenaga yang tinggi bersama kandungan protein kasar yang sederhana. Manakala kenaf menunjukkan potensi tinggi pada sumber serat bagi ruminan. Kajian ini juga menilai kegunaan ektrak malt kering, molases dan gula sebagai substrat penapaian bagi produksi ragi. Di dalam kajian ini, beberapa sumber tenaga telah digunakan bagi tujuan pengurangan kos dan juga membantu penambahbaikan formulasi. Dapatan kajian baharu di dalam kajian ini adalah di dalam penggunaan serangga bagi menggantikan mil kacang soya sebagai sebagai sumber protein di dalam formulasi makanan ruminan. Serangga telah pun digunakan secara menyeluruh di dalam industri unggas. Sungguhpun begitu, informasi bagi

penggunaan serangga sebagai sumber protein di dalam ruminan adalah masih terhad. Oleh yang demikian, bagi mengenal pasti nilai pemakanan pada bahan-bahan makanan, beberapa analisis pemakanan telah dijalankan bagi setiap bahan makanan. Analisis proksimat bagi bahan makanan telah di jalankan dan dihuraikan dalam bab 3 sehingga 7. Analisis ini termasuk kaedah Kjeldhal bagi protein, kaedah Soxhlet bagi lipid kasar, protokol serat kasar dan kaedah Van Soest serat asid detergen bagi serat. Analysis pada larva ulat kumbang beras menunjukkan protein kasar (CP) yang paling tinggi adalah 42.90%, ianya mempunyai nilai ketinggian yang bererti berbanding dengan makanan asas sebagaimana kebiasaannya. Manakala, nilai tertinggi bagi protein kasar dalam cengkerik telah direkodkan dengan nilai 56.95% lebih tinggi dibandingkan dengan ulat kumbang beras. Walau bagaimanapun, analisis serat kasar dan serat asid detergent membuktikan cengkerik mengandungi kandungan serat yang tinggi. Serat di dalam bahagian badan serangga adalah di dalam bentuk kitin yang tidak boleh dicernakan oleh haiwan ruminan. Oleh itu, serangga berbadan lembut seperti larva ulat kumbang beras adalah pemilihan yang terbaik. Serangga hanya dapat membekalkan kandungan protein yang tinggi bersama nutrien yang lain tetapi tidak serat. Penggunaan kenaf sebagai sumber serat telah menunjukkan batang pokok kenaf segar mengandungi 40.92% serat kasar, manakala kandungan bagi batang yang telah diproses adalah antara 53.65%-54.32% serat kasar. Batang kenaf yang telah diproses menunjukkan kandungan peratusan serat yang lebih tinggi ($p<0.05$) dibandingkan dengan kenaf segar. Tiga contoh sumber tenaga telah dianalisis. Ianya adalah molases, jagung, dan gandum, dan telah dikenal pasti dapat membekalkan tenaga yang tinggi iaitu antara 15.20MJ/kg-15.91MJ/kg dan tiada perbezaan bererti ($p>0.05$) antara bahan-bahan tersebut. Keseluruhan jagung dan gandum mengandungi 8%-12% protein kasar yang dapat menyumbang kepada jumlah kandungan protein di dalam makanan. Manakala, molases dikenali sebagai kandungan protein yang tidak bererti dan hanya dapat menyumbang kepada kandungan tenaga pada pemakanan semata-mata. Oleh itu, tiada pemilihan yang dibuat oleh kerana kombinasi pelbagai jenis sumber tenaga digunakan kesemuanya pada pengiraan bagi nisbah formulasi. Manakala campuran molases pula dapat meningkatkan selera dan juga membantu memberi tenaga. Di dalam bab seterusnya menunjukkan kandungan makanan pada ragi yang ditapai sebagai media pilihan di dalam cairan 5% ekstrak malt kering membuktikan ianya adalah terbaik dibandingkan ragi tapai yang lain. Formulasi makanan bagi ruminan yang menggunakan nilai dari analisis menunjukkan bahawa formulasi makanan bagi produk yang diusul adalah setanding dengan produk komersial dari segi kualiti pemakanan bagi tenaga, protein, dan lipid. Kesimpulannya, hasil kajian menunjukkan bahawa bahan makanan tidak komersial seperti serangga yang diberi makan dengan bahan makanan terbuang, kenaf dan bahan lain mempunyai potensi untuk digunakan di dalam makanan lengkap bagi ruminan.

MEALWORMS AND CRICKETS AS PROTEIN SOURCES IN COMPLETE RATIONS FORMULATED WITH KENAF, YEAST AND CEREAL GRAINS FOR RUMINANTS IN MALAYSIA

ABSTRACT

Mealworm (*Tenebrio molitor*) and field cricket (*Gryllus assimilis*) as a protein source were evaluated for the production of high quality ruminant feed in Malaysia. Nutrient evaluations were also conducted on fibre source, namely kenaf. Whereas molasses, corn and wheat grains were energy sources. Nutrients evaluation in ruminant feed production should not only focused on protein alone but also included metabolizable energy, crude fibre and crude lipid. The feedstuff evaluated in this study suggested that they are potentially high in protein and energy. Both mealworms and crickets were found to contain high amounts of protein, while corn and wheat contained high energy with moderate crude protein contents. While kenaf showed high potential as fibre source for ruminants. This study also evaluated the use of dried malt extract, molasses and sugar in substrates fermentation for yeast production. In this study, multiple energy sources were utilised which contributed to the lowering of feed costs while enhancing the feed formulation. The novelty in this research was the insects used to replace soybean meal as a protein source in ruminant feed formulation. Insects have been widely included as a protein source in poultry industry. However, information on the use of insects as protein source in the ruminants is still limited. Hence, in order to determine the nutritional value of feed ingredients, several feed analysis were also carried out in each ingredients. Proximate analysis on feed ingredients were conducted and reported in chapters 3 to 7. The analyses include the kjeldhal method for protein, Soxhlet method for crude lipid,

crude fibre protocol, and Van Soest acid detergent fibre procedures for fibres. Analysis of mealworms showed that the highest crude protein (CP) was found at the larvae stage 42.90%, which was significantly higher than those of conventional basic diet. However, crude protein in crickets with the value of 56.95% was higher than that of mealworms. However, the crude fibre and acid detergent acid analysis showed that cricket contain higher crude fibre content. Fibre in insects' body part is in the form of chitin which is not digested in for the ruminant. Thus, soft-bodied insect such as mealworm larvae is the better choice for protein source. Insects can only provide a high protein diet along with a few other nutrients but not fiber. The use of kenaf as fibre source, showed that fresh kenaf stem contained 40.92% crude fibre, while processed kenaf contained 53.65%-54.32% crude fibre. Processed kenaf stem showed higher percentage of fibre ($p<0.05$) compared to fresh stem. Three examples of energy sources were analysed. They were molasses, corns, and wheat, and were found to contain high energy in the range of 15.2%-15.91%, with no significant differences ($p>0.05$) among them. Whole corn and wheat were known to contain 8%-12% crude protein which contributes to the total protein content of the diet. However, molasses was known to have insignificant amounts of protein and solely contribute to the energy contents of the diet. Thus, no selection was made as all the energy sources were used in combination during the calculations for ration formulations. Molasses on the other hand, was added to the formulation due to its ability to increase feed palatability and at the same time provide energy. In the next chapter showed that nutritional value of yeast fermented in selected media from 5% dry malt extract solution proved to be better than the ratio of remaining fermented yeast. Formulations of diets for ruminants using nutrient values obtained in the analyses revealed that the proposed formulation was comparable to commercial product in terms of nutritional quality of energy, protein and lipid. In conclusion, finding suggested that the non-commercial feed ingredient such as insects supplied with food waste media, kenaf and other ingredients have the potential to be used in complete feed for ruminants.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Complete nutrient of animal feed is an important factor for ruminant management, and economically one of the most significant elements in animal production (Leng, 2004). Animal feed can account for up to 70% of the entire cost of animal productions (Geoffrey, 2012; Harinder, 2016b), thus, the optimization of unconventionally high nutrient feed may solve this issue (Harinder, 2016a; Makkar, 2018). However, one of the major issues and challenges faced by the people and the industry is high feed prices. Such problem has inevitably hindered the industry from blooming and growing efficiently (Abu, 2013; Melissa et al., 2016). Protein, fibre, energy and fat are the most important component and key nutrient requirement in ruminant feed (Corbett & Freer, 2003; Joseph et al., 2018). Thus, the proper feed analysis should be conducted in each type of feed ingredients before making a complete feed mixed formulation which calculated by a proper feed formulating software. The first example of the most essential nutrient for ruminant is protein. Protein is essentially necessary for maintenance, growth, pregnancy, and lactation (Luis et al., 2015; Charles & Glen, 2017). It also used to build muscle (Lobley, 2003), blood, internal organs, and skin (Gita, 2020). According to Leng (2004); Payne et al. (2016a), most insects show high nutritional values hence, they are a very promising option that can potentially be used for ruminant consumption. According to Leng (2004); Sarah (2017), insects have higher palatability with relative conversion and production rates, this conversion is aided by enzymes in larvae-stage insects which is relevant for animal production. Insects have the potential to provide suitable amount of protein, milk, and other nutrient contents. In insects, protein is one of the main nutrients needed by animals as widely reported (Lenka & Anna, 2016; van Raamsdonk., 2017). Amino acids in some insects for example, are very well characterized as the structural units that make up protein (Bukkens, 2005), which can help to improve dietary quality in ruminant animals (Sponheimer et al., 2005). Correspondingly, numerous reports have shown that growth rate of ruminants on base diets could be stimulated by proper supplementation of a protein meal (Broderick, 2018; Cristina et al., 2020). Yet, the protein level supplied has to be in the correct amount. However, excess protein in diet is converted to energy (Lene et al., 2019). When subjected to the results after enzymatic hydrolysis of water binding capacity, foaming, and gelation capabilities of mealworms and crickets remained unchanged, indicating that both species possessed comparable structural characteristics (Alexandra et al., 2020). In addition, similar protease enzyme present produced a comparable protein pattern in both species, which was another similarity between them (Merz et al., 2015). Protease is an enzyme which breakdown proteins and peptides, and their peptidase activity were similar in both insects (Grossmann et al., 2019). Eventhough, adult cricket and larvae of mealworm have high protein level (Zielińska et al., 2015), protein feed alone cannot give maximum production rate of ruminant animals, thus, to complete the total mixed ration of the feed, ruminants need several sources of nutrient such as fibre, energy, and other supplements/additives.

Fiber is the second crucial feed source that comes afterward. Ruminant commonly supplied with fibre in the form of cellulose and hemicellulose from plant source. However, insect are unable to provide common fibre to ruminants as its fibre is in the form of chitin (Finke, 2007). Thus, fibre from pasture, forbs, and browse are usually the primary and most economical fibre sources of nutrient for ruminants. In Malaysia, kenaf is another potential alternative nutrient, it has the potential to be used as feedstock (Saba et al., 2015a). According to Yusoff (2010) and Akil et al. (2011), kenaf contains high cellulose and hemicellulose and low lignin on a dry weight basis which constitute a good ratio for ruminant consumption. In addition, the young stems and leaves of kenaf are relatively palatable and can potentially be utilised as feed for livestock (Ning-Fang, 2006). After fibre and protein, energy feed source is very important to be supplied for the ruminant (Monica et al., 2011).

Ruminant get their energy mostly from a combination of fat (Harvatine & Allen, 2006; Bauman et al., 2003) and carbohydrates (Noziere et al., 2010; Pierre et al., 2010; Luis et al., 2016). Energy is mainly used to drive chemical processes that turn feed into meat (Vera et al., 2014). Unused energy nutrients are stored as fat until needed (Madison et al., 2022). Whereas, example of carbohydrates including in fibre, sugar, and starch (Noziere et al., 2010). Forages like pasture and roughages are the source of carbohydrate which is in the form of fibre (Mount et al., 2009). Whereas, sugars and starches found in grains type of feed are the source of main energy feed (Joseph et al., 2018). In general, the energy feed source for ruminant usually come from both sugar and starch from grains. Examples of most common energy source in Malaysia are molasses, corn and wheat. Molasses is another nutrient that is called a bonding agent which is produced from the process of refining sugarcane into sugar (Senthilkumar et al., 2016). It is a heavy source of sucrose and appears to be a worthwhile preference as a source of energy and very palatable component for cost management of feeds and pastures (Senthilkumar et al., 2016). It is widely used as feed for ruminants (Attilio et al., 2021). Corn grains, is another source of energy for ruminants which can encourage milk production in dairy cows due to its high starch content, fibre and minerals (Wright, 2012; Greg, 2018). Wheat grains is principally used as a source of energy in the form of carbohydrates similar to that of corns, but relatively higher but low in fibre (NASEM, 2016; Wenzhu & Yizhao, 2018), and can be served in mixture with other ingredients, or processed into concentrated feeds.

Finally, another important substance in feed ingredient is additive which has been an integral part in realizing this accomplishment (Fanelli, 2012). Feed additives are applied as their effect in the gut or on the gut wall cells of the animal (McDonald et al., 2010). Yeast microbe in brewing processes is commonly considered to be a conventional alternative by-product for livestock feed, by reason of its high nutritional value (Manzano et al., 2005; Sotiris et al., 2020). From the overall statement prove that, complete nutrient of animal feed is an important factor for ruminant management, and economically one of the most significant elements in animal production (Yasir et al., 2016).

1.2 The Rationale of the Study

Complete nutrition in feed is the most important requirement in ruminant production. However, one of the major issues and challenges faced by the people and the industry is high feed prices. Such problem has inevitably hindered the industry from blooming and growing efficiently (Abu, 2013; Melissa et al., 2016). Therefore, another alternative with protein and other diets must be supplied at an optimum level for animal feed, allowing for unceasing production of ruminant meat (Leng, 2004).

One complete ration of new potential ingredient mix for animal feed can be produced with the amalgamation of high protein supplement (insect meal), brewer’s yeast, fibre source (kenaf) and other vital ingredients. The mixture could be turned into nutritious formulation, containing an optimum nutrition value as compared to commercial products.

Most of the studies so far do not put a central focus on how insects can be an important source of protein for animal feed in Malaysia. Insects such as mealworm and field cricket can potentially be used as ruminant feed as they are very cost-effective and can be easily produced. This study is very significant to highlight the evaluation of new nutrition sources as potential main ingredients in animal feed formulation. On top of that, the findings will also benefit the ruminant industry in Malaysia tremendously. The ruminant industry is still facing a deficiency in nutritional supply. Insects could be a potential source which could make up to such deficit. However, studies on insects being a good nutrient composition are still very scarce. To bridge the gap, this research is aimed to explore the possibilities through its findings.

1.3 General Aim of the Research

The general aim of this study was to assess the nutritional composition of selected feed ingredients namely, mealworms, cricket meal, kenaf and brewer’s yeast and to formulate a ration containing these feedstuffs so that it provides sufficient nutrient for ruminants.

Specific objectives

1. To determine the nutrient content of mealworms and crickets reared in different media for production.

2. To evaluate the nutrient content of leaf and stem parts of kenaf as a fibre source for ruminant feed.

3. To identify the metabolizable energy, crude protein, crude fibre and crude lipid of three energy sources, namely molasses, corn grain and wheat.

4. To determine the metabolizable energy, crude protein, crude fibre and crude lipid of yeast fermented in dry malt extract as selected growth media.

5. To formulate a diet for ruminants using the above analysed feed ingredients and to compare the nutrient contents with a commercial feed.

CHAPTER 2

LITERATURE REVIEW

2.1 Constraints in feeding ruminants in Malaysia

In Malaysia, the livestock industry contributes 10% of the agricultural sector’s of gross domestic product (MESTECC., 2018; Rabiatul, 2021) and 20% of the labour force in the country's agriculture sector is employed by the ruminant sector (Hariz & Fairuz, 2011). Ruminant livestock in Malaysia includes buffalo, cattle, goat, and sheep. In addition, smallholder farmers make up the majority of Malaysia's ruminant livestock producers (Hariz & Fairuz, 2011). However, the lack of and variability in the quality and supply of animal feed throughout the year is the main constraints to the development of livestock in these nations (FAO, 2017). For sustainable ruminant production , it is crucial for this country to produce adequate supply of feeds from resources that do not compete with human food in order for the livestock sector to flourish sustainably (Adegbola et al., 2020).

2.2 Insects as animal feed

There are over 2000 insect species that are known to be edible; the most commonly consumed species are beetles, caterpillars, crickets, termites, dragonflies, flies and several others (Jongema, 2017). The *in vitro* study of Jayanegara et al. (2017b) evaluating diverse species of insects including (*Gryllus assimilis, Tenebrio molitor,* and *Hermetia illucens*) on rumen digestibility and methane emissions. In United States of America, Fukuda et al. (2022) measuring the properties of black soldier fly larvae as a protein supplement in ruminant and found that the animals receiving insect meals improved, favouring weight gain. In terms of digestibility, the substitution of insect meal had no negative effects on rumen ammonia-N production, volatile fatty acid production or rumen pH. In addition, the *in vitro* analysis by Renna et al. (2022) in small ruminant using different insects such as *H. illucens*, *Musca domestica* and *T. molitor c*onfirms the above data, evaluating the high substances of polyunsaturated fatty acids (PUFAs) which is remarkable practice to improve the quality of ruminant-derived food products. In Malaysia, insects are an uncommon ingredient used as ruminant feed. However, Rumpold & Schlüter (2013), have presented nutrient compositions for a number of edible insects where they showed that insects are potential protein sources in the future. According to Sponheimer et al. (2005) protein content in insects is considerally high and therefore, may be used as a protein source in animal feed to replace the traditional source which is soybean meal.

2.2.1 Protein content of insect meal

Protein is one of the most essential macronutrients for animals. They are necessary for the supply of amino acids, which are important in muscle and tissue formation, maintenance, and growth (Peter & Kenneth). Amino acids are also important in enzymes, hormones and the production of products such as milk, wool and eggs. There are various benefits of providing insects in ruminant feed, one of the vital example is that, insects are a good source for protein which would enhance milk production and correspondingly result to higher yields (van Raamsdonk, 2017). The insect-derived production is deliberated not only potential but also sustainable feedstuff elements in feed formulation, recognitions to the potential of insects to alter relatively low-value agri-food waste into high-quality proteins and fats (Finke & Oonincx, 2023). Furthermore, their production is considered to have a limited environmental footprint and simplification of their use in ruminant farming could contribute to moving towards a circular economy model (Gasco et al., 2020).

Nutritional values of insect meals differ greatly even within a group of insects and depends on the stages of metamorphosis, origin of the insects and their diet (Finke & Oonincx, 2014; Payne et al., 2016b). Table 2.1 shows selected literature on the protein content of edible insects. The table shows that protein content is in the range of 13%–60% of dry matter and there is a huge variation between and within insect orders. From the overall data, it shows that most of the species provide a potential level of protein content. Table 2.2, shows that insects are highly digestible, ranging between 50%-98%, which means it is highly digestible for animal feed.

Table 2.1 Literature reports on the protein content of selected edible insects.

Species	Protein (%)	References
Common insects	25.0-75.0	Finke, 2002 Finke, 2013 Finke, 2015 Oonincx & Dierenfeld, 2012 Barker et al., 1998 Bukkens, 1997 Cerda et al., 2001 Oonincx & Van der Poel, 2011
	13.0-77.0	Xiaoming et al., 2010
Adult cricket	8.0-25.0	Ruth et al., 2012
Common cricket	16.5	Finke, 2015
Adult house cricket	20.5	Finke, 2002 Payne et al., 2016a Payne et al., 2016b
Nymph house cricket	15.4-17.5	Nowak et al., 2016 Finke, 2015 Finke, 2002 Finke, 2007
Adult field cricket	15.8	Rumpold & Schlüter, 2013 Rumpold et al., 2013
Common mealworm	47.0-60.0	Harinder, 2014
Adult mealworm	24.1	Rumpold et al., 2013 Nowak et al., 2016 Finke, 2007
Larvae mealworm	25.0	Payne et al., 2016a Finke, 2015 Finke, 2007 Tang et al., 2018 FAO INFOODS, 2013
Larvae superworm	18.6	Finke, 2015
Larvae silkworm	17.9-23.1	Rumpold et al., 2013 FAO INFOODS, 2013 Finke, 2007
Larvae snout moths	16.1	FAO INFOODS, 2013 Finke, 2015 Finke, 2002 Finke, 2007

Values of protein were expressed in (%) unit.

Table 2.2 Literature reports on the protein digestibility of selected edible insects.

Species	Protein digestibility (%)	References
Common insects	77.0-98.0	Ramos-Elorduy et al., 1997
	76.4-93.3	Bosch et al., 2014, 2016
Larvae mealworm	65.5-68.7	Marono et al., 2015
House cricket	65.5	Poelaert et al., 2017
	91.7	Bosch et al., 2014, 2016
Common cricket	50.0	Kiiru et al., 2020
Black soldier fly	89.7	Bosch et al., 2014, 2016
	77.7	Bosch et al., 2014, 2016
	93.0-94.0	Azzollini et al., 2018
	93.0-94.0	Ottoboni et al., 2018
Mealworm	91.3-92.5	Bosch et al., 2014, 2016
	90.2	Azzollini et al., 2018
	90.2	Ottoboni et al., 2018
	85.0	Megido et al., 2018
	75.5	Poelaert et al., 2017
Termite and grasshopper	82.3-90.5	Kinyuru et al., 2010

Values of protein digestibility were expressed in (%) unit.

2.2.2 Fat, crude fibre and metabolizable energy content of selected edible insects

Besides protein, there are also other main nutrients present in insects, such as energy and fat (Lenka & Anna, 2016). Insects vary widely in term of fat and energy content. Fat content of insects ranges between 7%-77% dry matter, meanwhile energy value varies between 12.26MJ/Kg-31.88MJ/Kg dry weights and these values depend on insect species and diet (Bukkens, 2005), as presented in Table 2.3 and 2.4. The energy value of edible insects is influenced primarily by the fat content in which larvae or pupae usually have higher energy value as compared to adults (Xiaoming & Ying, 2010). However, high protein insect species have lower energy content (Bednářová, 2013). Other than the nutrients stated in Table 2.3 and 2.4, edible insects also contain a good amount of fibre. Insoluble chitin is the most common form of fibre in insects, which is abundantly found in their exoskeleton (Van et al., 2013). Any higher level of it may decrease the animals' digestibility, nevertheless, in most insect species, the level of crude fibre was very low as presented in Table 2.5.

Based on these literatures, it is suggested that insects can be used as protein source for ruminant consumption. Payne (2016a), reported that most of insect species evidently contain high amounts of nutrients, including protein, energy, fatty acids, mineral and vitamins making them a very suitable option for ruminant feed. Studies have also shown that insects have higher palatability and production rates have indicated that larvae enzymes may help improve feed conversion ratios and safe in cattle consumption (Sarah, 2017). In the case of determining suitable feed for ruminants like cattle, Sarah (2017) had identified on silkworm meal, which was found to contain a valuable amount of protein and amino acid. Insect-based feed production could potentially ignite economic spin-offs (FAO, 2018a).

Table 2.3 Literature reports on the fat contents of selected edible insects.

Species	Fat (%)	References
Common insects	10.0-70.0	Bukkens, 1997 Finke, 2013 Yang et al., 2006
	2.0-50.0	Lenka & Anna, 2016
	7.0-77.0	Ramos-Elorduy et al., 1997
Mealworm	31.0-43.0	Harinder et al., 2014
Common cricket	7.9	Finke, 2015
Adult house cricket	5.1	Finke, 2002 Payne et al., 2016a Payne et al., 2016b
Nymph house cricket	4.4-7.9	Nowak et al., 2016 Finke, 2015 Finke, 2002 Finke, 2007
Adult field cricket	5.5-5.8	Rumpold et al., 2013 FAO INFOODS, 2013
Adult mealworm	6.1	Rumpold et al., 2013 Nowak et al., 2016 Finke, 2007
Larvae mealworm	12.9	Payne et al., 2016 Finke, 2015 Finke, 2007 Tang et al., 2018
Larvae superworm	14.4	Finke, 2015
Larvae silkworm	4.3-5.0	Rumpold et al., 2013 FAO INFOODS, 2013 Finke, 2007
Larvae snout moth	24.9	FAO INFOODS, 2013 Finke, 2015 Finke, 2002 Finke, 2007
Larvae black soldier fly	7.0-39.0	Karol et al., 2017

Values of fat were expressed in (%) unit.

Table 2.4 Literature reports on the energy contents of selected edible insects.

Species	Energy (MJ/Kg)	References
Common insects	12.3-31.0	Ramos-Elorduy et al., 1997
Common cricket	5.0	Ruth et al., 2012
	5.8	Finke, 2015
Adult house cricket	6.4	Finke, 2002 Payne et al, 2016a Payne et al, 2016b
Nymph house cricket	5.8	Nowak et al., 2016 Finke, 2015 Finke, 2002 Finke, 2007
Adult field cricket	5.0	Rumpold et al., 2013 FAO INFOODS, 2013
Adult mealworm	7.5	Rumpold et al., 2013 Nowak et al., 2016 Finke 2007
Larvae mealworm	10.3	Payne et al., 2016a Finke 2015 Finke 2007 Tang et al., 2018
Larvae superworm	8.7	Finke, 2015
Larvae silkworm	7.2-9.6	Rumpold et al., 2013 FAO INFOODS, 2013 Finke, 2007
Larvae snout moth	11.5	FAO INFOODS, 2013 Finke, 2015 Finke, 2002 Finke, 2007

Values of energy were expressed in (MJ/Kg) unit.

Table 2.5 Literature reports on the fibre contents of selected edible insects.

Species	Fibre (%)	References
Adult house cricket	4.6	Finke, 2002 Payne et al, 2016a Payne et al, 2016b
Nymph house cricket	2.3	Nowak et al., 2016 Finke, 2015 Finke, 2002 Finke, 2007
Adult field cricket	3.4	Rumpold et al., 2013 FAO INFOODS, 2013
Adult mealworm	7.4	Rumpold et al., 2013 Nowak et al., 2016 Finke, 2007
Larvae mealworm	3.52	Payne et al., 2016a Finke, 2015 Finke, 2007 Tang et al., 2018
Larvae superworm	3.78	Finke, 2015
Larvae silkworm	1.0-22.2	Rumpold et al., 2013 FAO INFOODS, 2013 Finke, 2007
Larvae snout moth	2.1-3.4	FAO INFOODS, 2013 Finke, 2002, 2007, 2015

Values of fibre were expressed in (%) unit.

2.2.3 Potential and production of mealworms and crickets as animal feed

The quantity and quality of protein are the most important aspects to be considered when selecting protein sources for animal feed. On that account, more studies need to be conducted with regards to the potentials of using specific species of insect larvae and in livestock feeding (Mahmoud et al., 2017). Correspondingly, several research have looked into specific species of insects as a feed ingredient for different livestock (Aniebo et al., 2008; Tacon & Metian, 2008; Cickova et al., 2012; Tschirner & Simon, 2015). Insects such as crickets, grasshoppers, locust and several others have the specific nutrient requirements for optimum growth and development.

Mealworm and cricket are two common insect species available widely in Malaysia, and commonly sold in pet stores and fishing supply stores.

There is potential use of insect since it requires small space and water for its production, the use of insects in animal feed is currently being considered as an alternative (Kora et al., 2021). Mealworm and cricket are two of the twelve potential insects to be used as food and feed in the European Union, according to the European Food Safety Authority (EFSA, 2015). In addition, these insects are testified as an easy breeding and maintenance insect due to the low production cost. Besides, these insects have been evaluated animal feed as well (Belforti et al., 2015). Other than that, both of these species have similarities in nutrient characteristics stated in the Food Composition Database for Biodiversity (BioFoodComp) and in accordance with the World Health Organization and Food and Agricultural Organization of the United Nations food labelling guidelines, are regarded as rich in protein (Nowak et al., 2016).

On the other hand, the dry matter values for both species were considerably high and this difference may be correlated with the crude protein, lipid, chitin and ash contents. The chitin content were similar in both insects at 4.2% to 4.8% (Alexandra et al., 2020). Studies of the assessment of these two insect meals' functional qualities, showed that the water binding capacity, foaming and gelation properties did not change after enzymatic hydrolysis suggesting that both species exhibit similar structural properties (Alexandra et al., 2020). Other similarities in both species include protease enzyme which showed similar protein pattern for both species as well (Merz et al., 2015). Protease is an enzyme which breakdown proteins and peptides, and their peptidase activity were similar in both insects (Grossmann et al., 2019). The industrial perspective study demonstrated that the tested edible insects could provide protein extracts for possible fortification of human food with high-quality protein and technological traits. Insect protein can possibly be a future food ingredient with potential for applications in human food (Gabriella et al., 2022). Thus, when rearing insect for both animals and human consumption the source of food and conditions of rearing need to be regulated for food hygiene and safety in accordance with human food regulations.

Studies have shown that both insect species in terms of nutrient content, have possible novel food applications (Gabriella et al., 2022). Adult cricket and larvae of mealworm have well-balanced nutrient profiles especially amino acids, fatty acids and trace elements (Zielińska et al., 2015). It is also known that these insects have different nutritional profiles at different stages of growth, hence more work need to be conducted to investigate the nutritional value at different stages of their life cycle to be used for specific functional foods. Siemianowska et al. (2013) also reported that insects' dietary habits can also alter the nutritional composition of both species. Thus, different diet supplied for both mealworm and cricket will produce different insect meals containing different nutritional profiles.

2.2.4 Nutrient content in crickets and mealworms

Cricket is one of the highly potential sources of protein for animal feed and can be an alternative to replace soybean meal, the conventional protein source (Jayanegara et al., 2017a). High crude protein content is also shown in crickets, as confirmed by previous studies (Bovera et al., 2015; Cullere et al., 2016). Commercial cultivation of soybean in Malaysia has not been successful, and most of the soybean meal used in feed is imported (Ghani, 2017). If insect meals can be produced locally and can substitute soybean meal, then there will be great savings in foreign exchange of the country. According to Jayanegara et al. (2017a), insects like field crickets can be a potential feed ingredient for ruminants especially as protein supplements. It also rich in crude lipid and can supply essential fatty acid requirement for ruminants (Harinder et al, 2014; Jayanegara et al., 2017a). It is evident that insects protein content is relatively high, with many species ranging above 60% (Belluco et al., 2013).

Mealworms are the larvae of the darkling beetle species of the Tenebrionidae family which are indigenous in Europe and now distributed worldwide (Aguilar-Miranda et al., 2002; Hardouin & Mahoux, 2003). This species is easy to breed and feed on food wastes and discarded cereals. The larvae possess a valuable protein profile and are commonly produced on small scale basis as feed for pets and zoo animals including birds, reptiles, small mammals, amphibians, and fish (Veldkamp et al., 2012). Mealworm are used as live feed for fish, birds and other animals, however, they are also available in dried and ground to powder form and packed in tin cans (Veldkamp et al., 2012). The life cycle of mealworm is short, particularly in the larval stage. Harinder (2014) reported that mealworms at larval stage contain a high amount of crude protein in the range of 47%-60% and fat at 31%-43% and its fresh larvae contain about 60% water content. Mealworms contain essential amino acid and fatty acid compositions almost similar to that of house crickets (Harinder et al., 2014). Mealworms are easy to rear, as they are omnivorous, consuming plants and animal products such as meat and feathers and typically feed on cereal bran or flour (wheat, oats, and maize) supplemented with protein sources such as soybean flour, skimmed milk powder or yeast. Fresh fruits and vegetables (carrots, potatoes, and lettuce) are also included to provide moisture (Ramos Elorduy et al., 2002). Mealworms are able to survive on small quantity of water level in dry feeds (Hardouin & Mahoux, 2003). Thus, it is very convenient to rear this type of species. Moreover, mealworms can convert low quality plant waste materials into high-quality feed rich in energy, protein, and fat in a relatively short time. They also have lower chitin compared to crickets, hence have a higher digestibility and safe for animal consumption (Harinder et al., 2014).

2.2.5 Life cycle and morphology of cricket and mealworms

Mealworms

Like many insects, mealworms beetles (a type of darkling beetle) and crickets have an exoskeleton, which is a hard outer covering or shell, to protect their bodies (Marios et al., 2022). The mealworm beetle goes through the following four distinct life stages: eggs, larvae, pupae, and beetles. A varied number of larval instars are present during the *T. molitor* beetle post-embryonic development (Juan et al., 2010). The first stage of life is spent as an egg. Around 250 eggs can be laid by a female beetle at a time, and up to 500 can be laid in its lifetime (Ghaly & Alkoaik, 2009). The time between an egg hatching and the larva emerging is between one to four weeks. The second stage of life, which is spent as a brown larva, lasts for about eight weeks (Aguilar-Miranda et al., 2002). The larva is quite small when it first hatches but eventually reaches a length of 25-35mm. The larva needs to molt and lose its exoskeleton in order to grow. Ten to twenty molts will take place at this stage of life (Abdalbasit et al., 2017). The exoskeleton of a newly molted larvae will be fragile and whitish, but it will swiftly stiffen (Ghaly & Alkoaik, 2009). In order to build up energy for the upcoming change, a mealworm larvae spends its time feeding and growing (Anna et al., 2020). After few weeks it then changes to a pupa and with merely the ability to wiggle. After several days, the pupa will go through the stage of life for one to three weeks as an adult beetle with a body and organs. The beetle is initially white with a soft exoskeleton. Then the outer shell will first turn brown and then black as it becomes harder. Despite having hard wings, the beetle is unable to fly. Beetles start mating and reproducing after one to two weeks of adulthood. Female darkling beetles can produce hundreds of eggs during their adult lifespan, making them productive breeders (Aguilar-Miranda et al., 2002). The whole life cycle takes for about two months (Figure 2.1).

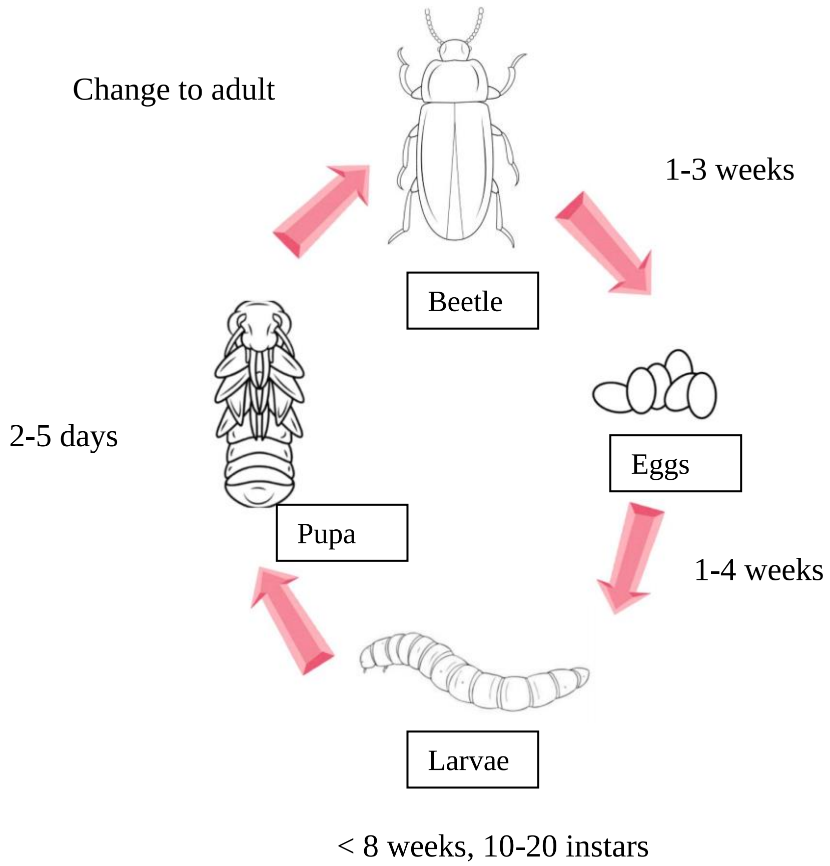

Figure 2.1 Life cycle of *Tenebrio molitor* beetle (mealworm)

Crickets

Crickets have three stages in their life cycle starting with egg, nymph, and adult (Vahed, 2020). Depending on their environment, they can live for more than six weeks and go through their whole life cycle in two months. A fertile female will lay eggs continually after mating. Female cricket will lay eggs on any moist substrate that is available using her ovipositor which is a tube-like device (Kelly et al., 2006). During its lifetime, a female can easily lay 100 eggs, and perhaps as much as 200 eggs (Mary et al., 2021). A cricket begins its life in an egg (Kelly et al., 2006). The insect will have transformed into a nymph after about 14 days (Hanboonsong & Durst, 2020). Nymphs resemble adult crickets in size, with few variances. They are not fully formed, thus during this stage they do not have wings or ovipositors in the females. Quite often the nymphs become prey for larger crickets and other insects. They also reported in their studies, in order to grow, a nymph has to shed its hard exoskeleton. This process which takes place 8–10 times is referred as moulting. The new exoskeleton is milky white and soft until it hardens in a few hours. A nymph's wings will start to develop after about a month. When a cricket reaches adulthood, its wings are completely formed, and its primary objectives are to eat and reproduce. Males will make an effort to entice fertile female. After mating, a female spends her time finding areas where she can lay her eggs (Mary et al., 2021). The whole life cycle takes for about two months as refer to (Figure 2.2).

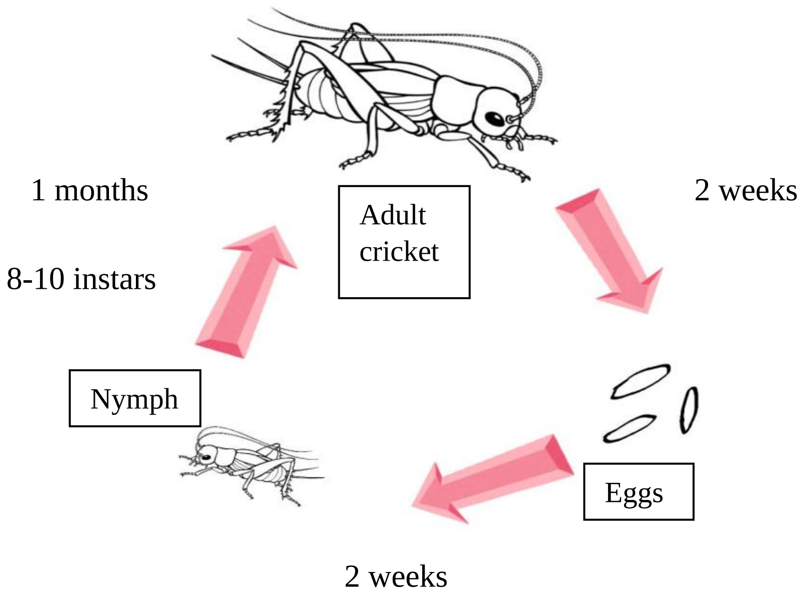

Figure 2.2 Life cycle of cricket (*Gryllus assimilis*)

2.2.6 Production of mealworms and crickets in different media

Crickets are, by nature, omnivores and their diet comprised of fruits, vegetables, and meat. Under natural conditions, they consume what they can find such as decaying leaves, decomposing fruits, vegetables, and other insects. On the other hand, mealworms are commonly fed on dog or cat food, expired cereals, chicken food, birdseeds, flour, fruits and vegetables. They also consume oatmeal, cornmeal and other grains (Melis et al., 2018). They consume fungus, seeds and rotting plants and can even ingest mycotoxin from contaminated wheat (Sanabria et al., 2019). Mealworms can consume leftover fruit and vegetable items, home garbage, waste from slaughterhouses, waste from mills, and other things as well (Ramos Elorduy et al., 2002).

The feeding capacity for the adequate use of the feed parameter for insects consumption, mealworms and crickets can tolerate up to 81% and 72.1%, respectively of food waste as feed (Kim, 2011). While, Changqi et al. (2020) reported that insects given at 71% of dry control feed, and 29% of variety of supplemented fresh feed, supplied the nutrients required for the insects to produce. This is supported by Michael et al. (2020) who showed that the supplementation of 22% fresh fruit wastes enhanced feed utilization and improved weight gain of insects. Thus, it can be concluded that the supplementation of fresh food wastes between 20% to 30% supported growth rates of insects.

As mentioned above, insect can also consume food waste in their diet (Ramos Elorduy et al., 2002). Food waste is the excess food contributed by humans, and biological residues from food handling plants, home, cafeterias and restaurants (Thyberg & Tonjes, 2016; Chen et al., 2017). The organic food waste from excess human food can be an important source of feed to insects despite the fact that protein and carbohydrate contents differ greatly. It depends on the insect's stage of growth productivity and on the phases and sex. The protein and carbohydrate requirements of adult females and males can be met by supplementing this source. Simpson & Raubenheimer (2009) reported that a fully-grown female insect cannot leverage on longevity and high egg production rate on a single diet, hence other diets such as excess human wastes with high protein quality need to be incorporated. However, the difference in nutritional requirements to achieve lifespan extension and to achieve optimum reproductive performance require formulations that are considerably different (Lee et al., 2008; Maklakov et al., 2008). There is a sexual variance in the adjustment between lifecycle and reproduction in females and males. This is because the females need high level of protein for reproduction, while males do not (Fanson et al., 2009).

Although protein is crucial for host resistance and produce immunological constituents to resist pathogen infections (Trudeau et al., 2001; Lee et al., 2006), subsisting on pure or higher than optimal level can badly affect the insect's growth and progress (Wilkinson et al., 2001; Cease et al., 2012). This is because protein diet alone is not sufficient to aid in mealworm growth and lifecycle hence other diets, such as organic wastes which comprise with variety of nutrient elements are required. South Korea and Taiwan are two countries which impose significant measures for animal feeds using food waste (Kim, 2011). In fact, insects supplied with feed composed of food wastes provided as good level of nutrition as the common basal diet. Waste food is considered an ideal alternative insect feed which is cost effective and environmentally friendly (Daniels, 2012).

2.3 Sustainable ruminant feed production in Malaysia

In feeding ruminants, it is important that some forage or fibrous feed source, such as grasses, legumes and agro-byproducts to maintain rumen function in ruminants. High concentrate diets can cause the lowering of pH in the rumen which lead to chronic acidosis, which can affect intake and utilization of nutrients. Concentrate, is complementary to roughage and usually referred as grains (wheat, corn) and it is low in fibre but high in energy or protein (Cheryl, 2010). In formulating diets for ruminants care must be taken to include at least 20%-25% of the diet with forages. Forages provide the cellulose which is digested by rumen microorganisms to produce volatile fatty acids which are the main source of energy for ruminants (Schröder et al., 2018). During the global feed crisis recently, the price of imported feeds rose steeply causing a decline in the livestock industry, and has helped to emphasise the significance of research and development in the use of insect meals in animal feed (FAO, 2021). The efficient utilisation of the non-conventional indigenous feed sources in livestock is another significant factor for increasing animal growth and development (FAO, 2018b). The participating nations also highlighted one of the top concerns to be addressed is the creation of ecologically friendly and economically viable techniques and their strategic application for managing the feed crisis (ECOSOC, 2008).

Protein, fibre, energy, and fat are the main deciding variables in the formulating of ruminant diets (Corbett & Freer, 2003). To complete the formulation of the feed, ruminants need several sources of nutrient such as fibre, energy, and additives. Overall, ruminants are best fed with the combination of forage, grain, protein supplement, and mineral (Yvonne, 2012). Ruminant feed can be divided into two types, roughage and concentrate (Jitendra et al., 2012; Rashid et al., 2016). Roughage is high in fibre and derives from plants and can be divided into two types which are grasses and browse which includes leaves, twigs, and shoots, and agricultural by-products, which include soybean hull, palm kernel cake, corn cobs, cottonseed hulls, sugar cane tops, cocoa pods and kenaf forage. Concentrate, on the other hand, is complementary to roughage and usually referred as grains and it is low in fibre but high in energy or protein (Cheryl, 2010). These two types of feed are significantly essential in a ruminant’s diet. In other countries, ruminants are usually supplied with specially formulated and balanced feed pellets, mash, cracked corns or barleys (Barbara, 2005). Some common feeds in other regions are corns, oats, barleys and soybean (Cheryl, 2010). In summer, ruminants browse their own feed on pasture or weed and during the winter season, they are usually kept indoors and given feed, such as hay or silage, water, and varying types of nutrients from various sources are necessary in order to cater to ruminant needs (Yvonne, 2012).