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Evaluation of Extruded Feed in Laying Hens: A Meta-analysis on Performance and Egg Quality

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ABSTRACT

The present study was designed to assess the impact of extruded feed on laying hens using a meta-analysis approach. The database was established based on 18 articles divided into processed and supplemented extruded feed ingredients. The information was analyzed using OpenMEE software, considering the specific studies as random and extruded feed as fixed effects. The results presented no statistically significant variance in the effects of extruded feed on hen-day production, but there was a significant variance in feed conversion ratio (FCR) and feed intake (P<0.05). Regarding egg quality, there were no alterations in albumin weight, Haugh units, or yolk weight between the processed and unprocessed feed ingredients. Egg weight and albumin height (P<0.05) increased significantly with processed extruded feed ingredients. In terms of comparison of supplementation with extruded feed, the performance of laying hens was not significantly higher with supplementation than without supplementation of extruded feed. The egg quality and egg weights of laying hens fed with the supplemented diets were significantly lower than those of hens fed with the diets without supplementation (P<0.05). There was no statistically significant variance in the effects of supplementation with extruded feed on albumen weight, Haugh unit, and yolk weight. In conclusion, the effects of processing extruded feed and supplemented extruded feed ingredients differ in performance and egg quality.

Key words: Poultry, Supplements, Extruded feed, Performance, Egg and meat quality.

INTRODUCTION

Hens are a crucial livestock commodity that meet human protein needs by producing nutritionally valuable products. The rearing of hens is widely practiced across small, medium-, and large-scale enterprises. Furthermore, technological advancements in laying hen farming have progressed more significantly than those in other livestock sectors (Olejnik et al. 2022). However, despite these advancements, several challenges and constraints persist, particularly with regard to feeding (Sumiati et al. 2025). Feed is the primary determinant of the quality and quantity of egg production. The productivity of laying hens is influenced by their egg physical appearance, composition, and overall performance (Huang et al. 2020). One of the key challenges in laying hen nutrition is the presence of anti-nutrients in feed ingredients, which necessitates the use of processing techniques to reduce or eliminate these compounds and optimize feed utilization (Sepehr et al. 2021).

Extrusion is a processing method that effectively mitigates the adverse effects of anti-nutrients (Clarke and Wiseman 2007). Extrusion, or short high-temperature treatment, is a feed-processing method that involves subjecting ingredients to high temperatures for a brief duration. This technique is considered effective for reducing the anti-nutrients in the feed. The principle of extrusion involves cooking feed ingredients under controlled temperatures and shear forces (Hejdysz et al. 2022).

The primary objective of extrusion is to modify the composition and bioavailability of nutrients by promoting starch gelatinization and inactivating antinutritional factors, including hemagglutinins, trypsin inhibitors,

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phytates, and tannins, all of which impair protein digestibility (Singh et al. 2007). As extrusion effectively eliminates these antinutrients, it enhances nutrient digestibility and improves poultry performance (Abd El-Khalek and Janssens 2010). However, a potential drawback of extrusion is the degradation of heat-sensitive vitamins and minerals. Extrusion processing significantly affects the stability of vitamins in extruded feed, as high barrel temperatures and low moisture conditions promote ascorbic acid degradation (Alam et al. 2016).

Despite these challenges, extruded feed has demonstrated various beneficial effects on performance and egg quality. Several studies have examined the effect of extruded feed on laying hens, but the findings have been inconsistent (Šašyte et al. 2016; Huang et al. 2018; Sepehr et al. 2021). Therefore, a meta-analysis is required to synthesize and scientifically evaluate the findings of these studies. Meta-analysis is a rigorous quantitative approach that consolidates previous research findings to provide a comprehensive assessment (Sauvant et al. 2008). Therefore, the current study aimed to conduct a meta-analysis on the use of extruded feed as a dietary supplement to enhance egg quality and performance in hens.

MATERIALS AND METHODS

Literature search and selection criteria

A database was established from several studies that reported the use of extruded feed as a supplement in a laying diet. The literature search was directed using Scopus, and the keywords used were “extrusion” or “extruded”, “feed”, and “laying hen”. The preliminary search resulted in 75 articles with the following selection criteria: (a) the article was in English, (b) direct comparison before and after extruded feeds, (c) studies conducted on laying diet, (d) comparison of the performance and egg quality of laying chickens, and (e) replication and variance represented by standard error of the mean (SEM) or standard deviation (SD). These criteria were tracked using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) procedures.

The assortment method is shown in Fig. 1. Briefly, the early search was checked according to the title and article type. Forty papers were excluded based on their titles and types. During the abstract screening, 17 papers were excluded for multiple reasons (irrelevant variables, unusable data, and inadequate data). The final manuscripts (n=18) were measured in databases for the post-evaluation meta-analysis (Table 1). These studies were divided into two categories. The first was an evaluation between the extruded and unextruded feed ingredients. The second group was a comparison experiment conducted before and after supplementation with the extruded feed ingredients.

Failsafe numbers (Nfs) detect publication bias instigated by unimportant studies that were not involved in the analysis. An Nfs>5N+10 is considered to be an indication of a robust meta-analytic model. The Nfs were determined using the Rosenthal (1979) approach. N is the smallest sample size from a single study.

Database development

The bibliography, type of ingredients, level of extrudate ingredients, basal diet, type of extruder, and raw ingredients were entered into a Microsoft Excel spreadsheet. The response variables in the database included laying performance, including feed intake, feed conversion (FCR), hen-day production, and egg quality parameters, including egg weight, albumen height, albumen weight, and yolk weight. All variables were converted into the same measurement units.

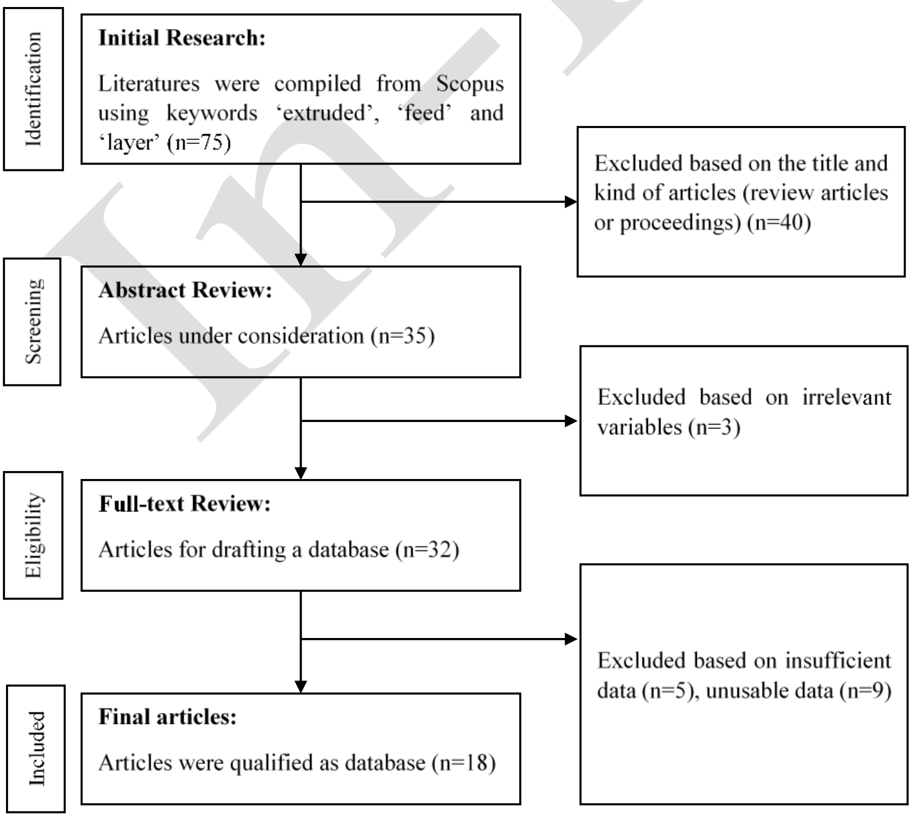

Fig. 1: Diagram flow for process selection in meta-analysis study.

Table 1: Studies selected to be included in the meta-analysis.

No.	References	Treatment comparison Type	Type of Laying hen	Age (Weeks)	Feeding during experimental period (weeks)	the Level of extrudate ingredients (%)	Feed ingredients
1.	(Lichovnikova et al. 2004)	Processed Vs Unprocessed extruded feed	Isa Brown Hen	21-41	9	13.5	Rapeseed
2.	(Nain et al. 2012)	Supplemented extruded feed	Lohmann	65	1, 2, 3	7, 10	flaxseed
3.	(Kakani et al. 2012)	Supplemented extruded feed	Lohmann	25	3	5, 10	Camelina
4.	(Popiela et al. 2013)	Supplemented extruded feed	Lohmann	24	10	5, 10	amaranth
5.	(Mahmud et al. 2015)	processed vs unprocessed extrusion	White leghorn	21	15	4, 8,12	Hatchery waste meal
6.	(Dalle Zotte et al. 2015)	processed vs unprocessed extrusion	Warren	24	9	10	Linseed
7.	(Baeza et al. 2015)	Supplemented extruded feed	NA	21	12	3.8, 4.7	Linseed
8.	(Imran et al. 2015)	Supplemented extruded feed	Babcock	24	8	10, 20, 30	flaxseed
9.	(Carrasco et al. 2016)	Supplemented extruded feed	Lohmann	18	NA	6.66	Alfalfa silage
10.	(Mattioli et al. 2017)		Hy-line	50	23	10	Flaxseed
11.	(Wüstholz et al. 2017)	processed vs unprocessed extrusion	Lohmann	18	20, 30	20	Alfalfa silage
12.	(Huang et al. 2018)	Supplemented extruded feed	White leghorn	58	8	7.5,15, 22.5	Flaxseed
13.	(Huang et al. 2020)	Supplemented extruded feed	White leghorn	58	8	3, 6, 9	flaxseed
14.	(Oryschak et al. 2020)	processed vs unprocessed extrusion	Brown nick	23	36	20	Brassica co-product
15.	(Corrales-Retana et al. 2021)	Supplemented extruded feed	White leghorn	65	24	0.05	linseed
16.	(Shahid et al. 2020)	processed vs unprocessed extrusion	Hy-line Brown	38	2, 4, 6, 8, 10,12	10	Flaxseed
17.	(Sepehr et al. 2021)	processed vs unprocessed extrusion	Hy-Line	75	9	3, 6, 9	Flaxseed
18.	(Maharjan et al. 2023)	processed vs unprocessed extrusion	White shavers	36	12	21.4	Soybean meal

Statistical analysis

A random-effects meta-analysis was used to examine all data. Hedges' standardized mean difference served as the basis for the computation, where the mean value of feeds before extrusion as a feed supplement was clustered into the control group (X^C), and the mean value of feeds after extrusion as a feed supplement was the mean value of the experimental group (X^E). The computation is as follows:

$$d = \frac{(\dot{x}^E - \dot{x}^C)}{S} J$$

J is the alteration factor for small sample size, while S is the shared standard deviation, defined as

$$J = 1 - \frac{3}{(4(N^C + N^E - 2) - 1)}$$

$$S = \sqrt{\frac{(N^E - 1)(s^E)^2 + (N^C - 1)((s^C)^2)}{(N^E + N^C - 2)}}$$

Where N^E represents the experimental set's sample size, N^C represents the control set's sample size, S^E represents the experimental set's standard deviation, and S^C represents the control set's standard deviation. The definition of hedged (V_d) variance is

$$V_d = \frac{(N^C + N^E)}{(N^C N^E)} + \frac{d^2}{(2(N^C + N^E))}$$

The collective effect size (d++) is expressed as

$$d_{++} = \frac{(\sum_{i=1}^{n} W_i d_1)}{(\sum_{i=1}^{n} W_i)}$$

Where Wi is the inverse of the sampling variance (Wi = 1/vd). The 95% CI or d ± (1.96×SD) was used to calculate the accuracy of the effect magnitude. Using a 95% CI, this equation was derived by Sánchez-Meca and Marín-Martínez (2010). The smallest sample size from individual investigations was determined using Cohen's benchmarks, which act as the legal judgment bound to establish the sample size. The benchmarks were 0.8 for significant effect sizes, 0.5 for medium, and 0.2 for small effect sizes, respectively. OpenMEE software was used to examine the data.

In a meta-analysis, heterogeneity denotes to the variation in outcomes between studies. This meta-analysis used the Q statistic test, τ^2, and I^2 to observe heterogeneity. The Q-statistic is the weighted sum of the squared values of each study's effect size deviation from the mean effect size of entirely studies. The approximation of the population variable tau (τ) is the standard deviation of the overall effect size, and τ^2 characterizes the variance of the overall effect size. I^2 measures the proportion of unexplained heterogeneity. To evaluate the connections between the response parameters and inclusion levels, meta-regression was also used. The following model was used to fit the meta-regression, which was created on linear models (LM):

$$\Delta Y_{ij} = \beta_0 + S_i + \beta_1 X_{ij} + \varepsilon_{ij}$$

where Xij is the continuous predictor variable matrix, ΔYij is the dependent variable's predicted outcome, β0 is the estimated intercept (fixed effect) and β1 is the continuous predictor's coefficient of linear regression (fixed effect). S_i is the random effect of the experiment, and ε_i is the residual error (St-Pierre, 2001). The data were analyzed using the OpenMEE application software (Wallace et al. 2017).

RESULTS

Profile of the selected studies

Small sample sizes and conflicting study findings may make certain meta-analysis results questionable due to publication bias. The fail-safe number (Nfs) indicates which research should be included in the conclusions. Fig. 1 shows that to make the early effect size a negligible variable, the sample research size must be increased. If Nfs > 5N + 10, where N is the study effect size used to derive the starting effect size, the result can be reflected in the final robust deduction (Rosenthal 1979). For the extruded processed experimental category, the Nfs results indicated that hen day production, FCR, and feed intake were not resilient parameters. Egg quality, egg weight, and albumin height were robust parameters, whereas the Haugh unit, albumin weight, and yolk weight were non-robust parameters. In the extruded feed supplementation category, the performance of laying hen parameters, including hen-day production, FCR, and feed intake, was robust. Meanwhile, egg quality, including the Haugh unit, albumin weight, and yolk weight, was not robust. Egg weight was used as a robust parameter in this study.

Based on Cohen's benchmarks for the processed extrusion experiment, the effect sizes of albumin weight and Haugh units were considered small. Hen-day production, FCR, feed intake, albumin height, and yolk weight were categorized as medium effects, and egg weight as a large effect. For the extruded supplementation experiment, the Haugh unit, albumin weight, and yolk weight were categorized as having a small effect size, whereas FCR, feed intake, and egg weight had a medium effect size. Hen-day production had a large effect size.

Statistical analysis and heterogeneity test

The data from the research manuscript were substantial heterogeneous (I2 > 50%); high heterogeneity was due to variances in the type of laying hen, age of chicken, duration of feeding, level of extruded ingredient, and feed ingredient processed or supplemented with extruded feed. Therefore, using a random effects model, we aggregated the effect values. Data on eight parameters pertaining to the effect of extruded feed on egg quality and performance were extracted.

A meta-analysis of the performance of laying hens on processed extruded feeds revealed that there was no statistically significant difference in the effects of extruded feed on hen-day production (P>0.05, I^2=81.25%), but there was a significant variance in feed intake (P<0.05, I^2=58.98%) and FCR (P<0.05, I^2=49.89%). Regarding egg quality, there was no difference in albumin weight (P>0.05, I^2=44.28%), Haugh unit (P>0.05, I^2=91.36%), or yolk weight (P>0.05, I^2=67.32%) between processed and unprocessed feed ingredients. Egg weight (P<0.05, I^2= 93.52%) and albumin height (P<0.05, I^2 = 90.36%) significantly increased in the processed extruded feed ingredients. Based on the heterogeneity Q statistic test, τ^2 and I^2 showed that hen-day production, egg weight, and albumin height were categorized as having high heterogeneity, whereas the others had low heterogeneity. In terms of comparisons between supplementation with extruded feed, the performance of laying hens was not significantly higher with supplementation than without supplementation with extruded feed. There was no significant variance in hen-day production (P>0.05, I^2= 94.68%) or feed intake (P>0.05, I^2 = 90.37%). In addition, the FCR with retention of extruded feed was not significantly decreased compared to that without supplementation (P>0.01, I^2= 83.96%). The egg quality of laying hens fed the extruded feed was significantly lower than that of laying hens without supplementation (P<0.01, I^2= 0%). There were no statistically significant differences in the effects of extruded feed supplementation on albumen weight (P>0.01, I^2=0%), Haugh unit (P>0.01, I^2=0%), or yolk weight (P>0.01, I^2=0%). Based on the heterogeneity Q statistics test, τ^2 and I^2 showed that hen-day production, feed intake, and FCR were categorized as having high heterogeneity, whereas others had low heterogeneity. Table 2 displays the comprehensive meta-analysis results of the effects of processed and extruded feed supplementation on laying hen performance and egg quality.

Table 2: Meta-analysis of the effects of extruded process and supplementation on laying hen performance and egg quality.

	Doc	NC	Estimate	Lower Bound	Upper Bound	Std error	p-value	τ^2	Q	Het.p-value	I^2
Processed Extruded											
Hen Day Production	5	18	-0.241	-0.666	0.184	0.217	0.267	0.674	90.684	<0.001	81.254
Feed Intake	6	19	0.229	0.033	0.424	0.100	0.022	0.100	43.883	<0.001	58.982
Feed Conversion	5	19	-0.219	-0.436	-0.001	0.111	0.048	0.112	35.926	0.007	49.897
Egg Weight	8	27	0.890	0.437	1.343	0.231	<0.001	1.292	401.356	<0.001	93.522
Albumen Height	4	17	0.589	0.012	1.166	0.294	0.045	1.296	166.027	<0.001	90.364
Albumen Weight	3	8	-0.073	-0.448	0.301	0.191	0.701	0.125	12.564	0.082	44.284
Haugh Unit	6	22	0.174	-0.351	0.698	0.268	0.516	1.406	243.291	<0.001	91.368
Yolk Weight	4	15	0.206	-0.062	0.475	0.137	0.132	0.172	42.850	<0.001	67.328
Supplemented Extruded											
Feed Intake	8	21	0.307	-0.112	0.727	0.214	0.151	0.850	207.678	<0.001	90.370
Feed Conversion	5	10	-0.534	-1.080	0.012	0.278	0.055	0.648	56.068	<0.001	83.948
Hen Day Production	6	13	0.680	-0.106	1.465	0.401	0.090	1.969	225.685	<0.001	94.683
Egg Weight	8	21	-0.264	-0.366	-0.138	0.065	<0.001	0.000	19.891	0.463	0
Albumen Weight	3	6	-0.075	-0.335	0.185	0.133	0.571	0.000	0.528	0.991	0
Haugh unit	4	5	-0.034	-0.200	0.268	0.120	0.777	0.000	0.291	0.990	0
Yolk Weight	6	16	0.134	-0.020	0.287	0.078	0.088	0.000	11.202	0.738	0

Note: Doc= document, N= number of data, Std error= standard error, τ2= variance of the effect size parameters across the population of studies; Q= weighted sum of squared deviations; Het p-value = p-value for heterogeneity; I^2= heterogeneity level between studies.

Sub-group and meta-regression analysis

Analysis of meta-regression showed that hen day production and feed intake parameters produced a curve with a P-value <0.05 and a positive slope value. This indicates that the higher the level of inclusion of extruded feed, the higher the hen day production and feed intake. A positive correlation was observed between extruded feed supplementation and hen-day production (Y=-1.43+0.231x) and feed intake (Y=-0.581+0.104x). In terms of egg quality, increasing the level of extruded feed had no effect on egg quality. Table 3 describes the detailed meta-regression results.

The outcomes of the subgroup analysis are presented in Fig. 2 and 3. This FCR parameter reflects the efficiency of feed use, which ultimately has an impact on economic value. Hen-day production is an important index for layer farms, measuring the number of eggs produced per hen per day, which is a good indicator of overall productivity. The subgroup analysis findings based on breed strain revealed that the use of extruded feed in the brown strain contributed to (P<0.05) reducing the FCR, and there was no difference between the white and brown strains in terms of hen day production.

DISCUSSION

Performance of laying hens in the extruded feed process

Comparing the properties of extruded and unextruded ingredients on the performance of laying hens is essential, given that extrusion requires a higher energy input and cost. Therefore, it is crucial to determine whether extrusion significantly enhances the performance of laying hens. Parameters such as feed intake, FCR and hen-day production showed varying results. Sepehr et al. (2021) reported that extruded feed increased feed intake, whereas Maharjan et al. (2023) reported a lower feed intake than unprocessed feed. Sepehr et al. (2021) demonstrated that extrusion reduced feed conversion, whereas Mahmud et al. (2015) reported no improvement in FCR. These discrepancies may be attributed to variations in extrusion parameters such as pressure, temperature, and exposure time which impacted to nutrional value (Goodarzi Boroojeni et al. 2016; Hejdysz et al. 2022).

Table 3: Meta-regression of the effect of extruded feed supplementation on laying hen performance and egg quality

Response variable	N	Model	Parameter estimates				Model statistics		
			Intercept	SE Intercept	Slope	SE Slope	p-value	I^2 (%)	R^2 (%)
Performance of laying hen									
Feed Intake	21	L	-0.581	0.559	0.104	0.045	0.020	95.11	15.39
Feed Conversion	10	L	-1.053	0.592	0.054	0.055	0.327	86.51	10.23
Hen Day Production	13	L	-1.453	1.018	0.231	0.075	0.003	97.19	44.61
Egg Quality									
Egg Weight	21	L	-0.397	0.150	0.013	0.013	0.522	7.43	4.8
Albumen Weight	6	L	-0.215	0.383	0.019	0.050	0.695	0.05	30.07
Haugh unit	5	L	0.142	0.304	-0.019	0.047	0.652	0.05	64.71
Yolk Weight	16	L	0.038	0.185	0.012	0.016	0.613	0.05	5.18

Note: N= number of data, L= Linear Model, R^2= Coefficient of determination

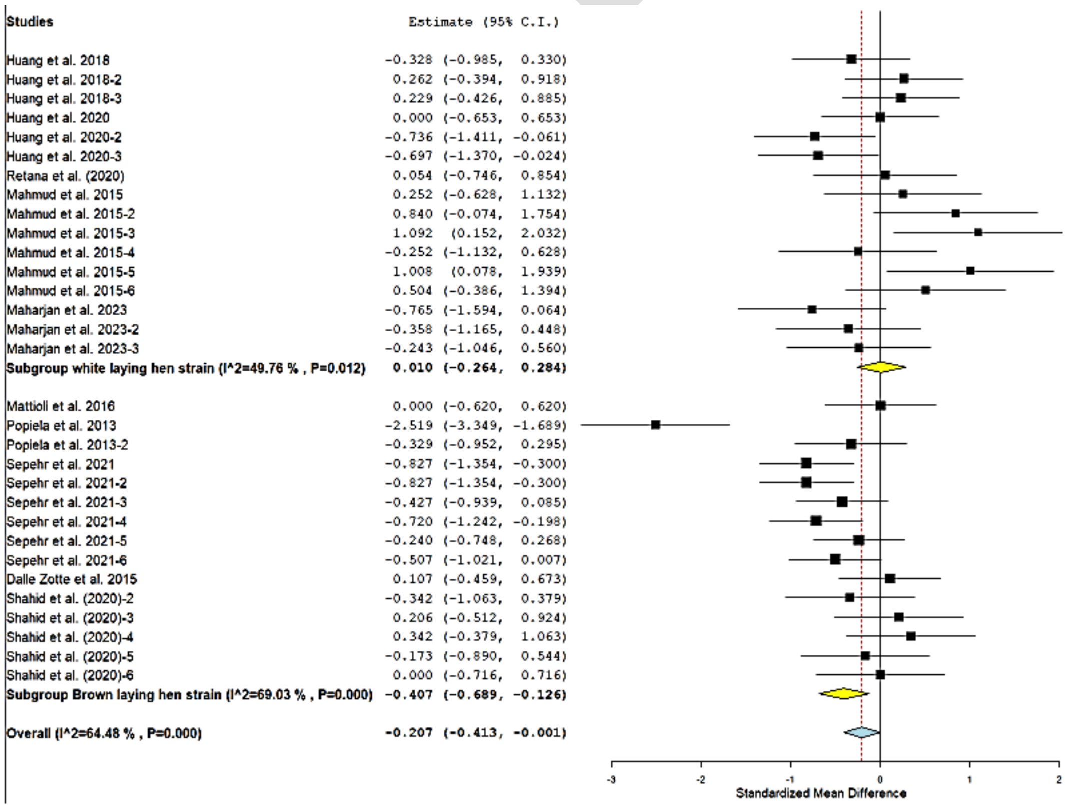

Fig. 2: Subgroup strain result of extruded feed on FCR of laying hen.

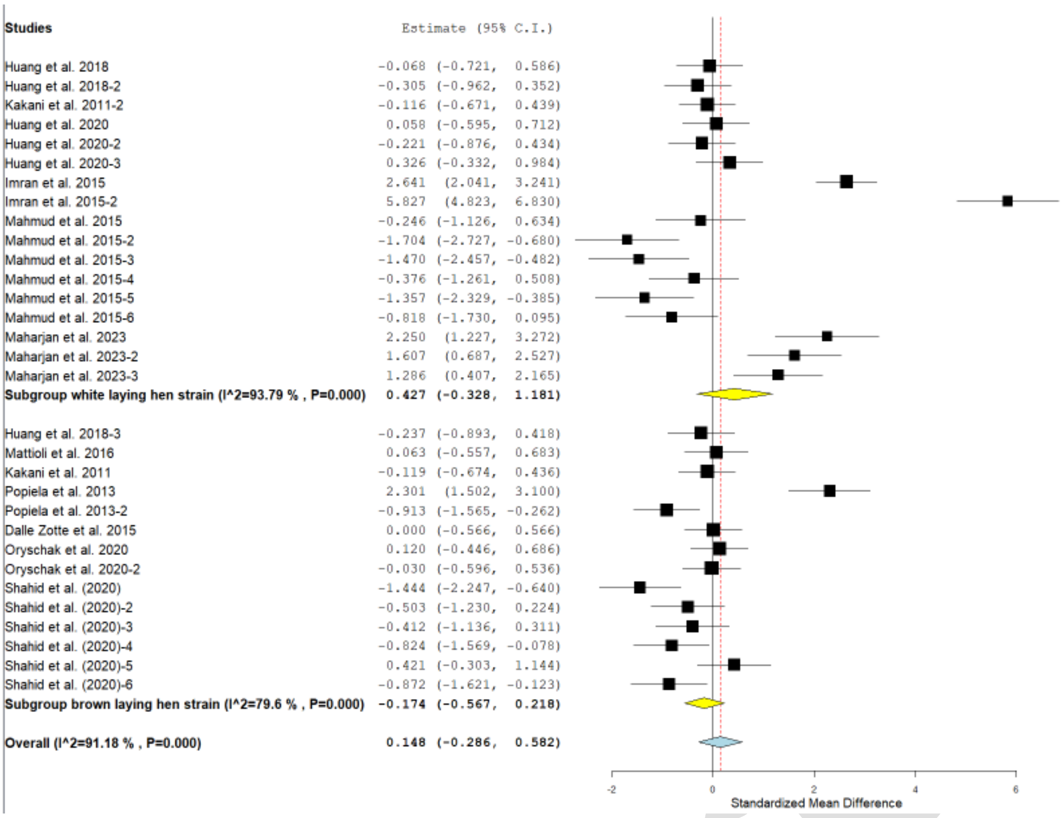

Fig. 3: Subgroup strain result of extruded feed on laying hen day production.

Constructed on the results of the meta-analysis, extruded feed significantly increased feed intake and decreased FCR. However, hen-day production declined, with no statistically significant variance between extruded and unextruded feeds. Although feed intake exhibited a slight increase, the substantial improvement in egg weight contributed to enhanced feed efficiency. The observed increase in feed intake may be linked to improved palatability, because extruded ingredients exhibit favorable functional properties, including water absorption, water solubility, oil absorption indices, expansion index, bulk density, and viscosity (Alam et al. 2016). This improvement in FCR may be attributed to the enhanced nutrient digestibility and apparent metabolizable energy (AMEn) values after extrusion. This enhancement is likely due to the breakdown of neutral detergent fiber (NDF), acid detergent fiber (ADF), resistant starch, and phytic phosphorus (Goodarzi Boroojeni et al. 2016). Furthermore, Lichovnikova et al. (2004) reported that extrusion positively affected the coefficient of total tract apparent digestibility (CTTAD) of fat, nitrogen retention, and essential amino acid digestibility but not lysine and histidine digestibility. However, the decrease in the CTTAD of these amino acids was not statistically significant in laying hens.

Egg quality of laying hens in the extruded feed process

Meta-analysis revealed that feeding extruded feed to laying hens significantly improved egg weight and albumen height. Although Haugh units and yolk weight were also enhanced, the differences were not statistically significant compared to the control (unextruded feed). However, albumen weight remained unaffected by the extrusion process. These findings align with those of Sepehr et al. (2021), who reported that feeding extruded flaxseed meal to laying hens enhanced shell strength, Haugh units, yolk weight, egg production, and egg mass compared to unextruded feed treatments. This improvement may be attributed to the regulation of hormone metabolism by dietary phytoestrogens, particularly estrogens (Novak and Scheideler 2001; Huang et al. 2018). Phytoestrogens in diets improved laying performance, egg quality and the antioxidative status (Saleh et al. 2019)

It may be concluded that the extrusion method improves the accessibility and bioavailability of phytoestrogens, including lignans and isoflavones, in the digestive systems of laying hens, which eventually results in higher-quality eggs (Huang et al. 2018). Estrogens and lignans are structurally identical phytoestrogens. Therefore, compared to the control, extruded feed probably increases the rate of absorption of polyunsaturated fatty acids (PUFAs), especially n-3 PUFAs (Dalle Zotte et al. 2015). Additionally, the findings showed that extruded feed had a beneficial effect on yolk weight, which increased egg weight.

Performance of laying hens with extruded feed supplementation

The meta-analysis suggested that extruded feed supplementation led to enhanced FCR, increased feed intake, and improved hen-day production. However, the difference between the supplemented and control groups was not statistically significant. Šašyte et al. (2016) reported that supplementing diets with 4.5% extruded full-fat rapeseed derived from double-zero cultivars improves laying intensity, egg production, and feed FCR. Conversely, Nain et al. (2012) found that dietary inclusion of up to 15% extruded flaxseed did not negatively affect laying hen performance. Similarly, Huang et al. (2020)

observed that dietary extruded flaxseed supplementation had no significant effect on daily egg production or FCR. Additionally, Lichovnikova et al. (2004) found that replacing soybean meal with up to 13.5% extruded rapeseed had no impact on laying performance.

The lack of a consistent effect on laying performance may be attributed to variations in Apparent Total Tract Nutrient Retention (ATTNR). Huang et al. (2020) suggested that although ATTNR was negatively impacted, this did not translate into adverse effects on laying performance. It is possible that the extrusion process, which involves high pressure and heat, effectively eliminates the heat-labile antinutritional factors present in flaxseeds. This finding aligns with Huang et al. (2018), who reported that feeding extruded flaxseed reduced the ATTNR of dry matter (DM), organic matter (OM), and gross energy (GE) at inclusion levels of 15% and 22.5%. Furthermore, the ATTNR of crude protein (CP) and AMEn was reduced at 22.5% extrusion levels, but no significant effect was observed on hen-day production or FCR.

Egg quality in laying hens with extruded feed supplementation

The meta-analysis revealed that the comparison of extruded feed supplementation with no supplementation significantly reduced egg weight but had no significant impact on albumen weight, Haugh units, or yolk weight. Previous studies have reported conflicting results regarding the effects of extruded feed on egg quality. Šašyte et al. (2016) found that supplementing diets with 4.5% extruded full-fat rapeseed improved the Haugh unit values and yolk colour intensity in eggs. In contrast, Huang et al. (2020) reported that egg weight and composition were unaffected by dietary treatment and feeding duration. Similarly, Nain et al. (2012) observed no effect of an extruded linseed diet on egg and yolk weights.

Egg weight was influenced by yolk weight, albumen weight, and shell thickness. The shell thickness and egg quality of laying hens typically decreases with age, especially during the late laying cycle. Egg weight increases, whereas the percentage of eggshell decreases with the age of hens (Park and Sohn 2018). A reduction in shell thickness necessitates dietary supplementation with vitamins and minerals. Vitamin and mineral deficiencies may arise because of an unbalanced diet or nutrient loss during processing. The heat involved in extrusion can degrade certain vitamins and minerals, leading to potential deficiencies (Brennan et al. 2011). In contrast, Imran et al. (2015) stated that extruded flaxseed rises protein-amino acid bioavailability by reducing anti-nutritional compounds, which may consequence in the production of weighty eggs. Changes in the nutritional component may significantly influence egg weight.

Meta-regression and subgroup analysis

Meta-regression results showed that a higher inclusion level of extruded feed increased hen day production and feed intake of laying hens. Šašyte et al. (2016) also compared the inclusion levels of 3.5% and 4.5% of extruded rapeseed on laying hens, hen day production at 4.5 % was higher than that at 3.5% during 27 until 34 weeks of laying hen ages. The increase in performance along with the increase in the percentage of inclusion can be attributed to the fact that extruded feed materials are easier to digest and have a high metabolizable energy value. According to Risyahadi et al. (2023), extruded feed has higher digestibility of dry matter, crude protein, and crude fat than unextruded feed. Furthermore, compared to the un-extruded feeds, the extruded feed ingredients exhibited better amino acids digestibility including Phenylalanine, Threonine, Tryptophan, Tyrosine, Alanine, Leucine, Methionine and Valine.

Meanwhile, meta-regression revealed that inclusion level had no effect on any of the egg quality parameters. Šašyte et al. (2016) also supported this result, as the inclusion of full-fat extruded rapeseed had no effect on the egg, albumen, and yolk weights. This result for yolk parameters may be due to the total lipid and cholesterol content. Imran et al. (2015) reported that the amount of total lipid and cholesterol in the hens' egg yolks did not significantly change as a result of any of the experimental diets.

Subgroup data are presented in Fig. 2 and 3, based on laying hen strain in the FCR and hen day production parameter, which is the main parameter for identifying the effect of extruded feed on production performance. Subgroup analysis based on breed strain revealed that the use of extruded feed in the brown strain contributed to reducing the FCR, and there was no difference between the white and brown strains in terms of hen-day production. The reduced FCR in brown hens may be due to their higher energy intake than that of white hens throughout the laying period (Özentürk & Yildiz 2021). Compared to eggs from white hens, those from brown hens have a lower pH and comparatively more albumen (Eck et al. 2023).

Conclusion

The meta-analysis indicated that processing raw feed ingredients by extrusion had a positive impact on laying performance, as indicated by a significant reduction in FCR, although there was no difference in the effects on hen-day production. No difference in egg quality was observed between the processed and unprocessed feed ingredients. Supplementation with extruded feed improved laying performance by decreasing the feed conversion ratio, increasing feed intake, and increasing the hen-day production rate; however, these results were not statistically significant. In addition, extrudate supplementation had no effect on egg quality. To assess and summarize the impact of extrusion on additional parameters, such as nutrient digestibility, blood hematology, and specific feedstuff types, additional equal meta-analysis would be the best option.

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REFERENCES

Abd El-Khalek E and Janssens GPJ, 2010. Effect of extrusion processing on starch gelatinisation and performance in poultry. World's Poultry Science Journal 66(1): 53–63. https://doi.org/10.1017/S0043933910000073

Alam MS, Kaur J, Khaira H and Gupta K, 2016. Extrusion and extruded products: changes in quality attributes as affected by extrusion process parameters: A Review. Critical Reviews in Food Science and Nutrition 56(3): 445–473. https://doi.org/10.1080/10408398.2013.779568

Baeza E, Chartrin P, Lessire M, Meteau K, Chesneau G, Guillevic M and Mourot J, 2015. Is it possible to increase the n-3 fatty acid content of eggs without affecting their technological and/or sensorial quality and the laying performance of hens? British Poultry Science 56(6): 748–754. https://doi.org/10.1080/00071668.2015.1113500

Brennan C, Brennan M, Derbyshire E and Tiwari BK, 2011. Effects of extrusion on the polyphenols, vitamins and antioxidant activity of foods. Trends in Food Science and Technology 22(10): 570–575. https://doi.org/10.1016/j.tifs.2011.05.007

Carrasco S, Wüstholz J and Bellof G, 2016. The effect of chopped, extruded and pelleted alfalfa silage on the egg quality of organic laying hens. Animal Feed Science and Technology 219: 94–101. https://doi.org/10.1016/j.anifeedsci.2016.06.001

Clarke E and Wiseman J, 2007. Effects of extrusion conditions on trypsin inhibitor activity of full fat soybeans and subsequent effects on their nutritional value for young broilers. British Poultry Science 48(6): 703–712. https://doi.org/10.1080/00071660701684255

Corrales-Retana L, Ciucci F, Conte G, Casarosa L, Mele M and Serra A, 2021. Profile of fatty acid lipid fractions of omega-3 fatty acid-enriched table eggs. Journal of Animal Physiology and Animal Nutrition 105(2): 326–335. https://doi.org/10.1111/jpn.13462

Dalle Zotte A, Andrighetto I, Giaccone V and Marchesini G, 2015. Dietary enrichment of n-3 PUFA for laying hens: Effect of different sources on production, composition and quality of eggs. Animal Science Papers and Reports 33(4): 411–424.

Eck LVan, Chen H, Carvalhido I, Enting H and Kwakkel R, 2023. The influence of breed , dietary energy and lysine on laying persistency and body composition of laying hens. Poultry Science 103(11): 104124. https://doi.org/10.1016/j.psj.2024.104124

Goodarzi Boroojeni F, Svihus B, Graf von Reichenbach H and Zentek J, 2016. The effects of hydrothermal processing on feed hygiene, nutrient availability, intestinal microbiota and morphology in poultry—A review. Animal Feed Science and Technology 220: 187–215. https://doi.org/10.1016/j.anifeedsci.2016.07.010

Hejdysz M, Kaczmarek SA and Bedford MR, 2022. The effect of different temperatures applied during extrusion on the nutritional value of faba bean and degradation of phytic P isomers. Animal Feed Science and Technology 285: 115221. https://doi.org/10.1016/j.anifeedsci.2022.115221

Huang S, Baurhoo B and Mustafa A, 2018. Effects of extruded flaxseed on layer performance, nutrient retention and yolk fatty acid composition. British Poultry Science 59(4): 463–469. https://doi.org/10.1080/00071668.2018.1476676

Huang S, Baurhoo B and Mustafa A, 2020. Effects of feeding extruded flaxseed on layer performance, total tract nutrient digestibility, and fatty acid concentrations of egg yolk, plasma and liver. Journal of Animal Physiology and Animal Nutrition 104(5): 1365–1374. https://doi.org/10.1111/jpn.13364

Imran M, Anjum FM, Nadeem M, Ahmad N, Khan MK, Mushtaq Z and Hussain S, 2015. Production of Bio-omega-3 eggs through the supplementation of extruded flaxseed meal in hen diet. Lipids in Health and Disease 14(1): 1–9. https://doi.org/10.1186/s12944-015-0127-x

Kakani R, Fowler J, Haq AU, Murphy EJ, Rosenberger TA, Berhow M and Bailey CRA, 2012. Camelina meal increases egg n-3 fatty acid content without altering quality or production in laying hens. Lipids 47(5): 519–526. https://doi.org/10.1007/s11745-012-3656-3

Lichovnikova M, Zeman L, Kracmar S and Klecker D, 2004. The effect of the extrusion process on the digestibility of feed given to laying hens. Animal Feed Science and Technology 116(3–4): 313–318. https://doi.org/10.1016/j.anifeedsci.2004.07.018

Maharjan P, Rahimi A, Harding KL, Vu TC, Malheiros R, Oviedo-Rondon EO, Mian R, Joseph M, Dean L, Anderson KE and Toomer O, 2023. Effects of full-fat high-oleic soybean meal in layer diets on nutrient digestibility and egg quality parameters of a white laying hen strain. Poultry Science 102(4): 1–9. https://doi.org/10.1016/j.psj.2023.102486

Mahmud A, Saima, Jabbar MA, Sahota AW, Hayat Z and Khan MZU, 2015. Effect of feeding hatchery waste meal processed by different techniques on egg quality and production performance of laying hens. Pakistan Journal of Zoology 47(4): 1059–1066.

Mattioli S, Ruggeri S, Sebastiani B, Brecchia G, Dal Bosco A, Cartoni Mancinelli A and Castellini C, 2017. Performance and egg quality of laying hens fed flaxseed: Highlights on n-3 fatty acids, cholesterol, lignans and isoflavones. Animal 11(4): 705–712. https://doi.org/10.1017/S175173111600207X

Nain S, Renema RA, Korver DR and Zuidhof MJ, 2012. Characterization of the n-3 polyunsaturated fatty acid enrichment in laying hens fed an extruded flax enrichment source. Poultry Science 91(7): 1720–1732. https://doi.org/10.3382/ps.2011-02048

Novak C and Scheideler SE, 2001. Long-term effects of feeding flaxseed-based diets. 1. Egg production parameters, components, and eggshell quality in two strains of laying hens. Poultry Science 80(10): 1480–1489. https://doi.org/10.1093/ps/80.10.1480

Olejnik K, Popiela E and Opaliński S, 2022. Emerging Precision Management Methods in Poultry Sector. Agriculture (Switzerland) 12(5): https://doi.org/10.3390/agriculture12050718

Oryschak MA, Smit MN and Beltranena E, 2020. *Brassica napus* and *Brassica juncea* extruded-expelled cake and solvent-extracted meal as feedstuffs for laying hens: Lay performance, egg quality and nutrient digestibility. Poultry Science 99(1): 350–363. https://doi.org/10.3382/ps/pez501

Özentürk U and Yildiz A, 2021. Comparison of performance parameters, stress, and immunity levels of native and commercial layers reared in different cage densities in Turkey. Turkish Journal of Veterinary and Animal Sciences 45(6): 1052–1064. https://doi.org/10.3906/vet-2012-91

Park JA and Sohn SH, 2018. The influence of hen aging on eggshell ultrastructure and shell mineral components. Korean Journal for Food Science of Animal Resources 38(5): 1080–1091. https://doi.org/10.5851/kosfa.2018.e41

Popiela E, Króliczewska B, Zawadzki W, Opaliński S and Skiba T, 2013. Effect of extruded amaranth grains on performance, egg traits, fatty acids composition, and selected blood characteristics of laying hens. Livestock Science 155(2–3): 308–315. https://doi.org/10.1016/j.livsci.2013.05.001

Risyahadi ST, Sukria HA, Retnani Y, Wijayanti I, Jayanegara A and Qomariyah N, 2023. Effects of dietary extrusion on the performance and apparent ileal digestion of broilers: a meta-analysis. Italian Journal Animal Science 22(1): 291–300

Rosenthal R, 1979. The file drawer problem and tolerance for null results. Psychological Bulletin 86(3): 638–641. https://doi.org/10.1037/0033-2909.86.3.638

Saleh AA, Ahmed EAM and Ebeid TA, 2019. The impact of phytoestrogen source supplementation on reproductive performance, plasma profile, yolk fatty acids and antioxidative status in aged laying hens. Reproduction in Domestic Animals 54(6): 846–854. https://doi.org/10.1111/rda.13432

Sánchez-Meca J and Marín-Martínez F, 2010. Meta-analysis in psychological research. International Journal of Psychological Research 3(1): 150–162. https://doi.org/10.21500/20112084.860

Šašyte V, Gružauskas R, Racevičiutè-Stupeliene A, Kliševiciute V, Daukšiene A and Alijošius S, 2016. The application of extruded full-fat rapeseed in isa brown laying hens' diets. Veterinarija Ir Zootechnika 73(95): 88–94.

Sauvant D, Schmidely P, Daudin JJ and St-Pierre NR, 2008. Meta-analyses of experimental data in animal nutrition. Animal 2(8): 1203–1214. https://doi.org/10.1017/S1751731108002280

Sepehr A, Bahari Kashani R, Esmaeili M, Safari O and Rombenso A, 2021. Effects of extruded, milled, and whole flaxseed (Linum usitatissimum) on egg performance, lipid components, and fatty acids concentrations in yolk and blood, and antioxidant system of commercial laying hens. Animal Feed Science and Technology 276: 114877. https://doi.org/10.1016/j.anifeedsci.2021.114877

Shahid MS, Raza T, Wu Y, Mangi MH, Nie W and Yuan J, 2020. Comparative effects of flaxseed sources on the egg ALA deposition and hepatic gene expression in Hy-Line brown hens. Foods 9(11): 1–18. https://doi.org/10.3390/foods9111663

Singh S, Gamlath S and Wakeling L, 2007. Nutritional aspects of food extrusion: A review. International Journal of Food Science and Technology 42(8): 916–929. https://doi.org/10.1111/j.1365-2621.2006.01309.x

St-Pierre NR, 2001. Invited review: Integrating quantitative findings from multiple studies using mixed model methodology. Journal of Dairy Science 84(4): 741–755. https://doi.org/10.3168/jds.S0022-0302(01)74530-4

Sumiati, Fadilah R, Darmawan A and Nadia R, 2025. Invited Review — Challenges and constraints to the sustainability of poultry farming in Indonesia. Animal Bioscience 38(4): 802–17 https://doi.org/10.5713/ab.24.0678

Wallace BC, Lajeunesse MJ, Dietz G, Dahabreh IJ, Trikalinos TA, Schmid CH and Gurevitch J, 2017. OpenMEE: Intuitive, open-source software for meta-analysis in ecology and evolutionary biology. Methods in Ecology and Evolution 8(8): 941–947. https://doi.org/10.1111/2041-210X.12708

Wüstholz J, Carrasco S, Berger U, Sundrum A and Bellof G, 2017. Silage of young harvested alfalfa (*Medicago sativa*) as home-grown protein feed in the organic feeding of laying hens. Organic Agriculture 7(2): 153–163. https://doi.org/10.1007/s13165-016-0151-9