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The Diet for Edible-Nest Swiftlets: Nutritional Composition and Cost of Life Stages of *Megaselia scalaris* Loew (Diptera: Phoridae) Bred on 3 Commercial Breeding Materials

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ABSTRACT: *Megaselia scalaris* (Loew) is one of the best-known diets for the swiftlet. Previous studies have addressed the problem of some mass rearing conditions for this insect; unfortunately, the details of the nutritional composition of the life stages and cost of the breeding materials were insufficiently reported, even though this information is crucial for farming the edible-nest swiftlet. We aimed to investigate the nutritional composition of the life stages of *M scalaris* on a cost basis using 3 common commercial breeding materials: chicken pellets (CPs), fish pellets (FPs), and mouse pellets (MPs). Modified Association of Official Analytical Chemists (AOAC) proximate and mineral analyses were carried out on the insect's third instar larvae, pupal, and adult stages to determine the nutritional composition. Regardless of the breeding materials, the adult stage of *M scalaris* had significantly higher crude protein than the other stages; the pupae were rich in calcium, which is required for egg production; and the third instar larvae had the highest amount of crude fat compared with the other stages. Regarding the energy content, there were no significant differences among the stages according to the breeding materials. In terms of nutritional cost, CP was the most economic breeding material and generated the highest amount of nutrients per US dollar (US $). Different life stages of *M scalaris* were used by the swiftlets by supplying the required nutrients, and future studies should focus on effective diet feeding methods.

KEYWORDS: life stages, diet, nutritional composition, nutritional cost

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Introduction

Over the past 2 decades, swiftlet captive farming has rapidly increased in Southeast Asia due to the high demand for this edible bird.[1] Edible-nest swiftlets refer to several species of swiftlet birds that can produce nests that can be eaten by humans. The nest is an important ingredient in Chinese medicine for health-enhancing effects and is traditionally used as a food delicacy in Asia.[2] Swiftlets, such as white-nest swiftlets (*Aerodramus fuciphagus*) and black-nest swiftlets (*Aerodramus maximus*), are bred in captivity in a specially designed building that is not their natural habitat, which may affect their dietary habits.[3] Although swiftlets do not necessarily select nutritionally adequate diets, some primary nutrients, such as carbohydrates and fats, are important as energy sources, and proteins are needed for tissue and enzyme construction and for growth. Minerals are also required: calcium is needed by reproductively active female birds for egg production, and phosphorus is needed in large quantities for bone construction.[4] Swiftlets are insectivorous, and the most common insects found in their boluses from prey composition are from the order Diptera.[5] The contents of the boluses indicate the feed that can be used in swiftlet captive farming, and due to its small size, soft body, ease of mass rearing, high nutritional value, and conversion rate, the Dipteran insect *Megaselia scalaris* (Loew) is a good candidate for a domestic swiftlet feed[6]; however, previous studies were not focused on the nutritional value of the other life stages of *M scalaris*. Most studies on *M scalaris* have focused on their roles in forensic science; their development using different breeding materials; and their rearing conditions, such as moisture, density, and temperature[7,8]; however, from the perspective of swiftlet captive farming, the nutritional composition of each life stage of *M scalaris* and the nutritional cost (the cost to generate certain nutrients) of breeding materials have not been studied. Therefore, we investigated the nutritional value and cost of each life stage of *M scalaris* by breeding the insect on 3 commercial breeding materials.

Materials and Methods

Megaselia scalaris colony

The life stages of *M scalaris* used in this study were larva, pupa, and adult. A *M scalaris* colony was obtained from the Department of Veterinary Services (Pusat Pembiakan Itik/Pusat Walit, Kampung Paya Jaras Hilir, Selangor, Malaysia). For the larval stage, third instar larvae were used due to the accumulation of nutrients at that stage and for convenience in identification. The colony was maintained in a polypropylene container (10 L, with a capacity of 100 adult flies) that was closed with a muslin cloth and subjected to 24 hours under a white fluorescent lamp light at 70% ± 5% relative humidity and 27°C ± 2°C. Adults were allowed to mate, and 25 g of larval diet (a mixture of chicken feed (3011 Poultry Focus, Cargill,

Table 1. Manufacturer, ingredients, nutritional content, and cost of the breeding materials.

ABBREVIATIONS	PRODUCT NAME	MANUFACTURER	INGREDIENTS	NUTRITION CONTENT (%)	COST (US $/KG)
FP	92300 Dindings Finisher Fish Pellet	Dindings	Soymeal, fish meal, wheat byproducts, fish oil, amino acids, vitamins and minerals, antioxidants, and a mold inhibitor	CP min 23 CF min 5 Cfib min max 5 Ash max 10 Moisture max 10	0.48
MP	702 Gold Coin Mouse Pellet	Gold Coin	Corn, soybean meal, grains, animal protein, vegetable oil, molasses, calcium carbonate, dicalcium phosphate, amino acids, vitamins, trace minerals and enzymes, antimicrobials, and additives	CP min 21 CF min 3 Cfib min max 5 Ash max 8 Moisture max 13	0.82
CP	Cargill 3011 Poultry Focus	Cargill	Animal peptides, plant proteins, grains and grain byproducts, oil, calcium & phosphorus, amino acids, antioxidants, mold inhibitor, minerals, antibiotics, and anticoccidial	CP min 21 CF min 4 Cfib min max 6 Ash max Moisture max 13	1.51

Abbreviations: CP, chicken pellet; FP, fish pellet; MP, mouse pellet.

Selangor, Malaysia) and water at a ratio of 1:1.5 by weight) was placed in a Petri dish (height 1.5 cm × diameter 9 cm) for egg collection. To maintain the stock colony, larvae were allowed to hatch after 8 hours and left in the container until pupation. Pupae were collected and transferred to a new polypropylene container for adult emergence.

Preparation of breeding materials

The breeding materials were obtained commercially in pellet form, and the selection of materials was based on the availability of the manufacturers, ingredients, nutritional content, and cost (Table 1).The breeding materials were prepared in bulk using an electronic mixer to homogenize the pellets with water (2:3 ratio) in a stainless-steel tank. The abbreviations for breeding materials used are FP, CP, and MP.

Chemical analysis

Megaselia scalaris sample. Ten milligrams of eggs from the stock colony was introduced to each of the FP, CP, and MP breeding materials. Third instar larvae were harvested by identifying the appropriate body length (~4 mm). For the collection of pupae and adults, 2 batches of third instar larvae were prepared, washed, and placed into 2 plastic cages (height 24.0 cm × diameter 22.5 cm). One cage was used for pupae collection; freshly emerged adults (less than 24 hours) from the other cage were harvested using a centrifuge (BSTZ-U1AA1; TECO, Prai Penang, Malaysia). All samples (third instar larva, pupa, and adult) were killed in a freezer at −20°C for 24 hours before nutrient analysis.

Proximate analysis. All of the reagents used in the analysis were of analytical grade. A slightly modified Association of Official Analytical Chemists (AOAC) (2000) proximate analysis[9] was conducted on the *M scalaris* samples, and all of the testing was performed with 3 replicates. Moisture content was measured by the gravimetric method (Method 925.40) with oven drying at 105°C. The moisture level was indicated by the difference in mass and was converted into a percentage.

The dried samples were used for protein analysis via the Kjeldahl method (Method 955.04). Initially, approximately 0.10 g of sample was first digested with concentrated sulfuric acid and a catalyst in a Kjeldahl flask. After the mixture was cooled to room temperature, sodium hydroxide was added to the flask. The flask was then placed in a distillation connection unit, and the distillate was mixed with boric acid and a few drops of methyl red. The distillate mixture was titrated with 0.40% hydrochloric acid, and the percentage of protein was calculated.

Determination of the lipid content was performed using the Soxtec method (Method 920.39). Food samples were weighed to approximately 0.20 g, and 4 mL of the solvent petroleum ether was used for the extraction. First, the mixture was homogenized using an ultrasonic homogenizer (Fisherbrand Model 505 Sonic Dismembrator; Thermo Fisher Scientific, Malaysia) and filtered with a Buchner funnel. The filtrate was transferred to a separating funnel and shaken with 20 mL of distilled water. The mixture was allowed to settle overnight, and the ether part was removed and dried in an oven at 60°C for 8 hours. The residue weight was lipid, which was expressed as a percentage.

For crude fiber (Method 935.53), the sample was weighed in a fiber capsule, inserted into a beaker containing approximately 300 mL of preheated reagent (1.25% sulfuric acid) and boiled for 30 minutes. The mixture was filtered and rinsed for approximately 30 seconds with hot distilled water and then rinsed with approximately 15 mL of acetone to remove the excess solution. The residue in the fiber capsule was dried in an oven at 100°C ± 2°C for 24 hours. The dried residue (D) was weighed and heated in a muffle furnace at 550°C for 4 hours to form ash (A). The fiber was the difference between D and A divided by the original weight of the sample and is expressed as a percentage.

To determine energy value, samples were weighed, and a pellet was formed by a tabletop pellet press. The sample pellet was placed in a sample cup connected to the heating element. Then, the sample cup was placed into a sealed bomb. The sealed bomb was placed in a bomb calorimeter, and the process took approximately 10 minutes. The energy value (J/g) was recorded.

Mineral analysis. Analyses were performed according to a slightly modified AOAC (2005) mineral analysis,[10] and all of the testing was performed with three replicates. The samples were burned in a muffle furnace at 550°C for 6 hours, and the ash was dissolved in concentrated hydrochloric acid. Calcium content was determined by atomic-absorption spectrophotometry (Model 3300; PerkinElmer), and phosphorus content was determined by visible spectrophotometry (600s; FEMTO, SP, Brazil) via ammonium phosphovanadomolybdate. Three readings of each triplicate were obtained, and the results are expressed in g/100 g.

Statistical analysis. We focused on the nutritional composition of third instar larva, pupa, and adult *M scalaris*. The nutritional content was expressed as a percentage due to the analysis of proportions in ecology, and the data were arcsine transformed prior to analytical tests. Moreover, the nutritional cost of the breeding material was obtained by converting the nutrients into the amount of nutrients per cost of breeding materials in US dollar (US $). The nutritional composition among the life stages and the nutritional cost for the breeding materials were compared by 1-way analysis of variance (ANOVA) followed by the least significant difference (LSD) post hoc test in SPSS 20.0 at $P < .05$.

Results

Regardless of the breeding material used, the crude protein of adults was significantly higher than that of the other stages ($F = 37.71$; $df = 2, 12$; $P < .05$) and was composed at least 63% of the total nutrients (Table 2). For calcium content, the pupal stage of *M scalaris* showed the highest quantity compared with the other life stages ($F = 30.25$; $df = 2, 12$; $P < .05$), which ranged from 0.77 to 1.06 g/100 g for the different breeding materials. As much as 31.94% of crude fat was obtained from third instar larvae of *M scalaris* using CP as the breeding material, and the crude fat content was also significantly higher than that in the pupa and adult stages ($F = 6.26$; $df = 2, 12$; $P < .05$), indicating that third instar larvae are a good source of crude fat for swiftlets. Nevertheless, regarding the energy contents, there were no significant differences among the stages regardless of the type of breeding material used. CPs were the cheapest (US $0.48/kg) among the breeding materials, and the nutritional content generated from CP was significantly higher than those of the other breeding materials (Table 3). When the nutritional cost of the breeding materials was compared (CP, FP, and MP), CP had the lowest cost per kilogram (US $0.48) and led to significantly higher nutrient levels than the other breeding materials (Figure 1).

Discussion

Animals may acquire different compositions of nutrients at different growth stages.[11] Swiftlets behave like wild birds; therefore, in captive farming, meeting their nutritional requirements is a challenging issue. Our study demonstrated that the 3 life stages (third instar larvae, pupae, and adults) of *M scalaris* are able to provide different nutrients if used to feed swiftlets. Three life stages provide different nutritional contents, which may be due to the nutrient requirements for that particular stage, as suggested by Turner et al[12]; for example, larvae have to gain a critical minimum weight and fat content before they can undergo pupation successfully. The results provide a detailed analysis of the nutritional composition of the life stages of *M scalaris* in support of the study by Kamarudin and Khoo,[6] in which small Diptera, such as *M scalaris*, were found to be a suitable diet for the swiftlet. The nutritional composition of Diptera insect life stages may vary by species; for example, the pupal stage of the house fly (*Musca domestica* L.) contained the highest crude protein,[13] but in the black soldier fly (*Hermetia illucens*), the highest crude protein content was at the prepupal stage.[14] Nevertheless, we showed that the crude protein of *M scalaris* was the highest at the adult stage, and this result was consistent with the study of Finke,[15] in which the crude protein for Diptera insects represented 37% to 61.4% of the total nutrients. As suggested by McWilliams et al,[16] protein is the key nutrient for muscle construction, particularly in the growing stages; therefore, adult *M scalaris* was suggested for use as a feed during the reproductively active and growing stages of swiftlets. In addition to the nutritional perspective, adult *M scalaris* were easier to release and feed because swiftlets usually prey on mobile insects.

Our results showed that the pupal stage of *M scalaris* was rich in calcium, indicating that pupae may be suitable for female swiftlets involved in egg production during the mating and reproduction season. Calcium is the critical mineral in egg shell construction, and a lack of this nutrient may result in a higher fatality rate of immature swiftlets. Studier and Sevick[17]

Table 2. Nutritional value (means ± SE) of *Megaselia scalaris* for different breeding materials and stages.

BREEDING MATERIALS	STAGE	CRUDE PROTEIN, %	CRUDE FAT, %	ENERGY, KJ/G	CRUDE FIBER, %	CALCIUM, G/100 G	PHOSPHORUS, G/100 G
CP	Larva	48.78 ± 0.66[a]	31.94 ± 0.47[a]	24.00 ± 0.18[a]	5.88 ± 0.20[a]	0.48 ± 0.09[a]	0.77 ± 0.04[a]
	Pupae	53.13 ± 1.24[b]	27.46 ± 0.95[b]	22.45 ± 0.21[a]	17.02 ± 1.24[b]	0.77 ± 0.16[b]	0.84 ± 0.07[a]
	Adult	66.10 ± 1.21[c]	18.48 ± 1.61[c]	22.48 ± 0.29[a]	8.43 ± 0.52[c]	0.29 ± 0.04[c]	1.18 ± 0.04[b]
FP	Larva	48.18 ± 0.83[a]	32.85 ± 1.29[a]	23.97 ± 0.36[a]	4.60 ± 0.10[a]	0.53 ± 0.05[a]	0.80 ± 0.04[a]
	Pupae	56.38 ± 1.96[b]	23.47 ± 2.22[b]	21.07 ± 0.43[a]	21.95 ± 1.05[b]	1.06 ± 0.18[b]	0.97 ± 0.03[a]
	Adult	63.99 ± 1.23[c]	20.43 ± 1.68[b]	22.84 ± 0.30[a]	9.08 ± 1.52[c]	0.28 ± 0.02[c]	1.14 ± 0.04[b]
MP	Larva	55.67 ± 1.01[a]	21.59 ± 2.95[a]	22.32 ± 0.47[a]	6.68 ± 0.36[a]	0.37 ± 0.06[a]	0.99 ± 0.08[a]
	Pupae	61.62 ± 1.44[b]	13.27 ± 1.84[b]	19.45 ± 0.43[a]	14.30 ± 0.82[b]	0.81 ± 0.06[b]	1.67 ± 0.13[b]
	Adult	69.93 ± 1.00[c]	10.17 ± 1.87[b]	21.17 ± 0.09[a]	8.98 ± 0.59[c]	0.28 ± 0.01[c]	1.08 ± 0.05[b]

Abbreviations: CP, chicken pellet; FP, fish pellet; MP, mouse pellet.
Different letters in the columns indicate that they are significantly different for the nutritional value at $P < .05$. All testing was performed with 3 replicates.

Table 3. Nutritional value based on US $1, nutrient (g/100 g) per US $ ± SE.

BREEDING MATERIAL	STAGE	CRUDE PROTEIN	CRUDE FAT	ENERGY	CRUDE FIBER	CALCIUM	PHOSPHORUS
CP	Larva	101.58 ± 1.38[a]	66.54 ± 0.98[a]	50.00 ± 0.38[a]	12.25 ± 0.42[a]	1.01 ± 0.19[a]	1.61 ± 0.08[a]
FP		58.76 ± 1.01[b]	40.05 ± 1.57[b]	29.23 ± 0.44[b]	5.60 ± 0.12[b]	0.64 ± 0.06[b]	0.97 ± 0.05[b]
MP		36.87 ± 0.67[c]	14.30 ± 1.95[c]	14.78 ± 0.31[c]	4.42 ± 0.24[c]	0.25 ± 0.04[c]	0.66 ± 0.05[c]
CP	Pupae	110.69 ± 2.58[a]	57.20 ± 1.98[a]	46.77 ± 0.44[a]	35.45 ± 2.58[a]	1.61 ± 0.30[a]	1.75 ± 0.40[a]
FP		68.76 ± 2.39[b]	28.62 ± 2.70[b]	25.70 ± 0.52[b]	26.77 ± 1.28[b]	1.30 ± 0.22[b]	1.19 ± 0.04[b]
MP		40.81 ± 0.95[c]	8.79 ± 1.22[c]	12.88 ± 0.28[c]	9.47 ± 0.54[c]	0.54 ± 0.04[c]	1.10 ± 0.09[c]
CP	Adult	137.70 ± 2.52[a]	38.50 ± 3.35[a]	46.83 ± 0.60[a]	17.55 ± 1.08[a]	0.60 ± 0.08[a]	2.46 ± 0.08[a]
FP		78.04 ± 1.48[b]	24.92 ± 1.96[b]	27.85 ± 0.35[b]	11.08 ± 0.63[b]	0.34 ± 0.05[b]	1.30 ± 0.05[b]
MP		46.31 ± 0.80[c]	6.73 ± 1.07[c]	14.02 ± 0.19[c]	5.94 ± 0.34[c]	0.19 ± 0.03[c]	0.72 ± 0.03[c]

Abbreviations: CP, chicken pellet; FP, fish pellet; MP, mouse pellet.
Cost was calculated based on 1 kg of CP = US $0.48, FP = US $0.82, and MP = US $1.51. Different letters in the columns indicate that they are significantly different for the nutritional value at $P < .05$.

and Graveland and Van Gijzen[18] found that the calcium composition of insects in most orders is less than 0.3% by dry mass. These results contrasted with our results, which showed that pupae of *M scalaris* generated at least 0.77 g/100 g (0.77%) calcium. This difference may be observed because pupae of *M scalaris* have calcified exoskeletons. However, supplying insects at an immobile developmental stage to aerial insectivorous birds, such as swiftlets, is challenging.

Crude fat serves as an energy resource during flight,[4] and as suggested by McWilliams et al,[16] birds may store fat in preparation for breeding. This study showed that crude fat was highest in the third instar larvae, a finding that was almost identical to those of the studies of Barker et al[19] and Finke,[15] in which most Diptera insects were found to preserve their fat content during their immature stage. The third instar larvae of *M scalaris* were a potential diet for swiftlets that were active in food foraging, consistent with the study of Molokwu et al,[20] who investigated the diet selection of foraging birds using fat- and carbohydrate-rich diets and found that the birds preferred the diet that had a significantly higher fat content. Fats are able to provide twice the amount of energy (39.5 kJ/g) as carbohydrates and proteins (16.9 and 23.6 kJ/g, respectively).[4]

The nutritional cost of supplying nutrients to birds raised for food or other products, such as poultry, ducks, ostriches, and

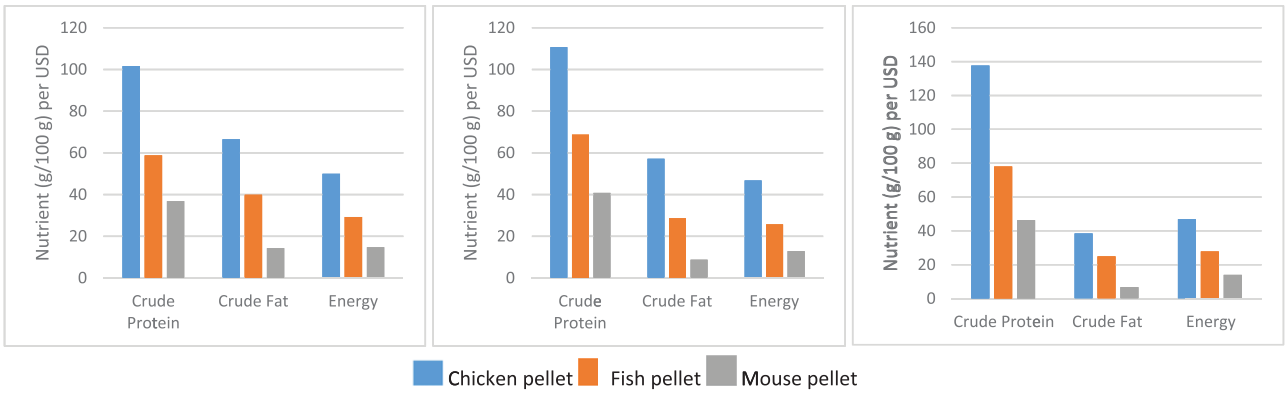

Figure 1. Nutritional value based on US $1—left: larvae; center: pupae; right: adult.

pheasants, has been well studied and measured, although the exact nutritional cost for most species of birds is still unknown, and the cost of avian diets for many species is extrapolated from the poultry industry. To the best of our knowledge, this study was the first to report the nutritional cost of swiftlets. There were no significant differences among the types of breeding materials used. This result could provide important information when mass rearing *M scalaris* is required, because a more expensive material, such as nutrient agar, is often used as a breeding material; therefore, the commercial animal feeds that we tested in this study may provide a good alternative. The result also suggested that when insects are used as the diet for birds, cost is more important than the nutritional composition of breeding materials because insects have a good nutritional conversion rate and can convert lower-cost materials to high amounts of nutrients.

Conclusions

The nutritional composition of *M scalaris* in the adult stage had the highest crude protein content, the pupal stage had the highest calcium content, and third instar larvae had the highest crude fat content of the 3 breeding materials (FPs, CPs, and MPs). For cost consideration, CPs generated significantly higher nutrients per US $. Future studies could be performed on swiftlet feeding trials with different life stages of *M scalaris* and on diet development for economically important avians.

Author Contributions

All authors contributed equally to the writing and editing of the first and final drafts of this article.

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