Egg production and quality responses of adding up to 7.5% defatted black soldier fly larvae meal in a corn–soybean meal diet fed to Shaver White Leghorns from wk 19 to 27 of age

Z. Mwaniki, M. Neijat, and E. Kiarie

Department of Animal Biosciences, University of Guelph, Guelph N1G 2W1, ON, Canada

ABSTRACT We examined egg production and quality responses of adding up to 7.5% defatted black soldier fly larvae meal (BSFLM) in a corn–soybean meal diet fed to pullets (19 to 27 wk of age). The concentration of CP and crude fat in BSFLM sample was 59.3 and 7.0% DM, respectively. A corn–soybean meal diet was formulated with 0 or 5.0 or 7.5% BSFLM and fed (n = 6) to a total of 108, 19-wk-old Shaver White pullets placed in conventional cages (6 birds/cage). The birds had free access to feed and water. Hen-day egg production (HDEP) and average egg weight were monitored daily and feed intake (FI) weekly. Egg quality parameters were assessed on individual eggs collected on the 5th d of wk 22, 24, and 26 and included individual EW (IEW), albumen height (HU), yolk color (YC), egg shell-breaking strength (SBS) and thickness (ST). A quadratic response (P < 0.02) was observed for HDEP, EW and egg mass. Specifically, birds fed 0 and 7.5% BSFLM diets had similar (P > 0.05) values for these parameters with birds fed 5.0% BSFLM showing lower (P < 0.05) HDEP than 0 or 7.5% BSFLM fed birds. The HDEP was 89.4, 84.8, and 87.8 for 0, 5.0, and 7.5% BSFLM, respectively. Feeding BSFLM linearly (P < 0.01) increased FI and feed conversion ratio (FCR) (FI/egg mass). There was no diet effect (P > 0.05) on IEW and HU, however, BSFLM linearly (P = 0.02) reduced CV of IEW. The IEW was 53.7, 52.3, and 53.0 g for 0, 5.0, and 7.5% BSFLM-fed birds, respectively and corresponding CV values of IEW were 7.9, 5.2, and 5.1%. Feeding BSFLM linearly (P < 0.01) increased YC, SBS, and ST. In conclusion, birds fed 7.5% BSFLM had similar HDEP and egg mass but poor FCR relative to corn–soybean meal diet without BSFLM. The effects of BSFLM on egg quality characteristics warrant further investigations.

Key words: black fly soldier fly meal, egg production, egg quality, feed conversion

INTRODUCTION

Feed cost accounts for more than 65% of variable cost of producing poultry products, and energy and amino acids account for more than 90% of this cost (Kiarie et al., 2013). In the recent past, the global feed industry has seen soaring and volatile prices of traditional feedstuffs commonly used in livestock and poultry diets due to competition with the food and ethanol industries (Woyengo et al., 2014). Moreover, in the context of anticipated human population growth, the current animal protein production will need to increase 60% or more by 2050 (FAO, 2011). This increase in animal protein demand will need enormous resources, the feed being the most challenging because of the limited availability of natural resources, climate change pressure and food–feed–fuel competition (FAO, 2011). This trend has clearly demonstrated the danger of relying on a limited pool of ingredients to formulate feeds and underscored the need to characterize nutritive value of other feedstuffs with potential to serve as alternatives to or can complement traditional feedstuffs.

It has been estimated that more than 1.3 billion tons of organic waste are produced on a global scale resulting in enormous environmental, social, and economic costs (Makkar, 2017). In Canada, $27 billion worth of food ends up in landfills or composters each year (Parizeau et al., 2015). The nutrients in the organic waste could be recycled back for animal feeding through insect rearing (Rumpold and Schluter, 2013b; Makkar, 2017). Using insects as feedstuff can contribute to global food security via feed or as a direct food source for humans (Schader et al., 2015). Insects contain high amounts of energy, amino acids, fatty acids and micronutrients (Rumpold and Schluter, 2013a; Makkar et al., 2014).
The insect species with the highest potential for large-scale production are the black soldier fly (BSF) (Hermetia illucens), common housefly (Musca domestica), and yellow mealworm (Tenebrio molitor). Specifically, BSF larvae achieve high growth rate and excellent conversion of organic waste to produce a meal (BSFLM) with consistent amino acid concentration when raised on diverse substrates (Diener et al., 2009; Nguyen et al., 2015; Spranghers et al., 2017).

The use of BSFLM as a component of diet has been reported for poultry (De Marco et al., 2015; Marono et al., 2017; Secci et al., 2018), swine (Newton et al., 1977), and for several commercial fish species (St-Hilaire et al., 2007). Although the feeding value of BSFLM in commercial poultry diets has been reported, this field is in its infancy. Moreover, majority of insect meal research has focused on whole insect meal and defatting processes produce meal with crude fat content of as low as 5% DM depending on fat extraction procedures (Fasakin et al., 2003; Schiavone et al., 2017). The typical crude fat content in whole BSFLM is 15 to 35% DM (Makkar et al., 2014) and defatting processes produce meal with crude fat content of as low as 5% DM depending on fat extraction procedures (Fasakin et al., 2003; Schiavone et al., 2017). Defatting has been shown to increase crude protein from 40 to 44% DM in whole BSFLM (Makkar et al., 2014; Spranghers et al., 2017) to a high of 65.5% DM (Schiavone et al., 2017). Moreover, defatted BSFLM was shown to have higher or comparable digestible amino acids concentration to typical animal and plant protein sources used in poultry feed (Schiavone et al., 2017). Defatting is also seen as critical control point for BSFLM as fat component has been shown to be the most variable component in larva grown on diverse substrates (Spranghers et al., 2017). To our knowledge, limited studies have been reported on feeding defatted BSFLM to poultry particularly the egg-laying strains. Therefore, the objective of the present study was to evaluate effects of 0, 5, and 7.5% inclusion of defatted BSFLM in practical corn–soybean diet fed to laying hens.

METHODS AND METHODS

The use of animals was approved by the University of Guelph Animal Ethics Committee and complied with the Canadian Code of Practice for the Care and Use of Animals for Scientific Purposes (CCAC, 2009).

Insect Meal and Diets

Defatted BSFLM (approximately 6% crude fat as fed) was procured from a commercial manufacturer and vendor (Enterra feed Corp., Vancouver, BC, Canada). The meal is a dry, powder product derived from larvae of the BSF (Hermetia illucens) reared on pre-consumer recycled food collected from local farms, food processors, and grocery stores. The meal is approved by the Canadian Food Inspection Agency for feeding poultry. A standard corn–soybean meal (0% BSFLM) diet was formulated to meet the nutrient requirements for 19 wk of age pullets according to Shaver White commercial management guidelines. The BSFLM was included at 5.0 and 7.5% to maintain iso-caloric and iso-nitrogenous specification (Table 2). All diets were prepared in crumble form at Arkell research station feed mill, University of Guelph.

Birds, Housing and Experimental Procedures

One hundred and eight, 19-wk-old pullets (Shaver White Leghorns) were placed in cages (6 birds per cage) and allocated to experimental diets based on BW in a completely randomized design to give 6 replications per diet. The diets were fed from wk 19 to 27. The birds had free access to feed and water throughout the experimental period. Hen-day egg production (HDEP, number of eggs laid per d/number of hens) and average egg weight (AEW) per cage were recorded on daily basis. Feed intake was determined on weekly basis and BW at the end of wk 21, 23, 25, and 27. All eggs collected on the 5th d of wk 22, 24, and 26 were submitted for egg quality analyses on the same day.

Egg Quality Measurements

The individual egg weight (IEW), height of albumin (haugh units, HU), and yolk color were determined by egg Analyzer (ORKA Food Technology Ltd, Ramat HaSharon, Israel). The system detect, calculate, and report values for yolk color (1 to 15 colors scale based on DSM/Roche yolk color fan), HU and egg weight (g). Prior to measurements, the unit was calibrated as per manufacturer recommendations. The egg shell thickness (ST) was measured using a high-resolution non-destructive device that measures ST without breaking using precision ultrasound (ESTG-1, ORKA Food Technology Ltd.). Briefly, gel was applied on the egg followed by placement of the egg on cradle to read ST in mm. Shell-breaking strength (SBS, kgf) was measured by Force Reader (ORKA Food Technology Ltd.), the unit measures accurately the breaking point of the egg shell by applying mechanical force on vertically placed egg on the cradle.

Chemical Analyses

Samples of BSFLM and diets were finely ground in a coffee grinder and thoroughly mixed for analyses. Samples were analyzed for DM, CP, gross energy, crude fat, starch, ethanol soluble carbohydrates, neutral detergent fiber (NDF), and minerals. Dry matter determination was carried out according to standard procedures method 930.15 (AOAC, 2005). Nitrogen was determined by combustion method 968.06 (AOAC, 2005) using a CNS-2000 carbon, N, and sulfur analyzer (Leco Corporation, St. Joseph, MI). The CP values were derived by multiplying the assayed N


determined by combustion method 536.15 (AOAC, 2005) using a CNS-2000 carbon, N, and sulfur analyzer (Leco Corporation, St. Joseph, MI). The CP values were derived by multiplying the assayed N
values by a factor of 6.25. Gross energy was determined using a bomb calorimeter (IKA Calorimeter System C 5000; IKA Works, Wilmington, NC). The NDF content was determined according to Van Soest et al. (1991) using Ankom 200 Fiber Analyzer (Ankom Technology, Fairport, NY). Crude fat content was determined using ANKOM XT 20 Extractor (Ankom Technology, Fairport, NY). Samples for AA analysis were prepared by acid hydrolysis according to the method of AOAC (2005, method 982.30), and as modified by Mills et al. (1989). Briefly, about 100 mg of each sample was digested in 4 mL of 6 N HCl for 24 h at 110°C, followed by neutralization with 4 mL of 25% (wt/vol) NaOH and cooled to room temperature. The mixture was then equalized to 50 mL volume with sodium citrate buffer (pH 2.2) and analyzed using an AA Analyzer (Sykam, Germany). Samples for analysis of sulfur containing AA (Met and Cys) were subjected to performic acid oxidation prior to acid hydrolysis. Tryptophan was not determined. The samples were wet acid digested with nitric and perchloric acid mixture (AOAC, 2005; method 990.08) and concentrations of minerals (Ca, P, K, Mg, and Na) read on an inductively coupled plasma mass spectrometer (Varian Inc., Palo Alto, CA). Ethanol soluble carbohydrates and starch were analyzed in a commercial laboratory (SGS Canada Inc., Guelph, ON, Canada).

### Statistical Analyses

Data were analyzed using GLM procedures (SAS Inst. Inc., Cary, NC). The model had fixed effects of diet and wk and interaction. The cage was the experimental unit. Contrast coefficients from unequally spaced BSFLM were generated using the interactive matrix language procedure of SAS. An α level of $P \leq 0.05$ was used as the criterion for statistical significance.

### RESULTS AND DISCUSSION

The analyzed chemical composition of BSFLM sample and experimental diets are shown in Tables 1 and 3, respectively. The crude fat concentration was lower than the values of 15 to 35% DM reported for non-defatted BSFLM (Makkar et al., 2014) but comparable to defatted BSFLM sample (Marono et al., 2017; Schiavone et al., 2017). The concentration of CP was higher than the values of 40 to 44% DM for whole BSFLM (Makkar et al., 2014; Spranghers et al., 2017) but within the range of 47.6 to 65.5% DM for defatted BSFLM (Marono et al., 2017; Schiavone et al., 2017). Crude protein variations in BSFLM are indications of variable fat and chitin concentrations as well as growth substrates (Liu et al., 2012). The concentrations of Lys, His, and Val were higher than the values reported for defatted BSFLM (~crude fat 4.7% DM) (Schiavone et al., 2017). However, the concentrations of other AA were comparable to defatted sample (Schiavone et al., 2017). The concentration of Ca was somewhat lower (5 to 8% DM) whereas concentration of P comparable (0.6 to 1.5% DM) to literature values (Makkar et al., 2014). Black soldier fly larvae are converters of organic waste into edible biomass, of which the composition of the meal depends on the substrate (Diener et al., 2009; Nguyen et al., 2015). However, in a recent study, it was demonstrated that the concentration of CP and AA is very consistent, and fat was variable in a meal from larvae grown on diverse substrates (chicken feed, vegetable waste, biogas digestate, and restaurant waste) (Spranghers et al., 2017). This suggested a defatted BSFLM could be a very attractive protein feed ingredient for poultry diets. The diet with 5% BSFLM assayed slightly lower CP relative to other diets but was above formulation target of 17% (Table 2). However, the AME and AA concentrations were comparable across all diets.

The effects of BSFLM inclusion on HDEP are shown in Table 4. There was a quadratic effect ($P < 0.01$) on HDEP with birds fed 5% BSFLM showing lower HDEP than birds fed 0 or 7.5% BSFLM. Similarly, BSFLM inclusion had quadratic ($P < 0.021$) response on AEW and egg mass with 5% BSFLM-fed birds showing lower EW relative to 0% BSFLM. Feed intake was linearly and quadratically increased ($P < 0.05$) by inclusion of BSFLM with birds fed 7.5% BSFLM showing the highest feed intake relative to the 0 or 5% BSFLM. As a result, a linear ($P = 0.003$) increase in feed

---

Table 1. Chemical composition of defatted black soldier fly larva meal, as fed basis.

| Item                  | Amount  |
|-----------------------|---------|
| DM (%)                | 97.5    |
| CP (%)                | 56.1    |
| Gross energy (kcal/kg)| 4973    |
| Fat (%)               | 6.84    |
| Starch (%)            | 5.97    |
| Ethanol soluble carbohydrates (%) | 4.55 |
| Ca (%)                | 1.21    |
| P (%)                 | 0.95    |
| K (%)                 | 1.58    |
| Mg (%)                | 0.39    |
| Na (%)                | 0.20    |
| Amino acids (%) (%) of CP |
| Indispensable         |         |
| Arg                   | 2.72 (4.8) |
| His                   | 5.51 (10.1)   |
| Ile                   | 2.38 (4.2)     |
| Leu                   | 3.81 (6.8)     |
| Lys                   | 3.22 (5.7)     |
| Met                   | 0.9 (1.6)      |
| Met + Cys             | 1.3 (2.3)      |
| Phe                   | 2.11 (3.8)     |
| Thr                   | 2.26 (4.0)     |
| Val                   | 3.38 (6.0)     |
| Dispensable           |         |
| Ala                   | 3.8 (6.8)      |
| Asp                   | 5.13 (9.1)     |
| Cys                   | 0.40 (0.7)     |
| Glu                   | 6.67 (11.9)    |
| Gly                   | 2.99 (5.3)     |
| Pro                   | 3.34 (6.0)     |
| Ser                   | 2.5 (4.5)      |
| Tyr                   | 2.76 (4.9)     |
conversion ratio (FCR) was observed with increasing level of BSFLM. Generally, HDEP, AEW, egg mass, and FI increased as expected from wk 19 to 27. However, interaction ($P < 0.05$) between diet and wk was observed for egg mass and FI.

Energy and AA intakes are the greatest driver of egg production and egg size (Leeson and Summers, 2005). The 5% BSFLM diet had comparable AME and AA with other diets, it is thus rather difficulty to explain why we observed reduced HDEP and EW in birds-fed BSFLM (17% BSFLM) in diets for Lohmann Brown classic (wk 24 to 45) indicated birds-fed BSFLM had lower HDEP, EW, egg mass, and FCR than birds-fed soybean meal (Marono et al., 2017). In contrast, egg production, feed intake, and FCR of Lohmann White laying quails fed up to 10% BSFLM in practical diets (Widjastuti et al., 2014). The high feed intake of birds-fed BSFLM might be due to higher fiber content in the diet. The implications for the current study were such that the birds fed 7.5% BSFLM consumed more feed to meet requirements. In this context, it is noteworthy that 7.5% BSFLM diet had slightly lower crude fat and gross energy concentration compared to other diets. Feeding BSFLM linearly increased BW in wk 23 and 27 (Table 5). In wk 27, the BW was 1.67, 1.71, and 1.72 kg for 0, 5.0, and 7.5% BSFLM, respectively. In contrast,
Table 4. Effects of inclusion of black soldier fly larva meal (BSFLM) in corn–soybean meal diet fed to laying pullets (19 to 27 wk of age) on egg production, average egg weight, egg mass, and FCR.

| Item | Hen day egg production (%) | Average egg weight (g) | Egg mass (g/d) | Feed intake (g/bird/d) | FCR |
|------|---------------------------|------------------------|----------------|------------------------|-----|
| Main effect of BSFLM inclusion (%) | 0.0 | 89.4<sup>a</sup> | 50.5<sup>a</sup> | 45.8<sup>b</sup> | 92.2<sup>b</sup> | 2.256<sup>b</sup> |
| | 5.0 | 84.8<sup>b</sup> | 50.1<sup>b</sup> | 43.0<sup>b</sup> | 92.0<sup>b</sup> | 2.385<sup>a,b</sup> |
| | 7.5 | 87.8<sup>a</sup> | 50.4<sup>a,b</sup> | 44.8<sup>a</sup> | 95.7<sup>a</sup> | 2.430<sup>a</sup> |
| SEM | | 0.642 | 0.123 | 0.327 | 0.350 | 0.042 |
| Main effect of age (wk) | 19 | 46.0<sup>d</sup> | 42.3<sup>g</sup> | 19.4<sup>g</sup> | 63.8<sup>f</sup> | 4.250<sup>a</sup> |
| | 20 | 73.9<sup>c</sup> | 44.2<sup>f</sup> | 32.7<sup>f</sup> | 89.4<sup>d</sup> | 3.050<sup>b</sup> |
| | 21 | 89.0<sup>b</sup> | 46.5<sup>e</sup> | 41.4<sup>e</sup> | 96.5<sup>c</sup> | 2.044<sup>c</sup> |
| | 22 | 94.4<sup>a</sup> | 49.8<sup>d</sup> | 47.0<sup>d</sup> | 94.6<sup>d</sup> | 2.044<sup>c</sup> |
| | 23 | 96.3<sup>a</sup> | 51.8<sup>c</sup> | 49.9<sup>c</sup> | 95.7<sup>a</sup> | 2.430<sup>a</sup> |
| | 24 | 96.0<sup>a</sup> | 53.4<sup>b</sup> | 51.3<sup>b</sup> | 102.2<sup>b</sup> | 1.901<sup>c</sup> |
| | 25 | 96.2<sup>a</sup> | 54.4<sup>a,b</sup> | 52.3<sup>a,b</sup> | 110.2<sup>a</sup> | 1.901<sup>c</sup> |
| | 26 | 96.6<sup>a</sup> | 54.9<sup>a</sup> | 53.1<sup>a</sup> | 110.2<sup>a</sup> | 2.089<sup>a</sup> |
| | 27 | 97.2<sup>a</sup> | 55.3<sup>a</sup> | 53.7<sup>a</sup> | 109.1<sup>a</sup> | 2.045<sup>a</sup> |
| SEM | | 0.929 | 0.197 | 0.511 | 0.561 | 0.067 |

Probabilities

| BSFLM | Week | P-value |
|-------|------|---------|
| <0.01 | <0.01 | <0.01 |
| 0.089 | 0.034 | 0.011 |

Response to BSFLM inclusion

| Linear | Quadratic |
|--------|-----------|
| <0.01 | <0.01 |
| 0.005 | 0.017 |

Note: Means assigned different letters (a–f) within a factor of analysis (BSFLM, wk) are significantly different, P < 0.05.

Table 5. Effects of inclusion of black soldier fly larva meal (BSFLM) in corn–soybean meal diet fed to laying pullets (19 to 27 wk of age) on body weight (kg).

| Black soldier fly larva meal inclusion (%) | BSFLM response |
|-------------------------------------------|----------------|
| Week | 0 | 5.0 | 7.5 | SEM | P-value | Linear | Quadratic |
|------|---|-----|-----|-----|--------|--------|-----------|
| 19<sup>1</sup> | 1.376 | 1.382 | 1.394 | 0.018 | 0.782 | – | – |
| 21 | 1.377 | 1.425 | 1.419 | 0.016 | 0.097 | 0.052 | 0.335 |
| 23 | 1.409<sup>b</sup> | 1.544<sup>a</sup> | 1.453<sup>b</sup> | 0.020 | <0.01 | 0.031 | <0.01 |
| 25 | 1.650<sup>b</sup> | 1.683 | 1.693 | 0.015 | 0.141 | 0.052 | 0.798 |
| 27 | 1.668<sup>b</sup> | 1.709<sup>b</sup> | 1.724<sup>a</sup> | 0.014 | 0.034 | 0.011 | 0.853 |

<sup>1</sup>Initial body weight.

Note: Means assigned different letters (a, b) within a row are significantly different, P < 0.05.

Lohmann Brown classic (wk 24 to 45) hens fed 17% BSFLM had lower body weight because of depressed feed intake (Marono et al., 2017). Specific studies in application of BSFLM in poultry feeding have focused on growing poultry and limited studies exist in layers. As a component of a complete diet, BSFLM was reported to increase quails body weight gain driven by increased FI (Widjastuti et al., 2014).

The data for individual eggs collected on wk 22, 24, and 26 are shown in Table 6. There was no diet effect (P > 0.05) on IEW and HU, however, BSFLM linearly (P = 0.02) reduced CV of IEW. The IEW values were 53.7, 52.3, and 53.0 g for 0, 5.0, and 7.5% BSFLM, respectively and corresponding CV values were 7.9, 5.2, and 5.1%. This observation suggested that feeding BSFLM improved uniformity of egg size an important metric for egg producers. There was no wk and interaction (P > 0.05) on mean and CV of IEW, HU, and YC. Generally, the mean and CV of HU and YC increased from wk 22 to 26. Feeding BSFLM linearly (P < 0.01) increased yolk color, SBS, and ST. The yolk color improvement suggested the meal had pigments that increased intensity of yolk color. Indeed, recent report demonstrated that feeding laying hens BSFLM increased concentration of γ-tocopherol, lutein, β-carotene, and total carotenoids compared with egg yolks from birds-fed soybean meal (Secci et al., 2018). The improved egg shell characteristics were indicative of either improved Ca absorption in the gut and improved Ca metabolism or both. Indeed, although egg shell quality was not reported, feeding laying hens (wk 24 to 45) 17% BSFLM increased circulating serum Ca levels relative to the control (0% BSFLM) despite the 2 diets having similar Ca concentration (Marono et al., 2017). Edible insects contain a significant amount of fiber in the form of chitin (Finke, 2007; Liu et al., 2012). Egg shell is 99% calcium carbonate and daily egg shell formation equate to a removal of 2 to 3 g of Ca equivalent to 10% of the hen body Ca reserve (Gilbert, 1983; Etches, 1987). About 60 to 75% of Ca in egg shell is derived from diet and 25 to 40% was from the skeletal stores (Comar and Driggers, 1949).
Calcium homeostasis is created through a balance between intestinal absorption, renal excretion, and bone mineral metabolism to meet the bird’s requirements (Elaroussi et al., 1994). Although we did not quantify chitin in the present study, dietary NDF content increased with addition of BSFLM (Table 3). It is plausible that the high fiber may have increased ceca fermentation (Kiarie et al., 2014). Increased hindgut fermentation has been shown to increase mineral absorption (Metzler-Zebeli et al., 2010) and thus better egg shell quality in hens-fed BSFLM. Indeed, total replacement of soybean meal with BSFLM in laying hens diet from 24 to 45 wk of age resulted in a higher caecal production of butyric acid (Cutrignelli et al., 2017). It is also possible other mechanisms related to feeding BSFLM may have influence strong egg shell characteristics.

Characterizing nutritive and functional value of insect meal, risks, and potential economic benefits when formulated correctly in practical diets will be pivotal for the feed industry uptake. Our data shows that feeding up to 7.5% BSFLM supported similar performance to corn–soybean meal diet in early phase of egg production. However, the quadratic response on egg production and poor FCR warrant further investigations. Stronger egg shell might be indicative of improved Ca metabolism in birds-fed BSFLM.

### ACKNOWLEDGMENTS

Authors thankful for the analytical support by laboratories of Professor Tina Widowski (University of Guelph) for egg quality and Professor Martin Nyachoti (University of Manitoba) for amino acid. Technical assistance by L. Caston C. Zhu, I. Wilson, and D. Vandenberg appreciated. Funded by Ontario Ministry of Agriculture, Food and Rural Affairs, NSERC-Discovery program, and McIntosh Poultry Farm.

### REFERENCES

AOAC. 2005. Official Methods of Analysis of AOAC International. AOAC International, Gaithersburg, MD.

CCAC. 2009. Guidelines on the care and use of farm animals in research, teaching and testing. Pages 1–168. Canadian Council on Animal Care, Ottawa, ON, Canada. https://www.ccac.ca/Documents/Standards/Guidelines/FarmAnimals.pdf. Accessed March 2015.

Comar, C. L., and J. C. Driggers. 1949. Secretion of radioactive calcium in the Hen’s Egg. Science. 109:282–282.

Cutrignelli, M., M. Messina, F. Tulli, B. Randazzo, I. Olivotto, L. Gasco, R. Loponte, and F. Bovera. 2018. Evaluation of an insect meal of the black soldier fly (Hermetia illucens) as soybean substitute: Intestinal morphometry, enzymatic and microbial activity in laying hens. Res. Vet. Sci. 117:209–215.

De Marco, M., S. Martinez, F. Hernandez, J. Madrid, F. Gai, L. Rotolo, M. Belforti, D. Bergero, H. Katz, S. Dabbou, A. Kovitvadhi, I. Zoccarato, L. Gasco, and A. Schiavone 2015. Nutritional value of two insect larval meals (Hermetia illucens) as soybean substitute: Establishing optimal feeding program, and McIntosh Poultry Farm.

### Table 6. Effects of inclusion of black soldier fly larva meal (BSFLM) in corn–soybean meal diet fed to laying pullets (19 to 27 wk of age) on egg quality characteristics.¹

| Item                        | Individual egg weight Mean (g) CV (%) | Haugh units Mean (mm) CV (%) | Yolk color Mean CV (%) | Shell breaking strength Mean (kgf) CV (%) | Shell thickness Mean (mm) CV (%) |
|-----------------------------|--------------------------------------|-----------------------------|------------------------|------------------------------------------|-------------------------------|
| Main effects of BSFLM inclusion (%) |                                      |                             |                        |                                          |                               |
| 0.0                         | 53.7 7.92a                         | 64.6 19.1                   | 4.32b 20.5             | 4.70b 15.0                             | 0.404b 11.2                  |
| 5.0                         | 52.3 5.15b                         | 67.0 19.9                   | 4.68b 11.7             | 5.23a 14.7                             | 0.427a 9.11                  |
| 7.5                         | 53.0 5.08b                         | 68.1 21.8                   | 4.83b 11.3             | 4.95b 13.7                             | 0.431a 7.57                  |
| SEM                         | 0.40 0.016                         | 2.02 2.43                   | 0.091 3.61             | 0.083 1.69                             | 0.006 1.620                  |
| Main effects of age (wk)    |                                      |                             |                        |                                          |                               |
| 22                          | 50.2 5.80                         | 58.9 24.7                   | 4.23b 23.4a            | 5.10a 16.2                             | 0.406b 11.8                  |
| 24                          | 53.2 6.33                         | 72.7 16.1                   | 4.87a 10.4b            | 5.02b 14.2                             | 0.434a 7.98                  |
| 26                          | 55.6 6.01                         | 68.1 20.1b                  | 4.73b 9.63b            | 4.75b 13.1                             | 0.421b 8.10                  |
| SEM                         | 0.40 0.015                         | 2.02 2.43                   | 0.091 3.61             | 0.082 1.69                             | 0.006 1.620                  |
| Probabilities               |                                      |                             |                        |                                          |                               |
| BSFLM                       | 0.070 0.053                       | 0.464 0.737                 | <0.01 0.136            | <0.01 0.857                             | 0.003 0.294                  |
| Week                        | <0.01 0.016                       | <0.01 0.053                 | <0.01 0.015            | 0.010 0.417                             | 0.005 0.179                  |
| BSFLM wk                    | 0.133 0.441                       | 0.893 0.825                 | 0.191 0.595            | 0.038 0.263                             | 0.047 0.255                  |
| Response to BSFLM inclusion  |                                      |                             |                        |                                          |                               |
| Linear                      | 0.123 0.021                       | 0.218 0.482                 | <0.01 0.057            | 0.007 0.616                             | <0.01 0.122                  |
| Quadratic                   | 0.081 0.048                       | 0.978 0.742                 | 0.858 0.557            | <0.01 0.813                             | 0.515 0.870                  |

Note: Means assigned different letters (a, b) within a factor of analysis (BSFLM, wk) are significantly different, P < 0.05.
Kiarie, E., L. F. Romero, and C. M. Nyachoti. 2013. The role of added feed enzymes in promoting gut health in swine and poultry. Nutr. Res. Rev. 26:71–88.

Kiarie, E., L. F. Romero, and V. Ravindran. 2014. Growth performance, nutrient utilization, and digesta characteristics in broiler chickens fed corn or wheat diets without or with supplemental xylanase. Poult. Sci. 93:1186–1196.

Lecson, S., and J. D. Summers. 2005. Commercial Poultry Nutrition. 5th ed. University Books, Guelph, Canada.

Makkar, H. P. S., G. Tran, V. Henze, and P. Ankers. 2014. State-of-the-art on use of insects as animal feed. Anim. Feed Sci. Technol. 197:1–33.

Marono, S., R. Loponte, P. Lombardi, G. Vassalotti, M. E. Pero, F. Russo, L. Gasco, G. Parisi, G. Piccolo, S. Nizza, C. Di Meo, Y. A. Attia, and F. Bovera. 2017. Productive performance and blood profiles of laying hens fed Hermetia illucens larvae meal as total replacement of soybean meal from 24 to 45 weeks of age. Poult. Sci. 96:1783–1790.

Maurer, V., M. Holinger, Z. Amsler, B. Früih, J. Wohlfahrt, A. Stamer, and F. Leiber. 2016. Replacement of soybean cake by Hermetia illucens meal in diets for layers. J. Insects Food Feed VII:125–129.

Metzler-Zebeli, B. U., S. Hooda, R. Mosenthin, M. G. Ganzle, and R. T. Zijlstra. 2010. Bacterial fermentation affects net mineral flux in the large intestine of pigs fed diets with viscous and fermentable nonstarch polysaccharides12. J. Anim. Sci. 88:3351–3362.

Mills, P. A., R. G. Rotter, and R. R. Marquardt. 1989. Modification of the glucosamine method for the quantification of fungal contamination. Can. J. Anim. Sci. 69:1105–1106.

Newcombe, M., and J. D. Summers. 1984. Feed-intake and gastrointestinal parameters of broiler and leghorn chicks in response to dietary energy concentration. Nutr. Rep. Int. 29:1127–1136.

Newton, G. L., C. V. Booram, R. W. Barker, and O. M. Hale. 1977. Dried Hermetia illucens larvae meal as a supplement for swine. J. Anim. Sci. 44:395–400.

Nguyen, T. T. X., J. K. Tomberlin, and S. Vanlaerhoven. 2015. Ability of black soldier fly (Diptera: Stratiomyidae) larvae to recycle food waste. Environ. Entomol. 44:406–410.

Parizeau, K., M. von Massow, and R. Martin. 2015. Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph, Ontario. Waste Manage. 35:207–217.

Rumpold, B. A., and O. K. Schluter. 2013. Nutritional composition and safety aspects of edible insects. Mol. Nutr. Food Res. 57:802–823.

Rumpold, B. A., and O. K. Schluter. 2013. Potential and challenges of insects as an innovative source for food and feed production. Innov. Food Sci. Emerg. Technol. 17:1–11.

Schader, C., A. Muller, H.-N. Scialabba, J. Hecht, A. Iseusee, K. H. Erb, P. Smith, H. P. Makkar, P. Klocke, F. Leiber, P. Schwegler, M. Stolze, and U. Niggli. 2015. Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. J. R. Soc. Interface. 12:20150891.

Schiavone, A., M. De Marco, S. Martinez, S. Dabbou, M. Renna, J. Madrid, F. Hernandez, L. Rotolo, P. Costa, F. Gai, and L. Gasco. 2017. Nutritional value of a partially defatted and a highly defatted black soldier fly larval meal (Hermetia illucens L.) meal for broiler chickens: Apparent nutrient digestibility, apparent metabolizable energy and apparent ileal amino acid digestibility. J. Anim. Sci. Biotechnol. 8:51.

Secci, G., F. Bovera, S. Nizza, and N. Baronti. 2018. Quality of eggs from Lohmann Brown classic laying hens fed black soldier fly meal as substitute for soya bean. Animal. 8:1–7.

Spranghers, T., M. Ottoboni, C. Klotwijk, A. Ovyn, S. Deboosere, B. De Meulenaer, J. Michiels, M. Eeckhout, P. De Clercq, and S. De Smet. 2017. Nutritional composition of black soldier fly (Hermetia illucens) prepupae reared on different organic waste substrates. J. Sci. Food Agric. 97:2594–2600.

St-Hilaire, S., C. Sheppard, J. K. Tomberlin, S. Irving, L. Newton, M. A. McGuire, E. E. Mosley, R. W. Hardy, and W. Sealey. 2007. Fly prepupae as a feedstuff for rainbow trout, Oncorhynchus mykiss. J. World Aquac. Soc. 38:59–67.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Widjastuti, T., R. Wiradimadja, and D. Runsmana. 2014. The effect of substitution of fish meal by black soldier fly (Hermetia illucens) maggot meal in the diet on production performance of quail (Coturnix coturnix japonica). Sci. Pap. Ser. D Anim. Sci. LVII:125–129.

Woyengo, T. A., E. Beltranena, and R. T. Zijlstra. 2014. Nonrumi- nant nutrition symposium: Controlling feed cost by including alternative ingredients into pig diets: A review1,2. J. Anim. Sci. 92:1293–1305.