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Effect of Protein Content in Feed Formulas on Growth and Nutritional Values of Mealworms

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Absract An experiment was designed to determine the effects of high dietary protein feeding on the growth and nutritional values of mealworms. The experiment was designed as completely randomized design with 5 treatments consisting of 5 feeding formulas mixed on weight basis: I) wheat bran II) broiler chicken feed + soybean meal (3:1) III) broiler chicken feed+ soybean meal (1:3) IV) broiler chicken feed+ soybean meal (1:1) and V) broiler chicken feed + soybean meal (1:1) and 10 replications. Mealworms (850 insects) aged 2 weeks were raised in a plastic box at room temperature(35-38 ^{o}C) with carrot as water supplement for 8 weeks. Average weight gain, length measurement and percentage mortality were calculated every week over feeding periods. On the eighth week, the results showed that the mealworms raised with the formula I and III had maximum weight of 0.15 g. Their body length of mealworms from formula I were the longest (2.70 cm) and no statistically different was found in mortality rate among treatments ($p>0.05$). The results indicated that high protein feed did not have effect on weight and body length of mealworms. The cost of 5 feeding formulas in rearing 850 mealworms for 8 weeks was as follows :2.52, 3.91, 4.13, 4.02 and 4.00 $, respectively. The studies indicated that the mealworms fed with formula I had gained maximum growth with minimum cost of production.

An analysis of the chemical composition of the raw materials in feed formulas for mealworms indicated that soybean meal had highest protein content, following by soybean, broiler chicken feed, rice bran and carrot 48.82, 39.35, 21.18, 18.72 and 7.06%, respectively. Soybean had highest amount of fat, 20.14%. It was found that mealworms fed with formula IV had the highest protein of 54.89%. The mealworms raised from the formula I and II had the highest fat 29.54 and 29.88, respectively and highest energy found in mealworms from formua I, 6,193.22 cal/g. The pearson analysis showed a very strong positive relationship on protein and very weak positive correlation on fat in feed and in mealworms. In addition, the protein content in feed had no effect on mealworm growth.

Keywords: Proximate analysis, chemical composition, feeding formulas

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Introduction

Presently, food security is a key issue as the increase in world population every year resulted in the increase of agricultural and food products, as well as the use of energy. The use of renewable energy plants which affect food crop production. However, production of food crops reduced due to restrictions on land, available technologies, climate variability and the mobility of labor from agriculture to the industry as a result do not produce enough food to meet the needs of the world population. Focusing in poor countries with no puschasing power, these factors may contribute to the global food crisis especially protein foods (Ghaly and Alkoaik, 2009). Insects consumption is the hope of the future protein sources for human food. FAO campaign for the eatable insects as a low in fat but high in protein food and proper fiber as a food secure especially in poor countries such as Eastern Africa facing food shortage (FAO. 2013). As grasshoppers and other eatable insects were added to daily meals, most people would received enough protein and amino acids, minerals and energy for the better use of available protein (Ruiz *et al*., 2015). Insects have led to human food since the ancient times. The notes held by natives in various countries in Asia, Africa, Australia and the Americas are taking note of the many insects (Vane-Wright, 1991). To know that insects are edible or not, it is knowledge that has come from the previous generation.

Thailand, insects are both as food and feed, but also to play a sports game (Leuvanich, 1997). Survey of edible insects in Thailand, it was found 28 species. insects were imported from Cambodia were increased in value every year because there are fewer insects in nature. Currently, a popular insect consumption increases. Fried insects that are commonly sold include grass hoppers, bamboo caterpillars, giant water bugs, field crickets and cockchafer which are imported from neighboring countries and may have contamination with agricultural chemicals. Therefore, insect farming should be implemented and promoted to consumers particulary yellow mealworms. It can adapt to the various climate and being popular to culture to sell for animal food (Poopatanakul, 2011). They are used as food for poultry, fish, reptiles, birds and mamals. The protein content is 19.7 % by weight and widely used for animal feed and laboratory work but not in the list of edible insects. Nahuanong and Bumroongsook (2014) stated that comsumers rated overall acceptance of mealworm snack as like moderately. When consumers were informed that crispy fried mealworms were nutritious, the purchase intention was up to 74%.

Additionally, it is one of the insects that is clean and non toxic. The process of rearing is simple, and it can adapt to various climates. They are environmental friendly, produce less greenhouse gas, require much less space

as compared with milk, pork, chicken and beef production (Oonincx and De Boer, 2012). Moreover, seafood protein is known to have heavy metal contamination from untreated sewage industries as numerous heavy industries located along the Coast of the Gulf of Thailand discharged waste into the sea (Thongra-ar *et al*., 2008; Thongra-ar and Parkpian, 2002). Therefore, it would make yellow mealworms as persuasive rational for human food in the future.

The objective of this study was to determine the effect of protein and fat in feed on growth and protein content deposition in mealworms.

Materials and methods

The effect of feeding formulas on growth of yellow mealworms

The experiment was conducted at Entomological Laboratory, Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Thailand. The experimental design was a completely randomized design with 5 treatments and 10 replications as follows:1)formula I:wheat bran 2)formula II: broiler chicken feed mixed with ground soybean meal on weight basis (3:1) 3) formula III: broiler chicken feed mixed with ground soybean meal(1:1), 4)formula IV: broiler chicken feed mixed with ground soybean meal(1:3), 5) formula V:broiler chicken feed mixed with ground soybean(1:1). The series of feeds were formulated by weight ratio as described in each treatment. The experiment was conducted for 8 weeks. Each treatment was consist of 850 of larva aged 2 week placed in a plastic box (20x20x15 cm^3) kept at room temperature(35-38 ^oC) with carrot as water supplement. Feeding material, debris and feces including dead insects was changed and removed from the rearing container every week. The weight, length and mortality of mealworms was recorded weekly and being calculated.

Chemical composition of raw materials and yellow mealworms

The proximate analysis was conducted on crude protein, crude fat, crude fiber, ash, moisture, potassium, phosphorus and gross energy content in mealworms aged 8 weeks raised with 5 different formulas according to AOAC (2000)

Statistical analysis

Analyses of variance were conducted on the sample mean of protein, fat crude fiber, ash, moisture, potassium, phosphorus and gross energy. Statistically significant attributes were further analyzed for the mean

differences using Duncan Multiple Range Test at P=0.05. The pearson correlation analysis was performed to investigate relationship between the effect of protein and fat in feed formulas and in mealworms.

Results

The effect of the 5 feeding formulas on growth and development of yellow mealworm

In 8th week after the first experiment were performed, a mealworm raised with formula I and III had gained maximum weight 0.15 gm followed by the formula II and V which was equivalent weight of 0.14 gm/insect(Table 1). The yellow mealworms raised with formula IV had a minimum average weight, 0.13 gm. The analysis showed that mealworm weight from all treatments increased every week (Figure 1). After rearing for 8 weeks, length of mealworms from formula I was 2.70 cm, next following was formula IV and III equivalent to 2.67 and 2.61 cm, respectively (Table 2). The body length of mealworms increased from week 1-7 and began to level off from week 7-8 (Figure 2). The percentage mortality showed no statistically difference among treatments (Table 3). Mealworm production expense was consisted of rearing facility, feed and labor cost. The cost of feed formulas I-V was 2.52, 3.91, 4.02, 4.13 and 4.00 $/kg, respectively (Table 4). The formala I price was cost almost half the price of the others. For production cost comparsion, of mealworms with these feeds, the studies showed that 1 kg of mealworm raised by formula I was cheapest (6.52$/kg). Therefore, wheat bran was best fit for commercial mealworm production.

The proximate analysis of raw materials used in feeding formulas showed that soybean meal had highest protein content, following by soybean, broiler chicken feed, rice bran and carrot 48.82, 39.35, 21.18, 18.72 and 7.06%, respectively (Table 5). The analysis indicated that soybean showed highest amount of fat and energy. Phosphorus and fiber was found most in wheat bran and broiler chicken feed was highest amount of calcium, ash and moisture at 0.70, 7.03 and 5.46 %, respectively (Table 6).

The nutritional value of mealworms was performed and indicated feed formula had effect on protein content in mealworms. The highest protein was from formula IV, following by formula II, III, IV and I 54.89, 53.70, 52.95, 52.48 and 51.00 %, respectively (Table 7). The correlation analysis showed that there was a very strong positive relationship between protein in feed and mealworm (Pearson coeff. = 0.8744)(Table 8).

Table 1. Weight of a yellow mealworm reared on different feed formula

Formula[2/]	weight[1/](gm)							
	1	2	3	4	5	6	7	8 (wks)
I	0.01[a]	0.02[b]	0.06[a]	0.07[a]	0.08[c]	0.09[c]	0.13[b]	0.15[a]
II	0.01[a]	0.02[b]	0.04[c]	0.07[a]	0.10[a]	0.12[a]	0.13[b]	0.14[b]
III	0.01[a]	0.03[a]	0.04[c]	0.07[a]	0.10[e]	0.11[a]	0.14[a]	0.15[a]
IV	0.01[a]	0.02[b]	0.03[d]	0.06[b]	0.08[c]	0.10[b]	0.12[c]	0.13[c]
V	0.01[a]	0.02[b]	0.05[b]	0.06[b]	0.09[b]	0.10[b]	0.12[c]	0.14[b]

[1/]Values are mean of three replicates ± SEM, Means on the same column with the different superscripts are significantly different by DMRT (P<0.05)

[2/]Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

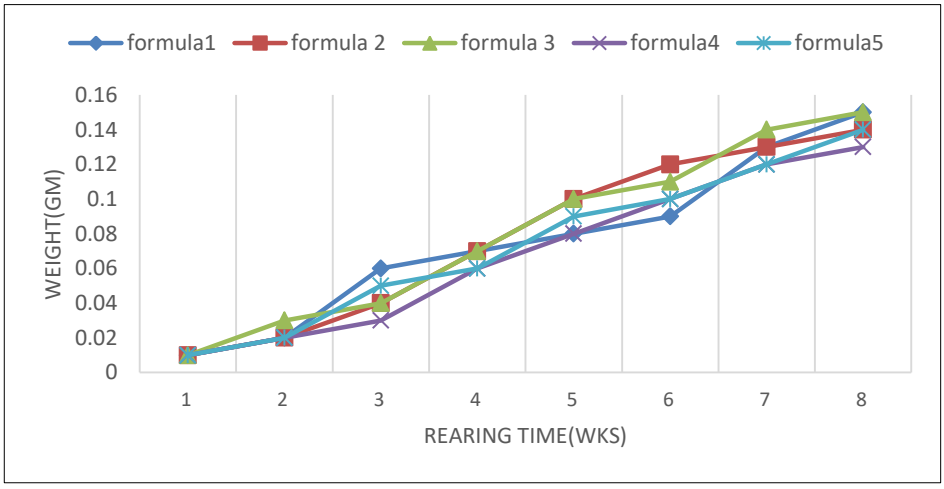

Figure 1. Effect of 5 different feed formulas on mealworm weight

Table 2. Length of yellow mealworm reared on different feed formula

Formula[2/]	Length[1/](cm)							
	1	2	3	4	5	6	7	8(wks)
I	1.24[a]	1.44[ab]	1.64[c]	1.99[a]	2.10[bc]	2.44[a]	2.69[a]	2.70[a]
II	1.25[a]	1.54[a]	1.81[b]	2.05[a]	2.16[b]	2.43[a]	2.53[d]	2.55[c]
III	1.26[a]	1.47[ab]	1.75[b]	2.03[a]	2.26[a]	2.48[a]	2.60[bc]	2.61[bc]
IV	1.25[a]	1.45[ab]	1.70[b]	2.05[a]	2.08[c]	2.33[b]	2.65[ab]	2.67[ab]
V	1.30[a]	1.37[c]	1.74[b]	2.02[a]	2.15[b]	2.32[b]	2.57[cd]	2.55 [c]

[1/]Values are mean of three replicates, Means on the same column with the different superscripts are significantly different by DMRT (P<0.05)

[2/]Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

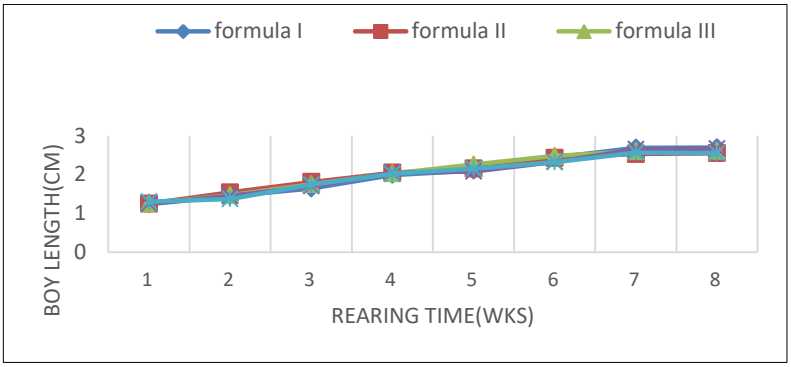

Figure 2. Effect of 5 different feed formula on mealworm body length

Table 3. Effect of 5 different feed formula on mortality rate of yellow mealworm

Formula[/2]	Percentage mortality[1/](%)							
	1	2	3	4	5	6	7	8 (wks)
I	0.88[a]	1.22[a]	1.88[a]	1.44[a]	1.22[a]	1.77[a]	0.88[a]	2.00[a]
II	1.22[a]	1.77[a]	1.00[a]	1.77[a]	1.55[a]	1.55[a]	1.55[a]	1.44[a]
III	1.22[a]	1.22[a]	0.88[a]	1.00[a]	1.33[a]	2.11[a]	2.77[a]	1.55[a]
IV	1.00[a]	1.77[a]	1.33[a]	1.66[a]	1.88[a]	2.22[a]	1.00[a]	1.77[a]
V	1.77[a]	1.66[a]	1.88[a]	1.22[a]	1.00[a]	1.11[a]	1.88[a]	1.66[a]

[1/]Values are mean of three replicates, Means on the same column with the different superscripts are significantly different by DMRT (P<0.05)

[2/]Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

Table 4. Mealworm production cost(1$=33.04 baht)

Formula[1/]	Cost of feed($/kg)	Production cost ($/kg)
I	2.52	6.52
II	3.91	10.52
III	4.02	10.53
IV	4.13	10.84
V	4.00	10.61

[1/]Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

Table 5. Protein, fat content, fiber and energy gross of raw material used in feeding formulars

Raw material	Chemical composition[1]			
	Protein(%)	Fat(%)	Fiber(%)	Energy(cal/g)
Wheat bran	18.72[d] ±0.16	3.63[b] ±0.04	9.26[a] ±0.23	4,253.10[c] ±5.23
Soybean	39.35[b] ±0.34	20.14[a] ±0.02	2.98[e] ±0.13	5,420.80[a] ±8.76
Soybean meal	48.82[a] ±0.06	1.06[e] ±0.02	6.27[c] ±0.13	4,426.50[b] ±6.78

Broiler chicken feed	21.18^{c} ±0.08	2.84^{c} ±0.02	3.54^{d} ±0.16	4,071.75^{d} ±0.21
carrot	7.06^{e} ±0.07	1.31^{d} ±0.13	7.97^{b} ±0.05	3,786.45^{e} ±5.58

[1]Values are mean of three replicates ± SEM, Means on the same column with the different superscripts are significantly different by DMRT (P<0.05)

Table 6. Calcium, phosphorus, ash and moisture in percentage of raw material used in feeding formulas

Raw materials	**Chemical composition(%)**[1/]			
	calcium	phosphorus	ash	moisture
Wheat bran	0.17^{b} ±0.04	1.03^{a} ±0.05	5.47^{d} ±0.04	2.83^{c} ±0.22
Soybean	0.20^{b} ±0.00	0.60^{c} ±0.00	5.57^{c} ±0.01	1.58^{d} ±0.02
Soybean meal	0.26^{b} ±0.01	0.64^{c} ±0.03	6.94^{a} ±0.01	1.44^{e} ±0.11
Broiler chicken feed	0.70^{a} ±0.03	0.95^{b} ±0.04	7.03^{a} ±0.07	5.46^{a} ±3.87
Carrot	0.26^{b} ±0.12	0.23^{d} ±0.01	6.79^{b} ±0.07	1.44^{e} ±0.11

[1/]Values are mean of three replicates ± SEM, Means on the same column with the different superscripts are significantly different by DMRT (P<0.05)

Table 7. Protein, fat content, fiber and energy gross of mealworms fed with different feeding formulas

Formula[2/]	**Chemical composition**[1/]			
	Protein(%)	Fat(%)	Fiber(%)	Energy gross(cal/g)
I	51.00^{d} ±1.40	29.54^{a} ±3.12	6.46^{a} ±0.62	5,898.23^{b} ±7.37
II	53.70^{b} ±0.39	29.88^{a} ±3.87	6.85^{a} ±0.90	6,193.22^{a} ±7.92
III	52.95^{c} ±0.41	23.84^{c} ±5.93	7.63^{a} ±0.80	5,722.25^{b} ±2.66
IV	54.89^{a} ±0.41	19.20^{d} ±6.83	7.34^{a} ±1.50	5,321.41^{c} ±8.96
V	52.48^{c} ±0.11	26.45^{b} ±6.06	6.77^{a} ±0.65	5,731.41^{b} ±1.35

[1/]Values are mean of three replicates ± SEM, Means on the same column with the different superscripts are significantly different by DMRT (P<0.05)

[2/]Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

Table 8. Correlation of protein content between feeds and mealworm

Formula[1]	**%protein in feed**	**%protein in mealworm**	**Correlation coefficient**
I	18.72	51.00	
II	28.09	53.70	Pearson
III	35.00	52.95	coeff.=0.8744
IV	41.91	54.89	
V	30.26	52.48	

[1]Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

The relationship between fat content in feed and mealworms was very weak positive correlation (Pearson coeff.=0.2426)(Table 9). The results also

indicated that high protein in feed did not have effect on weight and length of mealworms (Table1-2, 4 and 10).

Table 9. Correlation of fat content between feed and mealworm

Formula[1/]	%fat in feed	%fat in mealworm	Correlation coefficient
I	3.63	29.54	
II	2.40	29.88	Pearson
III	1.95	23.84	coeff.=0.2426
IV	1.51	19.20	
V	11.14	26.45	

[1/]Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

Table10. Calcium, phosphorus, ash and moisture in percentage of mealworms fed with different feeding formulas

Formula[2/]	Chemical composition(%)[1/]			
	calcium	phosphorus	ash	moisture
I	0.26^{a} ±0.20	0.75^{a} ±0.17	3.79^{a} ±0.90	5.64^{a} ±4.09
II	0.19^{a} ±0.04	0.64^{a} ±0.07	3.82^{a} ±0.24	2.86^{a} ±0.22
III	0.16^{a} ±0.01	0.79^{a} ±0.18	4.79^{a} ±0.87	5.50^{a} ±4.36
IV	0.16^{a} ±0.01	0.72^{a} ±0.16	4.42^{a} ±1.21	5.41^{a} ±5.15
V	0.17^{a} ±0.03	0.78^{a} ±0.16	4.42^{a} ±0.77	6.00^{a} ±3.42

[1/]Values are mean of three replicates ± SEM, Means on the same column with the different superscripts are significantly different by DMRT ($P<0.05$)

[2/] Formula I =wheat bran, II= broiler chicken feed mixed with ground soybean meal(3:1), III= broiler chicken feed mixed with ground soybean meal(1:1), IV= broiler chicken feed mixed with ground soybean meal(1:3), V=broiler chicken feed mixed with ground soybean(1:1)

Discussion

In addition, other factors impacted on protein content in insects such as insect stages of development, species and cooking methods (Xiaoming *et al.*, 2010; Bukkens, 1997; Ademolu *et al.*, 2010). It contains 16 essential amino acids required for human food(Ghaly and Alkoaik, 2009). Insect contained not only high protein but also fat (Aaron and Dossey, 2013; Womeni *et al.*, 2009) Mealworm from formula I and II had highest percentage of fat, 29.54 and 29.88, respectively and found 19.20% which was the lowest in mealworm raised with the formula IV. Analysis of the phospholipid fatty acid profile of yellow mealworm indicated that they consisted of palmitic, stearic, oleic and linoleic acids in high amount (Howard and Stanley-Samuelson ,1990; Finke,2002) Most polyunsaturated fatty acids were phospholipids (Howard and Stanley-Samuelson, 1990). Highest energy gross (6,193.22 cal/gm) was found in mealworms from formula II. Calcium, phosphorus, ash and moisture in

percentage of mealworms among different treatments showed no statistically different($p>0.05$) although these values in raw material were different. Larvae was heavier when it was reared with more moisture content food (Urs and Hopkins, 1973). Mealworm has been promoted as food and feed (Connally and Moores, 2015) Oonincx and De Boer (2012) has demonstrates that mealworms was a more sustainable source of edible protein.. They are environmental friendly, produce less greenhouse gas emissions, require much less land and the same amounts of energy as compared with pork, chicken and beef production.

Conclusions

Mealworms has a lot of potential as a human food source and animal feed. It has a high fecundity and is easy for mass rearing in large quantities in insect farm. They are environmental friendly, produce less greenhouse gas emissions, require much less less space as compared with traditional livestock production. Wheat bran is one of a best choice for mealworm production for marketable. High protein feed did not involve mealworm growth. The protein content in mealworms was depended upon rearing feeds. The higher protein content feeds were more expensive than the lower one. The cost of mealworm production can be lower when they were in mass production and use agricultural waste products available in the areas. Thus, mealworms and other edible insects could be less expensive protein sources for us in the future.

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