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Nutritional Value of Mealworm, *Tenebrio molitor* as Food Source

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Nutrition value of mealworm, *Tenebrio molitor* was analyzed due to increasing demand of usage as a protein source for domestic animals and even further for human consumption. The purpose of the present work was to determine the chemical compostion of the *Tenebrio molitor* larvae, adult that were maintained under standard condition for further usage of mass-rearing system and its exuvium, and excreta. *Tenebrio molitor*, larvae, adult, exuvium and excreta contained 46.44, 63.34, 32.87, and 18.51% protein respectively, suggested that even excreta could be used as an additional supplement in food recycling process. This protein was also rich in amino acids such as Isoleucine, leucine and Lysine which all met the nutritional value recommended by the Food and Agriculture Organization. Fatty acid composition was detected with high component of oleic acid (C18:1), along with linoleic acid (C18:2) and palmitic acid (C16) in all adult, larvae, exuvium and excreta. These oleic acid (C18:1), linoleic acid (C18:2) and palmitic acid (C16) components were the same or even highly contained in excreta of mealworm 22.29, 47.19 and 19.17% respectively. Longer chains of unsaturated fatty acids consisted of two to three double bonds are known as healthy product was recognized in large amount. These results show new ways to consume mealworms and its waste for animal and human consumption.

Key words: *Tenebrio molitor,* Protein, Fatty acids, Excreta

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Introduction

There will be a huge economical change involved, if insects become more considered as commonly acceptable food source for both human being and domestic livestock in industrial countries (Defoliart, 1992b). Insects has a potential being an agent in recycling waste products and resources for highly nutritive diet for many other domesticated animals as well as for human consumption. Economical attention on insects as protein source into both human and animal food marketing is increasing among food producers along with escalating conventional cost of protein source such as meat, fish meal and soybean meal (Ng, Liew et al., 2001).

Worldwide, nearly about 1500 species of edible insects are reported across 113 countries with 300 ethnic groups. As human nutrient source in traditional food, insects have potentially used among indigenous people in the history. (Defoliart, 1992a). Insects supply 5%-10% of animal protein source including fats, calories, vitamins, and minerals among some ethnic groups (MacEvilly, 2000).

Furthermore, as an attractive and important natural food source, insects have been used for various kinds of animals, such as birds, lizards, snakes, amphibians, fish, insectivore, and other mammals (McHargue, 1917; Frost, 1942; Brues, 1946). Previously, a number of studies have dealt with Nutritional value of muscoid(Diptera) larvae or pupae which are recommended to recycle the waste products from poultry manure and other organic wastes for high protein containing broiler production (Defoliart, 1946). The early use of mealworm known as animal food source for accessing to high protein source was summarized in Davis (Cotton and George, 1929).

Moreover, a large portion of invertebrates including mealworm are commonly used as food source for many species in captivity. Foods given to these species were based on the observation, however beside this behavioral aspect, it is important to analyze nutritional composition in formulating food (Barker *et al.*, 1998).

Present study conducted to support a more comprehensive summary of the nutritional content of mealworm, *Tenebrio molitor* that can be used as evaluated diets of animals in captivity, and even further for human consumption.

Material and Method

Insect samples were taken from the group that was maintained at insectariums of division of applied entomology at National Academy of Agricultural Science since 2011. Mealworm were then reared in constant indoor condition at 25±1°C, 50% (±10%) relative humidity with a 14 L: 10D photoregime. Wheat bran likely the main food for mealworm and vegetable such as cabbage, reddish and carrot etc was added as water source twice a week.
All the tests were taken place at Foundation of Agri. Tech commercialization and Transfer Analysis and Certification Division.

Protein, fatty acid and fiber analysis
Protein, fatty acid and fiber analysis was carried according to Randall, Soxtec and Diethylether Extraction-submersion method (AOAC, 2003). However different apparatuses were applied to proceed analysis such as Foss kieltec analyzer, Foss soxtec TM 2050 and ANKOM2000W for each crude protein, fat and fiber respectively. Ca 100-200 mg sample was weighted 1-5 g test portions into tarred cellulose thimbles. While draining each portion, test portion was measured into thimble. The filter paper that used for washing test portion into thimble was taken and dried at 102±2°C for 2 hours. In order to use filtration, 1-2 g ash, acid washed sand (EM SX0075-3, or equivalent CAS 14808-60-7) or Celite(545) were additionally poured to bottom of filter or mixed in with test portion prior to water extraction. Prevention of solvent and test materials from absorbing extraction water-soluble components including carbohydrates, urea, lactic acid, and glycerol were considered. Defatted cotton (soak medical grade cotton in diethyl ether of hexanes for 24 hours, agitating several times during this period) was put before absorbing the melted fat in the pre-dry step. Also, it was possible to add cotton on top of test portion before 102°C±2°C, 2 h drying step. Insert three to four 5 mm glass boiling beads into each cup, and dry cups for minimum 30 min at 102°±2°C. After transferring into desiccators and cooled down at room temperature, extraction cups were weighed to nearest 0.1 mg. Before attaching thimbles that contain dried test portions to extraction columns, extractor was preheated and condenser in cooling water had to turn on. While thimbles are in the boiling state, significant amount of solvent were applied to each extraction cup to cover test portion. The matches of cups with corresponding thimbles were checked after placed under extraction columns. Thimbles were reduced into solvent and boiled for 20 min. For sample extraction completion, the critical reflux rate was verified. Thimbles were extracted up to 40 min after raised out of solvent. In order to obtain solvent and attain apparent dryness, the possible amount of solvent was evaporated. Evaporating solvent was wrapped up when extraction cups (aluminum of glass, extraction temperature settings many differ; consult manufacturer's operating instructions) were removed from extractor and transferred into operating fume hood at low temperature. Moisture was removed by drying extraction cups in an oven set at 102°±2°C for 30 min; lastly, dry extraction cups were cooled in desiccators at room temperature and weighed to nearest 0.1 mg.

Amino acid, crude ash and minerals analysis
Amino acid, Crude ash and minerals contents of mealworm sample was performed by the methods of the Association of Official Analytical Chemists (AOAC, 1990). Hitachi L-8900 amino acid analyzer apparatus was used for amino acid analysis.

Moisture
The moisture content was determined by drying the wet sample to a constant weight in an air circulating oven at 70–80°C.

Crude ash
Vecstar Furnace divison apparatus used performed for crude ash test. For the preliminary process, cruciform was burnt at electric stove, 600°C for 1-2 hours and then cooled down for 40 mins. After weighing, 2-3 g sample was taken and put into increased temperature an electric furnace or gas burner prior to next step. Sample was again placed in electric stove to burn for 2 hours and cooled down at desiccators for 40 min. After drying, the crude ash content was found by burned sample weight.

Minerals analysis
Mineral samples were tested by using GBC Inductively coupled plasma integra XL ANKOM 2000W.

Mineral samples
Hydrolysates have been reduced by about half, covered with a watch glass, and then taken into a 100 ml Erlenmeyer flask samples 0.5~1.0 g ml of hydrochloric acid solution (1:1) ml by heating slowly filtered by the filtration method.
Fluid samples.

Hydrochloric acid solution (1:1) 1 ml samples takes a certain amount of liquid in 50 ml volumetric flask and put 10 ml of 5% lanthanum solution (solution of 1% lanthanum content to be), putting the flask with distilled water focuses preset 30-minute warm-up period. One atomic absorption spectrophotometer to measure the absorbance at the wavelength of 422.7 nm. To 0, 2, 4, 6, 8, 10 ppm mineral standard solution taken in 50 ml volumetric flask and then incubated here in lanthanum solution 10 ml then fill to the mark with distilled water.

$$\text{Mineral (\%)} = \frac{\text{Absorbance of the sample solution absorbance / 1ppm standard dilution}}{\text{Sample weight (g) * 10 (6square)}} * 100$$

Result

Table 1 illustrated the proximate composition of *T. molitor* larvae, adult, exuvium and excreta. The total protein content of *T. molitor* larvae, adult, exuvium and excreta were 46.44, 63.34, 32.87, and 18.51% respectively; resulted lower protein content (58.4% larvae) compare to the previous study (Aguilar-Miranda *et al.*, 2002). However the adult protein content (63.34%) was higher than the both larval result of previous and present study, indicating also, potential usage of adult mealworm. As it was reported in Mark (2002), mealworm contained sufficient amount of protein to meet requirements of National Research Council(NRC) for the laboratory rat growth. Moreover, Table 1 the total protein content was 18.51 in excreta showed, incredible high protein content as a waste product suggesting that the excreta even cold be used as additional supplement in food recycle process for animal feeding.

Next, the total fat content was 32.7, 7.59, 3.59 and 1.3% for *T. molitor* larvae, adult, exuvium and excreta respectively. The mealworm larvae presented an average fat content (32.7%) value when compared to human edible insects such as Locust, *Locustana spp*. (21.5%), Grasshoppers, *Zonocerus sp*.(3.8%) and termites, cooked (61.1%) (Bukkens, 1996).

Table 1. Proximal content of *Tenebrio molitor* larvae, Adult, Exuvium, and Excreta (Precent, Dry Basis)

Component	Larvae	Adult	Exuvium	*E*xcreta
moisture	5.33	3.54	13.02	12.2
crude protein	46.44	63.34	32.87	18.51
crude fat	32.7	7.59	3.59	1.3
crude fiber	4.58	19.96	25.96	13.66
crude ash	2.86	3.56	3.22	7.29

Amino acid composition

In Table 7, the result of amino acid content of larvae was compared with previous larval result and essential human requirements of amino acid (FAO/WHO/UNU, 1986). The result showed that amino acid composition met the requirements of not only domestic animals but furthermore human being. According to Table 7, in general, amount of detected amino acid was normal except Cysteine (CYS)+Methionine (MET) (1.18 g/100 g protein) and Phenylalanine(Phe)+Tyrosine (Tyr) (5.21g/100g protein).

Overall, insects contain higher amount in lysine and threonine which are deficient in most commonly used wheat, rice, cassava and maize, but lower amount of amino acids, methionine/ cysteine (Defoliart, 1992b).

Fatty acid composition

Remarkable composition of the long chain of fatty acids (C18-C22) in Table 3, were detected with the highest component oleic acid (C18:1) along with linoleic acid (C18:2) and palmitic acid (C16) as values 43.17, 30.23, 16.72%, respectively. Amazingly, these amino acids still

Table 7. Amino Acid content of *Tenebrio molitor* larvae, Adult, Exuvium, and Excreta (Grams per 100 g of Protein)

						FAO/WHO/UNO[2]	
Amino acid	Larvae	Adult	Exuvium	excreta	Larvae [1]	Child	Adult
Isoleucine (IIe)	3.556	3.918	1.9	0.33	2.6	2.8	1.3
Leucine (Leu)	3.405	5.165	1.981	0.368	4.6	6.6	1.9
Lysine (Lys)	2.906	2.227	1.009	0.193	1.6	5.8	1.6
Cysteine (CYS)+ Methionine(MET)	1.189	1.134	0.426	0.251	1.6	2.5	1.7
Phenylalanine(Phe)+Tyrosine (Tyr)	5.219	3.173	3.016	0.366	7.5	6.3	1.9
Threonine (THR)	1.807	2.153	1.124	0.276	2.7	3.4	0.9
Valine (VAL)	2.439	3.368	2.423	0.253	3.8	3.5	1.3
Histidine (His)	1.527	1.71	1.236	0.438	2.1	1.9	1.6

[1] Larvae information was adapted from E.D.Aguilar-Miranda (2002)
[2] Information from FAO/WHO/UNU (1986)

Table 2. Amino Acid content of *Tenebrio molitor* larvae, Adult, Exuvium, and Excreta (Grams per 100 g of Protein)

Amino acid	Larvae	Adult	Exuvium	Excreta
Cysteine (CYS)	0.517	0.587	0.316	0.186
Methionine (MET)	0.672	0.547	0.11	0.065
Aspartic acid (ASP)	3.591	3.95	1.886	0.486
Threonine (THR)	1.807	2.153	1.124	0.276
Serin (SER)	2.091	2.204	2.055	0.29
Glutamic acid (GLU)	5.676	5.236	3.129	0.559
Glycine (GLY)	2.41	5.443	3.901	0.53
Alanine (ALA)	3.685	4.786	2.815	0.302
Valine (VAL)	2.439	3.368	2.423	0.253
Isoleucine (IIe)	3.556	3.918	1.9	0.33
Leucine (Leu)	3.405	5.165	1.981	0.368
Tyrosine (Tyr)	3.46	1.635	2.036	0.168
Phenylalanine (Phe)	1.759	1.538	0.98	0.198
Lysine (Lys)	2.906	2.227	1.009	0.193
Histidine (His)	1.527	1.71	1.236	0.438
Arginine (Arg)	2.434	2.632	1.05	0.255
Proline (Pro)	3.019	3.433	2.659	0.396

Table 3. Fatty acid content of *Tenebrio molitor* larvae, Adult, Exuvium, and Excreta (Grams per 100 g of Protein)

Fatty acid	Larvae	Adult	Exuvium	Excreta
Myristic acid (C14:0)	3.05	1.84	2.89	1.21
Palmitic acid (C16:0)	16.72	18.65	26.12	19.17
Palmitoleic acid (C16:ln7)	2.67	2.2	3.67	1.7
Stearic acid (C18:0)	2.49	6.17	6.55	3.6
Oleic acid (C18:ln9)	43.17	36.74	33.15	22.29
Vaccenic acid (C18:ln7)	0.03	0.57	1.66	1.03
Linoleic acid (C18:2n6)	30.23	32.46	23.51	47.19
γ-Linoleic acid (C18:3n6)	0.05	0.16	0.09	0
Linolenic acid (C18:3n3)	1.36	0.74	1.29	3.19
Eicosenoic acid (C20:ln9)	0.24	0.45	1.06	0.63
Arachidonic acid (C20:4n6)	0	0	0	0
Eicosapentaenoic acid (EPA)(C20:5n3)	0	0	0	0
Docosatetraenoic acid (C22:4n6)	0	0	0	0
Docosahexaenoic acid (DHA)(C22:6n3)	0	0	0	0
Fatty acid (total)	100	100	100	100

remained with high amount in adult , exuvium and even excreta, indicating that most potential of recycling the all the products from mealworm including excreta. In the case of the amount of fatty acids of linolenic acid (C18:2)

Table 4. Mineral content of *Tenebrio molitor* larvae, Adult, Exuvium, and Excreta (mg of mineral / kg of sample)

Mineral	Larvae	Adult	Exuvium	Excreta
Plumbum (Pb)	0	0	0	0
ƒ´µÂ¼Ý(Cd)	0	0	0	0
Arsenic(As)	0	0	0	0
mercury(Hg)	0.05	0.084	0.13	0.077
Calcium(Ca)	434.59	484.39	801.14	1537.97
Phosphorus(P)	7060.7	8087.07	5252.29	14552.01
Potassium(K)	9479.73	10459.8	14725.66	21171.75
Iron(Fe)	66.87	78.71	55.86	127.75
Natrium (Na)	3644.84	4302.73	6343.16	3954.33
Magnesium(Mg)	2026.88	1932	1388.09	7135.14
Zinc (Zn)	104.28	108.98	265.18	101.31
Copper (Cu)	13.27	18.01	10.04	10.73

Table 5. Bacterium content of *Tenebrio molitor* larvae, Adult, Exuvium, and Excreta

Bacterium	Larvae	Adult	Exuvium	Excreta
E. coli	Undetected	Undetected	Undetected	Undetected
Salmonellaspp.	Undetected	Undetected	Undetected	Undetected

and palmitic acids (C16), which were richer in excreta (19.17 and 47.19%, respectively) than larval stage; but was lower compare to exuvium (26.12%) in palmitic acids (C16). In addition, comparatively high amount of omega 3, 46.1, 39.97 and 39.54% were found in larvae, adult, exuvium and excreta respectively. Oleic acid known as unsaturated fatty acid found in plant products and responsible to lower blood pressure and the level of cholesterol in human blood. Also the amount of omega 6 were detected 31.64, 33.36, 24.89 and 50.38% in each of larvae, adult, exuvium and excreta. Omega 6 acid, an essential polyunsaturated fatty acid that produces the lipid component of all cell membranes in our body was significantly observed. These essential fatty acids are mostly available in sea species were found mealworms is demonstrating that it can be used for many other purposes such as feeding of domestic animals , food supplement for human being and recycling supplement etc.

It has been reported that by insect's caloric value 50% were higher than soybeans; 87% were higher than corn; 63% were more than beef; 70% were higher than fish, lentils and beans; and 95% were higher than wheat, rye or teosintle (Defoliart, 1992a).

In Table 6, considerable high amount of unsaturated fatty acids 77.74, 73.34, 64.43 and 76.03% in larvae, adult, exuvium and excreta respectively were analyzed. In terms of degree of unsaturation of fatty acids, insects have similar composition to poultry and fish. In some groups,

Table 6. Fatty acid content of *Tenebrio molitor* larvae, Adult, Exuvium, and Excreta (Grams per 100 g of Protein)

Fatty acid	Larvae	Adult	Exuvium	Excreta
Saturated fatty acid	22.26	26.66	35.57	23.97
Unsaturated fatty acid	77.74	73.34	64.43	76.03
omega 3	46.1	39.97	39.54	25.65
omega 6	31.64	33.36	24.89	50.38

for instance essential fatty acids, linolenic acids and linoleic are even higher then fish and poultry (Defoliart, 1991).

Microbiology Analysis

Microbiology analysis showed that there were no detection of *E.Coli* and *Salmonellaspp* in larvae, adult, exuvium and excreta. These result further supporting the possibility of introducing mealworm in human food consumption.

Mineral composition

Mineral components are illustrated in Table 4. As the other insects, mealworm contained pour sources of calcium which were 434.59, 484.39, 801.14 and 1537.97 mg/kg for larvae, adult, exuvium and excreta respectively. However, the amount of calcium component was the highest in excreta and exuvium, indicating that it is beneficial to recycle the waste product from mealworm. Especially, the calcium contain is considerably low in mealworm, instead contains high levels of P (Allen *et al*., 1996). This problem is solved in resent investigation of improving mealworm's nutritional value for the growing chicks in their bone mineralization. According to the result Ca content of the mealworms was richest when it placed on chicken starter. Ca content increased within 24 hours linearly and declined after a week, this tendency was strongest with the highest levels of Ca supplementation. Ca amount in these mealworms was 76% which was same as Ca in oyster shell. Ca bioavailability was estimated through chick's bone ash and. Moreover, increasing Ca concentration didn't show any effect on P concentration of meal worm (Kirk *et al*., 2000)

Discussion

In terms of nutritional content, the edible insects have been stated to have more of it when compared to other conventional foods. Some species such as grasshoppers, crickets, termites, ants, beetle larvae, moth caterpillar and pupae are commonly consumed because insects in general are considered to be highly food conversion efficiency compare the other animals. For instance, The diet that were given to house cricket (*Acheta domesticus)* maintained at 30C or higher had the same nutritional value as the diet that used to fed conventional livestock .The result showed that the conversion of house cricket was twice as efficient as pigs and boiler chick, four times that of sheep, and six times higher than steer by estimating dressing percentage and losses in carcass (Capinera, 2004). Therefore consuming insects for protein source would provide effective smaller amount and more ecological in contrast with vertebrate protein source (lokeshwari and Shantibala, 2010).

Indigestibility of protein that are in insects is known to be lower efficiency of protein conversion product than protein from vertebrate animals.(Dreyer and Wehmeyer, 1982). In order to reach similar quality of products obtained from vertebrate is that eliminating chitin from insect protein. However, protein digestibility was increased from 71.5% to 94.3%, the protein efficiency ratio from 1.50 to 2.47 with the help of extraction obtained from dried adult honey bees (*Apis mellifera* L). (Ozimek *et al*., 1985).

Furthermore, earlier the mealworm (*Tenbrio moliotor*) as a diet for African catfish, *Clarias gariepinus,* was tested for alternative protein source. As a result, catfish showed a good performance of growth and utilization efficiency when it fed on 80% of mealworm-based diet. In addition, Catfish contained significantly higher amount of lipids in their carcass after fed on mealworm-based diet, suggested that mealworm is highly nutritive diet and acceptable as an alternative protein source (Ng *et al.*, 2001).

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