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GROUND YELLOW MEALWORMS (*Tenebrio molitor L.*) FEED SUPPLEMENTATION IMPROVES GROWTH PERFORMANCE AND CARCASS YIELD CHARACTERISTICS IN BROILERS

DESIREE A. BALLITOC*, SANGSOO SUN**
*Research Dev't, Extension and Training Department, Ifugao State University, Lamut, Ifugao, Philippines
**Department of Animal Science, Chonnam National University, Gwangju City, South Korea

ABSTRACT

Effects of ground yellow mealworms (Tenebrio molitor L.) as feed supplements on the growth performance and carcass yield in broilers were assessed. The study used 5 treatments at inclusion levels of 0, 0.5, 1, 2 and 10% ground yellow mealworms, and replicated twice. Results showed that overall body weight gain was significantly higher in T_2 group (1486 g) compared with control (1307 g), T_1 (1360 g), T_3 (1484 g) and T_4 (1470 g) groups. Overall feed conversion ratio values were significantly better for control group (2.10) compared with T_1 (1.94), T_2 (1.90), T_3 (1.87) and T_4 (1.72) groups, which shows a decreasing trend of FCR when the percentage of ground yellow mealworm added increases. The T_3 group remained significantly superior ($P<0.0001$) over the other groups in three weight categories of the carcass yield, which are slaughter weight, dressed carcass weight and eviscerated weight. Trends were highly variable among all internal organs. However, control group showed the highest mean weight (37.63 g) as compared to all other treatments. T_2 had the highest abdominal fat weight ($P<0.0001$), while T_3 had the lowest. Small intestines from T_2 had significantly higher than all other treatments. T_2 group showed significantly high percentage of moisture in the thigh region as compared to the control and other treatment groups, whereas T_2 had the lowest moisture content in the breast area. T_4 group showed the highest percentage of fat for thigh and breast, 6.30% and 1.25%, respectively. There is a slight increase of protein content in the treatment groups as compared to the control group. T_2 showed the highest percentage of protein in the breast portion of the meat. It is therefore concluded that addition of ground yellow mealworms to common feedstuff can improve the growth performance and carcass yield of broiler chickens. Specifically, inclusion level of 2% ground yellow mealworms projected the best results.

Keywords: yellow mealworms, feed supplementation, growth performance, carcass yield, broilers

INTRODUCTION

Rationale

Nowadays, one of the major problems in the poultry and livestock industry is the limited protein resources for animal feed. In terms of their protein concentration, soybean, fish meal and animal by-products are mixed in animal feed. However, shortage of conventional feedstuff like maize and soybean is occasioned by the competition between man and livestock for these feed sources (Das et al., 2009). Also, the high cost and scarcity of feedstuffs particularly the protein sources such as soybean, groundnut and fish meal are major factors militating against commercial poultry production (Adeniji, 2007). Hence, due the increasing demand for animal protein products, there is a need to look for an alternative, non-conventional and economic protein sources that will help address the problem.

Insects are well known as important natural source of food to many kinds of animals. They have many benefits to offer us but are often overlooked and underestimated (Anand et al., 2008). For example, they can be used in human and animal nutrition, in medicine and also as recycles of organic matter. Most edible insects are cheap, available and can provide good source of protein and minerals needed to complement cereal-based foods consumed in the developing countries (Ifie, et al., 2011). Black soldier fly pre-pupae, for instance, may be a suitable ingredient for partial replacement of fishmeal or fish oil in rainbow trout diets; especially if pre-pupae are enriched with omega-3 fatty acids (St-Hillaire, et al., 2007). Premalatha, et al. (2011) highlighted the relatively stronger sustainability of animal protein by way of insect farming because the production of insect protein takes less land and energy than the more widely consumed forms of animal protein. Furthermore, most insect species convert plant protein to insect protein very efficiently (Taylor, 1979).

Yellow mealworms (*Tenebrio molitor L.*) are common feedstuffs for pet animals including small mammals and reptiles and are a formidable source of insect protein with about 44-70% in their body tissues (Ramos-Elorduy, 1987). Agriculturally, edible insects such as the yellow mealworm have great potential because they contain superior grade of proteins, lipids, carbohydrates and vitamins (De Foliart, et al., 2009) that may provide a possible alternative source of nutrition for poultry broilers. The potential for insects as livestock feeds may also have an environmental impact as they cost less energy, use less land area and leave less environmental footprints during production (Pimental, et al., 1975). Studies that explored the potential of *Tenebrio molitor L.* for massive human and animal consumption have also shown that ground yellow mealworms emit no ammonia excretions (Oonincx, et al., 2010).

The objective of this study was to test different levels of ground yellow mealworms (*Tenebrio molitor L.*) as feed supplements and assess its effects on the growth performance and carcass yield of broiler chickens. By evaluating the carcass yield characteristics of *Tenebrio molitor L.* fed broiler chickens, we have shown that there is a significant increase in body weight and growth performance, which could be applied by small and large hold farmers in the poultry industry.

MATERIALS AND METHODS

Location and Feed composition

The study was conducted at Chonnam National University Poultry Farm in Gwangju City, South Korea situated at 37.41^o N longitude and 127.26^o E latitude at an altitude of 50 meters above sea level (maps-streetview.com). The mean annual rainfall of the area is 1,391 mm (54.764 inches) and the average minimum and maximum temperatures are 9.5 and 19.1 ^{0}C, respectively (Korea Meteorological Administration, 2010).

The composition of ingredients in the experimental rations and chemical compositions of the rations containing graded levels of ground yellow mealworms are shown in Table 1. Dietary rations used for this study were commercial broiler feed mixed with ground yellow mealworms (*Tenebrio molitor L.*). The same percentage of treatment feeds were given to the starter and finisher diets. The starter diet was given from the initial day of the experiment to 3 weeks of age and the finisher diet was supplied from 3 to 5 weeks of age. The chemical composition of feeds was based on the feed company’s computation. However, the crude protein, crude lipid and ash were recomputed based on the amount of additional yellow mealworms.

Table 1. Composition of ingredients in the experimental rations and chemical compositions of the rations containing graded levels of ground yellow mealworms (%)

	Treatments									
	CTL		T1		T2		T3		T4	
Components	starter	finisher	starter	finisher	starter	finisher	starter	finisher	starter	finisher
Feed composition (%)										
Commercial feed	100	100	99.5	99.5	99	99	98	98	90	90
Ground YM	0	0	0.5	0.5	1	1	2	2	10	10
Total	100	100	100	100	100	100	100	100	100	100
Chemical composition (%)										
Crude protein	20.0	18.0	20.33	18.33	20.66	18.66	21.32	19.32	26.61	24.61
Crude lipid	4.0	4.5	4.15	4.65	4.31	4.81	4.61	5.11	7.05	7.55
Crude fiber	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Ash	8.0	8.0	8.03	8.03	8.05	8.05	8.10	8.10	8.50	8.50
Calcium	0.8	0.75	0.8	0.75	0.80	0.75	0.8	0.75	0.8	0.75
Phosphorous	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
MET+CYS+	0.8	0.72	0.8	0.72	0.8	0.72	0.8	0.72	0.8	0.72
ME	3.0	3.05	3.0	3.05	3.0	3.05	3.0	3.05	3.0	1.05

CTL: control; T1: diet containing 0.5% ground YM; T2: diet containing 1% ground YM; T3: diet containing 2% ground YM; T4: diet containing 10% ground YM; MET+CYS+: Methionine Cystein; ME: Metabolizable Energy

The ground yellow mealworms, obtained from a reliable supplier in South Korea, were measured using an electronic balance and mixed to formulate the desired ration every feeding time, which was done in the morning and evening. The treatment rations: 0 (control), 0.5 (T_1), 1 (T_2), 2 (T_3) and 10% (T_4) inclusion of ground yellow mealworms were formulated.

Management of experimental birds

One hundred unsexed day-old Ross broiler chicks were randomly divided into five dietary treatments and two replications per treatment, thus having 10 birds per replicate or pen. However, transfer of one chick to another cage and one mortality occurred, thus, making some of the cages count 11, 10 and 9 heads each.

Before the start of the actual experiment, the experiment pens, watering and feeding troughs were thoroughly cleaned and disinfected against external parasites. The broiler chicks were housed into well-ventilated cages (1.5 x 2 x 1.5 m), using an incandescent bulb each pen were installed to provide heat and light, and using paper sack as litter material. The room temperature and percentage humidity were regularly checked twice a day. The average room temperature was 27^{o}C, while average percentage humidity was 58%. Regular feeds were given to all groups during the first week, while treatment feeds were given from the second week up to the finish time. Feeding was done *ad libitum* and clean tap water was available all the time throughout the experiment. Due to some infections, all broiler chicks were vaccinated with *PoulShot Gumboro* against Infectious Bursal disease and *PoulShot B1+IB* against Newcastle disease, which were mixed into the drinking water.

Measurements

Ground yellow mealworms

The ground yellow mealworms were mixed into the animals' ration every feeding time. It is done simply by weighing it using an electric balance and manually mixing them in to the broiler ration. The measurements were 0.5, 1, 2 and 10% of ground mealworms of the total weight of broiler ration.

Body weight gain, feed intake and feed conversion

The body weights were measured on a twice-a-week basis using an electric balance in a group per pen for the first week and individual body weight were taken from the second week up to the final week of experiment. The amount of feed offered and refused per pen was recorded daily since the beginning of the experiment. Feed intake was determined as the difference between the feed offered and refused. Feed conversion ratio was calculated as the proportion of gram feed consumed per gram weight gain.

Weight of internal organs and body composition

At the end of the experiment, three broiler chickens randomly selected from each treatment were starved for 16 hours and weighed immediately before and after slaughter. The chickens were exanguinated, by severing the neck and dressed before the internal organs and abdominal fat were taken out, according to the methods described by Deaton et al. (1974). The liver, kidney, spleen, heart, abdominal fat, small intestine, large intestine, ceca, pancreas, gizzard, crop and lung were weighed to calculate the percentage of each organ to carcass weight.

Dressed and eviscerated weights were calculated following the method of FAO (2001) as:

Dressed weight = Thighs + Wings + Ribs + Back + Heart + Liver + Gizzard + Neck + Feet + Head + Viscera (inedible offal)

Eviscerated weight = Dressed weight - viscera

Dressed and eviscerated percentages were determined following the method of FAO (2001) as:

$$\text{Dressing (\%)} = \frac{\text{Dressed weight}}{\text{Pre-slaughter weight}} \times 100$$

$$\text{Eviscerated (\%)} = \frac{\text{Eviscerated weight}}{\text{Pre-slaughter weight}} \times 100$$

Chemical analysis of meat

The chemical compositions of the carcass were determined according to common method of A.O.A.C. (1990). The chemical analyses to determine the content of protein, fat, water and minerals (ashes) of meat samples were carried out to establish the nutritive and economic value of the product. Samples of meat samples were finely ground and weight accurately for each respective chemical analysis. Meat samples from thigh and breast were used.

The determination of the moisture was done by drying an appropriate amount of the sample. Microwave oven was used for rapid determination of moisture content. The difference in weight between the fresh and dried samples represents the water content.

The protein content was determined at laboratory level by using the Kjeldahl method, where the meat samples were digested by acid to obtain the nitrogen compounds and then distilled and titrated to determine nitrogen quantitatively, with which the protein component can be calculated. In a simplified approach, protein is not chemically determined, but can be calculated (approximately) as the component, after water, fat and ash contents has been determined and subtracted from 100%.

Determination of the fat content is the most complicated component of meat analysis, as analytical equipment (Soxhlet apparatus) is needed. Samples for fat analysis were semi-dried before being subjected to ether-extraction using the Soxhlet apparatus. After complete extraction, the fat was obtained by evaporating and recovering the ether.

The defatted samples were then used for ash analysis by subjecting it to a temperature of +600^{o}C in a muffle furnace for two hours. The weight of the ash was used to calculate the mineral contents in % (weight of ash, divided by total sample weight, multiplied by 100).

Statistical analysis

The results of this experiment were analyzed by calculating the mean ± standard deviation between groups. Analysis of variance was done on the means of each feeding group. Statistical differences between groups were analyzed using the student's t-test, and the level of significance was at $P<0.05$.

RESULTS

Feed intake

Experimental feed inclusion of ground yellow mealworms started on week 2 up to the end on week 5. Feed intake was measured by weighing the feed residues and subtracting the value to the amount initially given on a weekly basis. Each group had two replicates with 9, 10 or 11 heads per group. Expectedly, there was an increasing trend in the amount of feed taken in each group (Figure 1). The control group initially showed higher feed intake than T_1, T_2, T_3 and T_4 groups in days week 2. However, T_2 group showed consistent increase in feed intake throughout the experimental period. Experimental group T_2 had the highest mean feed intake of 172 grams while T_4 had the lowest mean feed intake of 149 grams at the end of the experiment. Experimental groups T_3, control and T_1 had mean feed intakes of 166, 162 and 156 grams, respectively.

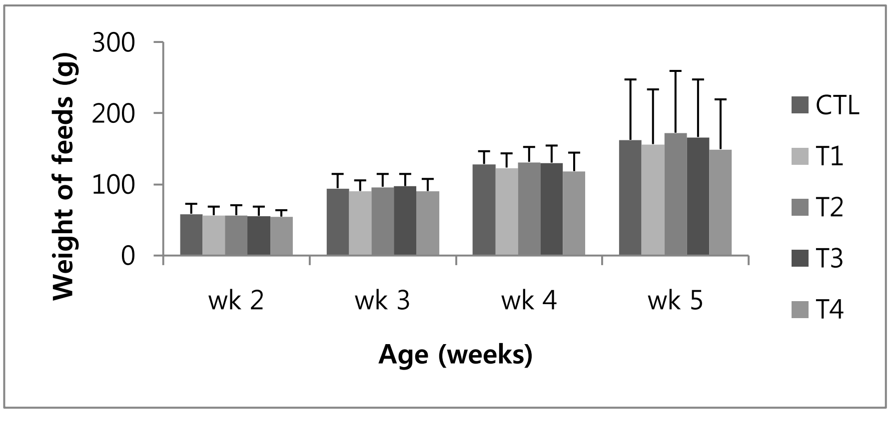

Figure 1. Average weekly feed intake of broiler fed with ground mealworms (g)

Body weight gain

On 3-4 day interval basis, the body weight of each experimental animal was measured. The mean body weights of each group were calculated. All groups exhibited a trend of increasing body weight gain from days 8 to 34, with a slight decrease in body weight on day 34 indicating a possible maximum potential reached at day 32 (Figure 2). The control group and the group fed with 0.50% ground yellow mealworms did not have any significant differences and had much lower body weights compared to groups fed with 1%, 2% and 10% of ground yellow mealworms.

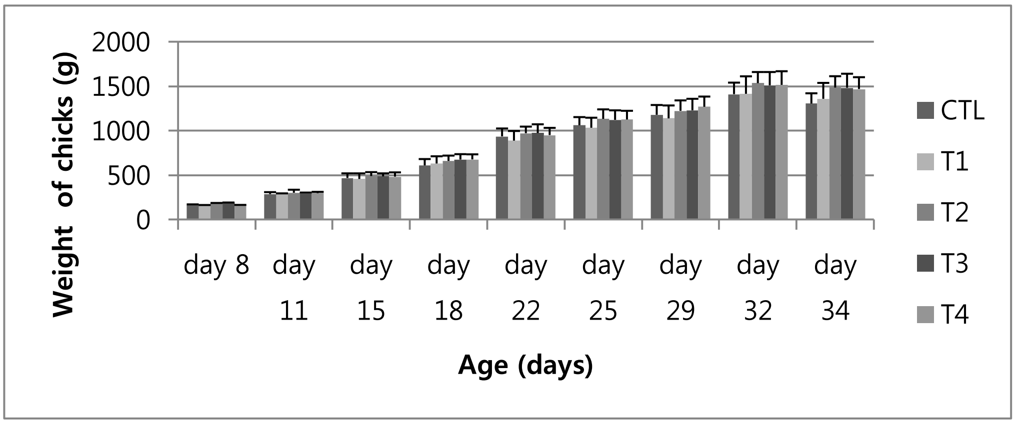

Figure 2. Average body weight measurement of animals in the control group, T_1, T_2, T_3 and T_4 at 3-4 day intervals

Groups which were fed with 1%, 2% and 10% ground yellow mealworms exhibited statistically significant increase in body weight with p values at 0.0001, 0.0002 and 0.0002, respectively. The group fed with 1% ground yellow mealworms (T_2) showed the highest average weight gain at 1486 g on day 34, as compared with the groups fed with 2% and 10% at 1484 g and 1470 g, respectively.

Feed conversion ratio

The feed conversion ratio (FCR) was calculated using the total amount of feeds consumed divided by the total weight gain of the chickens in each group. Figure 3 shows that with increasing percentage of ground yellow mealworms fed there is a decreasing trend in the overall FCR of each group. The group with the highest FCR value was the control group, which were not fed with ground yellow mealworms. On the other hand, the group with the lowest FCR value was T_4 group, which was fed with 10% ground yellow mealworms.

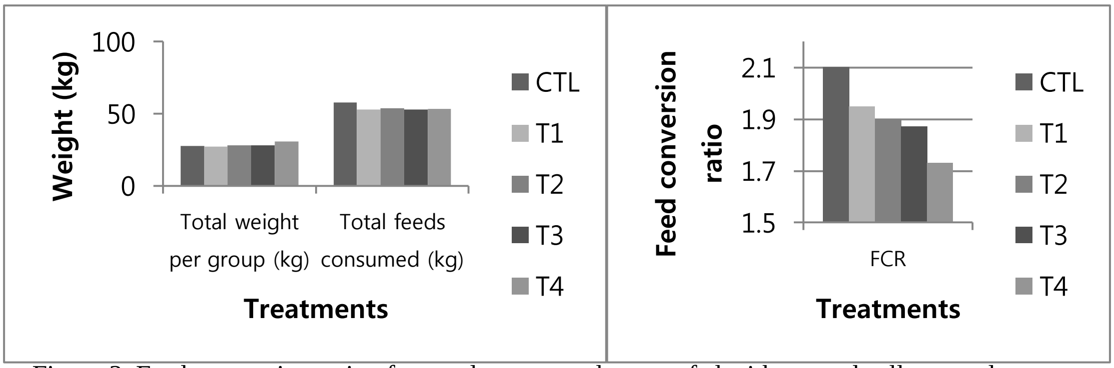

Figure 3. Feed conversion ratio of control groups and groups fed with ground yellow mealworms

Carcass yield

Carcass yield was evaluated based on slaughter weight, dressed carcass weight, eviscerated weight, and the percentages of the latter two. In all three weight categories, T_3 group ($p<0.0001$) remained significantly superior over all groups with the highest mean slaughter weight, dressed carcass weight and eviscerated weight. Among all groups, there was a trend of increasing slaughter weight, dressed carcass weight and eviscerated weight as the percentage of ground mealworms increased (Figure 4a) as compared to the control group with the lowest mean weight in all three categories.

The dressed percentage yield was highest in groups T_2 and T_3 at 92% (Figure 4b). On the other hand, T_4 group had the lowest dressed percentage at 90%. Eviscerated percentage was lower than dressed percentage, and contrastingly, T_2 had the lowest eviscerated percentage at 84%. Control group, T_1 and T_3 group showed the highest eviscerated percentage at 86%.

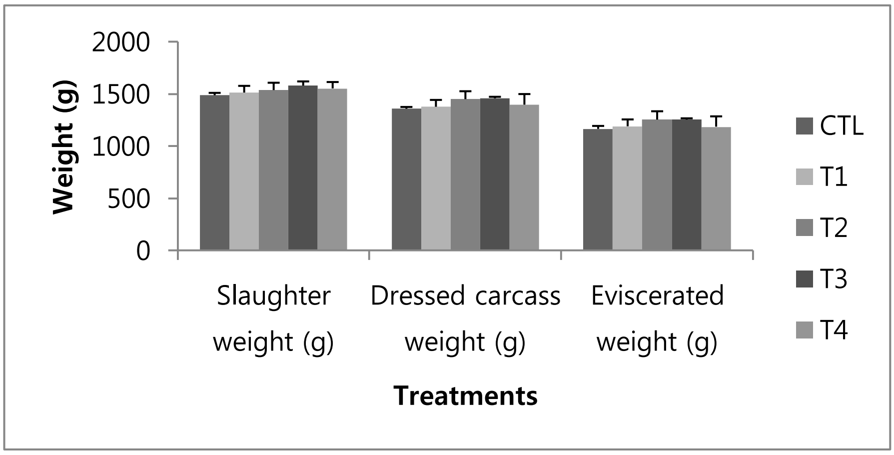

Figure 4a. Average carcass yield characteristics of broiler chickens fed with ground mealworms (g)

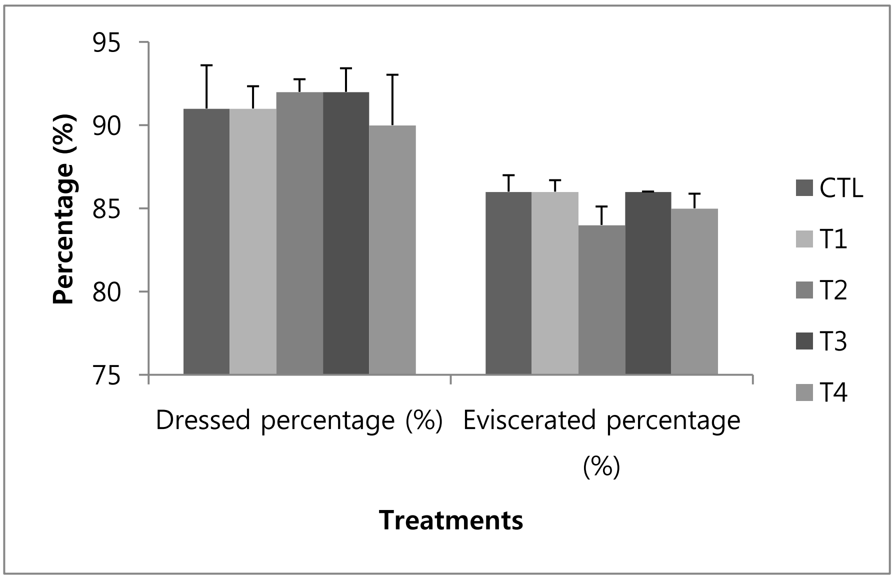

Figure 4b. Dressed and eviscerated percentages of broiler chickens fed with ground mealworms

Internal organs and digestive tracts

Upon sacrifice of the experimental animals, all internal organs and digestive tracts were harvested and weighed. Mean weight and differences were calculated for each experimental group. Trends were highly variable among all internal organs (Figure 5a). Notably, the liver and kidney in the control group showed the highest mean weight as compared to all other treatment groups, which had lower overall weight. Abdominal fat weight was highest in the T_2 group ($p<0.0001$) and lowest in the T_3 group ($p<0.0001$). Heart weight was also notable with groups T_2 ($p<0.0001$) and T_3 ($p<0.0001$) having the highest values.

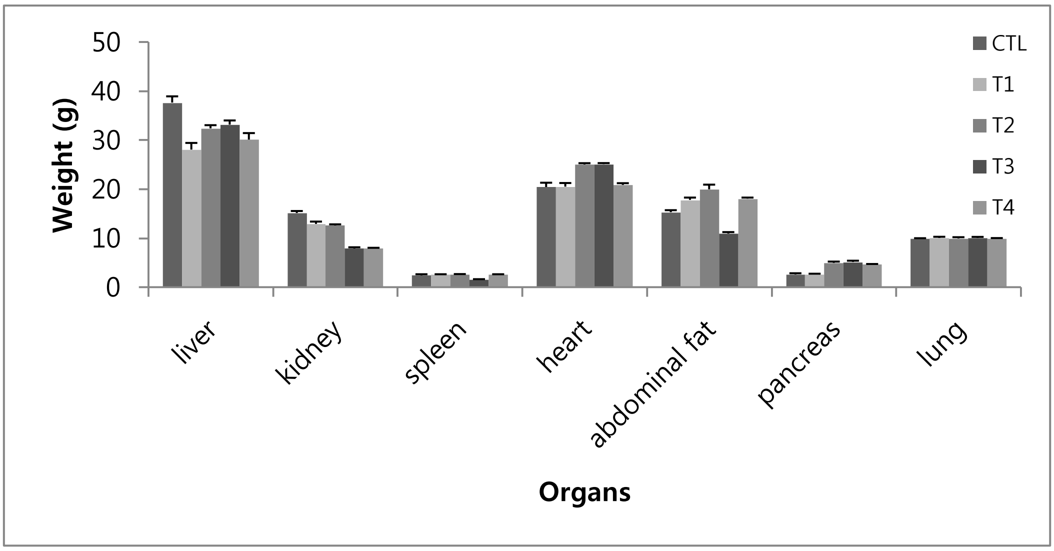

Figure 5a. Weight of internal organs of broiler chicken fed with ground mealworms

The digestive tracts of the animals were measured separately. Individually, the small and large intestines, as well as the ceca, gizzard and crop were collected and weighed. Data show that the small intestines from T_2 group ($p<0.0001$) had the highest recorded weight as compared to the control and other groups (Figure 5a).

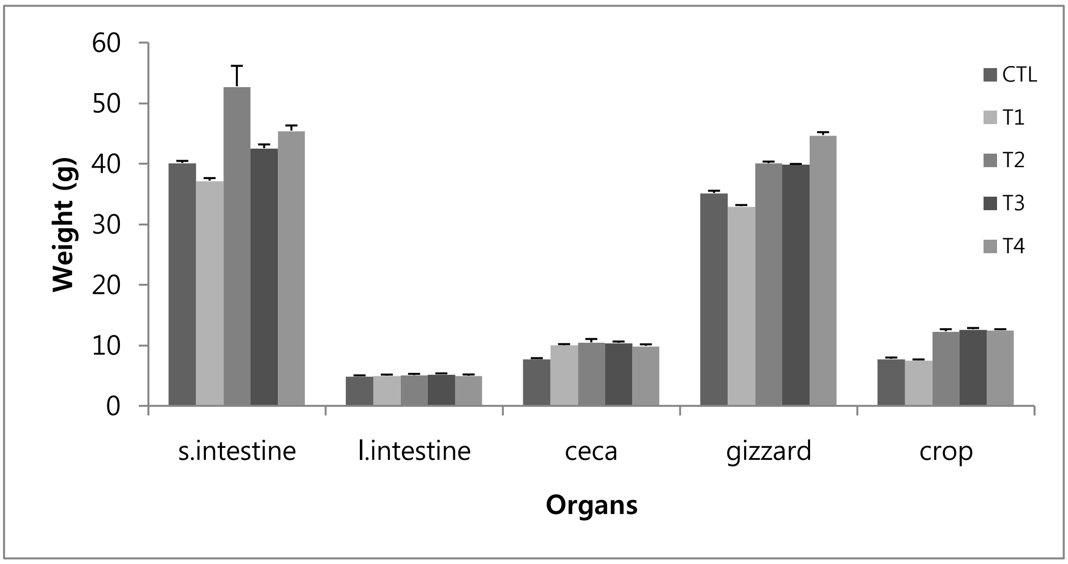

Figure 5b. Weight of digestive tract of broiler chicken fed with ground mealworms

Meat chemical analysis

Meat harvested from each group was analyzed for its moisture, fat, protein and ash content. Samples from the thigh and breast areas were used in order to perform meat chemical analysis.

Percentage of moisture in the thigh region was significantly high in the T_2 group as compared to the control group and other treatment groups. In contrast, T_2 group had the lowest moisture content in the thigh area (Figure 6a). Percentage of fat was also measured in the thigh and breast region, where the T_4 group showed highest percentage (Figure 6b). In the thigh and breast region, T_2 and T_1 showed the lowest percentage of fat.

In the thigh portion, the treatment and control groups did not show a consistent trend of increase in protein content. However, in the breast portion of the meat, there is a slight increase of protein content (%) in the treatment groups as compared to the control groups (Figure 6c). The group fed with 1% ground yellow mealworm (T_2) showed the highest percentage of protein content in the breast portion of the meat. There were no significant differences found in the ash content within all groups tested (Figure 6d).

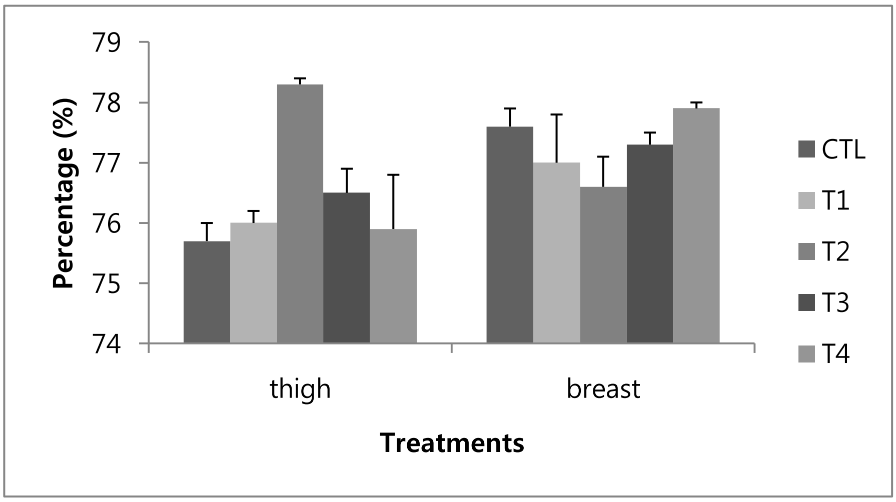

Figure 6a. Moisture content of meat of broiler chickens fed with ground mealworms

Figure 6b. Fat content of meat of broiler chickens fed with ground mealworms

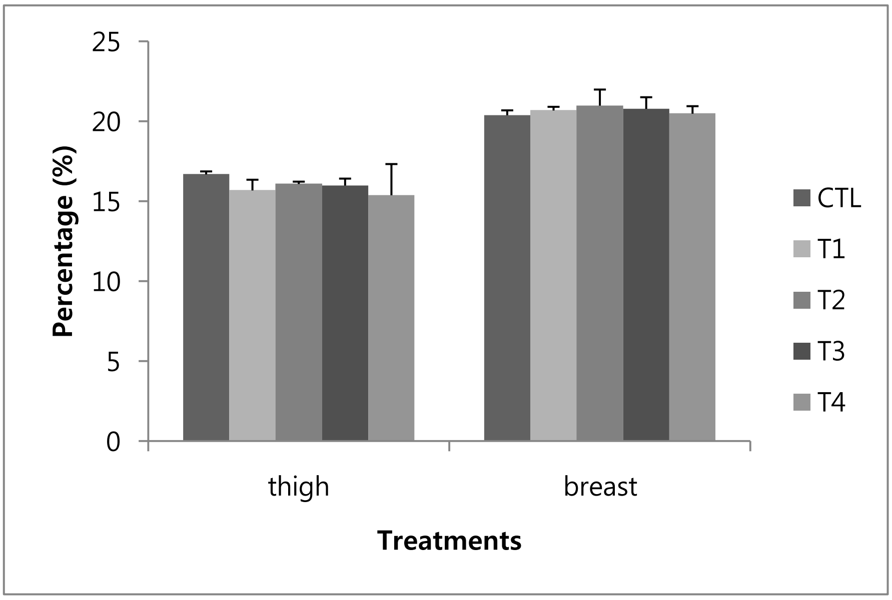

Figure 6c. Protein content of meat of broiler chickens fed with ground mealworms

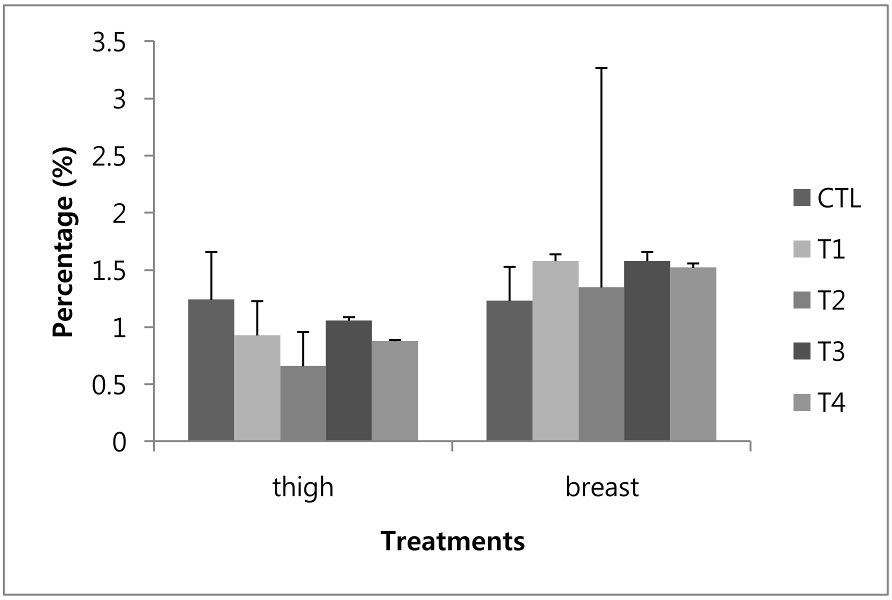

Figure 6d. Ash content of meat of broiler chickens fed with ground mealworms

DISCUSSION

Protein is a very important nutrient resource in poultry diets and is useful in maintaining and repairing tissues for organisms to enable proper growth and development (Bondari and Sheppard, 1981). And animal proteins have higher nutritive value than plant proteins because the former have larger amounts of essential amino acids required by poultry (Yen, 2009). Several poultry feed ingredients have been explored in recent decades in order to increase overall growth performance and health of broiler chickens. Different types of forages such as *Cichorium intybus L.* (Liu et al., 2011), probiotic mixtures such as mannan-oligosaccharides as well as other probiotic mixtures (Sohail et al., 2012) have shown to improve broiler production performance, gastrointestinal health and nutrition. In this study, the potential for an edible insect, *Tenebrio molitor L.* (ground yellow mealworms) as a feed supplement to broiler chickens was explored.

Four groups were fed with increasing concentrations of ground yellow mealworm in their daily diet at 0.5%, 1%, 2% and 10%. The consistent feed intake may suggest increased feed palatability with the addition of ground yellow mealworms in relation to the innate behavior of chickens. In their natural environment, chickens will dig up vermin from dirt or shallow water for consumption. With increasing time and feed intake, the body weights of animals in treatment groups T_2, T_3 and T_4 were significantly increased as compared to the control group and T_1 group. In poultry production, body weight gain is an important parameter to measure production performance, which translates to improved feed conversion ratio. Because of the significant increase in body weight gain in proportion to total feed intake, the feed conversion ratio was found to be lower in groups fed with increasing percentages of ground yellow mealworm. Lower feed conversion ratio may indicate a potential advantage to farmers in terms of economical benefits and profitability with the use of ground yellow mealworms.

Use of ground yellow mealworms in the diet also has effects on the weight of internal organs. Most notably, the heart, abdominal fat and small intestines were increased in groups fed with ground yellow mealworms suggesting that supplementation may improve muscle and fat mass in broiler chickens. Increase in fat content in meat has the ability to contribute to its flavor (USDA, 2011). The mean gizzard weight of groups fed with ground yellow mealworms was found to be increasing as compared to the control. The group fed with 10% ground yellow mealworm showed the highest mean gizzard weight, which may signify improved digestibility of ground yellow mealworms. In similar study, Okah and Onwunjiariri (2012) evaluated the performance of finisher boilers fed with maggot meals as replacement for fish meal and found out that replacement of a 4.0% dietary fish meal with 50% maggot meal gave superior performance characteristics, while Hwangbo et al. (2009) found that maggots significantly increased dressing percentage, breast muscle and thigh muscle. Also, Njidda and Isidahomenl (2010) fed rabbits containing levels of grasshopper meal and observed that carcass characteristics showed significant among treatments ($P<0.05$) for slaughter weight, dressing percentage, skin pelt, tail, feet and abdominal fat. Furthermore, the slaughter weight and carcass weight were better in groups receiving 2.5% grasshopper meal (50% fish meal replacement.)

Moisture content is an important factor in the keeping quality of meat products. The amount of moisture available in meat should be within 70-72% (Haitook, 2006) for raw poultry meat, however, there are many products in the market today that possess greater water content due to flavor enhancements included for packaging. High moisture content may also be detrimental for frozen meat products, due to large crystal formations that pierce through the cellular membrane of muscle cells during thawing, thereby decreasing its overall quality of appearance (USDA, 2011). This phenomenon occurs with slow- freeze operations which may depend entirely on the manufacturer's logistic capabilities. However, high moisture content found in the meat of groups fed with ground yellow mealworms may still be advantageous to both the consumer and manufacturer. Transportation of meat products from the slaughter house to the processing plant may reduce moisture content if kept in semi-frozen states. There is also significant water loss at the grocery store or market, where poultry meat products are displayed at higher temperatures (USDA, 2011). High moisture content may thus possibly improve the keeping quality of poultry meat, but shall remain to be investigated in future studies.

Higher protein content in T_2 group was also found to be statistically significant ($p=0.0153$) as compared to the control group at 21%. Protein content remains as a valuable aspect in poultry production, as chicken breast meat is considered as a very high protein food source in the market. Additional supplementation with ground yellow mealworms may thus improve meat quality that may be offered by small-hold farmers, as well as increase consumer satisfaction.

CONCLUSION

Overall, supplementation of 1% (T_2) ground yellow mealworms into chickens' diet gives high impact on the growth performance of broilers. Notably, these are the increase in feed intake, increase in body weight and efficiency of feed consumed due to lower FCR. It also increases dressed percentage yield and weight of internal organs, significantly produces high moisture content in the thigh region and protein content in the breast region, which are good signs of development.

The addition of 0.5% (T_1) ground yellow mealworms has shown a minimal impact in the study. Carcass yield and weight of internal organs were improved when 2% (T_3) ground yellow mealworms were supplemented into chickens' diet. On the other hand, addition of 10% (T_4) ground yellow mealworms produces heavier gizzard and high percentage of fat content within the meat.

In conclusion, this study has shown that the addition of *Tenebrio molitor L.* to common feedstuffs has the potential to be used as an additional source of nutrition to improve growth performance and carcass quality of poultry meat. Ground yellow mealworm appears to be attractive because of its economical benefits in production and offers no detrimental effects in broiler chickens.

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