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Impact of dietary *Sardinella lemuru* fish oil supplementation on egg production and fatty acid profile of laying quails in smallholder farming

Dampak suplementasi minyak ikan lemuru dalam pakan terhadap produksi telur dan profil asam lemak puyuh petelur pada sistem peternakan skala kecil

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ABSTRACT
Smallholder quail farms often face limitations in providing high-quality feed that can improve both productivity and nutritional quality of eggs, particularly in enhancing essential fatty acids such as omega-3. Bali sardinella (*Sardinella lemuru*) fish oil is a rich source of omega-3 fatty acids and holds potential as a dietary supplement to enhance egg nutritional value. This study aimed to evaluate the impact of *S. lemuru* fish oil supplementation in feed on egg production and fatty acid profile of laying quails under smallholder farming conditions. A randomized block design was applied with four treatments: T0 (0% LFO), T1 (2% LFO), T2 (4% LFO), and T3 (6% LFO), each with two replications and 50 adult female quails per unit. The results showed that *S. lemuru* fish oil supplementation had no significant effect on egg weight, egg length, viscosity, yolk diameter and height, or other physical egg parameters. However, T3 significantly reduced egg production. The 2% LFO treatment (T1) resulted in the highest crude protein content in the feed and relatively better performance and physical egg quality. The fatty acid profile of eggs was dominated by oleic, palmitic, and linoleic acids, with omega-3 levels increasing in line with higher LFO doses. These findings suggest that 2% *S. lemuru* fish oil supplementation is suitable for smallholder quail farming to improve egg quality without significantly increasing production costs.

ABSTRAK
Peternakan puyuh skala kecil memiliki keterbatasan dalam menyediakan pakan berkualitas tinggi yang mampu meningkatkan produktivitas dan kualitas nutrisi telur, terutama kandungan asam lemak esensial seperti omega-3. Minyak ikan lemuru (*Sardinella lemuru*) merupakan sumber asam lemak omega-3 yang berpotensi digunakan sebagai pakan tambahan untuk meningkatkan nilai gizi telur puyuh. Penelitian ini bertujuan untuk menganalisis dampak suplementasi minyak ikan lemuru dalam pakan terhadap produksi telur dan profil asam lemak puyuh petelur pada sistem peternakan skala kecil. Penelitian dilakukan menggunakan rancangan acak kelompok (RAK) dengan empat perlakuan: T0 (0% LFO), T1 (2% LFO), T2 (4% LFO), dan T3 (6% LFO), masing-masing dengan dua ulangan dan 50 ekor puyuh betina dewasa per unit. Hasil menunjukkan bahwa suplementasi minyak ikan lemuru tidak memberikan pengaruh yang signifikan terhadap berat telur, panjang telur, viskositas, diameter dan tinggi kuning telur, serta parameter fisik lainnya. Namun, perlakuan T3 menunjukkan penurunan signifikan pada produksi telur. Suplementasi 2% LFO (T1) menghasilkan kandungan protein kasar pakan tertinggi serta performa produksi dan mutu fisik telur yang relatif lebih baik dibandingkan perlakuan lainnya. Profil asam lemak telur menunjukkan dominasi asam oleat, palmitat, dan linoleat, dengan peningkatan kandungan omega-3 seiring peningkatan dosis LFO. Hasil ini menunjukkan bahwa suplementasi minyak ikan lemuru sebanyak 2% dapat diterapkan dalam sistem peternakan skala kecil untuk meningkatkan mutu telur tanpa meningkatkan biaya produksi secara signifikan.

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INTRODUCTION

The contribution of quail in providing a source of animal protein for the Indonesian people reaches more than 10%. Quail eggs are a livestock product that has high nutritional content (Tolik et al., 2014). Data on the quail population in Indonesia from 2014-2018 continued to increase, however egg production decreased (Directorate General of Animal Husbandry and Animal Health, 2018). Quail eggs contain omega 3 essential fatty acids which are useful for preventing stunting in Indonesia. Quail productivity is quite high, namely 250-300 eggs/head/year (Narinc et al., 2013). Quail productivity can still be increased further with the aim of ensuring sufficient availability of animal protein for the Indonesian people.

The high demand for omega-3-rich quail eggs requires quail farmers to optimize feed strategies both in terms of quality and cost-efficiency (Dewi et al. 2023). One of the keys to successful quail rearing is choosing the right nutritional feed. Quality feed can optimize the quantity and quality of quail egg production. Efficient production of functional products is the goal of many researchers by trying to engineer feed (Liang et al. 2020), including functional products of eggs that high in n-3. Oil can be used as an energy source in poultry feed, as can fish oil. Apart from that, oil is also useful in helping the absorption of fat-soluble vitamins and reducing dustiness in feed. *Sardinella lemuru* is one of several fish species that are abundant in omega 3 fatty acids found in Indonesia. Adding fish oil to quail feed is one solution so that omega-3 is directly available in the feed. *S. lemuru* fish oil contains 38.15% saturated fatty acids, 32.18% monounsaturated fatty acids, and 28.44% polyunsaturated fatty acids (Maulana et al. 2014). *S. lemuru* fish oil is a source of polyunsaturated fatty acids (PUFA) with the main content of high n-3 fatty acids such as eicosapentaenoic acid (EPA) 14.36% and docosahexaenoic acid (DHA) 4.60% (Suseno et al. 2014).

Providing *S. lemuru* fish oil in feed rations can increase metabolism and optimize fat utilization in the body. Fatty acid oxidation can conserve protein and energy, allowing organisms to use protein to increase egg quantity and quality. However, fish oil has a fishy odor which can affect the smell of quail feed. This can indirectly trigger reduced feed consumption, feed conversion value and ultimately reduce egg production. Although the addition of *S. lemuru* fish oil has been widely studied, most research has focused on controlled laboratory settings. Conditioning is carried out on temperature, air humidity, lighting, cage density and other environmental disturbances. Meanwhile, quail egg production is very dependent on the success of the quail farming business, the conditions of which are very different from laboratory conditions. This is important to study the application of feed engineering which is carried out directly by smallholder farmer. The aim of this research is to analyze the effect of adding *S. lemuru* fish oil to complete feed in smallholder farmer of quail on production performance, physical quality and fatty acid profile of eggs. This study addresses a practical gap by evaluating the dietary inclusion of *S. lemuru* fish oil under real-world smallholder farming conditions, aiming to provide applicable insights for sustainable quail production

MATERIALS & METHODS

Study site and experimental animals

This study was conducted at a smallholder quail farm located in Walantaka District, Serang City, Banten Province, under tropical lowland environmental conditions. A total of 200 adult female Japanese quails (*Coturnix coturnix japonica*) in the laying phase were used for the experiment. The birds were randomly allocated into four treatment groups, with each group consisting of 50 birds housed in colony cages of uniform dimensions under open-sided housing with natural ventilation.

The environmental conditions, including temperature and humidity, were monitored throughout the study period (Zhang et al. 2022). Artificial lighting was provided to maintain a photoperiod of 16 hours per day to stimulate egg production (Masrianih 2022). The experimental period included a two-week adaptation phase, followed by a six-week feeding trial. Feed adaptation refers to research by Citra et al. (2019). Feed and fresh drinking water were provided ad libitum throughout the study.

Dietary treatments

The experimental diets were based on a commercial complete layer feed, which was supplemented with different levels of *S. lemuru* fish oil . The oil was gradually applied by spraying it onto the daily feed ration to ensure even distribution and maintain the integrity of essential fatty acids (Ceylan et al. 2011). The four dietary treatments consisted of: a control group with 0% *S. lemuru* fish oil (T0), and three experimental groups with 2% (T1), 4% (T2), and 6% (T3) *S. lemuru* fish oil supplementation, respectively. Feeding was carried out twice a day, at 06:00 and 15:00 (GMT+7). The proximate nutrient composition of the diets, including dry matter (DM), crude protein (CP), ether extract (EE), crude fiber (CF), and ash, was determined following standard procedures (AOAC, 2019), and the results are presented in Table 1.

Tabel 1. Nutrient composition of the experimental diets (%)

Variable (%)	Treatment			
	T0	T1	T2	T3
DM	92.11	92.20	92.66	92.64
Ash	11.01	9.53	9.75	9.34
EE	6.36	9.09	9.39	11.80
CP	20.57	20.75	20.64	19.96
CF	3.87	4.30	4.56	4.31

Note. DM= Dry Matter, EE= Ether Extract, CP= Crude Protein, CF= Crude Fiber, T0 (control): addition of 0% *S. lemuru* fish oil in complete feed, T1: addition of 2% *S. lemuru* fish oil in complete feed, T2: addition of 4% *S. lemuru* fish oil in complete feed, T3: addition of 6% *S. lemuru* fish oil in complete feed.

Experimental design and statistical analysis

The study was arranged in a randomized block design (RBD) comprising four dietary treatments and two replications. Each replication consisted of one cage unit housing 50 laying quails. After the adaptation period, the birds were observed over a six-week experimental period. Data obtained from production performance and egg quality measurements were subjected to one-way analysis of variance (ANOVA). When significant differences were detected ($P < 0.05$), means were separated using Duncan's Multiple Range Test (DMRT) (Midway et al. 2020). All statistical analyses were conducted using IBM SPSS Statistics versi 25.0 (IBM Crop 2017).

Variables and data collection

The observed variables included production performance, physical egg quality, and the fatty acid profile of the egg yolks. Production performance was assessed based on daily feed intake (g/bird/day), egg production (% hen-day), and feed conversion ratio (FCR). These data were recorded continuously over 30 days and served as key indicators of feed efficiency and laying performance (Romero et al. 2022).

Physical egg quality was evaluated by collecting eggs on days 27 to 30 of the trial period. Parameters measured included egg weight, egg length and diameter, shell weight and thickness, yolk color, yolk diameter and height, albumen diameter and height, and egg viscosity. Measurements were conducted using digital calipers, a tripod micrometer, a yolk color fan, and an egg quality tester (Bain & MacLeod, 2020). These parameters were chosen based on their relevance to consumer preferences and functional egg quality.

To assess the fatty acid profile, three eggs per treatment group were randomly collected on day 30. The yolks were separated, pooled, and homogenized for analysis. Lipids were extracted and converted to fatty acid methyl esters (FAMEs) following a standard methylation protocol. The FAMEs were then analyzed using gas chromatography (GC) to determine the relative composition of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA), including key omega-3 fatty acids such as EPA and DHA (Ianni et al. 2020).

RESULTS & DISCUSSIONS

Feed nutrient composition

The addition of fish oil to feed will increase the ether extract (EE) content and can calculatedly reduce the percentage of CP and ash. The ingredients for quail feed generally consist of 70% energy sources and 25% protein sources. Supplementation of oil in poultry feed is an easy way to meet the energy and essential fatty acid needs of livestock (Stevanovic et al. 2018). The feed given to quail have a different nutrient composition from commercial feed. Based on the results of the formulated feed, data on the nutrient composition of quail feed was showed in Table 1.

According to SNI 3907:2023 regarding egg-laying quail feed, egg-laying quail feed must have a maximum standard moisture content is 34%, maximum ash is 14%, minimum ether extract 3%, minimum crude protein 17%, and maximum crude fiber is 7%. Adding fish oil to feed will increase the ether extract (EE) content. The fat content in feed T1, T2, and T3 is higher than feed T0, the percentage increase is up to 85.53%. Oil is a source of energy and contains essential fatty acids needed by the body. The addition of *S. lemuru* fish oil to quail feed have a role in reducing the cholesterol content of quail eggs. According to Suripta and Astuti (2007) giving 8% *S. lemuru* fish oil can reduce cholesterol to 54.82 mg/100 g.

The protein content in T3 feed, giving 6% fish oil, is lower than other feeds, but still in accordance with SNI standards. The quality of protein in feed needs to be considered because the need for amino acids, especially essential amino acids, must be available, because essential amino acids cannot be synthesized in the body. Deficiency of an amino acid will affect growth or decrease production (Lokapirnasari, 2017). The crude fiber content in the feed is also normal, because it is less than 7% beside on SNI 3907:2023 quail egg-laying feed quality and safety requirements.

Quail production performance

The addition of *S. lemuru* fish oil at the 6% level (T3) was significantly different to the feed consumption value (g/head/day). Differences in feed consumption can be caused by animal age, environmental temperature, animal health, cage type, feed container, feed nutritional content, stress, and feed size (Uzer et al. 2013). Apart from that, feed consumption in poultry is also affected by the shape, taste, texture, smell and temperature of the food that is felt after the food enters the mouth (Aviati et al. 2014). The effect of consuming little feed will have an impact on the availability of nutrients entering the livestock's body (Suryadi et al. 2018) which will affect the productivity of quail. The results of this study were different from the results of ration consumption using the fish oil microcapsule (MMI) method which was no significantly different at the 6% level. This can be caused by the form or purity of the fish oil given and mixed into quail feed. Fish oil given in pure form has a strong odor and can make the feed rancid more quickly, which can affect the level of preference of livestock for consuming the feed. Fish oil has a fishy odor (fish flavor) due to the formation of trimethyl amine from lecithin (Serfert et al. 2010), the accumulation of trimethyl amine in the body can cause an unpleasant aroma. Meanwhile, MMI is carried out by trapping fish oil with meat meal and coconut cake as a coating material and then drying with a spray dryer (Sestilawarti et al. 2013).

Generally, fish oil contains around 25% saturated fatty acids and 75% unsaturated fatty acids (Pandiangan et al. 2018). Omega-3 fatty acids are often found in sea fish, such as lemuru, herring, mackerel, salmon, tuna and anchovies. *S. lemuru* fish oil is rich in EPA, the amount of which can reach 7.1g/100g. *Sardinella longiceps* is a large by-product of the lemuru canning industry and its utilization is not yet optimal and has the potential to be a source of omega-3 fatty acids (Sari et al. 2015). Fish oil contains quite high energy, so quail's energy needs are met more quickly. This results in quail tending to reduce consumption if the body has sufficient energy from the feed consumed (Aviati et al. 2014). Feeding quail indefinitely (ad libitum) will cause excessive feed consumption, and result in excess energy which will be converted into fat deposits in the body. Feed restriction schedules are one of the main practices in growth arch management to intensify production effectiveness in fattening poultry species (Mahrose et al. 2020). Quail food consumption is 23.32 grams/head/day (Fransela et al. 2017).

Table 2. Quail production performance

Variabel	Treatment			
	T0	T1	T2	T3
Feed consumption (g/head/day)	25±0.00a	25±0.00a	25±0.00a	24.47±1.71b
Number of eggs (egg/day)	43.69±3.42a	44.31±4.97a	44.31±2.84a	42.66±3.94a
Egg production (%)	87.38±6.73a	88.63±9.79a	88.63±5.60a	85.31±7.76a
Egg mass (g egg/head)	427.91±68.60ab	442.69±92.50a	435.84±56.83a	394.77±78.39b
Total egg weight (g/day)	487.18±50.54a	494.62±50.74a	490.02±39.23a	458.73±52.68b
Egg weight (g/head/day)	11.16±0.89a	11.19±0.61a	11.06±0.62ab	10.75±0.65b
Feed conversion	3.01±0.55a	2.95±0.63a	2.92±0.38a	3.22±0.70a

Note. Numbers followed by the same superscript letters indicate based on Duncan's Multiple Range Test (DMRT) at α 5%. T0 (control): addition of 0% *S. lemuru* fish oil in complete feed, T1: addition of 2% *S. lemuru* fish oil in complete feed, T2: addition of 4% *S. lemuru* fish oil in complete feed, T3: addition of 6% *S. lemuru* fish oil in complete feed.

The percent value of egg production is used to determine the daily egg production of a livestock group at a certain age and determine peak production (Hastuti et al. 2018). This is different from the findings of Fransela et al. (2017) which stated that the production value of quail eggs was between 60.35-61.07%, lower than the research results. But this is in line with the findings of Kaselung et al. (2014), who stated that the peak egg production of quails can reach 98.5% at the age of 4-5 months. The weight of quail eggs is around 8% of the parent's body weight (Hamanay et al. 2022). Quail egg weight showed no significant effect on the treatment of 6% addition of fish oil in the complete ration, this was due to the natural pattern of egg production, feed and rearing management. Apart from that, insufficient feed consumption will affect the nutrients in the feed, such as the adequacy of protein and amino linoleic acid which also affects the weight of the eggs produced. The addition of *S. lemuru* fish oil in the complete ration does not increase the protein in the ration so that the weight of the eggs does not increase (Febrianto et al. 2015).

The treatment given in the study had a significant effect on egg mass. The lowest egg mass in the study was with T3 treatment. Egg mass is obtained from multiplying egg weight by hen-day production (HDP). The low egg mass value was due to the T3 egg weight being lower than other treatments. Egg weight is the accumulation of the weight of the shell, egg white and egg yolk. The treatment showed a significant difference in total egg weight. Giving *S. lemuru* fish oil 6% (T3) had the smallest total egg weight of 458.73 grams/day. It is hypothesized that the inclusion of high doses of fish oil may alter the hormonal balance, potentially affecting the ovulation cycle. According to Indi (2013), the use of *S. lemuru* fish oil speeds up the ovulation cycle, so that the time needed to form an egg is faster and will result in smaller eggs. The weight of eggs in this study was significantly different. Egg weight with 6% *S. lemuru* fish oil (T3) had the lowest value of 10.75 grams/head/day. The low egg weight could be due to the lower crude protein content in the T3 treated feed. According to Lokapirnasari (2017), a deficiency in an amino acid is always followed by slow growth or a decrease in egg production, which can result in smaller egg weights or decreased productivity. Giving 6% *S. lemuru* fish oil (T3) did not have a significant effect on egg mass. This was confirmed by research by Sestilawarti (2013) which explained that giving fish oil microcapsules up to 6% did not have a significant effect on egg mass. This was due to egg production and egg weight. which is no significantly different, where egg production and egg weight will affect egg mass.

The feed conversion ratio (FCR) value is used to determine the amount of feed consumed by livestock to produce one kilogram of egg weight (Sulaiman et al. 2019). The smaller the FCR value, the less feed used, which will reduce feed costs. Apart from that, factors that influence the FCR value are feed quality, feeding techniques, amount of feed consumed and livestock body weight condition (Fauzan et al. 2018). A low ration conversion rate indicates high ration efficiency, whereas a high ration conversion rate indicates low biological benefit value (Radhitya, 2015) and the genetic ability of livestock to utilize feed (Masili et al. 2019; Dako, 2019). Feed conversion is influenced by bird species, management, disease and feed used. The addition of *S. lemuru* fish oil up to 4% and L-Carnitine 0.02% did not affect the feed conversion value of quail (Febrianto et al. 2015).

From the result of number of eggs, egg production, and egg mass the addition of 2%-4% fish oil is recommended for smallholder farmer. In that range of addition farmer will get more income. From the research of Suhirman (2018) that quail farmers and quail home industries are able to influence income by 21% in Sumodikaran Village, Dander District, Bojonegoro Regency. Turus Village people profile is a farmer with time spend in a rice field and quail farmer. Adding *S. lemuru* fish oil expected will increase the profit of the eggs sales and adding more income for the farmer. Beside that the source of *S. lemuru* fish oil will determinate the feed's price, fish oil from fisheries industry waste has great potential to be used as a more economical.

Physical egg quality

The physical qualities of quail egg data were presented in Table 3. Adding *S. lemuru* fish oil had no significant effect on the egg weight, egg length, viscosity, yolk diameter, high yolk, diameter and height of albumen. The percentage shell weight in this study ranged from 13% - 15.66% which was greater than that reported by Silva et al. (2018) that the percentage shell weight ranged from 8.67% - 9.32%. It is hoped that the thick and heavy shell will protect the egg from damage, so that the contents of the egg are maintained.

Table 3. Physical quality of quail egg

Variabel	Treatment			
	T0	T1	T2	T3
Egg weight (g)	11.27±0.12a	11.3±0.26a	11.17±0.49a	11.17±0.31a
Shell weight (g)	1.47±0.06b	1.77±0.15a	1.63±0.06ab	1.50±0.20b
Shell thickness (mm)	0.2b	0.2b	0.3a	0.3±0.1a
Egg diameter	2.33±0.02ab	2.36±0.05ab	2.42±0.09a	2.30±0.05b
Egg length	3.00±0.13a	3.12±0.01a	2.96±0.10a	3.11±0.07a
Viscosity	1.67±0.58a	1.67±0.58a	1.67±0.58a	2.33±0.58a
Yolk color	8.00b	12.33±1.15a	13.00±1.00a	13.00±1.00a
Yolk diameter	2.22±0.11a	2.27±0.11a	2.25±0.07a	2.20±0.15a
Yolk height	0.97±0.06a	0.87±0.06a	0.97±0.06a	0.93±0.06a
Albumen diameter	4.06±0.36a	4.25±0.27a	4.03±0.52a	4.68±0.15a
Albumen height	0.3a	0.33±0.06a	0.3a	0.37±0.06a

Note. Numbers followed by the same superscript letters indicate based on Duncan's Multiple Range Test (DMRT) at α 5%. T0 (control): addition of 0% *S. lemuru* fish oil in complete feed, T1: addition of 2% *S. lemuru* fish oil in complete feed, T2: addition of 4% *S. lemuru* fish oil in complete feed, T3: addition of 6% *S. lemuru* fish oil in complete feed.

The shell thickness in this study ranged from 0.2-0.4 mm. The same result was reported by Dogan et al. (2018) that a shell thickness of 0.204-0.216 mm. The thicker the eggshell is, the better the quality of the egg because evaporation can be maintained. The Ca and P contents in feed play a role in the quality of egg shells, such as shell thickness, weight and egg shell structure (Park et al. 2016). The presence of strong and high levels of ovomucin is indicated by a high albumen viscosity.

The function of ovomucin is to bind water to create an albumen gel, which makes the albumen thick and high in consistency. Long storage periods and high temperatures can cause a continual loss of CO_2, which can reduce the viscosity of albumen (Fahri et al. 2019). The albumen egg's protein structure and the flow of water from the albumen egg into the egg yolk are both altered when eggs are stored (Ronald et al. 2019).

The color of the egg yolk is significantly influenced by the composition of the constituents in the diet, as it is influenced by carotene compounds such as xanthophyll in the feed. The inclusion of *S. lemuru* fish oil in the diet can raise the egg yolk color score since it contains high levels of carotene compounds (Lestari et al. 2021). This study's egg yolk color score was greater than Febrianto et al. (2015), who found that adding *S. lemuru* fish oil and L-carnitine to a commercial diet resulted in an egg yolk color score of 6.19–7.78.

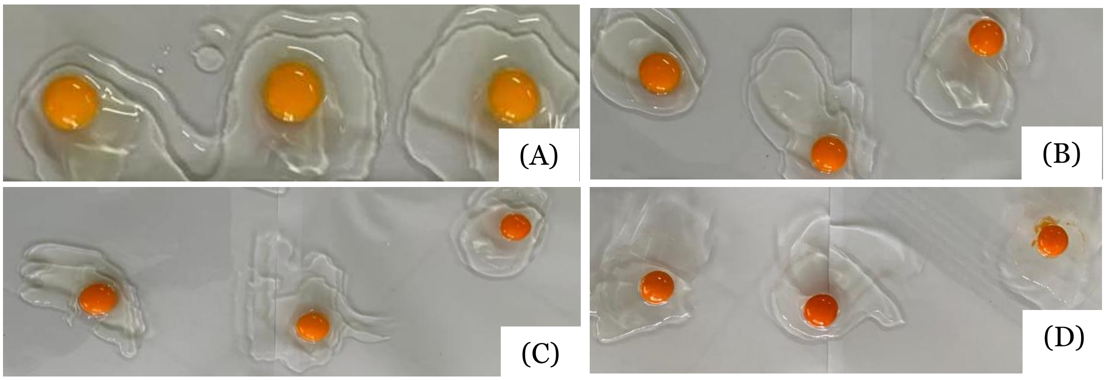

Figure 1. Egg yolk color (A) T0, (B) T1, (C) T2, (D) T3

Fatty acid profile

Monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs) are found in *S. lemuru* fish oil (Table 4). Descriptively, there was an increase in all types of fatty acids with the addition of *S. lemuru* fish oil . High levels of omega 3 fatty acids in balance with omega 6 can provide advantages to quail eggs which is produced. Use of oil in poultry rations as a source of energy and as a source of fatty acids omega-3 is widely researched to improve quality quail eggs. Fish oil contains fatty acids omega-3 is higher than vegetable oils such as sunflower oil, corn oil, soybean oil (Kamely et al. 2016).

Table 4. Fatty acid profile of quail eggs

Fatty Acid (%)	Treatment			
	T0	T1	T2	T3
Caprilyc acid C8:0	nd	nd	nd	nd
Lauric acid C12:0	2.80	2.96	3.17	3.84
Myristic acid C14:0	4.92	5.13	5.97	5.91
Palmitic acid C16:0	25.35	26.52	27.45	28.17
Stearic acid C18:0	0.87	1.13	1.40	1.77
Oleic acid C18:1n9c	40.11	40.87	41.77	41.98
Linoleic acid C18:2n6c	8.54	9.06	9.76	10.01
Linolenic acid C18:3n3	0.78	0.83	0.89	0.94
Total	83.37	86.50	90.41	92.62

Note. T0 (control): addition of 0% *S. lemuru* fish oil in complete feed, T1: addition of 2% *S. lemuru* fish oil in complete feed, T2: addition of 4% *S. lemuru* fish oil in complete feed, T3: addition of 6% *S. lemuru* fish oil in complete feed, nd: not defined.

The dominant fatty acids in quail egg yolk are oleic acid (MUFA), palmitic acid (SFA) and linoleic acid. The higher the percentage of *S. lemuru* fish oil added, the higher the linolenic acid (ω-3) produced in the egg yolk. The ratio of ω-3 and ω-6 in eggs is greatly influenced by the ratio of the two in the feed (Sumiati et al. 2016). So further research is needed regarding the ratio of *S. lemuru* fish oil to other feed ingredients so that the omega 3 and omega 6 content in egg yolks can be optimal. Considering sardine fish oil, particularly from *S. lemuru*, is often derived as a by-product of fish processing industries, its utilization in smallholder settings could represent a cost-effective strategy for feed fortification (Estiasih et al., 2017). This approach not only reduces production costs but also adds value to industrial waste, aligning with circular economy principles. Moreover, the incorporation of sardine fish oil has been shown to improve the nutritional profile of feed, which can enhance animal growth performance and reduce feed conversion ratio (FCR) (Suseno et al., 2015). A lower FCR indicates that less feed is required to produce a unit of body weight gain, translating into significant feed cost savings for smallholder farmers, who typically operate under tight economic constraints. Furthermore, issues such as strong odor and oxidative stability have been addressed through advancements in oil purification and encapsulation technologies, making daily application of sardine fish oil more feasible and acceptable in practical farming conditions. Given the local abundance of *S. lemuru* in regions such as Southeast Asia, especially Indonesia, the adoption of this by-product offers both economic and environmental advantages for small-scale livestock systems.

CONCLUSIONS

This study demonstrated that dietary supplementation of *S. lemuru* fish oil at different inclusion levels affected the production performance, physical quality, and fatty acid profile of eggs in laying quails raised under smallholder farming conditions. The 2% *S. lemuru* fish oil inclusion (T1) produced the most favorable outcomes, including optimal crude protein intake, stable egg mass, and enhanced omega-3 content in the yolk, without significantly compromising feed conversion efficiency. Higher supplementation levels (particularly 6%) increased omega-3 deposition but resulted in a notable decline in egg production, likely due to reduced palatability or metabolic stress. These findings suggest that moderate inclusion of *S. lemuru* fish oil (2%) in the diet is a viable and practical strategy to improve egg nutritional value in smallholder quail farms. However, this study was limited by the relatively short duration of the feeding trial and the lack of individual bird-level data, which may affect the generalizability of the results. Further research is needed to evaluate the economic feasibility, long-term effects, and implementation challenges of this supplementation strategy under diverse environmental and management conditions.

ETHICAL STATEMENT

The study was conducted in compliance with local ethical standards for animal welfare. Since the experiment involved only feed supplementation and did not include invasive procedures, formal ethical approval was not required.

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