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Effects of Black Soldier Fly Larva Meal Oil in the Diet on Production Performance, Feed Cost, and Egg Quality of Laying Hens

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Abstract. This study assessed the production performance, economics, and egg quality of laying hens fed with 0%, 4%, 8%, and 12% Black Soldier Fly larval meal oil or maggot meal oil (MMO). Forty-eight Hy-Line Brown hens (50–60 weeks old) were allocated to four treatments (three replicates of four hens) in a completely randomized design over 30 days. Feed intake, hen-day production (HDP), feed conversion ratio (FCR), and income over feed cost (IOFC) were measured, alongside external and internal egg quality. MMO inclusion up to 12% did not significantly alter feed intake, HDP, or FCR ($P > 0.05$), though 8% MMO yielded the highest intake (120.1 g/head/day) and HDP (93.8%), and 12% MMO achieved the best FCR (1.13). IOFC rose at an MMO level, peaking at Rp 45,340 for 12% MMO. All egg quality traits, including shape index, weight, shell strength, air-cell depth, albumen and yolk indices, and Haugh Units, remained within Grade A standards. These results indicate that MMO can be used up to 12% of the diet without compromising production or egg quality while improving economic returns, and this study recommends an inclusion of 8% MMO to optimize production efficiency and profitability.

Keywords: Black soldier fly, economic returns, egg quality, maggot, production performance

Abstrak. Penelitian ini mengevaluasi aspek performa produksi, ekonomi, dan kualitas telur ayam petelur yang diberi 0%, 4%, 8%, dan 12% minyak tepung larva lalat tentara hitam atau minyak tepung maggot (*maggot meal oil*/MMO). Empat puluh delapan ayam *Hy*-Line *Brown* (umur 50–60 minggu) dialokasikan ke empat perlakuan (tiga ulangan dari empat ayam) dalam rancangan acak lengkap selama 30 hari. Konsumsi pakan, produksi telur harian (*hen-day production*/HDP), rasio konversi pakan (*feed conversion ratio*/FCR), dan imbangan pendapatan atas biaya pakan (*income over feed cost*/IOFC) diukur, di samping kualitas telur eksternal dan internal. Penambahan MMO hingga 12% tidak mengubah konsumsi pakan, HDP, atau FCR secara signifikan ($P > 0{,}05$), meskipun penambahan 8% MMO menghasilkan konsumsi tertinggi (120,1 g/ekor/hari) dan HDP (93,8%), dan penambahan 12% MMO mencapai FCR terbaik (1,13). Nilai IOFC naik seiring kenaikan level penambahan MMO, dan mencapai puncaknya pada Rp 45.340 untuk penambahan 12% MMO. Semua sifat kualitas telur, termasuk indeks bentuk, berat, kekuatan kerabang, kedalaman sel udara, indeks putih telur dan kuning telur, dan Haugh Unit, tetap dalam standar Kelas A. Hasil ini menunjukkan bahwa penambahan MMO dapat digunakan hingga 12% dari pakan tanpa mengurangi produksi atau kualitas telur sambil meningkatkan keuntungan ekonomi, dan studi ini merekomendasikan penambahan 8% MMO untuk mengoptimalkan efisiensi produksi dan profitabilitas.

Kata kunci: Lalat tantara hitam, keuntungan ekonomi, kualitas telur, maggot, performa produksi

Introduction

The rising cost of conventional feed ingredients and increasing environmental concerns have intensified the search for sustainable alternatives. Black Soldier Fly Larva (BSFL), noted for their high bioconversion efficiency, are recognized as a viable solution for managing organic waste problems and mitigating the greenhouse effect. The oil derived from Black Soldier Fly (*Hermetia illucens*), referred to as maggot meal oil (MMO), is a promising feed ingredient extracted as a by-product of maggot meal production. MMO is rich in crude fat (≈81.6 %), bioactive fatty acids, antioxidant and antimicrobial properties (Purwan, 2020), as well as omega-3 and omega-6 fatty acids (Sumiati, 2020). Additionally, MMO contains 40.31% protein, 9.79% ash, 3.43% moisture, 27.81% crude fat, 7.81% crude fiber, 0.05% sodium chloride (Caroline, 2023). These nutritional properties highlight three practical advantages of MMO: (1) it is a lipid-rich by-product of maggot meal production, (2) it contains medium-chain fatty acids—particularly lauric and myristic acids—which are absent in common vegetable oils, and (3) it supports organic waste bioconversion and promotes local circular feed supply chains (Kim et al., 2020; Kim et al., 2022; Patterson et al., 2021). Thus, MMO can serve as a lipid source in poultry diets to increase dietary energy density and improve feed efficiency. Its effects are comparable to those of soybean oil, palm oil, coconut oil, fish oil, and poultry fat, albeit with a higher cost. This elevated price makes MMO imports more substantial and susceptible to market volatility, while also creating competition with the food and fuel sectors.

Despite its potential, MMO is expensive to produce and rarely available in the market, and empirical data on its effects in poultry diets remain limited. Previous studies have shown that dietary fats enhance palatability and energy density, thereby improving feed intake, conversion efficiency, and egg quality (Gopi et al., 2014; Stevanović et al., 2018). MMO is a relatively new feed ingredient, with limited information regarding its production and availability.

Consequently, farmers seldom use MMO, particularly for laying hens. Therefore, the selection of production and egg quality parameters in this study was directly linked to the anticipated functions of MMO. Feed intake was measured because supplemental lipids can alter palatability and energy density. Feed conversion ratio (FCR) and hen-day production (HDP) were assessed because dietary fat can influence energy utilization for maintenance and egg mass production. Egg weight, shell traits, air cell depth, albumen index, yolk index, and Haugh unit were measured to evaluate the effects of dietary lipids and hen age on yolk deposition and internal egg quality. Finally, income over feed cost (IOFC) was included, as the practical value of an alternative feed ingredient depends on balancing biological benefits with economic feasibility. Previous studies suggest that BSFL oil can replace soybean oil in laying hen diets without compromising performance or egg quality, although the upper inclusion limits and price competitiveness require further consideration (Kim et al., 2022; Patterson et al., 2021). Accordingly, this study aims to evaluate the impact of graded levels of MMO on production performance, feed cost, and egg quality of laying hens under practical farm conditions, addressing a critical gap in current knowledge.

Materials and Methods

Study Design and Location

This experiment was conducted at a rural commercial laying facility located in Sekar Putih village, Batu city, Indonesia, over a period of 30 days. A total of forty-eight Hy-Line Brown laying hens, aged 50 to 60 weeks and of similar body weight, were randomly assigned to a completely randomized design (CRD) comprising four dietary treatments (n = 12 per treatment). Each treatment group was further divided into three replicate pens, with four hens per replicate.

Diets and Treatments

The basal diet was formulated to meet the nutrient requirements for laying hens as specified by the National Research Council (NRC) and Indonesian National Standard (SNI, 2016). Maggot meal oil (MMO) was purchased from CV. Green Larva and incorporated into the diets at 0% (P0), 4% (P1), 8% (P2), or 12% (P3) inclusion levels. The ingredient composition and proximate analyses of the experimental diets are presented in Table 1 and Table 2, respectively.

Data Collection and Analysis

Data were collected on production performance, feed cost, and egg quality of laying hens throughout the study. Production performance parameters included feed intake, egg production, and feed conversion ratio (FCR). Feed intake was calculated as the difference between the daily feed offered and feed refusal,

Table 1. Ingredients composition of experimental diets

Diet Ingredients	Experimental Dietary Treatments Formulation (%)			
	P0	P1	P2	P3
Corn Meal	57.29	55.08	53.03	51.14
Rice Bran	14.04	13.50	12.99	12.53
Layer Feed	28.67	27.57	26.55	25.60
MMO	0.00	3.86	7.43	10.74
Total	100.00	100.00	100.00	100.00

Note: P0 = basal diet without MMO; P1, P2, and P3 = basal diet supplemented with nominal MMO levels of 4%, 8%, and 12%, respectively, relative to the basal mixture, normalized to 100% of the final mixed diet. MMO = maggot meal oil / black soldier fly larvae oil.

Table 2. Nutritional composition of experimental diet (100% DM)

Diet Ingredients	Price/Kg (Rp)	Dietary Nutritional Composition					
		ME (KKal/Kg)	CP (%)	EE (%)	CF (%)	Ca (%)	P (%)
Corn Meal [1)]	8,000	3,100	8.80	4.10	3.90	3.80	0.00
Rice Bran [1)]	2,500	2,931	13.00	10.20	10.10	0.40	0.00
Layer Feed [2)]	9,000	3,000	24.00	5.00	5.00	1.10	0.46
MMO [3)]	60,000	7,346*	0.00	81.62	0.00	0.00	0.00

Note: ME = metabolizable energy; CP = crude protein; EE = ether extract/crude fat; CF = crude fiber; Ca = calcium; P = phosphorus. 1) Result of Veterinary and Feed Analysis Laboratory of UNAIR; 2) commercial layer feed code PAR L1; 3) result of Chemistry Analysis Laboratory of UMM. *ME of MMO was not directly analyzed; the value was estimated from analyzed EE content using 9 kcal/g lipid x 81.62% = 7,346 kcal/kg.

Table 3. The average production performance of laying hens in this study

Treatment's Code	Feed Intake (g/head/day)	HDP (%)	FCR
P0	116.85 ± 2.93	91.67 ± 2.08	1.29 ± 0.05
P1	118.57 ± 2.03	93.06 ± 1.20	1.22 ± 0.02
P2	120.13 ± 4.20	93.75 ± 3.61	1.18 ± 0.08
P3	119.10 ± 3.67	92.36 ± 3.18	1.13 ± 0.01

divided by the number of birds (Leeson and Summers, 2005). Egg production was measured daily and expressed as hen-day production (HDP), using the formula: HDP = (total eggs laid/number of hens) × 100% (Bell and Weaver, 2002). FCR was calculated as the total feed intake divided by the total egg mass produced (Leeson and Summers, 2005). Feed cost analysis was based on income over feed cost (IOFC), representing the net income from egg sales after subtracting the cost of feed consumed (Olomu and Oluyemi, 2020). Egg quality was assessed by measuring egg size (egg shape index and egg weight), eggshell weight, air cell width, albumen index, yolk index, and Haugh Unit. These parameters were measured using standard tools such as calipers, balances, and rulers during three phases: feed adaptation, treatment administration, and experimental measurement. All data were subjected to one-way analysis of variance (ANOVA) using SAS 9.4 software. Where significant effects ($P < 0.05$) were detected, means were compared using the Least Significant Difference (LSD) test.

Results and Discussion

Production Performance Evaluation

The effects of MMO inclusion on laying hen performance are summarized in Table 3. The results indicate that hens in the P2 group (8% MMO) exhibited the highest feed intake (120.13 ± 4.20 g/hen/day) and HDP (93.75 ± 3.61%), while the best FCR was observed in the P3 group (12% MMO) at 1.13 ± 0.01. However, these differences were not statistically significant ($P > 0.05$). The inclusion of MMO at intermediate levels appears to enhance feed palatability and energy density, leading to increased voluntary intake and egg production. This observation aligns with previous reports that dietary fats can improve palatability and support higher HDP in laying hens (Gopi et al., 2014; Stevanović et al., 2018). In this study, the highest feed intake and HDP were achieved at 8% MMO inclusion, suggesting an optimal balance between energy supply and digestive efficiency (Brake and Thaxton, 2015).

The average feed intake observed in this study exceeds values reported in earlier studies, such as Bovera et al. (2018), who found a feed intake of 117.80 ± 2.10 g/hen/day with 10% BSFL meal, compared to 116.30 ± 1.90 g/hen/day in the control group. Similarly, Zawisza et al. (2023) reported feed intakes of 114.50 ± 1.20 and 113.90 ± 1.00 g/hen/day for 15% and 10% BSFL meal inclusion, respectively, with no significant difference from the control group. These values are also higher than those reported for hens fed only commercial concentrate, such as Afikasari et al. (2020; 115.20 ± 3.40 g/hen/day) and Luthfi et al. (2020; 112.70 ± 2.80 g/hen/day).

Similarly, the HDP achieved in this study (P2: 93.75 ± 3.61%) surpasses that of Bovera et al. (2018; 91.70 ± 1.30% with 10% BSFL meal) and Zawisza et al. (2023; 92.30 ± 1.00% with 15% BSFL meal), as well as the results from Afikasari et al. (2020; 88.20 ± 1.40%) and Luthfi et al. (2020; 87.60 ± 1.20%) for hens without maggot supplementation. These findings demonstrate the potential of MMO to enhance feed intake and HDP, whether incorporated as a meal or oil, and suggest that moderate BSFL inclusion (≤15%) does not adversely affect feed consumption or egg production in late-stage laying hens.

Conversely, the lowest FCR was observed in the P3 group (12% MMO: 1.13 ± 0.01), supporting the principle that higher dietary fat levels increase dietary energy density, thereby reducing the amount of feed required per gram of egg produced (Leeson and Summers, 2005). The improvement in FCR with increasing MMO inclusion can be attributed to the enhanced energy density and favorable fatty acid profile of the supplemented diets. The presence of medium- and long-chain fatty acids in BSFL oil, such as lauric, palmitic, and oleic acids, may promote efficient lipid digestion and protein utilization, leading to improved feed conversion.

This targeted nutrient utilization translates into less wastage and more efficient conversion of feed into egg mass. Several studies have demonstrated that incremental inclusion of BSFL-derived lipids in layer diets yields dose-dependent improvements in FCR. Bovera et al. (2018) found that replacing 10% of conventional fat sources with BSFL oil reduced FCR by up to 6% in commercial layers, mirroring the graded response observed here. Thus, the superior FCR in P3 (12% MMO) likely reflects the combined benefits of higher dietary energy density, improved lipid digestibility, and a more favorable fatty acid profile that promotes efficient egg production.

However, the lack of statistically significant differences among treatments ($P > 0.05$) suggests that the tested MMO inclusion levels fell within the physiological adaptability of the hens (NRC, 1994). The ability of laying hens to maintain performance across a range of dietary lipid sources reflects their nutrient utilization flexibility. Additionally, the observed variability may be influenced by the inherent biological differences among commercial layers, and smaller sample sizes may limit the detection of subtle treatment effects (Attia et al., 2019).

Several recent studies of alternative lipid inclusions in layer rations have similarly reported non-significant differences across moderate inclusion levels, attributing this to the hens' efficient mobilization of diverse fatty acid sources and the comparable metabolizable energy contributions of traditional and novel fats within customary dietary formulations. Taken together, the absence of significant treatment effects ($P > 0.05$) in the present study likely reflects both the hens' physiological adaptability to graded MMO inclusion and the expected experimental variability inherent in performance measurements.

Feed Cost Evaluation

Economic evaluation is essential in assessing the practical utility of MMO in laying hen diets. The key metric utilized for this purpose is income over feed cost (IOFC), which represents the balance between feed costs and egg production income. In the present study, the costs of basal ingredients and MMO were combined to calculate a unit diet cost for each treatment, and total feed costs were determined by multiplying the unit diet cost by actual feed consumption. Thus, differences in total feed costs among treatments reflect both variations in diet composition and feed intake, rather than arbitrary fixed MMO cost assignments, as shown in Table 4.

The corrected IOFC values provide a nuanced interpretation compared to earlier analyses. Although the P3 group (12% MMO) achieved the highest egg income, its feed costs increased substantially due to the high price of MMO (Rp 60,000/kg). Accordingly, the highest IOFC was observed in P0 (control), with decreasing IOFC values as MMO inclusion increased. This result does not imply that MMO lacks nutritional value; rather, it highlights that the economic feasibility of MMO is highly sensitive to its market price. Under the current price structure, MMO should not be recommended solely for short-term profit maximization. However, MMO could become economically attractive if its price decreases, if its inclusion is optimized in isocaloric replacement diets, or if eggs produced with circular feed ingredients command a premium in the market.

Egg Quality Performance Evaluation

Egg quality parameters as influenced by dietary MMO inclusion are summarized in Table 5 and compared with the Indonesian National Standard (SNI) for Grade A consumption eggs (BSN, 2023). Table 5 displays the egg quality performance of this study, which is presented quantitatively. These results are compared with SNI 3926:2023 concerning the quality standards of laying hens' eggs for consumption at the best quality, namely Grade A (BSN, 2023). The egg quality performance evaluation of this study includes some variables below.

Table 4. Corrected feed cost and IOFC calculation per hen during 30 days

Treatment	Diet cost (Rp/kg)	Feed consumed (kg/head/30 d)	Egg income (Rp/head/30 d)	Feed cost (Rp/head/30 d)	IOFC (Rp/head/30 d)
P0	7,515	3.506	68,160	26,343	41,817
P1	9,538	3.557	72,643	33,929	38,714
P2	11,412	3.604	76,440	41,127	35,313
P3	13,151	3.573	79,320	46,989	32,331

Note: Diet cost was calculated from the normalized ingredient composition in Table 1 and ingredient prices in Table 2. Feed consumed = feed intake x 30 d. IOFC = egg income - feed cost.

Table 5. The egg quality performance of laying hens in this study

Egg Quality Indicators	Treatments				SNI (Grade A)
	P0	P1	P2	P3	
Egg Shape Index (%)	72.48	75.81	74.31	72.05	72 – 76
Egg Weight (g)	56.80	59.30	62.40	66.10	> 60 (huge)
Eggshell Weight (g)	6.30	7.00	6.70	6.30	10–12% of egg's weight
Air Cell Depth (cm)	0.29	0.17	0.18	0.24	< 0,5
Albumen Index	0.05	0.06	0.05	0.04	0,13–0,18
Egg Yolk Index	0.45	0.53	0.43	0.36	0,46–0,52
HU	76.34	68.66	73.31	78.95	> 72*

Note: * based on SNI 01-3926-2006

Egg Shape Index

The egg shape index is sensitive to subtle changes in shell deposition and oviduct physiology (Peters et al., 2010). Previous research has shown that moderate dietary lipid inclusion (approximately 4%) can enhance membrane fluidity in the shell gland, facilitating more uniform calcium carbonate crystallization and yielding more "ideal" egg geometry (Bain et al., 2018). The elevated shape index in the 4% MMO group (P1) may reflect optimal biochemical support for shell formation without excessive lipid metabolism. However, as observed in multiple layer nutrition studies, improvements in egg shape index at low to moderate fat inclusion levels often do not reach statistical significance due to biological variability and the narrow range of physiological response (de Oliveira et al., 2020). In balanced diets, minor shifts in lipid source produce only incremental, variable changes in shell parameters. The absence of a significant treatment effect in this study aligns with meta-analyses, which suggest that while certain lipid types can modulate shell quality, pronounced effects are unlikely unless inclusion rates exceed 5–6% or the diet is otherwise limiting. Thus, the observed peak at 4% MMO likely represents a physiological optimum for shell gland function that, due to inter-individual variability and sample size, does not result in statistically significant differences under these experimental conditions.

Egg Weight

Egg weight is another important indicator of the impact of MMO supplementation on egg quality. As presented in Table 5, the use of MMO in diets showed a tendency for increased egg weights, with P2 (62.40 g) and P3 (66.10 g) classified as Grade A "huge" eggs (>60 g), while P0 and P1 groups were classified as medium (50–60 g) according to SNI standards (BSN, 2023). Although the highest mean egg weight was observed in the P3 group (12% MMO), differences among treatments were not statistically significant ($P > 0.05$). These results suggest that the dietary inclusion of lipid-rich ingredients like MMO can increase the energy density of layer rations, supporting greater lipid deposition in the developing oocyte and resulting in heavier eggs. Cullere et al. (2018) reported that replacing a portion of dietary fat with insect-derived oils increased average egg weight by enhancing yolk lipid content, without negative effects on hen health. Likewise, Ribeiro et al. (2020) found a linear increase in egg mass with up to 12% inclusion of BSFL fat, attributing it to improved energy availability during yolk formation. The results of this study, with higher egg weights in the P2 and P3 groups compared to the control, are consistent with findings by Gopi et al. (2014), who observed that incremental increases in dietary fat are associated with heavier eggs until a plateau is reached. Nevertheless, the lack of statistical significance among treatments is consistent with the modest effect sizes often reported when increasing lipid levels within moderate ranges (de Oliveira et al., 2020). Biological variability among hens and the relatively small sample size likely contributed to broad confidence intervals, potentially obscuring subtle but genuine performance advantages.

Eggshell Weight

Eggshell weight, typically expressed as the ratio of shell mass to total egg mass, is a critical indicator of shell thickness and strength, which are essential for the mechanical resilience of eggs during handling, packaging, and storage. Thicker, denser shells (≥10% of egg weight) indicate robust ossification, reducing the risk of cracking and limiting microbial ingress (Roberts, 2004). Eggshell weight is influenced by feed composition, hen health and breeding management, and environmental conditions (Gautron et al., 2021). In this study, dietary inclusion of MMO resulted in an inverse relationship between eggshell weight and total egg weight. As shown in Table 5, mean eggshell weights for treatments P1–P3 declined sequentially (7.00 g, 6.70 g, and 6.30 g); P1 achieved the highest relative eggshell weight (11.80%), classifying it as SNI Grade A (10–12%) despite no statistically significant differences among treatments (P > 0.05). These findings highlight the importance of eggshell weight not only for physical protection but also for physiological functions, such as gas exchange and maintenance of albumen integrity during storage (Gautron et al., 2021). Eggshell weight also reflects maternal bone mineralization and dietary calcium adequacy, offering an indirect measure of skeletal health and efficacy of feed formulations (Rao et al., 2017). Moreover, as egg size increases, the shell surface area expands faster than volume, and the shell gland's capacity for calcium deposition may not scale accordingly; thus, larger eggs often have relatively thinner shells (Freeman and Harper, 2017). The absence of significant treatment effects aligns with previous observations that interventions increasing egg size may lead to reductions in shell deposition efficiency (Gautron et al., 2021; Freeman and Harper, 2017).

Air Cell Depth

Air cell depth is a widely recognized indicator of egg freshness and internal quality. Freshly laid eggs have very small air cells, typically less than 2 mm deep; as eggs lose moisture and carbon dioxide through shell pores over time, the air cell gradually enlarges (Yuceer and Karaçiçek, 2009). Regulatory standards (SNI 3926–2023) employ air cell measurements to classify egg grades, with Grade A eggs required to have an air cell no greater than 5 mm when measured at the large end under specified lighting conditions (BSN, 2023). In this study (Table 5), all eggs from hens fed diets supplemented with MMO exhibited air cell depths below 5 mm, thus meeting Grade A criteria. An enlarged air cell indicates increased water loss, which concentrates the yolk and albumen solids, negatively affecting texture and flavor, and also reduces structural support for the albumen—resulting in albumen thinning and lower Haugh Unit scores (Koelkebeck and Mueller, 1998). Conversely, shallow air cells reflect minimal moisture and gas loss during storage, thereby preserving albumen viscosity and yolk index (Stadelman and Cotterill, 1995). Expansion of the air cell is directly attributable to egg mass shrinkage via water evaporation and gas release during storage, with air cell depth increasing as storage duration lengthens (Bilyaro et al., 2021). Because all eggs in this study were from hens of the same strain and were stored for the same duration (two days), no statistically significant differences in air cell depth were observed among treatments (P > 0.05). Therefore, inclusion of MMO up to the tested levels did not compromise internal egg freshness or quality, as indicated by air cell depth measurements.

Albumen Index

The albumen index is calculated as the ratio of the thick albumen height to its mean diameter (the average of its length and width) (Stadelman and Cotterill, 1995). This metric is widely used to assess internal egg quality, as both the height and viscosity of the thick albumen progressively decrease during storage, leading to a thinner, less cohesive albumen layer (Silversides and Budgell, 2004). As storage time increases, enzymatic and pH-driven changes cause the albumen to lose firmness, reducing both the albumen index and overall egg quality (Gao et al., 2021). These changes are primarily driven by the diffusion of CO_2 out of the egg, which raises the albumen pH, destabilizing the protein network and resulting in liquefaction and spreading of the albumen (Silversides and Budgell, 2004). In this study (Table 5), eggs from hens fed diets containing 4%, 8%, and 12% MMO exhibited albumen indices of 0.06, 0.05, and 0.04, respectively—values that fall within the SNI Grade C range (0.05–0.09), rather than Grade A

(>0.13) (BSN, 2023). Statistical analysis revealed no significant differences among treatments (P > 0.05), indicating that all groups had relatively low albumen indices, reflecting thinner and less viscous albumen layers. Although some studies suggest that higher dietary lipid levels can influence albumen viscosity, moderate fat inclusions, including insect-derived oils such as MMO, generally have minimal impact on albumen structure (Roberts, 2004). The absence of statistically significant effects across all levels of MMO inclusion up to 12% suggests that these dietary modifications neither accelerate nor impede the natural decline in albumen quality under the storage and management conditions used in this study.

Egg Yolk Index

The egg yolk index, calculated as the ratio of yolk height to diameter, is a measure of yolk firmness and quality, reflecting both freshness and structural integrity (Abiola et al., 2014; Sekeroglu, 2017). In this study, the 4% MMO group (P1) achieved the highest mean yolk index (0.53), qualifying as SNI Grade A, though differences among treatments were not statistically significant (P > 0.05). These results are consistent with evidence that moderate dietary lipid enrichment can enhance yolk lipid deposition, thus increasing viscosity and height (Singh et al., 2019). The lack of significant variability suggests that hens maintain homeostatic control over yolk formation up to a physiological threshold, beyond which further improvements plateau (Lee and Kim, 2020). These findings underscore the potential value of a 4% MMO inclusion rate for optimizing yolk quality, though further research on underlying mechanisms and sensory attributes is needed.

Haugh Unit

Egg quality was further assessed using the Haugh unit (HU), a widely recognized indicator of egg freshness (Silva et al., 2010). HU values decline progressively during storage, with eggs measured shortly after laying exhibiting higher HU values that reflect superior freshness (Haugh, 1937). Studies have shown that HU decreases in an approximately linear fashion during refrigerated storage (Silva et al., 2010). In this study, HU values ranged from 68.66 in the P1 group to 78.95 in the P3 group, with only P1 falling just below the SNI Grade A threshold of 72. The highest HU observed in P3 is consistent with evidence that moderate inclusion of dietary lipids can help preserve or even enhance albumen viscosity and freshness (Hua et al., 2017). Moreover, the absence of statistically significant differences in HU across treatments (P > 0.05) suggests that laying hens are able to maintain albumen quality across a broad range of MMO inclusion levels. This finding aligns with previous research indicating that moderate dietary fat enrichment stabilizes albumen parameters without adverse effects (Singh et al., 2019).

Conclusions

MMO supplementation at nominal levels of 0–12% did not significantly affect feed intake, HDP, or FCR in 50–60-week-old Hy-Line Brown laying hens. The 8% nominal level produced the highest numerical feed intake and HDP, while 12% produced the lowest numerical FCR. However, feed-cost analysis showed that IOFC declined as MMO inclusion increased, primarily due to the high market price of MMO. Egg shape index and air cell depth met SNI Grade A criteria, and Haugh Unit values were generally within acceptable limits, but albumen index was low across treatments and does not qualify as Grade A. Therefore, MMO can be used as a supplemental lipid ingredient without adverse short-term effects on production or most egg quality traits, but its economic use is not currently justified at prevailing market prices. Future research should investigate isocaloric and isonitrogenous replacement diets, longer feeding periods, larger sample sizes, fatty acid deposition in egg yolk, nutrient digestibility, and consumer acceptance of eggs produced with BSFL-derived lipid ingredients.

References

Abiola, OE, AM Bamgbose, and SK Adesina. 2014. Influence of Dietary Oil Supplementation on Egg Quality Characteristics of Laying Hens. Journal Of Animal Physiology And Animal Nutrition. 98(1): 54–60.

Afikasari, S, A Nugroho, dan R Wijayanti. 2020. Feed Intake and Production Performance of Lohmann Brown Layers Aged 50–60 Weeks. Jurnal Ilmu Peternakan. 16(2): 87–94.

Afrin, S, A Nowshin, and S Hossain. 2022. Economic Evaluation of Alternative Protein–Lipid Feedstuffs in Commercial Layer Diets. Journal Of Applied Poultry Research. 31(3): 100245. https://doi.org/10.1016/j.japr.2022.100245.

de Almeida, PV, PB Rodrigues, and JR de Oliveira. 2019. Statistical Power and Variability in Layer Hen Feeding Trials: Implications for Diet Formulation Research. Journal Of Applied Poultry Research. 28(2): 349–358.

Attia, YA, C Kamel, M Korish, and F Bovera. 2019. Use of Hermetia illucens (Black Soldier Fly) Larvae Oil in Layer Diets: Effects on Performance, Egg Quality, and Nutrient Digestibility. Poultry Science. 98(4): 1900–1908.

Attivi, DV, S Seyedalmoosavi, and A Ahmad. 2022. Effects of Insect-Derived Lipid Supplementation on Feed Efficiency and Egg Production in Laying Hens. Poultry Science. 101(7): 101234. https://doi.org/10.1016/j.psj.2022.101234.

Bain, MM, MM Taylor, and W Luo. 2018. Dietary Lipid Supplementation and Its Impact on Egg Geometry and Shell Quality in Commercial Layers. Journal Of Animal Science. 96(3): 1123–1131.

Bell, DD, and WD Weaver Jr. 2002. Commercial Chicken Meat and Egg Production. 5th ed. Kluwer Academic Publishers.

Bilyaro, W, D Lestari, and AS Endayani. 2021. Identifikasi Kualitas Internal Telur dan Faktor Penurunan Kualitas Selama Penyimpanan. Journal Of Agriculture And Animal Science. 1(2): 55-62.

Bovera, F, HPS Makkar, C Mèo, and HAR Suleria. 2018. Effects of Partial Replacement of Soybean Meal with Hermetia illucens Larvae Meal on Performance and Egg Quality of Laying Hens. Poultry Science. 97(4): 1122–1130.

Brake, J, and P Thaxton. 2015. Economic Considerations in Layer Management. D. Guenter and M.R. Bedford Eds. Poultry Science: Management and Production. pp. 201–220. Poultry Science Association.

BSN. 2023. SNI 01-3926:2006 Telur Ayam Konsumsi. Badan Standardisasi Nasional. Jakarta.

Caroline, G. 2023. Comparative Study of Maggot Oil Profiles and Applications. Bulletin Of Veterinary Research. 12(2):45–50.

Cullere, M, G Tasoniero, V Giaccone, EA de Carlo, L Rizzi, and A Schiavone. 2018. Nutritional Value of a Partially Defatted Black Soldier Fly (Hermetia illucens) Larva Meal and Its Incorporation in Broiler Diets. Poultry Science. 97(1), 94–100.

Dzuhri, A, JR Manullang, and A Wibowo. 2022. Produktivitas Ayam Petelur Fase Layer dengan Tingkat Kepadatan Kandang Baterai dan Umur yang Berbeda. Jurnal Peternakan Lingkungan Tropis. 5(1): 45. https://doi.org/10.30872/jpltrop.v5i1.6339.

Freeman, BM, and DE Harper. 2017. Relationship of Egg Size to Eggshell Quality Traits in Laying Hens. Poultry Science. 96(11): 3893–3904.

Gao, Z, J Zheng, F Li, J Zheng, and G Xu. 2021. Effect of Dietary Fat Levels on Performance and Egg Quality of Laying Hens. Poultry Science. 100(4): 1234–1242.

Gautron, J, L Stapane, N Le Roy, Y Nys, AB Rodriguez-Navarro, and MT Hincke. 2021. Avian Eggshell Biomineralization: An Update on Its Structure, Mineralogy and Protein Tool Kit. BMC Molecular And Cell Biology. 22(11). https://doi.org/10.1186/s12860-021-00350-0.

Gopi, M, AK Panda, and SVR Rao. 2014. Influence of Dietary Fat Sources on Performance and Egg Quality in Layers. Asian-Australasian Journal Of Animal Sciences. 27(10): 1446–1452.

Haugh, RR. 1937. The Haugh Unit for Measuring Egg Quality. US Egg & Poultry Magazine, 43, 552–555.

Hua, X, H Yang, and F Ma. 2017. Effects of Dietary Fat Sources on Laying Performance and Egg Quality. Poultry Science. 96(6): 2043–2051.

Kim, B., Kim, M., Jeong, J. Y., Kim, H. R., Ji, S. Y., Jung, H., and Park, S. H. 2022. Black soldier fly (Hermetia illucens) larvae oil as an alternative fat ingredient to soybean oil in laying hen diets. Animal Bioscience. 35(9):1408-1417. https://doi.org/10.5713/ab.22.0052.

Kim, Y. B., Kim, D. H., Jeong, S. B., Lee, J. W., Kim, T. H., Lee, H. G., and Lee, K. W. 2020. Black soldier fly larvae oil as an alternative fat source in broiler nutrition. Poultry Science. 99(6):3133-3143. https://doi.org/10.1016/j.psj.2020.01.018.

Koelkebeck, KW, and CJ Mueller. 1998. Relationship of Egg Weight Loss to Air Cell Size and Physical Quality of Eggs during Storage. Journal Of Applied Poultry Research. 7(2): 105–110.

Lee, KW, and CH Kim. 2020. Effects of Dietary Supplementation of Omega-3 Fatty Acids on Egg Quality and Health Status of Laying Hens. Journal Of Poultry Science. 57(1): 1–9.

Leeson, S, and JD Summers. 2005. Commercial Poultry Nutrition. 3rd ed. Nottingham University Press.

Luthfi, I, S Susilo, and B Prasetyo. 2020. Comparative Evaluation of Feed Intake in Layers Supplemented with Insect Meals. Indonesian Journal Of Animal ScienceS. 19(1): 45–52.

National Research Council (NRC). 1994. Nutrient Requirements of Poultry. Ninth Revised Edition. The National Academies Press. Washington DC.

Okatama, MS, S Maylinda, and VMA Nurgiartiningsih. 2018. Hubungan Bobot Telur dan Indeks Telur dengan Bobot Tetas Itik Dabung di Kabupaten Bangkalan. Jurnal Ternak Tropika. 19(1): 1–8. DOI: 10.21776/ub.jtapro.2018.019.01.1.

de Oliveira, AB, ES Santos, and TR Souza. 2020. Meta-Analysis of Dietary Fat Inclusion and Shell Quality Outcomes in Laying Hens. Journal Of Applied Poultry Research. 29(4): 739–751.

Olomu, JM, and JA Oluyemi. 2020. Economic Evaluation of Maggot Meal as A Feed Ingredient in Layer Diets. Journal Of Poultry Science. 57(2): 112–118.

Patterson, P. H., Acar, N., Ferguson, A. D., Trimble, L. D., Sciubba, H. B., and Koutsos, E. A. 2021. The impact of dietary black soldier fly larvae oil and meal on laying hen performance and egg quality. Poultry Science. 100(8):101272. https://doi.org/10.1016/j.psj.2021.101272.

Peters, CL, PA Jackson, and CE Stephenson. 2010. Effects of Dietary Fat Source and Level on Shell Gland Histology and Egg Shape Index in Laying Hens. POULTRY SCIENCE. 89(8): 1542–1550.

Purwan, B. 2020. Applications of Black Soldier Fly Larvae Oil in Animal Nutrition. Tropical Animal Science Journal. 1(1): 16–24.

Rao, SV, DA Roland, and P Vijayagopal. 2017. Relationship of Dietary Calcium and Eggshell Quality to Plasma Osteocalcin and Shell Ca-ATPase Activity in Laying Hens. Poultry Science. 96(4). 1068–1075.

Ribeiro, LM, DGAB Oonincx, and JJA van Loon. 2020. Insect-Based Diets for Laying Hens: Effects on Performance, Egg Quality, and Nutrient Digestibility. Journal Of Applied Poultry Research. 29(3): 383–394.

Roberts, JR. 2004. Factors Affecting Egg Internal Quality and Egg Shell Quality in Laying Hens. Journal Of Poultry Science. 41(3): 161–177. https://doi.org/10.2141/jpsa.41.161.

Sekeroglu, A. 2017. Egg Quality Evaluation with Emphasis on Albumen and Yolk Indices. World's Poultry Science Journal. 73(1): 11–18. https://doi.org/10.1017/S0043933917000109.

Silva, P, S Leite, and I Estevez. 2010. Effect of Storage Time on Haugh Unit and Albumen pH in Chicken Eggs. Poultry Science. 89(6): 1279–1283.

Silversides, Fg, And K Budgell. 2004. Effect Of Storage And Strain Of Hen On Quality Of Eggs Stored In Shell. Poultry Science. 83(6): 1610–1615.

Singh, P, B Roy, and AK Singh. 2019. Influence of Dietary Fat Supplementation on Egg Quality Characteristics in Layers. Veterinary World. 12(2): 192–198. https://doi.org/10.14202/vetworld.2019.192-198.

Stadelman, WJ, and OJ Cotterill. 1995. Egg Science and Technology. 4th ed. Food Products Press.

Stevanović, Ž., D Gavranović, and V Iljić. 2018. Effects of Dietary Fat Addition on Laying Hen Performance and Egg Quality. ARCHIVES OF Animal Nutrition. 72(4): 301–310.

Sumiati, S. 2020. Hidden potential of BSF larvae for poultry feed. AiniOnline. Available at: https://ainionline.org/2020/07/16/potensi-tersembunyi-maggot-untuk-pakan-unggas/.

Yuceer, M, and U Karaçiçek. 2009. Quality Changes in Eggs During Refrigerated and Room Temperature Storage. Food Control. 20(9): 800–803.

Zawisza, S, M Heuel, and J Böhm. 2023. Inclusion of Hermetia illucens Larvae Meal Up to 15 % in Layer Diets: Effects on Feed Intake, Performance, and Egg Quality. Journal Of Insects As Food And Feed. 9(1): 45–56.