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Assessment of the Nutritional Value of Yellow Mealworm Cultivated on Fruit Waste

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ABSTRACT

Poultry meat is the inexpensive sources of protein for the humans. Poultry meat acceptability always depends on meat quality. Cereals, fishmeal, soybean are commonly used protein sources for Poultry Protein is major nutrient costing higher value compared to other ingredients. worms can be used as protein source because of limited resources. One such is the insect meal, which has come up as an alternative feed for poultry. This also improves the quality and taste of poultry meat which is desired by many people. The study involved rearing of fresh and dried mealworm (Tenebrio molitor) on fruit waste and their nutritional value will be analyzed. Mealworms are easy to breed and do not require large area for production. Therefore, yellow mealworm (Tenebrio molitor) meal can serve as a dietary protein in meat type poultry. This is because larvae of Tenebrio molitor (mealworms) are highly nutritious, containing high levels of protein and lipids. Using fruit waste is better means for confronting with waste pollution because it is a cheap and excellent organic material. An essential aspect involves understanding the nutritional profile of mealworms raised on fruit waste, and subsequent tests are performed to comprehensively evaluate their characteristics. However, further research is needed to explore the possibility of using mealworms as an alternative protein source to soybean, potentially reducing feed costs without compromising bird performance. T. molitor larvae show promise as a poultry protein source, but challenges include toxin mitigation, consumer acceptance, and pricing. Careful consideration of nutrition, biosafety, and market factors is needed for widespread adoption.

INTRODUCTION

Population is expanding rapidly. The requirement for food sources escalates. Poultry meat, a commonly available and affordable food source for humans [1]. Insects enriched with proteins could be an economical alternative to expensive protein supplements for chickens [2]. Protein sources rank as the second most significant component in the poultry sector [3]. Soybean and fish meal have been traditionally used as protein source while formulating feeds for broiler chicks, laying hens and other poultry birds. Soybean is most ideal due to its protein content, adequate amino acids proportion, whereas fishmeal serves an important protein source around the globe [1]. However, soybean and fish meals are expensive and scarce. In recent years, insect meal has come to the frontline as the affordable substitute for poultry feed which is rich in protein [1].

Yellow mealworms (Tenebrio molitor) they're insects emerging as sustainable protein sources, packed with vital nutrients. Yellow mealworm is an important insect which may be used as substitute for soybean meal or fishmeal providing valuable protein, energy and fatty acids. Mealworm is rich in protein 45.83%, lysine 4.51%

and methionine 1.34% [4]. The crude protein (CP) in mealworm meal (MWM) ranges between 25 and 60 percent while the fats range from 15 to 40 percent [1]. The scope of this research has several key areas. Firstly, the study will analyze the nutritional value of yellow mealworms reared on fruit waste, involve macronutrients, micronutrients, amino acids, fatty acids, and minerals. Secondly, the research will explore the environmental sustainability of raising mealworms on fruit waste by examining resource efficiency, greenhouse gas emissions, and waste reduction potential.

Additionally, Mealworm used as bio-indicators to monitor environmental conditions [3]. Moreover, it has been suggested as a valuable ingredient in chicken feed formulations, offering potential benefits in poultry nutrition [3].

Existing study include, mealworm feed on wheat bran, mare potatoes [5]. The mealworms are being fed a blend of semolina, flour, and oat flakes. [6]. However, there is a gap in understanding the impact of rearing mealworms on fruit waste on their nutritional composition. This study aimed to raise mealworms using fruit waste such as (apple cores, banana, Orange peels, etc) maintaining optimal temperature and humidity conditions. After rearing, evaluate the nutritional value of the mealworms, including protein content, amino acid profile, fat content, crude ash, and other relevant factors. The objective of this study to evaluate the nutritional value of yellow mealworms fed on fruit waste in order to discover whether mealworm farming is a possible substitute for protein. Life cycle monitoring will encompass larval development, pupation, and adult reproduction. Evaluating economic viability will include setup and operating costs, exploring the potential for increased protein yield with reduced waste. Research remains essential as commercial insect farms feed T. molitor with synthetic diet, hence the need for more studies on the subject [1]. Soybean and fish meal are used as protein source in the feed of poultry animals [1]. Due to the high demand of soybean and fishmeal their prices are high. Besides, the widespread use of soybean brings forth some environmental problems like deforestation, shrinkage of water resources and chemical application [1]. The quality of using fish meal also largely depends on fish catch that is prone to extinction of marine resources [1].

Insect farming has gained popularity over the years as insects being viewed as an animal feed and human food [2]. Besides, some elements in insect meal, which include chitin, lauric acid or antimicrobial peptides, contribute positively to a chicken's health [6]. Insects represent the most diversity with more than 1 million species described [6]. As far back as 1975, the suggestion of insects being used for human food and animal feed was made by Meyer-Rochow [6]. In 2017, the EU (Commission Regulation European Union) approved seven types of insects for use as pet food and aqua feed sources. In 2021, they were also admitted for use in poultry and pig sectors too [6]. However, among them insects are considered to be the protein source of the future because they are produced with less environmental impact, compared to traditional protein sources (fishmeal, soymeal, rapeseed meal and cottonseed meal) [6]. Insects have short lifespans, breed extensively, and convert plant protein into animal protein very well [7].

Yellow mealworm important insects used as alternative source of protein [1]. Essential amino acid index (EAAI) in MWM is higher compared to soybean meal and almost same or higher as in case of fishmeal [2]. Mealworms are the juvenile form of darkling beetles. Mealworms are cylindrical larvae with a tough exoskeleton and six small legs. progressing through four life stages: egg, larva, pupa, and adult. Found in decaying organic matter, they scavenge grains, vegetables, and detritus. Nocturnal and solitary, they burrow during the day. Reproduction occurs through eggs laid by adult darkling beetles. People use them widely as feed for pets, as fishing bait, and even as a food source for themselves. Mealworms have a life cycle lasting between 280 and 630 days. Female *Tenebrio molitor* beetles typically lay around 500 eggs, which hatch within 3-9 days and develop into larvae at a temperature of 25°C. The larval stage can last 1-8 months and has light yellow-brown color. Pupation lasts 5-28 days at 18°C, followed by an adult stage lasting 2-3 months. Larvae typically measure between 2.0-3.5 cm or larger, while adults are approximately 1 cm in size. [8]. They can take low-quality vegetable waste and turn it into high-quality protein, fat, and energy within a short period [9]. In commercial settings, Tenebrio molitor beetles are primarily fed cereal bran or flour (such as wheat, oats, and maize), with fruits and vegetables added for moisture [8].

Mealworm farming provides a promising solution for enhancing food and feed security. These insects grow and reproduce quickly [4]. Mealworm meal prices are reasonable [10]. The amino acid profile of yellow mealworm is close to the profile of soybean meal used as a reference [11]. In China, Mealworm is a famous dish for local people [3]. In Uganda, feed traders, processors, and poultry farmers are willing to accept insects, such as mealworms, as a protein alternative in poultry diets. Mealworms' nutritional content varies between fresh and dried larvae. Live mealworms have around 20% protein, 13% fat, and 62% moisture, while dried ones have higher protein (53%), fat (28%), and lower moisture (5%) levels [12]. Since 2000, the insect industry has seen rapid growth, marked by the emergence of several companies across the USA, Canada, China, South Africa, and Europe [13].

Microbiological analysis of mealworms with a focus on *Escherichia coli (E. coli)* and *Salmonella spp.* showed that they were not present thereby showing the safety in consuming meal worms by humans and animals. Nutritionists argue that such food may pose danger to health if not carefully selected and dried but some of them prefer to feed live (fresh) insects to birds in order to keep them healthy [1]. Use of fresh MWM in poultry diets has been reported: however, no case is reported for fish diet [1]. Meat quality was also improved following the inclusion of insect meal into diets for broiler chicks due to the functional constituents in the insects. Also, the whole fat MWM diet can be effective in reducing certain bacteria clustering in broilers [1]. It has lesser impacts on the environment, like global warming, decrease in diversity of species and soil erosion which have been associated with conventional production practices.

One of the major challenges is caused by the escalating the human population is increase in waste generated by economic works. By 2025, global urban populations are set to double. For instance, the Food and Agriculture Organization (FAO) reported that in 2007 alone, 1.6 billion tons of food waste were generated worldwide (14). To combat landfill overflow, researchers are exploring methods to reduce organic waste, such as utilizing mealworms (14). Insects hold potential for waste recycling, nutrition for animals/humans. Sustainability grows. Research has delved into the nutritional value of insect larvae, especially muscoid (*Diptera*) larvae, recommended for waste recycling like poultry manure. Early uses of insects like mealworms as animal food sources for their high protein content have been documented [15].

As the world's population increasingly escalates, food steadily gets consumed, which affects chicken meat production Sustainable feeds are an important matter and yellow mealworm manifest potential as an alternative one. Yellow mealworm shows promise for feed [9]. Using insects instead of traditional feed helps to increase efficiency and reduce hunger risk. Fish feeds contribute to 50% of aquaculture costs, leading to increased prices. Yellow mealworms, the most popular insects in Europe's bioconversions, produce valuable and high in nutrients food from waste [16]. Small-scale poultry farming which is very important for poverty reduction and protein supply. Increased feed costs and climate change represent the main hurdles for farmers. Research considers farmers' attitude towards adding yellow mealworm to poultry feed for further enhancing the goal of sustainable development, a circular economy, and food security [17].

In the Nordic countries, the dependence on local animal feed production is relatively low. Involving the use of mealworms from local agricultural by-products will enlarge a regional feed ingredient supply. Mealworms have high digestibility (~90%) for both dry matter (DM) and crude protein (CP). Research reveals that the fact that mealworm-based feed won't negatively affect birds' growth and it reduces the feed conversion ratio instead of soybean meal (SBM) [18]. In-vitro study shows insect meal digestibility of DM is similar to SBM and slightly lower CP rumen digestibility because of high fat content [18]. Meanwhile, their unsaturated fat may cause an improvement in methane emissions [19]

Insect rearing is environmentally promising due to low greenhouse gas emissions [20]. Insects require minimal land to produce 1 kg of [20]. In Asian countries, insect has been seen as food for its high protein content since long time ago [13]. North and South Korea have contrasting approaches to insect use: North Korea forbids insects being included in animal feed since they account for semi-animal proteins whereas South Korea uses both in human and animal diets [13]. South Korea decided to have insect legislation deregulated in 2015, and can be used without a specific rule and requirement [13]. In Canada, the Animal Feed Division of the Canadian Food Inspection Agency is responsible for feed regulations and accepts feed and feed ingredients records [13]

Mealworms, also known as Tenebrio molitor, have high magnesium and zinc but lack calcium. They're rich in niacin, pyridoxine, riboflavin, folate, and vitamin B12. Their protein-fat-carb ratio rivals' beef and poultry. Calcium-enriched diets are used to address their calcium deficiency [21]. Commercial mealworm farming is more environmentally friendly than chicken or beef production, requiring similar energy but less land and emitting fewer greenhouse gases and ammonia [22]. The mealworm beetle's microbiota is affected by antibiotics, reducing bacterial diversity and load, yet remains stable against environmental factors [23]. Sterile mealworms show poor performance [23]. This indicates that the microbiota contributes to the efficient digestion and detoxification of harmful phytochemicals [23]. Antibiotic use in other insects can shorten development time and decrease egg numbers [23].

MATERIALS AND METHODS

This innovative technique in breeding of the mealworms mainly uses kitchen trimmings as a natural environment that has high concentrations of the minerals and vitamins. A good, vented container preferably made of plastic or wood coupled with a lid for humidity. That includes kitchen wastes such as fruit like (apple, banana, grapes, etc.) and vegetable peels, like (carrot, radish, potato etc.) coffee grounds, eggshells, and breadcrumbs except acidic citrus fruits. Wheat bran or oats acts as a layer of bedding under which meal worms will pupate and be maintained with correct humidity. Evaluating feed potential, growth capacity and nutritional quality of Yellow Mealworm. 50 Beetles will be purchased from a Rumi farmer a local market in Karachi as a sample. A good, vented container preferably made of plastic or wood coupled with a lid for humidity. Firstly, investigate the influence of food to their mortality and/or lifecycle. For 20 days, the beetles are reared in a plastic container of 750 ml (width 5inch, length 7inch, height 2.5inch). 20g fruit waste was offered to the beetles into 20g of wheat bran provides as a substrate. Afterwards, a small number of *Tenebro molitors* larvae are introduced into the separate container in an effort to ensure uniformity. The larvae need to eat, and for this purpose; a moisture-retaining sponge or cotton ball can serve as a water source. The beetles are maintained at an ambient temperature of 25°C, at 70% relative humidity, and under constant dark surroundings. HTC1 temperature, humidity meter (Didilog Electronics) is a device to measure humidity. Larva consume 20g feed in 3 days. Then, after 20 days adults are relocated in new containers as their room for nestlings is vacant. Larvae remain in the container. The rearing environment must have a constant room temperature of about 24–27 °C, with natural sunlight or low intensity artificial light. Moisture level monitoring, as well as the general health and development of mealworms is accomplished by subjecting regular inspections. Understanding the nutritional profile of mealworms raised on kitchen waste is essential for performed following tests.

Figure 1

(a) Darkling beetles feed on fruit (b) Vermibed of mealworms contains wheat bran as substrate and fruit waste as a food source.

Figure 2

(a) juvenile of darkling beetle at day 1. (b) Adult mealworms after rearing of 120 days.

Proximat Analysis

Crude Ash Determination

Weigh 1-2 gram of sample into pre-weighed porcelain crucible. The crucible will be heated on an oxidizing flame until no smoke is evolved. The crucible will then be placed in a muffle furnace at 550°C for four hours. After four hours, the crucible will be transferred to a desiccator and allowed to cool to room temperature. The crucible, now containing ash, will be weighed as quickly as possible to prevent moisture absorption. The weight of the ash will be calculated by subtracting the weight of the empty crucible from the weight noted in the above step.

Formula

$$\text{Ash\%age} = \frac{\text{weight of Ash}}{\text{weight of sample}} \times 100$$

Dry Matter Estimation

The weighing dish will be kept in a drying oven for one hour at 105°C. After one hour, the dish will be transferred to a desiccator, and after cooling, it will be weighed (a). Approximately 5 grams of the sample will be taken in the dried dish, and the collective weight of the dish and sample will be noted (b). The dish, now containing the sample, will be kept in a drying oven at 105°C for one hour.

Subsequently, the temperature will be reduced to 65°C until a constant weight is achieved. The dish will be cooled down in a desiccator. The collective weight of the dish and dried sample will be noted (c), and the weight of the dried empty dish will be subtracted from it.

The dry matter will be calculated using the following formula.

Formula

$$\text{Dry method \%} \ \frac{\text{Weight of sample}}{\text{weight of sample before drying}} \times 100$$

Protein Analysis

Used a protein analysis method such as the Kjeldahl method to determine the total protein Content. The feed sample of Mealworm will weigh 1-2 grams. The feed sample will be boiled with concentrated H2SO4 in the presence of the digestion mixture. The digested material (NH4)SO4 will produced is then diluted and distilled in the presence of 40% NaOH solution. Add 40-50 ml of distilled water to the digested material and transfer the mixture to volumetric flask. A 10 ml portion of this diluted material, along with 10 ml of 40% NaOH, will be placed in the Kjeldahl apparatus. We will collect the NH3 gas evolved from the distillation in a 2% boric acid solution containing 1-2 drops of methyl red or mixed indicator. A 10 ml portion of the distilled material will be taken in a conical flask. The sample will be titrated against N/10 H2SO4. The percentage of nitrogen will be multiplied by the factor 6.25 to obtain the percentage of protein in the sample.

C.P estimation is carried out in three following steps:

- Digestion
- Dilution & Distillation
- Titration

Fatty Acid Analysis

Hydrolysis procedure for samples of dry animal feed , this method is used to determine the total crude fat content. Petroleum ether, 40-60C, with an evaporation residue not higher than 10mg/l. Boiling stones. 70ml of solvent will poured into the glass extraction vessel, previously will weighed with a tolerance margin of 1mg. 60 min with the crucible dipped in the boiling solvent. 60 min of reflux washing. The vessels with extracted with boiling stones in an oven at 103 c for 30 mints. Cool in a dissector. The glass extraction vessels containing the extract will weighed with a tolerance margin of 1 mg.

Formula

Total crude fat %age= W2-W1/SW ×10

Ether Extraction

The feed sample is boiled in the presence of ether by using the Soxtherm apparatus. This warmed ether dissolves the fat from the sample and we get fat free material. The feed sample will be weighed, 1-2 grams of the sample will be carefully placed onto a 10x10 filter paper. The filter paper will then be folded and securely stapled to prevent any excretion of the feed sample. The folded filter paper, containing the feed sample, will be placed into the thimble of the Soxtherm apparatus and closed tightly. In a beaker, 30-40 ml of ether will be added, and the beaker will be placed on a heater plate to boil the ether. As the ether boils, it will rise and flow towards the thimble, facilitating the dissolution of fat from the sample. Tap water will be introduced into the process to cool down the boiled ether through condensation. This process will be continued for 30 minutes, and the step will be repeated 2-3 times to ensure thorough fat extraction. The warmed ether will dissolve the fat from the sample, resulting in the production of a fat-free material.

Formula

$$\text{E. E\%age} = \frac{\text{Initial weight}}{\text{Final wight of sample}} \times 100$$

Crude Fiber Estimation

The resultant product of the ether extract will be mixed with 200 ml of 1.25% H2SO4. The mixture will be boiled for 30 minutes. After boiling, the solution will be filtered using a piece of linen cloth to obtain the filtrate. The filtrate will be mixed with 200 ml of 1.25% NaOH. The solution will be boiled again for 30 minutes. After boiling, the solution will undergo a second filtration using a piece of linen cloth. The obtained filtrate will be placed in an oven for 30 minutes at 105°C for drying purposes. The weight of the dried material will be recorded, representing the residue weight. The residue obtained will be placed in a muffle furnace for 3-4 hours at 550°C. After the muffle furnace treatment, the sample will be weighed again. This final weight will be referred to as the residue weight after complete combustion.

Formula

$$\text{Crude fiber \%age} \frac{\text{Residue weight}}{\text{Final weight of sample}} \times 100$$

Microbiology Analysis

25 grams of substrate and around 60live mealworm larvae were collected, cut up using a sterile scalpel and mixed with 20 ml of sterile peptone water dissolved per liter solution contained in a test tube. This microbial enumeration used 10-fold dilution of samples with a hundred microliters taken for EB, TAC and YM enumeration. Three M Petri film and SGC2 agars were used for counting of enterobacteria and mold/yeast determination. To make sure that the results were strong and true, this microbial analysis was carried out 4 times.

Statistical Analysis

After determining normality and homoscedasticity, the data will be presented as mean ± standard error and subjected to a one-way ANOVA using the GLM technique of IBM SPSS Statistics for Windows (version 25.0, IBM Corp., Armonk, NY, USA). A 2 x 2 factorial layout will be used for the data in the low CP groups. Particular probabilities between low CP groups will be given in the tables to improve the understanding of the results. Tukey's honestly significant difference (HSD) test will be used to evaluate treatment differences at a significance level of 5%. The purpose of this statistical method is to enable the detection of significant differences between the experimental groups and to give a solid analysis.

Nitrogen Free Extract
Nitrogen free extract will be determined by subtracting the percentage of ash, crude protein, crude fiber extract from 100.

Formula
NFE% = 100 – (ash %age + crude fiber %age + ether extract %age + protein %age)

Gross Energy (Keal/Kg)
To measure the Higher Heating Value (HHV) of biomass fuel using a Bomb Calorimeter, the sample preparation involved grinding about 1 gram of biomass, condensing and pelletizing the fine samples into capsules, and then weighing and recording the data of both sample pellets. These pellets were loaded into the capsule, which was then placed into the bomb cylinder and capped. Oxygen was filled into the bomb using the Calorimeter Operation menu, and the bomb was carefully placed into the pail, which was placed in the calorimeter. Ignition wires were connected to the bomb head, and 2 liters of water at 25-27oC were added to the pail. The bomb's leakage was checked, and the calorimeter lid was closed. The Operation Mode was set as Determination, and the sample ID, bomb ID, and sample weight were inputted sequentially. After pressing Start, the calorimeter processed the sample. The result was printed upon completion of the test. Subsequently, the lid of the calorimeter was opened, and the pail with the bomb was removed. The bomb was taken out, and its valve knob was slowly loosened to release pressure. Finally, the bomb head and cylinder were rinsed, dried, and cleaned for the next test.

PH test
The pH test of mealworms was conducted by measuring the acidity or alkalinity level of their environment or bodily fluids. A sample of mealworms and their substrate or bodily fluids was collected, and pH testing strips or a pH meter was used to determine the pH level. This test helped assess the overall health and conditions of the mealworms' environment, aiding in their care and management.

Duration of Study
Laval stage of mealworm will be fed on fruit waste for about 3 months.

Ethical Considerations
All the birds and the experimental protocols in this study were approved by the Departmental Animal Care and Use Committee of Superior University, Lahore, Pakistan.

Data Collection Procedure
Human sources, articles, internet.

RESULTS AND DISUSSION
According to [8], The crude protein content of T. molitor larvae averages at 52.4%, with a range between 47.0% and 60.2%. This surpasses the protein content of conventional soybean meal (49.4%) and falls short of fishmeal (67.5%). I aspect that our CP value of mealworms is greater than this study. The chitin exoskeleton, composed of glucosamine and N-acetylglucosamine polysaccharides, is classified as non-protein nitrogen and deemed indigestible protein. Recent studies propose that the nitrogen-to-protein conversion factor for T. molitor larvae ranges between 4.74, 4.75, or 5.41 [8].

The crude fat content of T. molitor larvae surpasses that of SBM (1.4%) and fishmeal (10.4%) as reported by the National Research Council (NRC). Conversely, the average crude ash content (4.2%) of T. molitor larvae is lower compared to SBM (7.2%) and fishmeal (17.2%) also reported by the NRC. The range of crude ash content for T. molitor larvae spans from 2.65% to 6.99% [8].

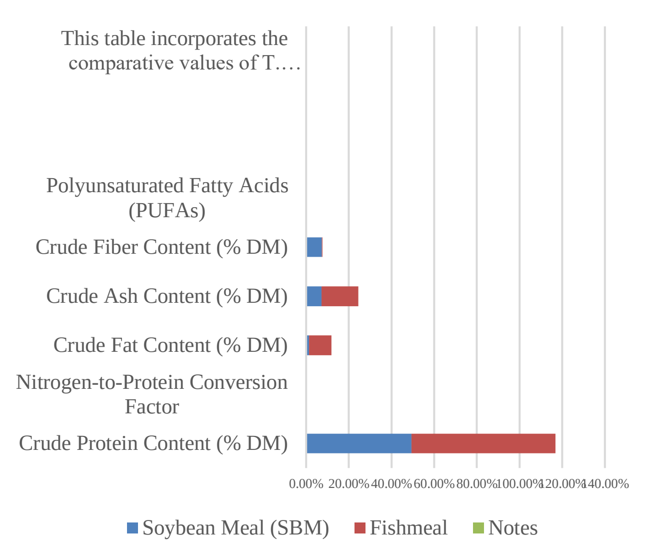
The average crude fiber content of T. molitor larvae is 7.43%, with a range from 4.19% to 22.35%. This average is comparable to that of SBM (7.43%) and notably higher than that of fishmeal (0.26%) [8].

Table 1

Nutrient	T. molitor Larvae	Soybean Meal (SBM)	Fishmeal	Notes
Crude Protein Content (% DM)	52.4% (Range: 47.0%–60.2%)	49.4%	67.5%	Expected higher CP value in current study
Nitrogen-to-Protein Conversion Factor	4.74–5.41	N/A	N/A	Non-protein nitrogen due to chitin
Crude Fat Content (% DM)	Higher than 10.4%	1.4%	10.4%	Expected higher fat content in current study
Crude Ash Content (% DM)	4.2% (Range: 2.65%–6.99%)	7.2%	17.2%	T. molitor ash content is lower
Crude Fiber Content (% DM)	7.43% (Range: 4.19%–22.35%)	7.43%	0.26%	Expected higher fiber content in current study
Polyunsaturated Fatty Acids (PUFAs)	Omega-3: 46.1–47.3 g/100g	N/A	N/A	Expected higher PUFA values in current study
	Omega-6: 31.1–31.6 g/100g			

This table (1) incorporates the comparative values of T. molitor larvae with SBM and fishmeal, highlighting areas where your expected values may surpass those from the referenced study.

Figure 3
shows the comparative analysis of soybean, fishmeal and notes



Moreover, T. molitor larvae contain essential polyunsaturated fatty acids (PUFAs), including omega-3 and omega-6 acids. Specifically, they contain between 46.1 to 47.3 g/100 g of omega-3 acid and 31.1 to 31.6 g/100 g of omega-6 acid.

The values of crude protein, fatty acids, and fiber in my mealworm larvae will be higher than those reported in this study by proximate analysis.MWM has more crude protein (CP) than traditional protein sources [1]. Diet significantly influences insect growth and performance. Therefore, it's crucial to develop a good artificial diet for insect farming systems, including mass production of beneficial arthropods, phytophagous insects, and insects raised for food or feed as a nutrient source [2]. In the case of T. molitor, efforts have been concentrated on developing artificial diets for T. molitor to enhance larval biomass production while ensuring high nutritional value. The study examined the effects of different food byproducts and compound feeds on the larvae of *T.molitor* are feed in various food sources such as wheat bran, durum wheat flour, corn flour, and white flour. Additionally, they were observed in the two tested compound feeds: egg-layer hen feed and milk-based feed. Results revealed that feeding larvae with high-protein milk-based feed or chickpea flour led to larvae with high protein content [2].

Accordingly [5], mealworms were divided into 3 groups Each group was assigned a specific type of feed: the 1st group received wheat bran, the 2nd group received ware potatoes, and the 3rd group received dried whey. Results showed that 1st, 2nd, 3rd groups CP was (58.0%, 54.0%, 59.0%), fat content was (0.0342, 0.050, 0.043), respectively.

The experiment included starter and grower phases for each diet, followed by regular finisher feeds. The experimental diets for each phase were iso-nitrogenous and iso-energetic and their ingredients and chemical nutritional characteristics were shown. Among the three treatments, one was the control group (C), which was fed a standard commercial diet (crude protein, CP = 23.75%, metabolizable energy, ME = 12.66 MJ/Kg at starter phase and CP = 21%, ME = 13.21 MJ/Kg at grower phase) during the experimental period. Another two experimental rations were formulated by substituting 2.5% and 5% of the basal diet by TM meal [11].

Rearing insects, particularly mealworms, using organic waste has gained attention as an eco-friendly method for waste management and protein production. Kitchen waste, including fruit and vegetable leftovers, grains, and other organic materials, serve as easily accessible feed for mealworm breeding. This study aims to assess the nutritional value of mealworms raised on fruit waste, focusing on protein content, fatty acid, vitamins, minerals, and environmental sustainability.

Mealworms reared on fruit waste exhibit notable protein content, rendering them a viable source of protein. It is higher than other previous studies. This protein content is essential for muscle development, growth, and overall health.

Mealworms reared on fruit waste have been found to possess adequate fat content, providing a valuable source of essential fatty acids such as omega-3 and omega-6. These fatty acids contribute to heart health, brain function, and inflammation regulation, thereby enhancing the nutritional value of mealworms as a dietary component. Sea species are a primary source of essential fatty acids, but recent research shows that mealworms can also provide these nutrients. This discovery highlights mealworms' potential for various applications beyond their traditional use, including feeding domestic animals, serving as a food supplement for humans, and contributing to recycling efforts.

Fruit waste contains a spectrum of vitamins, including vitamin A, vitamin C, and various B vitamins. Through bioaccumulation, mealworms reared on fruit waste can assimilate these vitamins into their biomass, enriching their nutritional composition. The inclusion of mealworms in the diet can thus provide a natural source of vitamins, potentially addressing micronutrient deficiencies in both human and animal diets.

Furthermore, the crude fiber content of mealworms reared on fruit waste is a notable aspect of their nutritional value. While traditionally associated with plant-based foods, dietary fiber plays a crucial role in digestive health and nutrient absorption. The utilization of fruit waste as a feed source introduces dietary fiber into the mealworm diet, contributing to the overall fiber content of their biomass. This dietary fiber content can have positive implications for gastrointestinal health and may confer additional health benefits to consumers.

CONCLUSIONS/RECOMMENDATIONS

T. molitor larvae demonstrate considerable promise as a protein source for poultry. Certain countries have approved commercially produced *T. molitor* larvae or protein concentrate products for use as protein supplements. Numerous studies have been conducted to assess the efficacy of incorporating *T. molitor* larvae into diets for monogastric animals. Nevertheless, the utilization of *T. molitor* remains constrained by its ability to mitigate toxins and heavy metals. Additionally, consumer acceptance of meat products from monogastric animals fed insects, along with the pricing of *T. molitor* larvae, poses significant challenges that must be addressed for widespread adoption as an alternative protein source in feed. Thus, the integration of *T. molitor* larvae into monogastric animal feed as a sustainable protein source necessitates careful consideration of factors such as nutritional value, biosafety, consumer perception, and market pricing.

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