The impact of dietary Black Soldier Fly larvae oil and meal on laying hen performance and egg quality

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ABSTRACT Recently, the US FDA and Association of American Feed Control Officials approved Black Soldier Fly larvae (**BSFL**) as a feed ingredient for poultry. The objectives of this work were 1) to evaluate the nutritional profile of BSFL oil and meal in laying hens, and 2) measure the impact of the BSFL treatments on hen performance and egg quality. In 2 experiments, BSFL oil and meal were fed to replicate hens from 43 to 47 wk and from 51 to 55 wk of age. The hens were fed isocaloric, isonitrogenous diets with 3 treatment levels of BSFL oil (1.5, 3, and 4.5%, Exp. 1) or BSFL meal (8, 16 and 24%, Exp. 2). Data were analyzed by one-factor ANOVA for the main effect of diet and Tukey's multiple comparison for mean separation when significant. Exp. 1 results suggest BSFL oil could readily substituted for soybean oil with commercial hens at inclusion levels up to 4.5%. ADFI, BW, egg production, FCR, and egg weight were not impacted by the oil treatments ($P > 0.05$). Yolk color among hens fed the BSFL oil was greater averaging 7.88 compared to 7.37 from Control hen eggs ($P = 0.0001$). Exp. 2 diet formulation replaced soybean oil and meal with BSFL meal, and some additional corn was used in the higher BSFL diets. Diet amino acid balance at the highest level of inclusion (24% BSFL meal) indicates arginine and tryptophan are limiting and ADFI, BW and egg production were reduced ($P < 0.05$). Egg production averaged 85.14% for the Control, 8 and 16% BSFL meal hens and was significantly greater than hens fed 24% meal at 77.01%. However, 8 and 16% BSFL meal levels had no negative impact on performance and were not significantly different than the Controls. Yolk color was again higher among the meal treatments compared to the control ($P = 0.0351$). These experiments indicate that BSFL oil and meal can be used as dietary energy, protein and amino acids for hen maintenance, egg production and yolk coloration, although there may be upper limits of dietary inclusion.

Key words: Black Soldier Fly larvae, dietary, oil, meal, laying hens

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INTRODUCTION

Black Soldier Flies (*Hermetia illucens*) have been utilized for commercial poultry to colonize manure and reduce house fly (*Musca domestica*) breeding, manure volume, manure nitrogen content and associated problems with large manure accumulations in confined poultry operations (Sheppard, 1983; Sheppard et al., 1998; Sheppard and Newton, 2000). More recently, it has been documented that Black Soldier Fly larvae (**BSFL**) are able to feed on many substrates including fish offal, brewery by-products, restaurant waste, sewage sludge and others (Lalander et al., 2019; Meneguz et al., 2018; Spranghers et al., 2017; St-Hilaire et al., 2007). Furthermore, high-fat insect larvae fed on organic waste have potential for energy reclamation and biodiesel production when raised under intensive management systems for commercial applications (Nguyen et al., 2019).

Recent research has documented BSFL have potential as alternative foods and feedstuffs for a burgeoning population that may exceed 11 billion people by the year 2100 (United Nations, 2019), currently 7.7 billion. While the FAO has identified 1,900 edible insect species and estimated in 2005 that there were more than 2 billion insect consumers worldwide (Thompson, 2013); in western society eating insects is still a cultural taboo. Furthermore, Islamic interpretation suggests scorpions are forbidden

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and prohibits eating all animals that creep including insects (Adam and Leicester, 2015) and in Judaism most insects are not considered kosher for consumption (Abramowitz, 2013). Therefore, livestock and poultry products derived from animals fed insects may be a more legitimate avenue to capture their nutrients because of the implicit ethnic, religious, and cultural hurdles for insects as direct foodstuffs for people in western societies. Furthermore, insect foraging and consumption are a natural part of most animals' evolutionary feeding habits.

Depending on stage in their development, BSFL can contain upwards of 40% crude protein and are rich in essential amino acids including lysine, methionine, cysteine, arginine and tryptophan (Makkar et al., 2014). They are also a concentrated source of lipids (28%) and minerals such as calcium and phosphorus (Wang and Shelomi, 2017). When the lipids are expressed from the meal it can even be a more concentrated source of protein and amino acids. Marono et al. (2017) and Mwaniki et al. (2018) reported on BSFL meals fed to laying hens with protein and fat percentages of 61.3/4.61% and 56.10/6.84% respectively. Mwaniki et al. (2018) fed 0, 5, and 7.5% BSFL meal to young hens from 19 wk of age and reported a linear increase in BW at 27 wk with greater BSFL inclusion, but a negative impact on hen day production, egg weight and mass at the 5% level. Marono et al. (2017) reported reduced feed intake, BW, egg production, egg weight, and mass at 17% inclusion replacing soybean meal. Schiavone et al. (2017) compared the apparent ileal amino acid digestibility coefficients of a partially defatted (55.3/18.0%, CP/EE) and highly defatted (65.5/4.6%) BSFL meal for broiler chickens and determined there was no statistical difference among the essential amino acid coefficients averaging 0.80 and 0.81, respectively. The lowest and highest digestibility coefficients for histidine and valine averaged 0.635 and 0.905, respectively. However, crude protein total tract apparent digestibility of the meals averaged only 0.62 and the authors concluded chitin may not be the only factor responsible for the moderate digestibility observed.

Because little is known about the impact of substrate type on the nutritional value of the BSFL, Swedish researchers compared 11 diets from 4 waste streams (muscles, bread, fish, and food waste) on larvae fatty acid composition. Irrespective of the diet, the larvae lipids consisted mainly of lauric acid (C12:0; between 29 and 52%) and other saturated fatty acids (between 50 and 76%) (Ewald et al., 2019). The average concentration of linoleic acid was only 6.1% from the 11 substrate diets. When the larvae grow and gain weight the percentage of MUFA, PUFA, and omega-3 fatty acids decrease. Therefore, these authors were skeptical about the potential of diet to influence the fatty acid profile of BSFL for feeding fish, but rather recommended the fat be used as a substitute for vegetable oils in food and feeds or the production of biofuels. Despite the low-to-moderate apparent digestibility of BSFL crude protein, Schiavone et al. (2017) found total tract apparent EE digestibility of both partially and highly defatted BSFL to be very high at 0.98 and 0.93, respectively.

Therefore, because of the influence of BSFL production practices, nutritional substrates and processing on nutritional profile and quality, the objectives of this work were to evaluate the nutritional value of BSFL oil and meal as alternatives to soybean oil and meal for laying hens and measure the impact of the dietary BSFL treatments on hen performance and egg quality.

MATERIALS AND METHODS

Birds and Housing

Experiment 1 Commercial Single Comb White Leghorn hens (n = 216) from 43 to 47 wk of age were divided into 4 groups of 54 hens with one Control group and three dietary treatment groups fed BSFL oil. The birds were randomly placed into 72 cages with 3 birds per cage and 3 cages per experimental unit. The study included 6 replicate units for the Control and each BSFL oil treatment. During the entirety of the experimental period, the birds were housed in an environmentally controlled room that followed the lighting, nutritional and management recommendations of the breeder (Hy-Line, 2016).

Experiment 2 After a 4 wk down time fed a nutritionally balanced commercial hen mash, the same commercial Single Comb White Leghorn hens (n = 216), now 51 to 55 wk of age were transitioned from the former Exp 1, Control (0%), 1.5, and 3.0% BSFL oil diets to Exp 2, 8, 16, and 24% BSFL meal diets, respectfully. The former Exp 1, highest, 4.5% BSFL oil fed hens were transitioned to the Control, 0% BSFL meal in Exp 2.

The birds were again, 3 birds per cage and 3 cages per experimental unit. The study included 6 replicate units for the Control and each dietary BSFL meal treatment. During the entire experiment, the birds were housed in the same environmentally controlled room following the Hy-Line (2016) lighting, nutrition, and management recommendations. The training of the personnel and procedures followed during these experiments were approved by The Pennsylvania State University Institutional Animal Care and Use Committee, IACUC #47845.

Diet Formulation and Treatments

Experiment 1 The Control hens were fed a reference diet of corn, soybean meal, and soybean oil (Table 1). The treatment hens were fed a similar corn and soybean meal diet with levels of 1.5, 3, and 4.5% BSFL oil replacing soybean oil. The isocaloric, isonitrogenous diets were formulated to meet the Hy-Line (2016) W-36 nutrient recommendations for their age and stage of production and either met or exceeded the nutrient recommendations of the National Research Council (1994).

Experiment 2 The nutrient profile of the BSFL meal is described in Table 2. Control hens were again fed a reference diet of corn, soybean meal and soybean oil (Table 3). The treatment hens were fed a similar diet with levels of BSFL meal at 8.00, 16.00, and 23.93% replacing both soybean meal and soybean oil. The diets

Table 1. Black Soldier Fly larvae oil dietary treatment ingredients and calculated nutrients (% as is), Experiment 1.

	Dietary treatment			
Ingredient (%)	Control	Oil-1.5	Oil-3.0	Oil-4.5
Corn	57.15	56.94	56.77	56.56
Soybean meal (48%)	25.95	26.00	26.00	26.05
Limestone	4.95	4.95	4.95	4.95
Calcium chips	4.94	4.94	4.94	4.94
Mono-dical phosphate	1.87	1.87	1.87	1.87
Vitamin-trace mineral premix	0.40	0.40	0.40	0.40
Salt	0.39	0.39	0.39	0.39
DL- Methionine	0.18	0.18	0.18	0.18
Soybean oil	4.17	2.83	1.50	0.16
BSFL oil[1]	—	1.50	3.00	4.50
Nutrients (%)	Calculated analysis			
Metabolizable energy (kcal/kg)	2860	2860	2860	2860
Crude protein	16.50	16.51	16.49	16.50
Ether extract	6.58	6.71	6.84	6.96
Linoleic acid	3.65	3.14	2.64	2.12
Crude fiber	1.99	1.98	1.98	1.98
Ash	10.30	10.30	10.30	10.30
Lysine	0.8985	0.8994	0.8990	0.8999
Methionine	0.4429	0.4434	0.4431	0.4435
Methionine + cystine	0.7108	0.7113	0.7107	0.7112
Arginine	1.0844	1.0854	1.0848	1.0858
Tryptophan	0.1921	0.1923	0.1922	0.1924
Isoleucine	0.7091	0.7096	0.7092	0.7097
Valine	0.7756	0.7760	0.7754	0.7758
Calcium	4.3000	4.3000	4.3000	4.2999
Phosphorus, total	0.6855	0.6853	0.6849	0.6847
Phosphorus, available	0.4700	0.4700	0.4700	0.4700

[1]EnviroFlight. 2020a.

Table 3. Black Soldier Fly larvae meal dietary treatment ingredients and calculated nutrients (% as is), Experiment 2.

	Dietary treatment			
Ingredient (%)	Control	Meal-8.0	Meal-16.0	Meal-24.0
Corn	57.99	60.38	62.72	65.06
Soybean meal (48%)	25.30	17.00	8.75	0.55
Limestone	4.22	4.00	3.78	3.51
Calcium chips	6.00	5.75	5.50	5.30
Mono-dical phosphate	1.76	1.42	1.08	0.74
Vitamin-trace mineral premix	0.40	0.40	0.40	0.40
Salt	0.39	0.36	0.33	0.30
DL- Methionine	0.15	0.17	0.19	0.21
Soybean oil	3.79	2.52	1.26	—
BSFL meal[1]	—	8.00	16.00	23.93
Nutrients (%)	Calculated analysis			
Metabolizable energy (kcal/kg)	2840	2840	2840	2840
Crude protein	16.25	16.25	16.26	16.25
Ether extract	6.22	5.90	5.58	5.25
Linoleic acid	3.46	2.96	2.46	1.97
Crude fiber	1.98	2.33	2.68	3.03
Ash	10.63	11.08	11.52	11.97
Lysine	0.8819	0.8661	0.8516	0.8366
Methionine	0.4085	0.4271	0.4459	0.4647
Methionine + cystine	0.6733	0.6729	0.6729	0.6729
Arginine	1.0650	0.9634	0.8634	0.7634
Tryptophan	0.1884	0.1823	0.1765	0.1706
Isoleucine	0.6973	0.6770	0.6578	0.6382
Valine	0.7639	0.8161	0.8892	0.9214
Calcium	4.4000	4.4000	4.4000	4.3999
Phosphorus, total	0.6647	0.6370	0.6096	0.5823
Phosphorus, available	0.4500	0.4500	0.4500	0.4500

[1]EnviroFlight, 2020b.

Table 2. Black Soldier Fly larvae meal[1] nutrient concentrations (% as is, unless otherwise noted), Experiment 2.

Nutrient	Amount
Dry matter	96.94
AME_n	2857 kcal/kg
Crude protein	46.30
Ether extract	11.90
Linoleic acid	2.23
Crude fiber	7.40
Ash	10.80
Arginine	2.1874
Glycine	2.6784
Serine	1.9196
Histidine	0.9821
Isoleucine	1.9106
Leucine	3.2052
Lysine	2.7231
Methionine	0.5982
Cystine	0.4196
Methionine + Cystine	1.0178
Phenylalanine	1.8303
Tyrosine	2.6517
Threonine	1.7321
Tryptophan	0.5625
Valine	2.8749
Calcium	3.46
Phosphorus	1.03
Potassium	1.54
Sodium	0.17
Magnesium	0.35
Iron	191 mg/kg
Copper	10.7 mg/kg
Manganese	166.0 mg/kg
Zinc	103.0 mg/kg

[1]EnviroFlight, 2020b.

were formulated to meet or exceed both the Hy-Line (2016) W-36 and National Research Council (1994) nutrient recommendations for their age and stage of production. However, both arginine and tryptophan in the Meal-24 treatment only provided approximately 88% of the Hy-Line (2016) recommendation. Throughout the duration of both experiments feed and water were provided ad libitum.

Body Weight, Egg Production, and Egg Quality Measurements

The hens were individually wing banded before they were housed in their cages and were all weighed individually at the beginning and end of each the 28-d experimental period. Feed intake and conversion (kg feed/kg egg and kg feed/dozen eggs) were calculated on an average bird basis within a replicate experimental unit (3 cages of 3 birds each for a total N = 9 birds per unit). Eggs laid each day were recorded and a sample of eggs were randomly collected and labeled the second to last day of the period for quality parameters. At the conclusion of the period, albumen height, Haugh unit, blood and meat spots, and yolk color were all analyzed for egg quality. Albumen height was measured (mm) using a digital QCD and QCH albumen height gauge (TSS York, York, England), and Haugh units were calculated using egg albumen height and individual egg weight.

Figure 1. Black Soldier Fly larvae oil[1]. [1]EnviroFlight, 2020a.

The yolk color of each egg was measured with a Roche yolk color fan and blood and meat spots were recorded if they were observed during the egg quality measurements.

Statistical Analysis

Data were analyzed by one-factor ANOVA using the PROC GLM procedures of SAS Institute Inc. (SAS, Cary, NC) for the main effect of diet. Hen day egg production was analyzed using PROC GLM as well, after an ARC SIN transformation of the percentage data. Tukey's multiple comparison (Steel and Torrie, 1960) was used for mean separation when the F test was significant ($P < 0.05$). When the F test was significant, orthogonal contrasts, both linear and quadratic, were employed since treatment levels of BSFL oil and meal were equally spaced in both experiments 1 (0, 1.5, 3.0, and 4.5%) and 2 (0, 8, 16, and 24%), respectively.

RESULTS AND DISCUSSION

Experiment 1

Ingredient Analyses and Diet Formulation The BSFL oil has a clear amber color and is a liquid at room temperature (Figure 1). The results of the analysis and calculations determined that the oil contains 98% dry matter, 97% EE, 15.29% linoleic acid, 0% CP, CF, and ash with 7,840 kcal/kg AME_n on an as is basis. The treatment diets were formulated to contain 1.5, 3.0, and 4.5% BSFL oil and provide nutrients to the levels recommended by Hy-Line (2016) for the W-36, Layer-2 phase of production (Table 1). The diets were formulated to be isocaloric, isonitrogenous with similar levels of macro minerals. Based on the calculated analysis there was no difference between the Control and treatment BSFL oil diets for their ME, CP, AA profile, or mineral levels. Linoleic acid levels were reduced with greater inclusion of BSFL oil at the substitution for soybean oil, however, requirements for linoleic acid were maintained at greater than 2-times the Hy-Line requirement (2016) in all diets.

Bird Performance The results of the BSFL oil supplementation on the laying hen performance are shown in Table 4. There was no significant difference between the treatment and Control hens regarding BW at either the start (mean = 1,634 g) or end of the 4-wk study (mean = 1,678 g). The hens consumed between 104 and 106 g of feed per day, laid 26.1 eggs per period, or 89.6% production with no differences between the Control and BSFL oil treatments suggesting no palatability or egg production issues ($P > 0.05$). There was no significant difference for egg weight or FCR averaging 62.26 g,

Table 4. Impact of dietary Black Soldier Fly larvae oil on laying hen performance, Experiment 1.

Treatment	Body wt (g) (before	- after)	Feed intake (g/hen/day)	Eggs per period	Hen day egg prod (%)	Egg wt (g)	Feed conversion (kg feed/ dozen egg)	Feed conversion (kg feed/ kg egg)
Control	1,627	1,666	104	25.67	88.51	61.58	1.418	1.919
Oil-1.5	1,632	1,679	105	25.76	88.83	62.45	1.412	1.885
Oil-3.0	1,609	1,680	105	26.37	90.93	62.63	1.389	1.848
Oil-4.5	1,666	1,685	106	26.17	90.23	62.39	1.417	1.893
SEM	16.81	16.88	1.65	0.248	0.86	0.68	0.025	0.0340
P-value	0.115	0.860	0.802	0.179	0.179	0.705	0.826	0.536

Table 5. Impact of dietary Black Soldier Fly larvae oil on egg quality, Experiment 1.

Treatment	Egg specific gravity	Albumen ht (mm)	Haugh unit	Blood spots	Meat spots	Yolk color
Control	1.0777[ab]	8.69	92.44	0.10	0.00	7.37[b]
Oil-1.5	1.0765[b]	8.99	93.74	0.00	0.00	7.77[a]
Oil-3.0	1.0778[ab]	9.12	94.32	0.03	0.03	7.93[a]
Oil-4.5	1.0795[a]	9.27	95.29	0.00	0.03	7.93[a]
SEM	0.00059	0.16	0.79	0.050	0.02	0.09
P-value	0.007	0.065	0.085	0.547	0.574	0.0001
Orthogonal contrast (*P*-value)						
Linear	0.015	—	—	—	—	0.0001
Quadratic	0.014	—	—	—	—	0.025

[a-b]Means within a column with no common superscripts differ significantly ($P \leq 0.05$).

1.409 kg/doz and 1.886 kg/kg, respectively, for the experimental period. While to our knowledge there are no other laying hen studies feeding BSFL oil, Kim et al. (2020) compared BSFL oil, coconut oil and corn oil at 5% of the diet to one another for broiler chickens to 30 d of age. Their study indicated there were no differences in ADFI or BW, but FCR was significantly improved by the BSFL and coconut oil treatments (1.49[b] and 1.46[b]) compared to the corn oil (1.58[a], $P <$ 0.021). The results of the experiment herein indicate that supplementing BSFL oil at 1.5, 3, and 4.5% of the diet had no positive effect on FCR like Kim et al. (2020) had noted with broilers, yet no negative impact on hen performance either, indicating BSFL oil could be used as a potential source of energy for laying hens.

Egg Quality The effects of the BSF oil supplementation on egg quality are found in Table 5. There was no statistical difference between the treatment and Control diets for egg albumen height, Haugh Unit, or blood and meat spots ($P > 0.05$). However, egg specific gravity was enhanced by greater dietary BSF oil inclusion in both a linear and quadratic fashion (Table 5). The Oil-4.5 eggs were the highest and significantly greater than the Oil-1.5($P < 0.05$), while the Control and Oil-3.0 eggs were intermediate and not significantly different. Furthermore, the yolk color of the eggs was impacted by the BSFL oil supplementation. The Control group had an egg color average of 7.37 on the Roche color fan. The treatment diets all averaged a darker yolk color at 7.77, 7.93, and 7.93 for the 1.5, 3.0, and 4.5% oil treatments, respectfully. Historically insects have been used for dye production (Miranda et al., 2020) and kermes and cochineal insects are known for producing red and crimson color utilized in paintings and textiles (Baranyovits, 1978). Ushakova et al. (2017) studying BSF's determined their melanin pigments are synthesized in all life cycle stages of larvae, pre-pupae, pupae and adult files. Melanin was isolated not only in its pure form but also complexed with lipids. The bulk of the larvae complexes with melanin were fatty acids, specifically lauric acid (C12:0) accounting for more than 80%. These findings indicated that a linear increase in the dietary percentage of BSFL oil results in darker yolk color.

Experiment 2

Ingredient Analyses and Diet Formulation The BSFL meal is a fine, uniform powder with good flowability and a rich brown color (Figure 2). The results of the analysis and calculations determined that the meal contains 96.94% dry matter, 46.30% CP, 7.40% CF, 10.80% ash, 11.90% EE, 2.23% linoleic acid, and 2,857 kcal/kg AME_n on an as is basis (Table 2). The total concentration of key essential amino acids includes: 2.72% lysine, 0.60% methionine, 0.42% cystine, 2.19% arginine and 0.56% tryptophan. Total calcium and phosphorus are 3.46 and 1.03%, respectively and additional amino acids and minerals are reported in Table 2. The treatment diets were formulated to contain 8.00, 16.00, and 24.00% (actually 23.93%) BSFL meal (Table 3) and provide Layer-3 phase nutrients recommended by Hy-Line (2016). Linoleic acid levels were reduced with greater inclusion of BSFL meal and a corresponding reduction in soybean oil; however, requirements for linoleic acid were maintained at nearly 2-times the requirement (Hy-Line, 2016) in all diets. Based on the calculated analysis there was no nutritional differences

Figure 2. Black Soldier Fly larvae meal[1]. [1]EnviroFlight, 2020b.

between the Control and BSFL meal treatment diets for ME, CP, methionine, methionine+cysteine or mineral levels. Lysine, methionine, arginine, tryptophan and isoleucine levels were reduced with increasing levels of BSFL meal supplementation in the treatment diets (Table 3). However, total lysine levels more than met the Hy-Line W-36 (2016) recommendation of 0.78% and methionine and cysteine concentrations were maintained with DL-methionine supplementation. Isoleucine levels in the Meal-24.0 treatment diet just met the Hy-Line (2016) recommendation of 0.63%. However, arginine and tryptophan levels were less than the Hy-Line (2016) recommendation of 0.79 and 0.18%, respectively in the Meal-24.0 diet. Therefore, this high level of BSFL-meal inclusion would be marginal and require additional supplementation of synthetic amino acids.

Bird Performance While there was no significant impact of the BSFL meal treatments on egg weight or FCR at the highest level of inclusion, ADFI, BW, and egg production were negatively impacted by the Meal-24.0 treatment (Table 6, $P < 0.05$). There was no significant difference between the 8 and 16% BSFL meal treatments with the Control for any of the hen performance parameters, suggesting these levels of substitution with soybean meal and oil would sustain normal hen performance.

However, others have had mixed results feeding BSFL meal to commercial hens. Maurer et al., (2016) fed a high-quality meal with 59% CP, 3.09 % lysine and 0.98% methionine to Lohmann hens at 12 and 24% of the diet replacing soybean cake. In the 3-wk study they saw no significant difference in ADFI, egg production,

Table 6. Impact of dietary Black Soldier Fly larvae meal on hen production, Experiment 2.

Treatment	Body wt (g) (before-after)		Feed intake (g/ hen/day)	Eggs per period	Hen day egg prod (%)	Egg wt (g)	Feed conversion (kg feed/ dozen egg)	Feed conversion (kg feed/ kg egg)
Control	1,631	1,668	98.56^{a}	24.94^{a}	83.97^{a}	63.01	1.412	1.871
Meal-8.0	1,622	1,643	97.41^{ab}	24.78^{a}	85.44^{a}	61.73	1.359	1.835
Meal-16.0	1,671	1,663	97.25^{ab}	24.35^{a}	86.02^{a}	61.70	1.368	1.848
Meal-24.0	1,650	1,603	92.40^{b}	22.33^{b}	77.01^{b}	59.96	1.442	2.009
SEM	17.29	18.10	1.504	0.52	1.795	0.95	0.0278	0.0469
P-value	0.194	0.051	0.041	0.007	0.007	0.189	0.153	0.058
Orthogonal contrast (*P*-value)								
Linear	—	—	0.012	0.020	0.020	—	—	—
Quadratic	—	—	0.232	0.008	0.008	—	—	—

[a-b]Means within a column with no common superscripts differ significantly ($P \leq 0.05$).

Table 7. Impact of dietary Black Soldier Fly larvae meal on egg quality, Experiment 2.

Treatment	Egg specific gravity	Albumen ht (mm)	Haugh unit	Blood spots	Meat spots	Yolk color
Control	1.0782[ab]	8.43	90.83	0.00	0.03	9.05[b]
Meal-8.0	1.0763[b]	8.27	89.97	0.03	0.00	9.13[ab]
Meal-16.0	1.0784[ab]	8.08	89.02	0.00	0.09	9.51[a]
Meal-24.0	1.0799[a]	8.28	90.72	0.00	0.05	9.33[ab]
SEM	0.00076	0.17	0.95	0.012	0.04	0.123
P-value	0.009	0.516	0.492	0.383	0.390	0.035
Orthogonal contrast (*P*-value)						
Linear	0.043	—	—	—	—	0.034
Quadratic	0.026	—	—	—	—	0.297

[a-b]Means within a column with no common superscripts differ significantly ($P \leq 0.05$).

FCR, mortality or hen health compared to the hens fed their control diet. Although egg weight and albumen weight were numerically reduced by the BSFL meal inclusions. Later Marono et al. (2017) fed a dark brown, low moisture, low fat, high protein (61.3%) BSFL meal to Lohmann Brown hens from 24 to 45 wk of age at 17% of the diet replacing soybean meal. These authors reported ADFI, BW, egg production, egg weight and mass were significantly reduced by the BSFL meal treatment diet compared to a corn/soybean meal control. Although the analyzed nutrients of their BSFL meal were adequate and formulated to Lohmann specifications, the dark brown color of the meal indicated possible heat damage from drying that may have affected nutrient, and amino acid availability and performance.

Egg Quality In this experiment, greater levels of dietary BSFL meal resulted in greater egg specific gravity among the Meal-24.0 eggs compared to the Meal-8 ($P <$ 0.05), while the Control and Meal-16 eggs were intermediate and not significantly different (Table 7). Egg Haugh units, blood spots and meat spots were not impacted by the dietary treatments. However, yolk color was enhanced by all levels of the BSFL meal and the Meal-16.0 yolk color was significantly greater than the Control yolks ($P < 0.05$). These observations coincided with greater color noted in Exp 1 with increasing levels of BSFL oil. It's worth noting the residual oil remaining in the BSFL meal was nearly 12% (Table 2).

Others have noted a similar impact of BSFL meal on egg yolk color. Mwaniki et al. (2018), (2020) fed a BSFL meal (56.1% CP and 6.84% fat) to Shaver White hens in 2 phases from 19 to 27 wk and 28 to 43 wk of age in corn, soybean meal and wheat basal diets. In the first phase hens were fed diets with 0, 5.0, and 7.5% BSFL meal. While there was no impact of BSFL diet treatments on egg weight or Haugh units; yolk color, shell thickness and breaking strength were increased with greater levels of the BSFL meal compared to the controls ($P < 0.01$). In the second phase, Mwaniki et al., (2020) formulated BSFL meal into the diets at 0, 10, and 15% at the substitution of soybean meal. Yolk color was increased again with greater amounts of BSFL meal, but it had no impact on Haugh units, shell thickness or breaking strength in the second phase ($P > 0.05$).

From these experiments it would appear both BSFL oil and meal have a legitimate place as dietary ingredients for commercial laying hens. The oil expressed from BSFL has considerable energy (7840 kcal/kg) and linoleic acid (15.29%) that can readily substitute for soybean oil in laying hen formulations. Both hen performance and egg quality were maintained with greater levels in the diet, and likely melanin-lauric acid complexes in the amber color of the BSFL oil are imparted to increase egg yolk color with greater levels of dietary inclusion. The BSFL meal has considerable protein and fat for both amino acids and energy. The meal substitutes well for soybean meal and oil, however, there are upper limits of inclusion because of amino acid density (Arginine and Tryptophan) but hen performance and egg quality were maintained at both 8 and 16% of the diet. And like the BSFL oil, there was a positive impact of the meal on egg yolk color. This increase in yolk color imparted by both the BSFL oil and meal warrants further investigation to further identify the composition of the pigments, their absorption and deposition in the egg yolk.

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DISCLOSURES

The authors declare no conflicts of interest.

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