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Research article

Optimization of broiler growth and organ traits: Insights from a meta-analysis of feed form effects

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Abstract

Feed form is an essential factor influencing nutrient use, feeding behavior, and overall efficiency in broilers. Since feed represents the largest portion of production costs, there is a need to select the appropriate feed to improve performance and profitability. Therefore, this meta-analysis aimed to examine the effects of feed form on broiler performance, carcass traits, and organ development using 283 data points from 46 published studies. Data reliability was assessed using a fail-safe number (Nfs), which showed robust parameters for daily feed intake (Nfs > 620) and daily weight gain (Nfs > 1000), while mortality and organ weight had low values. The results showed that feed form significantly improved ($P < 0.05$) broiler performance, particularly conversion ratio and final body weight. However, high heterogeneity ($I^2 > 80\%$) showed that differences in diet composition, management, and environmental conditions strongly influenced the outcomes. Carcass traits significantly improved ($P < 0.05$), with increased weight observed in the total carcass, breast, thigh, and wing. Abdominal fat deposition showed a relatively smaller but significant ($p<0.05$) reduction. The effect on organ development was variable, with gizzard and pancreas weights decreasing significantly ($P < 0.05$), indicating low mechanical and enzymatic demands of processed feeds, while liver weight was unaffected. Intestinal morphology showed mixed outcomes, with significant ($P < 0.05$) reductions in duodenum length and non-significant trends for jejunum and ileum lengths. This indicated that feed form substantially enhanced broiler productivity, carcass quality, and feed efficiency. However, variability across studies showed the need to consider management and environmental factors, indicating the need for future investigation to identify sources of heterogeneity.

Keywords: Broiler performance, Carcass characteristics, Feed efficiency, Feed form, Meta-analysis, Organ traits.

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INTRODUCTION

The physical form of feed, including mash, crumbles, or pellets, is essential in broiler growth performance, efficiency, and physiological development (Massuquetto et al., 2020). This is because each feed form differs in physical and nutrient accessibility, leading to various performance outcomes. Compared to mash feed, pellets and crumbles, with uniform size, high palatability, and superior nutrient availability, promote faster growth and better feed conversion ratio (FCR) (Amoozmehr et al., 2023). These benefits support commercial broiler production, where feed efficiency significantly impacts profitability. However, mash feed stimulates greater development of gastrointestinal organs, particularly the gizzard, because of the grinding activity required during digestion (Xu et al., 2015; Rueda et al., 2024). This supports gut motility and nutrient digestibility, but is accompanied by lower feed intake and reduced feed efficiency.

Numerous studies have consistently shown the effect of feed form on broiler performance and organ development. Amerah et al. (2007) reported that pellets significantly improved growth rates, FCR, and feed use, due to higher nutrient density and lower waste. Similarly, Rueda et al. (2024) emphasized the benefits of pellet productivity in commercial systems. These results demonstrate that processed feed forms, such as pellets and crumbles, can enhance performance under typical production conditions.

Despite the favorable outcomes, some studies reported significant reductions in gizzard, liver, pancreas, and duodenum length associated with pellets (Amerah et al., 2007; Yousefian Astaneh et al., 2023). This is due to low mechanical stimulation in the gastrointestinal tract and altered digestive organ development (Amerah et al., 2007). Although pellets can improve growth performance and feed efficiency, there is a significant association with compromised organ functionality, potentially affecting broilers long-term health and welfare (Abdollahi et al., 2014).

Due to diversity and inconsistency of results across studies, a meta-analysis is essential to clarify how feed form affects broilers. Combining data strengthens statistical reliability (Ridla et al., 2025), showing existing knowledge gaps that require further investigation. Therefore, this meta-analysis aims to evaluate the collective impact of feed form on broiler growth performance, efficiency, and organ development. The results are expected to guide feed formulation, improve productivity, and ensure welfare in broiler production systems, benefiting the study and industry stakeholders.

MATERIALS AND METHODS

Database development

A comprehensive database was compiled from various open-source scientific literature investigating the effect of feed form on broiler performance, carcass characteristics, and organ development. The literature search was conducted through Scopus and Semantic Scholar, using keywords such as "physical form", "feed form", "mash", "pellet", "crumble", and "broiler". Subsequently, relevant studies were identified, while titles and associated parameters were systematically recorded. The database was finalized in December 2024, providing a robust foundation for further analyses.

The selection process in Figure 1 followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009). Initially, 1,249 studies were identified through searches, including 189 Scopus and 1,060 Semantic Scholar. Among these studies, 966 were excluded based on non-relevant titles, reviews, or conference proceedings. A total of 283 studies were evaluated for full-text evaluation, leading to the exclusion of 237 due to the lack of comparative data (n=57), irrelevance of content or variables (n=98), and insufficient or incomplete data (n=82). Finally, 46 studies met the eligibility criteria and were included in the meta-analysis.

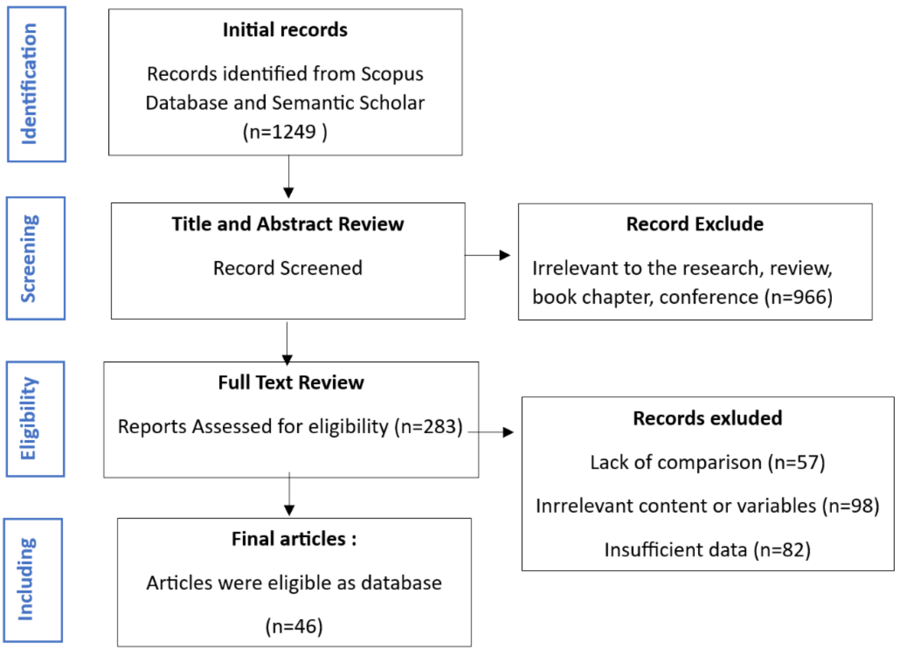

Figure 1 The selection process of the studies.

Data extraction

Data were analyzed using the random-effects meta-analysis method following the procedure described by Ridla et al. (2024). The mathematical modeling of one-way random effects follows the formula (Sánchez-Meca, 2010; Cheung and Vijayakumar, 2016):

$$y_i = \theta + v_i + \varepsilon_i$$

In this equation, (y_i) represents the effect size (Hedge's d) for the ith observation, (θ) is the general parameter for the combined effect size, (v_i) is the actual variation in the effect size, and (ε_i) is the error for the ith observation. The effect size (d) was calculated based on Hedges'd standardized mean difference, with the formula:

$$\mathrm{d} = \frac{(\bar{X}E - \bar{X}C)}{S} J$$

where ($\bar{X}^E$) is the mean of the experimental or pellets and crumbles form, ($\bar{X}^C$) is the control group or mash form, (S) is the pooled standard deviation, and (J) is the correction factor for the small sample size.

The pooled standard deviation is (S) defined as:

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

where: N^E – sample size of the experimental group, N^c – sample size of the control group, S^E – standard deviation of the experimental group, S^C – standard deviation of the control group.

J is the correction factor for the small sample size, i.e.:

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

The between-study variance (τ^2) was estimated using the DerSimonian and Laird method (DerSimonian and Laird, 1986), calculated as:

$$\tau^2 = \frac{Q - \mathrm{df}}{C}$$

In this equation, Q is the weighted sum of squares, df stands for degrees of freedom, and C is a constant. A meta-analysis for performance variables was conducted using OpenMEE software (Wallace et al., 2016), and a cumulative forest plot with a 95% confidence interval was generated using MedCalc software (2024).

RESULTS

All literature searches were compiled into data table, while descriptive statistics were used to create Tables 1 and 2. Small or inconsistent studies were considered unreliable due to publication bias favoring positive results. To assess robustness, fail-safe number (Nfs) was calculated, which identified trustworthy studies for conclusions. Nfs represents the extra sample size needed to weaken initial results to non-significance. Studies with Nfs exceeding five times the initial effect size (N) plus 10 are considered robust and included in the conclusions (Rosenthal, 1979). Based on observation, Nfs criteria identified robust parameters for broiler performance, such as daily feed intake (N = 122, Nfs > 620) and daily weight gain (N = 198, Nfs > 1000). However, parameter like mortality (N = 68, Nfs < 350) was considered unreliable.

Organ weight, such as liver (N = 25, Nfs < 135) and pancreas (N = 25, Nfs < 135), was considered unreliable. This analysis assessed variation in results (heterogeneity) using Q statistic, τ^2, and I^2. The Q statistic combined the squared differences between each and the overall average effect. In the equation, τ^2 represented the estimated variation across all studies, while I^2 index quantified the portion of this variation not explained by the analysis.

The results showed differences between variables, where breast (Q = 1178.89) and thigh weight (Q = 306.81) had high variation, as indicated by the Q statistic exceeding available comparisons (NC-1). The variation was due to the number of studies included, differences in effect sizes between and within each study, alongside feed formulation, additional treatments applied, specific pellet production, and processing methods.

Feed form improves broiler growth and organ traits, but high heterogeneity (I^2 > 80%) reflects differences in strains, feed, management, and environment. Future studies should standardize methods to explore these variations. Table 3 summarizes the results of a large-scale meta-analysis examining feed form, while Figure 2 shows the forest plot, indicating the effect of feed form on daily weight gain, final body weight, feed conversion ratio (FCR), and organ weight, such as the gizzard and pancreas.

Broiler performance

The meta-analysis results showed the significant impact of feed form on most broiler performance parameters, playing a role in optimizing growth and feed efficiency. However, there was a considerable variability in outcomes across studies, which was influenced by experimental and environmental factors. Daily feed intake showed a significant increase of 2.37 g/day (95% CI: 2.04 to 2.69, P < 0.001) based on 122 comparisons. This result showed that feed form substantially enhanced broiler daily consumption rates due to improved palatability and accessibility. However, the high heterogeneity (I^2 = 82.78%) suggested that differences in feed composition, particle size, or environmental conditions could influence the results.

Total feed intake was significantly higher, with an average increase of 1.49 g (95% CI: 1.19 to 1.79, P < 0.001) across 273 comparisons. This showed that feed form positively affected overall consumption over the production cycle. However, high heterogeneity (I^2 = 89.56%) indicated variability in results due to differences in feed processing methods, feeding management, or broiler strains.

Table 1 Articles that use broilers as a subject of study were included in the meta-analysis.

No.	Reference	Feed Form Type	Combination Treatment	Periode
1	Abdollahi et al., 2014	Pellet	-	Starter
2	Abadi et al., 2019	Pellet	Particle size and pellet binder	Finisher
3	Al-Nasrawi et al., 2016	Crumble and Pellet	-	Starter, grower, finisher
4	Amerah et al., 2007	Pellet	-	Finisher
5	Amirabdollahian et al., 2014	Pellet	Different pelleting temperatures	Starter
6	Amornthewaphat, et al., 2005	Pellet	Conventional and extruded	Finisher
7	Ariyadi et al., 2019	Crumble and Pellet	-	Finisher
8	Attia et al., 2012	Crumble	Added phytase + Multienzyme	Starter
9	Azizian and Saki, 2020	Pellet	-	Finisher
10	Azizian and Saki, 2021	Pellet	-	Starter, Grower, Finisher
11	Boazar et al., 2021	Pellet	Add fiber source	Starter, Grower, Finisher
12	Brink et al., 2022	Pellet	-	Starter, grower, finisher
13	Cardoso et al., 2022	Pellet	Thermoneutral tempratures	Finisher
14	Chehraghi et al., 2013	Crumble and Pellet	-	Starter, Grower, Finisher
15	Chewning et al., 2012	Pellet	Particle size	Starter, Grower, Finisher
16	Corzo et al., 2012	Pellet	Percentage of pellet used	Finisher
17	Dozier et al., 2010	Pellet	High, low quality pellet and post pellet	Starter, Grower, Finisher
18	Attia et al., 2014	Crumble and Pellet	-	Starter, Grower, Finisher
19	Fasuyi and Odunayo, 2015	Crumble and Pellet	-	Starter
20	Habibi et al., 2019	Crumble and Pellet	-	Starter, Grower, Finisher
21	Hasani et al., 2017	Pellet and Crumble	Temprature	Starter, grower, finisher
22	Hossain et al., 2017			Starter, finisher
23	Hosseini and Afshar, 2016	Crumble and Pellet	Xylanase	Starter, grower, finisher
24	Idan et al., 2020	Crumble and Pellet	-	Starter
25	Jafarnejad et al., 2010	Crumble	Dietary protein and energy level.	Starter
26	Jiménez-Moreno et al., 2016	Pellet	Insoluble fiber sources	Starter
27	Karimirad et al., 2020	Crumble and Pellet	-	Finisher
28	Kuleile and Malopo, 2019	Crumble and Pellet	-	Starter
29	Lemme et al., 2006	Pellet	Good and bad quality	Finisher
30	Lv et al., 2015	Crumble and Pellet		Starter, grower, finisher
31	Massuquetto et al., 2018	Pellet	Conditioning time	Starter
32	Massuquetto et al., 2019	Pellet	Percentage of pellets used	Finisher
33	Massuquetto et al., 2020	Pellet	Different levels of metabolic energy	Finisher
34	Moreno et al., 2016	Pellet	Adding fiber	Starter, grower, finisher
35	Musa and Sa'adu, 2021	Crumble and Pellet	-	Starter, grower, finisher
36	Omede and Iji, 2018	Crumble	-	Starter, grower, finisher
37	Ommati et al., 2013	Crumble and Pellet	-	Finisher
38	Pirzado et al., 2015	Crumble	-	Starter, grower, finisher
39	Rubio et al., 2020	Crumble and micro pellet	-	Finisher
40	Rueda et al., 2024	Pellet	Particle Size	Starter, Grower, Finisher
41	Serrano et al., 2012	Crumble and Pellet	-	Starter, Grower, Finisher
42	Serrano et al., 2013	Crumble and Pellet	-	Starter, grower, finisher
43	Skinner-Noble, 2005	Pellet	-	Starter, grower, finisher
44	Tavakolinasab et al., 2020	Crumble and Pellet	-	Starter, grower, finisher
45	Xu et al., 2015	Crumble	Different level of coarse corn	Starter
46	Zang et al., 2009	Pellet	-	Starter, Grower, Finisher

Table 2 Summaries of the meta-database from articles

Variable	Unit	NC	Control				Treatment			
			Max	Min	Mean	SD	Max	Min	Mean	SD
Broiler performance										
Daily feed intake	g/bird/day	122	189.91	9.91	73.31	47.54	185.44	10.12	80.30	48.84
Total feed intake	g/bird	244	5149.00	94.25	1706.36	1335.13	5423.21	111.23	1809.05	1423.38
Daily weight gain	g/bird/day	198	283.50	7.70	54.24	38.56	319.67	8.10	60.96	42.30
Body weight (BW)	g/bird	241	3053.21	144.72	1147.95	32.23	3333.03	146.32	1285.78	91.83
FCR		278	2.38	0.723	1.59	0.30	2.15	0.615	1.50	0.28
Mortality	%	62	8.30	0	1.26	1.79	12.8	0	1.77	2.71
Carcass yield										
Total carcass (TC)	% BW	57	72.84	58.49	68.82	5.10	78.52	59.83	69.87	6.87
Breast	% TC	47	44.65	28.63	32.12	33.33	46.69	29.54	34.67	34.84
Thighs	% TC	21	31.32	20.89	22.39	1.19	32.63	21.61	23.53	1.21
Wings	% TC	18	13.46	11.39	14.32	1.87	15.66	12.12	14.67	1.48
Abdominal fat	% TC	28	9.3	0.82	1.99	1.56	12.2	1.28	2.24	2.01
Organ's weight										
Gizzard	g/100g	32	3.08	1.00	1.87	0.52	2.60	0.80	1.37	0.50
Liver	g/100g	25	4.00	0.34	2.24	1.113	3.60	0.36	2.25	1.10
Pancreas	g/100g	25	2.00	0.22	0.74	0.67	1.80	0.18	0.50	0.60
Organ's relative length										
Duodenum	cm/kg BW	19	36.23	16.12	25.22	6.19	30.23	17.17	24.34	4.74
Jejunum	cm/kg BW	19	95,14	28.85	63.87	25.59	100.63	31.49	64.12	24.27
Ileum	cm/kg BW	19	96.74	24.61	64.99	30.36	112.49	24.43	64.29	29.89

Abbreviations: FCR, feed conversion ratio; Max, maximum value from the data; Min, minimum value from the data; NC, number of observed variables; SD, standard deviation.

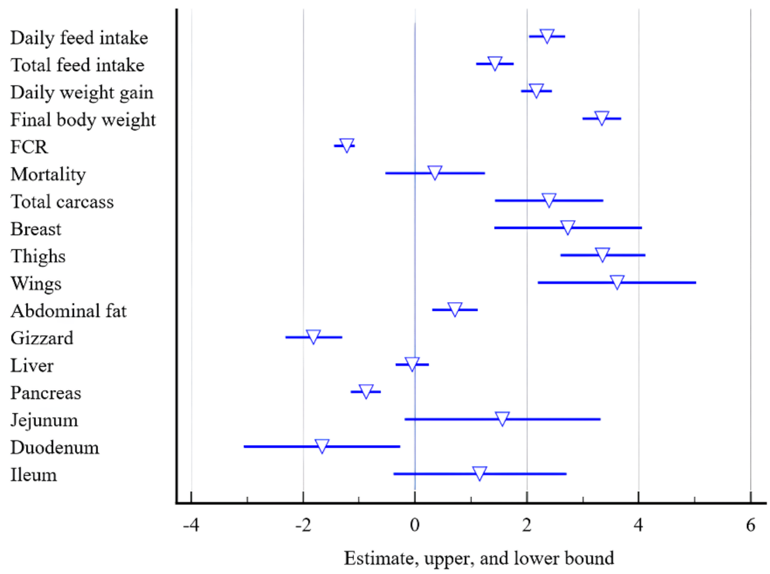

Figure 2 Forest plot of the effect of feed form on broiler performance, carcass yield, and organ.

Table 3 Effects of feed form on broiler performance and organ weight

Variables	NC	Estimate	Lower bound	Upper bound	Std. error	*p*-Value	τ^2	Q	Het. *p*-Value	I^2
Performance										
Daily feed intake	122	2.366	2.044	2.687	0.164	<0.001	2.586	702.798	<0.001	82.783
Total feed intake	244	1.427	1.094	1.760	0.170	<0.001	5.441	2438.885	<0.001	90.036
Daily weight gain	198	2.171	1.896	2.445	0.140	<0.001	3.086	1369.578	<0.001	85.616
Final body weight	241	3.337	2.987	3.687	0.178	<0.001	5.972	2230.833	<0.001	89.242
FCR	278	- 1.217	-1.441	-1.074	0.093	<0.001	1.842	1569.599	<0.001	82.352
Mortality	50	0.359	-0.531	1.249	0.454	0.429	6.812	697.527	<0.001	92.975
Carcass yield										
Total carcass	57	2.395	1.425	3.366	0.495	<0.001	9.100	782.771	<0.001	92.846
Breast	47	2.733	1.421	4.055	0.672	<0.001	13.791	941.941	<0.001	95.116
Thighs	21	3.354	2.598	4.110	3.859	<0.001	13.687	306.810	<0.001	93.481
Wings	18	3.610	2.195	5.025	0.722	<0.001	6.388	191.538	<0.001	91.124
Abdominal fat	28	0.714	0.313	1.116	0.205	<0.001	0.742	97.131	<0.001	72.202
Organ weights										
Gizzard	32	-1.812	-2.318	-1.306	0.258	<0.001	1.417	125.153	<0.001	75.23
Liver	25	-0.049	-0.352	0.253	0.154	0.749	0.240	40.706	0.018	41.041
Pancreas	25	-0.879	-1.146	-0.613	0.136	<0.001	0.119	32.464	0.116	26.073
Organ's relative length										
Jejunum	19	1.564	-0.183	3.310	0.891	0.079	11.909	274.638	<0.001	93.446
Duodenum	19	-1.663	-3.059	-0.268	0.712	0.019	8.218	236.996	<0.001	92.405
Ileum	19	1.157	-0.388	2.703	0.789	0.142	9.825	252.595	<0.001	92.874

Abbreviations: FCR, feed conversion ratio; I^2, heterogeneity level of the meta-analysis model; Q, weight of sum square; τ^2, absolute value of variance between studies; Std. error, error within a study; NC, number of observed variables.

Daily weight gain improved significantly, with an estimated increase of 2.17 g/day (95% CI: 1.89 to 2.44, P < 0.001) across 198 comparisons, showing the efficiency of optimized feed form in promoting growth. Final body weight increased significantly by 2.98 g (95% CI: 2.98 to 3.68, P < 0.001) based on 241 comparisons. Both variables showed high heterogeneity (I^2 = 85.62% for daily weight gain and I^2 = 89.24% for final body weight), suggesting that results are influenced by feed nutrient composition, management practices, and environmental conditions.

FCR showed a significant improvement, with a reduction of 1.22 (95% CI: -1.39 to -1.04, P < 0.001) across 307 comparisons. This showed that feed form could significantly reduce the consumption rate per unit of weight gain. However, the high heterogeneity (I^2 = 83.26%) indicated variability caused by differences in formulations and production conditions.

Mortality was not significantly affected by feed form, with an estimate of 0.29 (95% CI: -0.85 to 1.42, P = 0.62). The very high heterogeneity (I^2 = 95.15%) suggested that disease management, housing conditions, or genetic differences were more influential than feed form. Compared to other factors, feed form improved broiler performance, regarding intake, growth rates, and efficiency. This showed the importance of optimizing feed form in broiler production systems to achieve better productivity. However, the significant heterogeneity across studies showed the need for study-specific variables and production conditions when interpreting the results. Therefore, future studies should vary sources and investigate interactions between feed form and other management practices to provide practical insights for maximizing broiler production system.

Carcass yield

The meta-analysis results provided information on the effects of feed form regarding carcass characteristics, showing significant positive impacts on most parameters with varying degrees of heterogeneity across studies. Total carcass weight increased significantly by an average of 2.28 units (95% CI: 1.44 to 3.13, P < 0.001) based on 63 comparisons. This result showed the positive influence of feed form on overall carcass yield due to high nutrient availability and feed efficiency. However, the high heterogeneity (I^2 = 92.68%) suggested that study-specific factors such as broiler genetics, feeding duration, and dietary composition could contribute to outcome variability.

As a key component of broiler carcasses, breast weight showed a significant increase of 3.50 units (95% CI: 2.05 to 4.95, $P < 0.001$) across 53 comparisons. This indicated that an optimized feed form could effectively enhance breast muscle development due to better energy and protein utilization. Despite the results, the heterogeneity was very high ($I^2 = 95.59\%$), indicating substantial variability influenced by differences in nutrient formulations or feeding programs across studies.

Thigh weight showed the most pronounced increase, with an estimated improvement of 3.35 units (95% CI: 2,59 to 4,11, $P < 0.001$) based on 21 comparisons. The substantial gain showed the significant role of feed form in supporting thigh muscle growth. However, the heterogeneity was extremely high ($I^2 = 93.48\%$), indicating the influence of variations in study designs or broiler strains.

Wing weight increased significantly by 3.57 units (95% CI: 2.32 to 4.83, $P < 0.001$) across 20 comparisons. This showed that feed form positively impacted wing development, although heterogeneity remained high ($I^2 = 90.68\%$), suggesting differences in experimental setups and environmental conditions. In comparison, abdominal fat showed a smaller but significant increase of 0.62 units (95% CI: 0.23 to 1.01, $P = 0.002$) based on 30 comparisons, which had moderate heterogeneity ($I^2 = 71.61\%$). This suggested that, despite influencing fat deposition, the effect of feed form was less variable compared to other carcass parameters.

The meta-analysis showed the significant positive effects of feed form on carcass yield and specific components such as breasts, thighs, and wings, particularly in enhancing carcass quality. However, the high heterogeneity observed among studies shows that further work is needed to understand how feed form interacts with other factors. This knowledge will support more precise feeding strategies to improve carcass yield and quality in broiler production.

Organ weight

The meta-analysis provided valuable insights into the impact of feed form on the weight of various organs and the length of intestinal segments in broilers. The results showed both significant and non-significant effects, indicating a nuanced influence of feed form on gastrointestinal and metabolic organ development. Specifically, gizzard weight decreased significantly by an average of -1.66 units (95% CI: -2.17 to -1.16, $P < 0.001$) based on 34 comparisons. This was due to low mechanical stimulation associated with pellets and crumbles. High heterogeneity ($I^2 = 76.88\%$) suggested variability across studies, potentially influenced by differences in feed processing, particle size, or broiler age.

Based on 25 comparisons, liver weight showed no significant effect of feed form (estimate = -0.05; 95% CI: -0.35 to 0.25, $P = 0.75$). The moderate heterogeneity ($I^2 = 41.04\%$) showed some variability caused by composition or other experimental factors. Pancreas weight decreased significantly by -0.88 units (95% CI: -1.15 to -0.61, $P < 0.001$) across 25 comparisons. The reduction was due to changes in digestive enzyme requirements associated with processed feed form. The relatively low heterogeneity ($I^2 = 26.07\%$) suggested the effect was consistent across studies.

Organ length

Jejunum length showed a non-significant trend toward an increase of 1.56 units (95% CI: -0.18 to 3.31, $P = 0.08$) across 19 comparisons. Although the effect was not statistically significant, the high heterogeneity ($I^2 = 93.45\%$) suggested substantial variability, which was influenced by feed composition, broiler strain, or management practices.

Duodenum length decreased significantly by -1.66 units (95% CI: -3.06 to -0.27, $P = 0.02$) based on 19 comparisons. The reduction was caused by reduced need for extended digestion and nutrient absorption with more digestible feed forms. Furthermore, high heterogeneity (I^2 = 92.41%) showed considerable variability due to differences in feed nutrient profiles and experimental conditions.

Ileum length showed a non-significant trend toward an increase of 1.57 units (95% CI: -0.39 to 2.70, P = 0.14) across 19 comparisons. Although the result was not statistically significant, the very high heterogeneity (I^2 = 92.87%) suggested that feed form was inconsistently influenced by other factors. This analysis showed a significant reduction in gizzard and pancreas weight, underscoring the impact of processed feed form on digestive organ development. Compared to other parameters, liver weight remained unaffected. Intestinal segment lengths varied, with only the duodenum showing a significant decrease. Heterogeneity emphasized the influence of feed, age, and management conditions. The results indicated that feed form affected digestive organ development, particularly nutrient use and broiler health. Therefore, further studies are recommended to understand how feed form works alongside other dietary and environmental factors.

DISCUSSION

This meta-analysis comprehensively evaluated the effects of feed form on broiler performance, carcass characteristics, as well as organ weight and length, providing insights into how feed processing influenced growth, efficiency, and physiological development. The results showed significant positive impacts on performance and carcass traits, with mixed outcomes for organ development and gastrointestinal tract morphology.

Broiler performance

Feed form plays a significant role in broiler performance, affecting feed intake, weight gain, final body weight, and FCR. Generally, pellets and crumbles increase intake and growth due to high density, palatability, and low wastage (Ridla et al., 2025). This form reduces the energy cost of eating, allowing more energy to support growth. The improvement in FCR shows more efficient feed use and overall productivity gains (Abadi et al., 2019; Lancheros et al., 2020).

Pelleting compresses finely milled ingredients into uniform pellets through various stages such as grinding, mixing, conditioning, pelleting, cooling, and sieving (Lancheros et al., 2020). The process results in consistent, digestible, and palatable feed (Abadi et al., 2019). Before pelleting, ingredients are ground to uniform particle sizes to improve mixing, binding, and digestion, followed by checking for nutrient quality and safety. Subsequently, the ground materials are accurately blended to ensure even distribution of nutrients, vitamins, and additives.

Pelleting improves feed digestibility by causing starch gelatinization, protein denaturation, and reducing heat-labile antinutritional factors (Abdollahi et al., 2013). Heat and pressure also break starch structure, improving enzyme access and energy use (Aftab et al., 2018; Wang et al., 2023), thereby deactivating trypsin inhibitors in soybean meal (Liao et al., 2017). Fiber structure is altered to improve young broiler digestion, and uniform pellets limit feed sorting (Idan et al., 2023). These changes lead to faster growth, improved FCR, less nutrient waste, and better litter quality (Abu et al., 2023; Vakili, 2023).

High feed efficiency is caused by low energy expenditure during consumption. This was observed by Jensen et al. (1962), where broiler chickens consuming pellets spent significantly less time eating, leading to a 67% reduction in energy expenditure. Moreover, the inclusion of additives like enzymes and probiotics can optimize nutrient availability and support gut health, enhancing overall feed efficiency (Abdelaziz, 2021; Jaelani et al., 2024).

The improvement in FCR with pellets is related to pre-conditioning using steam. According to previous studies, standard industry practice uses steam conditioning at 80–90°C for 25–30 seconds, increasing moisture to 15–18% (Aftab et al., 2018). This process softens starch, denatures proteins, and lowers antinutritional factors, improving digestibility (Vakili, 2023). Enhanced starch digestion is specifically important since starch is the main energy source in broiler diets (Zaefarian et al., 2015; Wang et al., 2023).

Performance differences across studies show the influence of feed composition, broiler strain, and environmental conditions. Particle size, processing methods, moisture levels, steam use, conditioning temperature, and feed formulation also contribute to variability (Buchanan et al., 2010; Tillman et al., 2020; Vakili, 2023). However, feed form does not affect mortality, indicating that gains in productivity are from improved growth rather than survival (Shabani et al., 2015).

Carcass yield

Feed form affects carcass weight and the yield of breast, thigh, and wing by influencing digestion and nutrient absorption (Habibi et al., 2019; Rubio et al., 2019; Massuquetto et al., 2020; Brink et al., 2022). Specifically, pellets and crumbles enhance digestibility by altering the physical and chemical properties of feed during processing (Ayoola, 2020; Wang et al., 2023). Heat and pressure gelatinize starches and denature proteins, making nutrients more accessible to digestive enzymes (Barua et al., 2021). Pellets prevent feed sorting, ensuring consistent intake and supporting lean muscle growth (Idan et al., 2023; Svihus et al., 2024). Consequently, broiler-fed pellets gain more weight and develop lean muscle efficiently, increasing carcass weight and yields of valuable cuts. Variability remains due to genetics, feeding strategies, and environmental factors (Maharjan et al., 2021; Musigwa et al., 2024).

Organ weight

The meta-analysis found that processed feed reduced gizzard and pancreas weights, reflecting lower mechanical and enzymatic demands compared to mash (Ebtesam et al., 2021; Rueda et al., 2024). Reduced gizzard size suggests less mechanical grinding and shorter digesta retention, raising concerns about long-term function, because gizzard is essential for gut motility and efficient nutrient use (Xu et al., 2015).

Pancreas weight is an important indicator of digestive activity because this organ synthesizes the enzymes required for nutrient breakdown and absorption. Smaller pancreas weight indicates decreased enzyme production due to enhanced nutrient digestibility, showing reduced enzymatic workload (Lancheros et al., 2020; Rueda et al., 2024). Liver weight remained stable, indicating broad metabolic roles beyond digestion, although variability exists across studies (Omede et al., 2017; Abadi et al., 2019; Karimirad et al., 2020).

Intestinal length

Intestinal measurements showed a significant reduction in duodenal length, while jejunum and ileum remained largely unchanged. Shorter duodenum shows lower digestive demand, because processed feed is more easily digested (Rueda et al., 2024). Slight increases in distal segments suggest structural adaptation to enhanced nutrient availability (Lancheros et al., 2020; Ebtesam et al., 2021). High heterogeneity across studies shows the influence of feed composition, age, and housing conditions, emphasizing significant interaction with other environmental and management factors on intestinal development.

Overall implications

This meta-analysis shows significant effects of feed form on broiler performance, carcass traits, and organ development. Although pellets and crumbles are efficient, there is a reduction in digestive organ weights, particularly the gizzard and pancreas, showing variation between productivity and digestive physiology. Since gizzard stimulation affects gut health, further investigation into long-term consequences is essential (Abadi et al., 2019; Lancheros et al., 2020).

The variability across studies underscores the importance of considering feed formulation, environment, and broiler genetics. These results support evidence-based decisions to optimize feed processing. However, future investigation should clarify heterogeneity and explore interactions with dietary and management factors to optimize production strategies.

CONCLUSIONS

In conclusion, this meta-analysis shows the significant impact of feed form on broiler performance, carcass traits, and organ development. The results show that pellets and crumbles enhance growth performance, feed efficiency, and carcass yield, particularly breast and thigh muscles. However, gizzard and pancreas weight are reduced, suggesting low mechanical and enzymatic activity. There are variations in intestinal length outcomes, indicating compensatory adaptations in nutrient absorption. The high heterogeneity across studies underscores the importance of context-specific feeding strategies. In line with the results, feed form optimization is crucial for maximizing productivity while balancing potential impacts on digestive physiology and broiler welfare.

CONFLICT OF INTEREST

The authors declare no conflict of interest with any financial, personal, or organizational interests related to the material discussed in this meta-analysis.

AUTHOR CONTRIBUTIONS

Dwi Robiatul Adawiyah : contributed to formal analysis, data curation, conceptualization, visualization, and validation.
Muhammad Ridla : contributed to the original draft, review, editing, software, methodology, investigation, formal analysis, data curation, and conceptualization.
Nahrowi : contributed to visualization, validation, supervision, and data curation.
Sukarman : contributed to formal analysis, data curation, and conceptualization
Rita Mutia : contributed to formal analysis, data curation, and conceptualization.

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