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Crickets (Orthoptera: Gryllidae) as a food for faster growth and better quality of tilapia

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The use of insects as an alternative food source in the fishing industry has been long practiced, but a less in-depth study has been conducted to understand its effectiveness. The objective of this study is to evaluate the effects of tilapia growth and quality when crickets are given as food. We used 180 hybrid tilapia *Oreochromis s*p. which were fed with crickets, *Gryllus bimaculatus* and three commercialized fish pellets, namely: Cargill 6113, Bintang BT01 and Bintang BT04. The result showed that crickets had caused a significantly higher fish growth rate compared to when the fish were fed with pellets. Tilapia fed cricket had a mean body weight of 188.31±5.73 g and a length of 21.17±0.19 cm as compared to the best commercial food at 121.27±2.45 g and 18.76±0.19 cm for body weight and length, respectively. There was no significant difference on the fish quality assessment. The crickets as food also produced fishes rich in protein (19.9 g/100g), comparable with Cargill 6113 pellet (20 g/100g), fat (0.8 g/100g) equivalent to Bintang BT01 pellet, and provide the highest energy (365 kJ) compared with other pellets. Carbohydrates are found only in fish fed Bintang BT01 pellet (0.7 g/100g). The requirement of tilapia towards a specific combination of essential amino acids from food sources may explain the different protein contents in the harvested fish. Fish fed cricket has the lowest accumulation of all types of amino acids tested. The use of crickets is the most cost-effective because it is only worth RM 0.007 per gram of fish compared to Cargill 6113 pellet (RM 0.012).

Key words: Tilapia, crickets, growth, quality, food sources.

INTRODUCTION

Data obtained from the Food and Agriculture Organization of the United Nations (FAO) stated that approximately 200 thousand tonnes of freshwater fish were produced from Malaysian fisheries in 2013. The fishing sector plays an important role in providing the main protein supply to the local population as well as contributing to the national economy and serving as a source of income (FAO, 2009). In 2012, the consumption of fish by Malaysians was 52.0 kg per year per person, which brings about 30% or 15.6 kg of consumption per national capita. The world is currently experiencing unstable fish prices and, among other things, is the growing demand for fish, health awareness, lack of efficient fishing ports, increased operating costs, and weak marketing systems (Rozaina, 1997).

Therefore, it is undeniable that the world is currently experiencing a dramatic rise in fish food prices (Tacon and Metian, 2008). In recent years, an increasing demand for fish meal has become an issue of global concern due to the lack of fish meal resources, the variety of quality products, and the unsteady price increase (Nguyen and Davis, 2009). The price fluctuation in a short period was due to changes in supply and demand in the current market and, in the long term, the price of fish-based food was said to be influenced by technology development and trade control (New and Wijkstrom, 2002).

Based on the study of Bondari and Sheppard (1981), insects can be applied to replace the use of commercial fish feed and is acceptable to consumers. Insects are

Table 1. Nutrition content for each food type.

Food Type	Cargill 6113	Bintang BT01	Bintang BT04	Cricket
Crude Protein (%)	32.4 (34[a])	34.0 (32[a])	21.6 (20[a])	18.5 (58.3[b])
Fat (%)	6[a]	6[a]	4[a]	10.3[b]
Fibre (%)	5[a]	7[a]	5[a]	-
Ash (%)	-	12[a]	12[a]	2.96[b]
Moisture (%)	11[a]	11[a]	11[a]	-

[a]Source: as described on packaging; [b]Source: Wang et al., 2005

organisms that have a short-term life expectancy, high fertility rates, easy breeding and flexibility in a variety of situations. Insects are also known to contain high nutrient content (Tran et al., 2015), which include carbohydrates, iron and essential amino acids. For example, crickets have a protein content of 58.3% per 100 g of weight, while fish powder contains 60.8% (Wang et al., 2005). Taufek et al. (2013) showed that this insect has a high potential value as a protein substitute for African catfish. The fish that fed on cricket exhibited an increase in the growth performance, activity of antioxidant enzymes and hematologic response (Taufek et al., 2016). There are also studies on the association of crickets with poultry livestock, such as chickens and ducks (Defoliart et al., 1982) and their nutrition in reptiles (Rich and Talent, 2008).

Other insects that have been studied in the fishing industry include the larvae of black soldier fly (Bondari and Sheppard, 1981), the larvae of mealworms (Ng et al., 2001), silkworm pupae (Nandeesha et al., 1990) and locusts (Balogun, 2011). To date, the studies conducted on the insect and its relation to the fishing sector are still inadequate. Therefore, this study focuses on the use of crickets in the fishing industry to reduce dependence on standard fish pellets.

The aims of the study were to evaluate the effect of growth and quality of tilapia fed with crickets and to compare the effect of cricket and standard fish pellets on fish growth.

MATERIALS AND METHODS

Experimental setup

This experiment was carried out at the Global Fresh Agro fish breeding centre in Sungai Siput, Perak for 90 days. Twelve concrete tanks were set up with PVC pipes that drain freshwater continuously from the nearby hills and the Korbu River. The pH and temperature readings of the water were taken daily. A total of 180 tilapia fish were reared separately according to different foods. All tanks were drained and cleaned every 4 weeks during sampling.

Preparation of crickets

The crickets, *Gryllus bimaculatus* (Orthoptera: Gryllidae) were selected and bred commercially in a breeding centre in Sungai Siput, Perak. The crickets were fed with fish pellets when newly hatched up to 10 days. Then, they were given chicken rice bran into adulthood. Frozen and live crickets given to tilapia as food fish are between 20 to 30 days.

Fish preparation

Black tilapia *Oreochromis sp*. used in this study is a hybrid species of Nile tilapia and Taiwanese tilapia. The fingerlings belonging to the same parent were purchased from the local market. A total of 180 fishes with an average weight of 40.08±0.85 g were randomly divided into four groups (treatments) with each in triplicate of 15 fishes. The pellet were given 3% of the fish body mass and the experimental feed was administered twice daily to the fishes during the 90-day trials.

Feeding trial

The type of food given was three standard commercial food products (pellets) containing material or different nutritional quality (Cargill 6113, Bintang BT01, Bintang BT04) and fresh live crickets. The Cargill 6113 pellet was identified as the highest quality pellet since it has the highest percentage of crude protein. Fish in Pond (treatment) A is given the highest quality pellet (Cargill 6113), Pond B with a moderately high quality pellet (Bintang BT01) and Pond C had a low quality pellet (Bintang BT04), while the crickets were given to the fish in pond D. Each treatment had three replicates. Parameters such as weight (g) and length (cm) of the fish were measured and recorded every two weeks. The protein content of each food was obtained through the UNIPEQ laboratory test. The content of other nutrients for each pellet was described in the package (Table 1), while the nutrient content for the crickets was obtained from Wang et al. (2005) (Table 1). At the end of the feeding trial, samples of two fish from each pond were sacrificed for chemical and proximate analysis according to AOAC 16th Edi. 981.10. Another sample of four fishes from each pond was sacrificed for a sensory assessment to determine the quality of the raw and cooked fish.

Data analysis

The weight-length relationship was determined by using the formula equation of Log W = log a + b log L, where b exponent determines the fish growth rate. A regression line and a good growth rate were drawn, often ranging between 2.5 and 3.5 (Carlander, 1969). Whereas, b=3 denotes an isometric growth of a fish. Positive allometric growth denoted by b>3 and negative growth by the value of b<3.

The evaluation of fish growth and feed utilization were determined by calculating the specific growth rate (SGR) = (In (final weight in grams) - In (inital weight in grams))/days of experiment; food conversion ratio (FCR) = food fed (g)/ live weight gain (g); protein efficiency ratio (PER) = body weight gain (g)/ protein intake (g); Survival rate (SR) = (final number of fish - initial number of fish) x 100. All calculations were measured according to the triplicate tank treatments.

Chemical and proximate analysis

Fish samples from each treatment were sacrificed and 100 g of fish meat were analysed to determine the protein, ash, fat, carbohydrate, ash, moisture and energy content in tilapia fish at the UNIPEQ laboratory, National University of Malaysia.

Studies on the content of heavy metals in each food type (fish pellets and crickets) and in tilapia were also tested at the UNIPEQ laboratory. The obtained data were compared with that of Food Act 1983 (Food Regulations (Amendment) (No.2)) (Ministry of Health Malaysia, 2013), which specifies the maximum allowable permissible level for metal contamination in food.

Sensory evaluation of raw and cooked fish

Fish quality assessment uses a sensory system involving several panels that act as consumers to assess the effect of food on fish quality and to study the level of acceptance of raw and cooked fish fed on respective food. The panels consist of staff and students of the Faculty of Science and Technology, UKM. The fish were frozen at -18°C for 10 days and then tested for raw fish assessment. The quality assessment scheme (Table 2) for raw fish was carried out in accordance with Larsen et al. (1992). Each characteristic was assigned a demerit score ranging from 0 to 3. The sum of all the scores signifies consumer acceptance. The scale gives a zero score for absolutely fresh fish, while the total score that approaches 20 is the result of fish deterioration.

The simple evaluation method for cooked fish was done based on FAO (1995). To do it, two fishes from each type of food were wrapped in an aluminium wrap and steamed for 15 min. The panel gives marks according to the acceptance towards the smell and taste of the fish. The acceptance level of fish freshness is at least 4 and the highest score of 10 signifies the most fresh odour/ flavour characteristic of species, while score 1 indicates strong off-odours/ flavours of the fish.

Estimated food cost

The estimated calculation of the food cost to breed a fish is needed to determine whether the use of crickets as a fish diet is a cost-effective alternative. Food prices are assessed per gram of fish, aimed at identifying the amount of food needed to increase the weight of fish by 1 gram. Food prices per gram of fish = (food price per fish) / (fish weight gain (g))

Statistical analysis

All tests were analysed by one-way analysis of variance (ANOVA) using Minitab version 17.0 (Minitab Inc., Pennsylvania, USA). Whereas, two-way analysis of variance (ANOVA) was used to analyse fish growth rate (food type and week). The differences between the means were compared by Tukey's post hoc test with a probability level of 5% (p<0.05).

RESULTS

The result of the two-way ANOVA analysis (food type and week) showed that cricket-fed fish had a significantly heavier weight (P < 0.05) than the fish fed on other food (pellets) starting from weeks 3 to 13, where the highest weight (188.31 g) was recorded (Figure 1). Among the fishes fed with pellets (Cargill 6113, Bintang BT01 and Bintang BT04), the weight was significantly lower (P < 0.05) for fish fed with Bintang BT04 (90.22 g) than fed with other pellets. Figure 2 shows that the mean length of the cricket-fed fish was always significantly longer (P = 0.001) than pellet-fed fishes and that the longest was at week 13 (21.17 cm). Among pellet-fed fishes, those fed with Bintang BT04 produced fish that were significantly shorter (17.34 cm) from weeks 3 to 13 compared to fish fed with other pellets. There was no significant difference in both weight and length of fish fed with Cargill 6113 and Bintang BT01 pellets throughout the study period.

The result of the regression showed a positive allometric growth in fish that develops faster in weight than in fish length when fed with Bintang BT04 (b =

Table 2. Quality assessment scheme for raw fish (Larsen et al., 1992)

Quality parameter	Character	Score
General appearance	Skin	0 Bright, shining 1 Bright 2 Dull
	Bloodspot on gill cover	0 None 1 Small, 10-30% 2 Big, 30-50% 3 Very big 50-100%
	Stiffness	0 Stiff, in rigor mortis 1 Elastic 2 Firm 3 Soft
	Belly	0 Firm 1 Soft 2 Belly burst
	Smell	0 Fresh, seaweed/metallic 1 Neutral 2 Musty/sour 3 Stale meat/rancid
Eyes	Clarity	0 Clear 1 Cloudy
	Shape	0 Normal 1 Plain 2 Sunken
Gills	Colour	0 Characteristic, red 1 Faded, discoloured
	Smell	0 Fresh, seaweed/metallic 1 Neutral 2 Sweaty/slightly rancid 3 Sour stink/stale, rancid
Sum of scores		(min. 0 and max. 20)

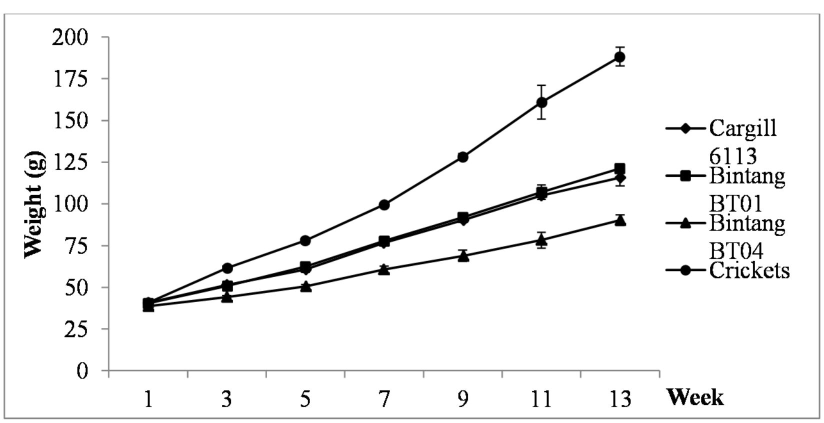

Figure 1. Growth rate (weight) of the fish weight for 13 weeks

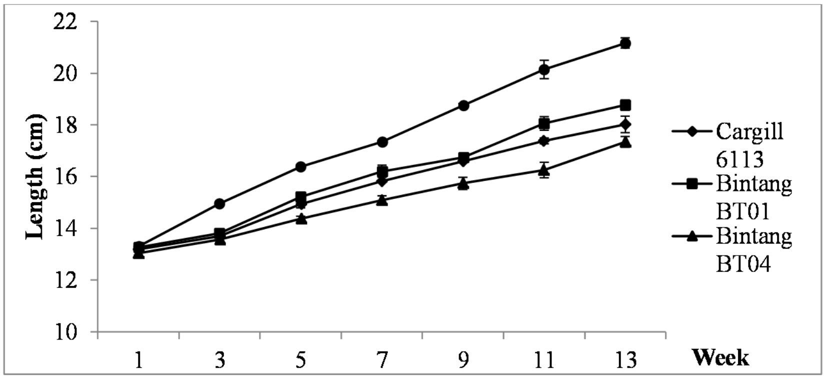

Figure 2. Growth rate (length) of the fish length for 13 weeks

Table 3. Growth performance of fish fed with four different food types.

Parameter	Food type			
	Cargill 6113	Bintang BT01	Bintang BT04	Cricket
Initial weight (g)	40.73±0.78[a]	40.40±0.77[a]	38.64±0.42[a]	40.53±1.41[a]
Final weight (g)	115.58±4.68[b]	121.27±2.45[b]	90.22±3.16[c]	188.31±5.73[a]
Feed taken (g)	178.32±1.81[a]	179.11±5.02[a]	143.26±5.08[b]	70.50±0.00[c]
Body weight gain (g)	74.84±4.87[b]	80.87±3.00[b]	51.58±2.73[c]	147.78±6.89[a]
SGR (g/days)	1.16±0.05[b]	1.22±0.03[b]	0.94±0.03[c]	1.71±0.10[a]
FCR (g/g)	2.40±0.14 [ab]	2.22±0.14[b]	2.78±0.06[a]	0.48±0.11[c]
PER (g/g)	3.74±0.25[bc]	4.70±0.17[b]	2.80±0.15[c]	7.43±0.35[a]
Survival rate (%)	100.00±0.00	100.00±0.00	100.00±0.00	100.00±0.00

SGR, specific growth rate; FCR, feed conversion ratio; PER, protein efficiency ratio; [a] All values are means ± SE for triplicate feeding groups and values with different superscripts are significantly different (P< 0.05)

Table 4. Chemical and proximate analysis of fish fed with different food types

Parameter	Cargill 6113	Bintang BT01	Bintang BT04	Cricket
Protein (g/100g)	20	17.2	18.4	19.9
Total fat (g/100g)	0.5	0.8	0.6	0.8
Total carbohydrate[a] (g/100g)	0	0.7	0	0
Ash (g/100g)	1.2	1.2	1.2	1.2
Moisture (g/100g)	78.3	80.1	79.8	78.1
Energy (kcal/100g)	85 (357kJ)	79 (332kJ)	79 (332kJ)	87 (365kJ)

[a] %Total carbohydrate = 100 - (%Ash + %Moisture + %Protein + %Fat)

3.531) and Bintang BT01 (b = 3.453) (Figure 2). In contrast, a negative growth was shown by fish that were fed with cricket (b = 2.979) and Cargill 6113 pellet (b = 2.605), thus growing faster in length than in weight. However, the fish that grew almost isometrically was the one that was fed with cricket, as the b exponent value approaches 3.

The body weight gain is the most notably highest in fish fed with crickets (147.78 g), while the lowest was that of the Bintang BT04 pellets (51.58 g) (Table 3). In general, various types of foods significantly (P = 0.00) affect SGR. Cricket-fed fish showed the highest weight gain of 1.71 g per day compared to pellet-fed fish and the lowest SGR value was recorded in fish fed with Bintang BT04 (0.94). The lowest FCR was recorded in fish that were fed with crickets at 0.48 and the ANOVA analysis shows significant differences (P = 0.001). The findings also showed that food type significantly (P=0.00) affected the PER and the value was also the highest in fish fed with crickets (7.43). During the 90 days of the study, no fish death was recorded, thus the survival rate was 100%.

Based on Table 4, the protein content in the fish was

Table 5. Heavy metal composition in food and in tilapia.

Heavy metal	Food type	In food (mg/kg)	In fish (mg/kg)
Lead			
	Cargill 6113	0.13	0.05
	Bintang BT01	0.05	-
	Bintang BT04	0.18	-
	Cricket	0.05	-
Cadmium			
	Cargill 6113	0.06	0.07
	Bintang BT01	0.06	0.06
	Bintang BT04	0.07	0.06
	Cricket	0.05	0.06
Mercury			
	Cargill 6113	0.04	-
	Bintang BT01	0.16	-
	Bintang BT04	0.09	-
	Cricket	0.02	-
Antimony			
	Cargill 6113	0.13	0.02
	Bintang BT01	0.44	0.08
	Bintang BT04	0.68	-
	Cricket	0.35	-
Arsenic			
	Cargill 6113	2.32	2.61
	Bintang BT01	0.73	2.03
	Bintang BT04	0.71	1.60
	Cricket	0.18	0.83

approximately the same in the Cargill 6113 pellet (20.0 g / 100g) and in the cricket (19.9 g / 100g). Fish fed with Bintang BT01 pellet had the lowest protein content of 17.2 g / 100g, but the amount of carbohydrate was high (0.7 g / 100g) and was not detected at all in other foods, including cricket. The fat content was relatively higher in fish fed with cricket and Bintang BT01, and was lowest in fish fed with Cargill 6113. The ash content for every 100 g of fish weight was the same for all fish fed with different foods. However, the moisture content in fish fed with crickets was lower (78.1 g / 100g) than fish fed with pellets. Fish fed with cricket also had the highest amount of energy at 365 kJ, while 357kJ, 332kJ, and 332kJ for fish fed with Cargill 6113, Bintang BT01 and Bintang BT04, respectively.

The lead content in fish was low or undetectable than in its food, but more in fish fed with Cargill 6113 pellet than on other pellets (Table 5). Lead content in foods was highest in the Bintang BT04 pellet (0.18 mg/kg) and lowest in Bintang BT01 pellet and crickets (0.5 mg/kg). The content of cadmium in food and fish showed no differences, but Bintang BT04 pellet recorded the highest cadmium content at 0.07 mg/kg. No mercury content was detected in all fish, although this heavy metal was detected in each type of food. The Bintang BT01 pellets recorded the highest levels of mercury content (0.16 mg/kg), while the cricket recorded the lowest value (0.02 mg/kg). Antimony content was lower in fish than in food and was only detected in fish fed with Cargill 6113 (0.02 mg/kg) and fish fed with Bintang BT01 pellet (0.08 mg/kg). The highest antimony content in foods of 0.68 mg/kg was detected in the Bintang BT04 pellet and lowest in the Cargill 6113 pellet (0.13 mg/kg). Surprisingly, the arsenic content was higher in all fish than in its food types. Cargill 6113 pellets had the highest arsenic content (2.32 mg/kg), while the crickets had the lowest value (0.18 mg/kg). Fish fed with Cargill 6113 had the highest arsenic content (2.61 mg/kg), but the most notable increase in arsenic was in fish fed with Bintang BT01 pellets at 1.3 mg/kg.

Sensory evaluation of raw and cooked fish

The sensory evaluation of raw fish showed that the type of food did not significantly ($P > 0.005$) affect the quality of raw fish in all the tests conducted (Table 6). Despite this, the sum of the scores was lowest in fish fed with cricket (4.50), marking the freshest quality. Fish fed with crickets had the lowest marks in terms of the general appearance of the fish (2.50), and fish fed with Bintang BT01

Table 6. Mean scores for quality assessment of raw and cooked fish

Fish type	Parameter	Cargill 6113	Bintang BT01	Bintang BT04	Cricket
Raw fish	General appearance	5.75±0.95	4.75±0.95	5.50±0.96	2.50±0.87
	Eyes	1.00±0.41	0.50±0.2	1.00±0.41	1.25±0.48
	Gill	0.75±0.25	0.75±0.25	0.75±0.25	0.75±0.25
	Total	7.50±1.26	6.00±1.00	7.25±1.25	4.50±0.87
Cooked fish	Smell	8.25±0.24	7.75±0.90	6.88±0.79	8.00±0.66
	Taste	7.75±0.66	7.00±0.51	6.50±0.47	8.75±0.94
	Texture	8.00±0.24	7.50±0.31	6.75±0.61	8.50±1.00

Table 7. Estimated cost of the food needed per tilapia for 90 days.

Cost parameter	Cargill 6113	Cricket
Selling price	RM4.53/kg	RM15/kg
Selling price per gram	RM0.00453	RM0.015
Body weight gain (g)	69.87±4.88	155.8±6.89
Feed taken (g)	178.32±1.81	70.50
Feed price per fish	178.32 g x RM0.00453 = RM 0.81	70.50 g x RM0.015 = RM 1.06
Feed price per gram of fish	RM 0.81/ 69.87 g = RM 0.012	RM 1.06/ 155.8 g = RM 0.007

produced the highest quality of fish eyes (0.50), whereas the fish gills displayed the same score for all food types.

The quality assessments performed on cooked fish indicate that food type had exceeded the consumer acceptance level (Table 6). There was no significant difference (P> 0.005) between the type of food and the quality of the steamed fish in all the tests carried out. Fish fed with Cargill 6113 have the highest marks (8.25) in terms of fish smell. Meanwhile, the fish fed with cricket scores the highest mark in the fish taste and texture, 8.89 and 8.67, respectively.

Estimated food cost

The estimated food cost needed to grow a fish within the 90-day period is as shown in Table 7. Cargill 6133 pellet sales price is RM 4.53 /kg, much cheaper than the prices of crickets, RM 15 /kg. However, pellet-fed fish requires 178.32 g of food to reach 115.58 g of weight, while only 70.50 g of crickets are required for fish to achieve 188.31 g of weight gained. This makes the food price for a fish fed with crickets to be RM 1.06, which was still higher than fish pellets. However, the cost of food per gram of cricket-fed fish is much cheaper at a cost of RM 0.007 per gram of fish than the cost of fish fed with other food sources.

DISCUSSION

The fish growth rate is influenced by the food availability and consumption, genetics, age and size, environmental factors, and nutritional requirements (Lee et al., 1997). Food intake is probably the most important factor in affecting fish growth rate (Lee et al., 1997). The statistical analysis results show that different types of foods have different effects on fish growth, where fish fed with cricket as a daily diet are heavier and longer than fish fed with pellets (Figures 1 and 2). Shyama and Keshavanath (1993) also found that the defatted silkworm pupa as fish food could increase the growth rate and lifespan of carp fish, *Tor khurdee*. The lowest increase was recorded in fish fed with Bintang BT04 pellet, proving that it was a low grade pellet. The study by Aksnes et al. (1997) on seabream fish, *Sparus aurata* also explains that fish fed with low-quality pellets exhibit low food efficiency and less body weight gain. The protein source along with amino acids or additional protein sources in food types, in this study, has influenced the growth and composition of fish bodies (Smith et al., 2013). There are also records on the use of other insects, such as black soldier fly larvae, *Hermetia illucens* as a food substitute for African catfish, *Clarias gariepinus* (Aniebo et al., 2009) and blue tilapia fish, *Tilapia aurea* (Bondari and Sheppard, 1981). As such, there is a potential for cricket to replace standard fish pellets.

The fish weight-length relationships indicate the state and growth pattern of the fish (Bagenal and Tesch, 1978). In this study, the value of b exponent is within a good range of growth and it proves that the type of food given does not adversely affect the fish weight and length. Positive allometric growth implies that as the fish grow longer, it becomes relatively stouter or deeper-bodied, whereas the fish that experience negative growth becomes more slender as their weight increases (Riedel et al., 2007). Nehemia et al. (2012) obtained a value of b = 2.94 for *Tilapia zilii* fish cultured in freshwater areas, while b = 2.07 for seawater area, thus clarifying that the weight-length relationships are influenced by salinity and dissolved oxygen content. Some studies have found that species of adult females catfish are growing in weight faster than males of African catfish (Ayo-Olalusi, 2014) and *Labeo boga* fish (Pervin and Mortuza, 2008).

The specific growth rate (SGR) determines the weight gain of the fish within a day after being given certain foods such as cricket. In this study, the cricket causes fish to grow three times faster than Bintang BT04 pellets when given as food within a day. However, the value of SGR will decrease when the need for fish growth and maintenance decreases as the fish ages (Guillaume et al., 1991). The food conversion ratio (FCR) is influenced by food intake, nutrient loss through waste, energy used for maintenance, weight gain, and gonad production (Gjedrem, 2005). Our study showed that the FCR value is best in fish fed with cricket (0.48) and this value is lower than the FCR of Nile tilapia (1.72), which feeds on pellets containing 30% protein diet (Siddiqui et al., 1988; Table 3). This means that the crickets are highly efficient to increase the fish weight, consuming 0.48 g of food to raise 1 g of fish weight. In contrast, the fish fed with standard pellets need more food to reach the same weight of cricket-fed fish. The protein efficiency ratio (PER) was also highest in cricket, in which 1 g of protein was utilized to increase 7.43 g of fish body weight. The value of PER in tilapia fish was much lower when 100% substitute was given for soybean (1.09) (Shiau et al., 1989) and 60% *Imbrasia belina* worm (2.80) (Rapatsa and Moyo, 2017). The survival rate (SR) was found to be significantly unaffected by the stock density of the Nile tilapia, although its size was small and there was no space for competition (Khattab et al., 2004). SR was also not affected by the level of protein content, but was significantly ($P \leq 0.005$) affected by nutritional levels and the interactions between levels of protein and nutrition (El-Saidy and Gaber, 2005).

It has been proven that the cricket-fed fish was rich in protein, as did the fish fed with Cargill 6113 pellet. In addition, the cricket induces a faster growth rate of fish than the standard pellets, although the crickets only provide 18.5% protein content. Whereas, the Bintang BT04 pellet containing the lowest protein is capable of producing more protein in fish than in Bintang BT01 pellet. Santiago and Lovell (1988) explained the need for a combination of amino acids for the development of Nile tilapia, which is specific to a certain amount: lysine, 5.12; arginine, 4.20; histidine, 1.72; valine, 3.00; leucine, 3.39; isoleucine, 3.11; threonine, 3.75; tryptophan, 0.80; methionine, 3.21; phenylalanine, 5.54. Meanwhile, the amino acid requirement for red tilapia fish is different, namely the arginine, 4.00; histidine, 1.60; valine, 3.00; leusine, 4.50; isoleusine, 2.60; threonine, 3.30; tryptophan, 0.60; methionine, 3.50; phenylalanine, 4.90 (Khaled, 2007). Wang et al. (2005) reported that the cricket has a higher percentage for all types of amino acids than fish pellets, except histidine. In contrast to cricket, the application of 100% diet of soybeans as a protein substitute was unable to meet the methionine requirements of *Tilapia* sp. (Shiau et al., 1989). Therefore, it can be concluded that different species of fish require different amino acids and each food source will produce different proteins in fish. However, the presence of crude fiber such as α-cellulose in fish food may also reduce the protein concentration in trout (Davies, 1985). It is important to note that fish need the highest protein requirement during the newly hatched (40%), but less at thejuvenile level (30%; Siddiqui et al., 1988; Al Hafedh, 1999).

Tilapias are able to utilize lipids efficiently as a source of energy (El-Sayed and Garling, 1988) and its fats requirements are different for each species (El-Sayed, 2006). Fat is a macronutrient that can replace protein for growth compared to carbohydrates (El-Sayed and Garling, 1988). Therefore, the carbohydrate content is relatively lower than the amount of fat in fish (FAO, 1995). Fish also tends to oxidize deaminated amino acids more efficiently than glucose to yield energy (Lovell, 1989). The results of this study (Table 4) showed that carbohydrates are only found in fish fed with Bintang BT01 pellet and are likely to affect or be associated with low protein content in fish as a result of low proteins provided by the Bintang BT01 pellet. Our result tends to agree with that of Jauncey (1982) on juvenile tilapia fish *Sarotherodon mossambicus*, where the fish fed with the lowest level protein diet tends to have a low protein content, a high lipid content and a low moisture content.

Fish energy is influenced by the protein and fat content found in its food source (Cho and Kaushik, 1990). Cricket provides proteins and high fat content, 18.5% and 10.3%, respectively, to tilapia fish, leading to the highest energy earned and faster growth compared to other food types (Table 1). Fish also requires specific energy levels to perform physical activities such as breathing and swimming. Cricket and fish have a prey-predator relationship, thus having an active lifestyle because the fish utilized a lot of energy to catch the live cricket thrown into the pond and this may drive the fish to be more active than in its natural state, thus causing them to be healthier than those pellet-fed fishes. During swimming, the energy consumption of the myotome muscles increases at the appropriate speed to meet the thrust requirements, especially in the posterior myotome where the power output muscle is greatest (Gerry and Ellerby, 2014).

In the fishing industry, fish is commonly used as a bioindicator for detecting heavy metal contamination (Authman et al., 2015). The cricket-fed fish has the lowest accumulation for each type of heavy metal in its body. Lead was only detected in the fish fed with Cargill 6113, and its migration to fish was probably due to its natural presence in groundwater or from the usage of appliances other than stainless steel during sampling (MOH Malaysia, 2013). There were no noticeable differences in the cadmium content in fish and food (Table 5). These results show that the fish are taking entirely heavy cadmium from the food. The mercury content was not detected at all in fish, which means no mercury absorption is performed by the fish, although this heavy metal is detected in their food. The arsenic content was detected high in fish, although the content is comparatively lower in food. Other than its food source, there may be arsenic around the fish, such as sediment or water source from river and soil, as mentioned earlier (Cheng et al., 2013). This is because arsenic dissolves easily in groundwater depending on the pH, temperature and composition of the solution (Nordstrom, 2012), thus flowing into the river.

Sensory evaluation of raw fish showed that the cricket-fed tilapia has the best physical quality. The features of the skin are black, shiny, and display vibrant bands. Whereas, the tilapia fed with pellets had a relatively fader and less shiny skin color. The body of the fish fed with Bintang BT04 pellet was found to have a lot of slimes and was very slippery when held, whereas fish fed with crickets where the least slimy, but difficult to hold because of its larger size and more active movement. This slimes serve to control the loss of water between the gill comb and between the front brachia arch (Smith and Sanderson, 2007), but an excessive amount may cause obstruction in the interlamella space (Poleo, 1995). Fish that eat crickets also have a more solid and compact body than fish fed with pellets. However, the recorded scores are inconsistent because sensory test results can be affected by the chemical composition in the fish, the catching techniques, the fish storage temperature and the weather conditions (Kietzmann et al., 1969).

Geosmine and 2-methylosoborneol are two types of volatile compounds that are involved in freshwater fish damage and are easily absorbed by fish, thus producing the earthy and musty smell (Elmore, 2011). The presence of these two compounds is likely to explain the sour and stale smell released by the fish fed with Bintang BT04 pellets. The quality test results show a tasteless, neutrality and sweetness as a result of different food sources. The lipid content in fish pellets is an important factor in the taste and texture of rainbow trout (Johansson et al., 2000). Fish texture tests also gave positive results on cricket-fed fish that had the most solid, elastic and juicy textures. The difference in texture between fishes from different food sources is probably due to the different protein content and structure found in each of these foods in which the sarcoplasmic proteins and muscle fiber diameter can affect the content of fish firmness (Hatae et al., 1990). Therefore, it is likely that the texture of the protein in fish fed with cricket has thinner muscle fibers than those fed with standard pellets.

The cost per gram is cheaper for crickets than for Cargill 6113 pellets as food due to the rapid weight gain of a cricket-fed fish that indirectly takes a shorter time to reach a marketable size. Although the price of pellets in the market is lower than the crickets per kilogram, the quantity of pellets needed for fish growth is high, thus making the food price to be expensive in producing readily harvested fish. In fact, the cost of cricket farming can also be further reduced by exploiting its available food sources, such as the use of wasted, but still good vegetables or overripe fruit, and the use of self-cultivated vegetables and nuts (Harris, Global Fresh Agro 2016 - personal communication).

Conclusion and Recommendation

The use of crickets is the most cost-effective because it only worth RM 0.007 per gram of fish compared to the Cargill 6113 pellet (RM 0.012). With these results also, farmers will increase their income with the use of cricket, since the cost for fish feeding reduces 58.3% per gram without degrading their fish quality. Hence, it is highly recommended to fish farmers to use crickets as food in their fish farm.

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