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Research article

Impact of pellet binder on feed quality, broiler performance, carcass yield, and organ development: A Meta-Analysis

Muhammad Ridla[1,2,*] , Dwi Robiatul Adawiyah[1], Nahrowi[1,2] and Sukarman[3]

[1] Department of Animal Nutrition and Feed Technology, Faculty of Animal Science, IPB University, Bogor 16680, Indonesia
[2] Center for Tropical Animal Studies, IPB University, Bogor 16680, Indonesia
[3] National Research and Innovation Agency, Jakarta 10340, Indonesia

Abstract

This meta-analysis aimed to evaluate the inclusion of pellet binders on pellet quality and broiler performance, including growth metrics and organ development. A total of 130 data points acquired from 21 published articles were used as a database for determining the effectiveness of pellet binders on pellet quality, performance, and health of broilers. The Hedges'd value was employed as a measure of effect size (ES) in the present meta-analysis. The data were analyzed using a random effects model in OpenMEE software. The addition of pellet binders significantly increased the pellet durability index (PDI), pellet hardness, and moisture content ($p<0.05$). However, the meta-analysis results suggest that broiler performance, including feed intake, body weight, and FCR, as well as broiler carcass yield, including total carcass, breast, and thighs, were not impacted ($p>0.05$). In addition, pellet binders did not significantly affect ($p>0.05$) the relative organ weights, including the gizzard, heart, duodenum, jejunum, and ileum. However, liver weight was significantly different ($P<0.01$). The meta-analysis showed that pellet binders improved feed quality metrics such as pellet durability, hardness, and moisture, but did not impact broiler performance metrics, including feed intake, body weight, FCR, carcass yield, or other organ weights. Overall, pellet binders did not enhance efficiency in broiler production.

Keywords: Broiler Production, Feed Quality, Pellet Binders, Physical Quality

[*]**Corresponding author**: Muhammad Ridla, Department of Animal Nutrition and Feed Technology, Faculty of Animal Science, IPB University, Bogor 16680, Indonesia. E-mail: hmridla@apps.ipb.ac.id.

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INTRODUCTION

Pelleting is a crucial process in animal feed production, particularly in broiler feed manufacturing. It involves compressing finely ground feed ingredients into small, dense, and uniform pellets through a series of steps: grinding, mixing, conditioning, pelleting, cooling, screening, packaging, and storage (Lancheros et al., 2020). The goal of pelleting is to create a feed that is easy to digest, has a consistent nutrient profile, and is appealing to the animal (Abadi et al., 2019b).

To improve the pellet quality, manufacturers often use pellet binders to enhance the pellet's strength, durability, and water resistance (Abadi et al., 2019a). Common pellet binders used in broiler feed include lignosulfonates, bentonite clays, starch, molasses, fat, carboxymethyl cellulose (CMC), polyvinyl alcohol (PVA), and synthetic binders (Abadi et al., 2019a; Abdelaziz, 2021; Jaelani et al., 2024). The choice of binder will depend on the specific needs of the animal, the type of feed being produced, and the desired pellet quality. By selecting the right binder and following proper pelleting procedures, manufacturers can create high-quality pellets that meet the nutritional needs of broilers and other animals.

By using pellet binders, the durability, and hardness of pellets are improved. Binders strengthen the structural integrity of pellets, making them more resistant to breaking and crumbling during handling (Supriadi et al., 2020). This minimizes the production of fines and dust, maintains a cleaner feed production environment, reduces feed wastage, and preserves the quality of the feed during transport (De Jong et al., 2014; Cardeal et al., 2014).

Durable and well-formed pellets are more palatable to animals, encouraging consistent feed intake and reducing selective feeding. Binders also help protect the nutritional content of the feed by reducing exposure to air and moisture, preventing degradation. Improved pellet quality leads to reduced wastage and better feed conversion rates, resulting in cost savings for feed producers and farmers (Jaelani et al., 2024; Abu et al., 2023). In addition, the process of making a pellet including production rate, moisture steam, and conditioning temperature could affect the pellet quality (Vakili, 2023).

Since numerous studies have reported varying effects of pellet binders on pellet quality and subsequent broiler performance, including growth metrics and organ development, it is necessary to conduct a meta-analysis. This reliable method for synthesizing published data will help determine whether the inclusion of pellet binders in feed rations is justified, considering the increased cost of pellet production may not always lead to improved efficiency in broiler growth.

This meta-analysis study investigates the role of pellet binders in enhancing feed quality and their subsequent effects on broiler performance. By examining various binders and their influence on pellet durability, hardness, and broiler growth metrics, the study provides comprehensive insights into the benefits of using pellet binders in poultry feed production.

MATERIALS AND METHODS

Database development

A comprehensive database was created by compiling various literature sources that reported on the impact of pellet binders in improving feed quality and broiler performance. The literature search was performed using Scopus and Semantic Scholar with the keywords ‘pellet,’ ‘binders,’ and ‘feed.’ Relevant literature titles and additional pertinent information were gathered. The database was established in May 2024

The selection process, depicted in Figure 1, follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009). Initially, 400 documents were identified (159 from Scopus and 241 from

Semantic Scholar). Of these, 314 articles were excluded for reasons such as non-relevant titles, review articles, or conference proceedings. Subsequently, 86 articles underwent full-text evaluation, resulting in the exclusion of 65 articles due to lack of comparison (n=24), irrelevant content or variables (n=21), and insufficient data (n=20). As a result, 21 articles were deemed suitable for inclusion in the meta-analysis.

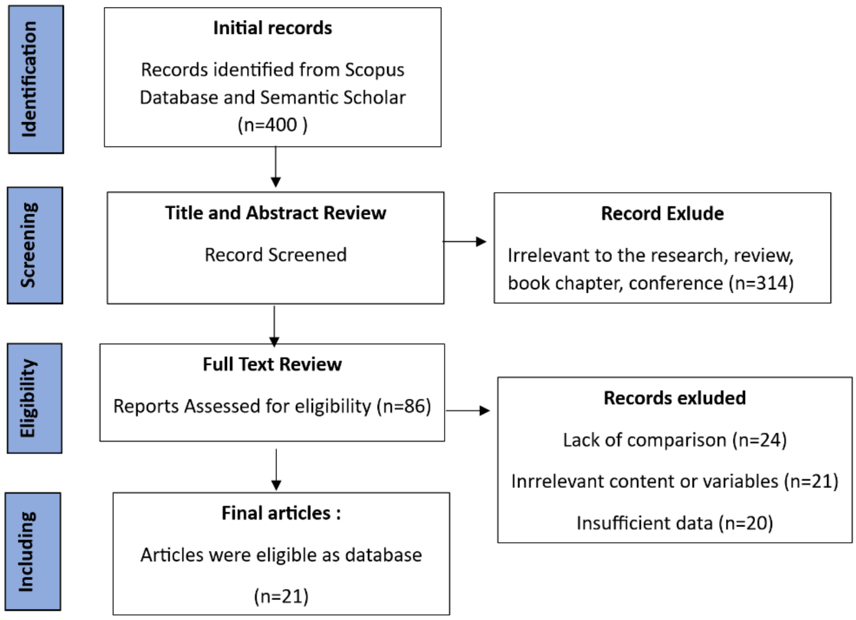

Figure 1 The selection process of the studies.

Data extraction

The data underwent analysis using the random-effects meta-analysis approach, following the methodology outlined by Ridla et al. (2024). The statistical modeling employed a one-way random effects model, as described by Cheung et al. (2016) and Sánchez-Meca and Marín-Martínez (2010), utilizing the formula:

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

In this equation, (yi) denotes the effect size (Hedge's d) for the i^{th} observation, (θ) represents the overall parameter for the combined effect size, (vi) signifies the observed variation in effect sizes, and (εi) represents the error associated with the i^{th} observation. The effect size (d) was computed using Hedge's d standardized mean difference, as formulated by:

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

Where the mean of the experimental or binder addition means is ($\bar{X}^E$), the control group or without binder addition means is ($\bar{X}^C$), and the pooled standard deviation is (S) defined as:

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

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

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

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. The variance of Hedges'd (V_d) is described as follows:

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

The cumulative effect size (d ++) was formulated as follows:

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

where: Wi – the inverse of the sampling variance: Wi = 1/vd. The precision of the effect size was described using a 95% confidence interval (CI), i.e. d ± (1.96 × SD). All the above equations were derived from the study of Sánchez-Meca and Marín-Martínez (2010). The calculated effect size was statistically significant if CI did not reach a null effect size.

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

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

Q represents the weighted sum of squares, df denotes degrees of freedom, and C is a constant. The meta-analysis for performance variables was conducted using OpenMEE Software (Wallace et al., 2016), and a cumulative forest plot with a 95% confidence interval (CI) was generated using MedCalc Software (2024).

To address potential publication bias resulting from omitted studies, a fail-safe number (Nfs) was computed following Rosenthal's (1979) method. An Nfs value exceeding 5N + 10, where N is the smallest sample size among the individual studies, indicates robustness against such bias.

RESULTS

The data from all literature sources were summarized and inputted into the data table. Descriptive statistics and parameters were subsequently utilized to create Tables 1 and 2. Inconsistent research and small studies cast doubt on reliability, potentially due to publication bias favoring positive results. A fail-safe number (Nfs) identifies trustworthy studies for conclusions. Nfs represents the extra sample size needed to weaken initial findings to non-significance. Studies with Nfs exceeding 5 times the initial effect size (N) plus 10 are considered robust and included in the conclusions (DerSimonian and Laird, 1986).

The fail-safe number criteria identified robust parameters for physical pellet quality (pellet durability index, pellet hardness, and moisture content) and broiler performance (body weight and daily feed intake). However, other measures of broiler performance, like total feed intake, feed conversion ratio (FCR), and carcass yield (total carcass, breast, and thighs), were deemed unreliable. Similarly, the weights of various organs (gizzard, liver, heart, duodenum, jejunum, and ileum) were also considered unreliable.

This analysis assessed variation in study results (heterogeneity) using three methods: Q statistic, τ^2, and I^2. The Q statistic combined the squared differences between each study's effect and the overall average effect. τ^2 represented the estimated variation across all studies, while the I^2 index quantified the portion of this variation not explained by the analysis.

The results showed differing levels of variation between variables. Some, like pellet quality, broiler performance, and intestinal organs, consistently had high variation (indicated by a Q statistic exceeding available comparisons, Nc-1). This variation likely stemmed from several factors, including the number of studies included, the differences in effect sizes between studies, and the variation within each study. In this case, the analysis suggests factors like the type of binder used, any additional treatments applied, and the specific methods of pellet production and processing might have contributed to the variation.

Table 1 Articles included in the meta-analysis

No.	Reference	Binder type	Binder level (%)	Combination treatment	Animal	Periode
1	(Evan et al., 2021)	Dry calcium lignosulfonate), liquid cane molasses), commercial liquid molasses, and commercial liquid lactose blends.	0 - 0.5	-	-	-
2	(Abadi et al., 2019a)	Bentonite, sugar beet molasses	0 - 2	1 % molasses	Broiler	Finisher
3	(Abadi et al., 2019b)	Bentonite, Calcium lignosulfonate, Soybean Oil, Calcium fat powder	0 - 3	1.5-3% fat	Broiler	Finisher
4	(Pour et al., 2021)	Activated sodium bentonite	0 - 1.5	2-4 (min) conditioning	Broiler	Grower
5	(Corey et al., 2014)	Calcium lignosulfonate	0 - 1	1-3% fat	Broiler	Finisher
6	(Tabil et al., 1997)	Collagen protein, Hydrated lime, Lignosulfonate, Bentonite, Pea starch	0 - 1	-	-	-
7	(Nurshahida et al., 2021)	S. polycystum, K. alvarezii (seaweed)	0 - 10	-	Broiler	Starter, Grower
8	(Abdollahi et al., 2012)	Commercial	0 - 0.3	Heat treatments 60^{0}Cand 90^{0}C	Broiler	Starter, Grower, Finisher
9	(Pappas et al., 2014)	Bentonite	0 - 1	Mycotoxin	Broiler	Starter, Grower, Finisher
10	(Saleh et al., 2021)	Wheat middlings, calcium lignosulfonate	0 - 4	-	Broiler	Grower, Finisher
11	(Dorrani, 2023)	Fat powder, Soybean oil	0 - 6	-	Broiler	Grower, Finisher
12	(Medany et al., 2021)	Calcium lignosulfonate	0 - 0.8	-	Broiler	Starter, Finisher
13	(Gao et al., 2020)	Gelatin, Carboxymethyl cellulose	0 - 5	-	-	-
14	(Gopar et al., 2022)	Molasses, Bentonite	0 - 5	-	-	-
15	(Brika et al., 2009)	Seaweed	0 - 3	-	-	Finisher
16	(Wecker et al., 2018)	Lignosulfonate	0 - 0.6	Pasta by product	-	Finisher
17	(Acar et al. 1990)	Calcium Lignosulfonate	0 - 1.25	-	Broiler	Grower
18	(Abdelaziz, 2020)	Calcium Lignosulfonate	0 - 0.8	-	Broiler	Starter, Grower, Finisher
19	(Damiri et al., 2011)	Bentonite	0 - 3.75	-	Broiler	Starter, Grower
20	(Moradi et al., 2019)	Sodium bentonite, wheat gluten	0 - 20	-	Broiler	Starter, Grower, Finisher
21	(Besseboua et al., 2019)	Sodium bentonite	0 - 5	-	Broiler	Finisher

Table 2 Summarizes of meta-database from articles

Variable	Unit	N	Control				Treatment			
			Max	Min	Mean	SD	Max	Min	Mean	SD
Pellet Quality										
Durability index	%	119	93.90	35.20	67.84	16.71	96.10	31.20	77.15	19.57
Hardness	Newton	41	5.52	3.31	3.96	0.82	7.70	1.80	4.60	1.440
Moisture content	%	78	9.20	6.20	7.70	1.03	9.30	5.50	7.40	1.098
Broiler performance										
Body Weight (BW)	g/bird	95	2697.00	188.00	1559.99	677.39	2745.00	176.00	1575.33	694.51
Daily Feed Intake	g/bird/d	115	206.67	23.14	109.07	52.81	230.00	24.00	114.65	58.10
Total Feed Intake	g/bird	115	4390.00	162.00	2016.22	1292.45	4472.00	168.00	2003.10	1296.05
FCR		107	2.49	1.14	1.68	0.34	2.80	1.14	1.67	0.35
Carcass yield										
Total Carcass (TC)	% BW	29	72.26	57.53	66.81	5.61	74.15	57.53	67.00	4.63
Breast Meat	% TC	30	25.17	20.48	22.58	1.63	27.40	17.70	22.33	2.11
Thigh	% TC	30	31.00	17.29	20.17	4.99	34.30	17.07	34.30	4.98
Organ's weight										
Gizzard	g/100g	39	3.39	0.87	1.56	0.82	3.94	0.22	1.55	1.05
Liver	g/100g	50	3.04	1.77	2.49	0.41	3.28	1.11	2.33	0.45
Heart	g/100g	24	0.66	0.44	0.56	0.09	0.75	0.44	0.57	0.08
Duodenum	g/100g	21	18.00	6.38	10.63	4.60	13.5	6.41	9.44	2.18
Jejunum	g/100g	21	27.25	15.00	23.02	5.26	57.53	66.81	5.61	3.83
Ileum	g/100g	21	23.40	13.44	17.89	4.69	27.10	12.62	16.82	4.04

Note: FCR= feed conversion ratio; Max= maximum value from the data; Min= minimum value from the data; N = number of observed variables; SD= standard deviation

Table 3 summarizes the findings of a large-scale analysis (meta-analysis) that examined the effects of adding binders to pellets. The analysis looked at various aspects of the pellets themselves (durability, hardness, moisture content) and how they impacted the broilers that consumed them (feed intake, weight gain, feed conversion ratio, carcass yield of different cuts, and organ weights). Figure 2 shows the Forest plot of the effect of binders on pellet quality, moisture, broiler performance, carcass yield, and organ weight.

The results indicated that binders significantly (P <0.01) enhanced the physical properties of the pellets, including durability, hardness, and moisture content. However, the presence of binders did not significantly impact broiler performance metrics such as feed intake, weight gain, and feed conversion ratio, nor did it affect carcass yield (total yield, breast meat, and thigh meat). Similarly, there were no significant differences in the weights of various organs, including the gizzard, heart, and intestines, between birds fed pellets with and without binders. The exception was the liver, which was significantly (P <0.01) smaller due to binder application.

Table 3 Effects of binder addition on pellet quality, performance, and organ weight

Variables	N	Estimate	Lower bound	Upper bound	Std. error	p-Value	τ^2	Q	Het. p-Value	I^2
Pellet Quality										
Durability index	119	1.54	1.06	2.03	0.25	< 0.01	5.21	915.09	<0.001	87.11
Hardness	41	0.50	0.24	0.75	0.13	<0.01	0.45	131.05	<0.001	69.48
Moisture content	78	0.99	0.57	1.40	0.21	<0.01	2.60	367.43	<0.001	79.04
Performance										
Body Weight	95	-0.07	-0.47	0.33	0.20	0.73	2.92	626.72	< 0.001	85.00
Intake Daily Feed	115	0.13	-0.07	0.33	0.10	0.19	0.67	286.03	<0.001	60.14
Total Feed Intake	115	-0.19	-0.52	0.14	0.17	0.26	2.40	628.99	<0.001	81.88
FCR	107	0.09	-0.09	0.28	0.10	0.33	0.48	218.21	<0.001	51.42
Carcass yield										
Total Carcass	29	-0.15	-0.38	0.09	0.12	0.22	0.02	29.14	0.41	3.92
Breast Meat	28	-0.14	-0.38	0.11	0.12	0.28	0.00	19.48	0.85	0.00
Thigh	30	0.19	-0.04	0.41	0.16	0.11	0.00	18.40	0.94	0.00
Organ's weight										
Gizzard	39	-0.05	-0.25	0.15	0.10	0.64	0.00	28.85	0.86	0.00
Liver	50	-0.29	-0.48	-0.09	0.10	<0.01	0.00	45.11	0.63	0.00
Heart	24	0.00	-0.52	0.25	0.13	1.00	0.00	12.96	0.95	0.00
Duodenum	21	0.21	-0.38	0.80	0.30	0.49	1.49	92.68	<0.001	78.42
Jejunum	21	-0.62	-1.30	0.07	0.35	0.08	2.08	113.30	<0.001	82.35
Ileum	21	-0.14	-0.69	0.42	0.28	0.63	1.27	83.16	<0.001	75.95

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

DISCUSSION

Pellet durability index (PDI) and hardness

The Pellet Durability Index (PDI) and hardness measure the durability and strength of pellets. Several factors affect the PDI, including ingredients, particle size, processing, moisture, steam, and conditioning temperature (Tillman et al., 2020; Vakili, 2023), as well as feed formulation (Buchanan et al., 2010). Optimal PDI can be achieved when the feed ingredient particle size is around 650 microns (Mores et al., 2020). The results are even better if the pelleting process is performed at a temperature of 85°C for 20 seconds in the conditioning chamber (dos Santos et al., 2020). Another factor influencing PDI is the addition of fat. Abadi et al. (2019a) reported that adding 1.5% fat during processing in the mixer produced the best PDI for broiler diets. A common ingredient used in feed formulations to improve PDI is a pellet binder. Pellet binders such as lignosulfonates, bentonite, starches, and fat improve PDI and hardness by enhancing the cohesiveness of the feed particles. High PDI and hardness indicate that pellets are strong and can withstand handling, transportation, and storage without breaking apart. This ensures that the nutritional content of the feed remains consistent and reduces waste due to pellet degradation (Abdollahi et al., 2013; Abadi et al., 2019a).

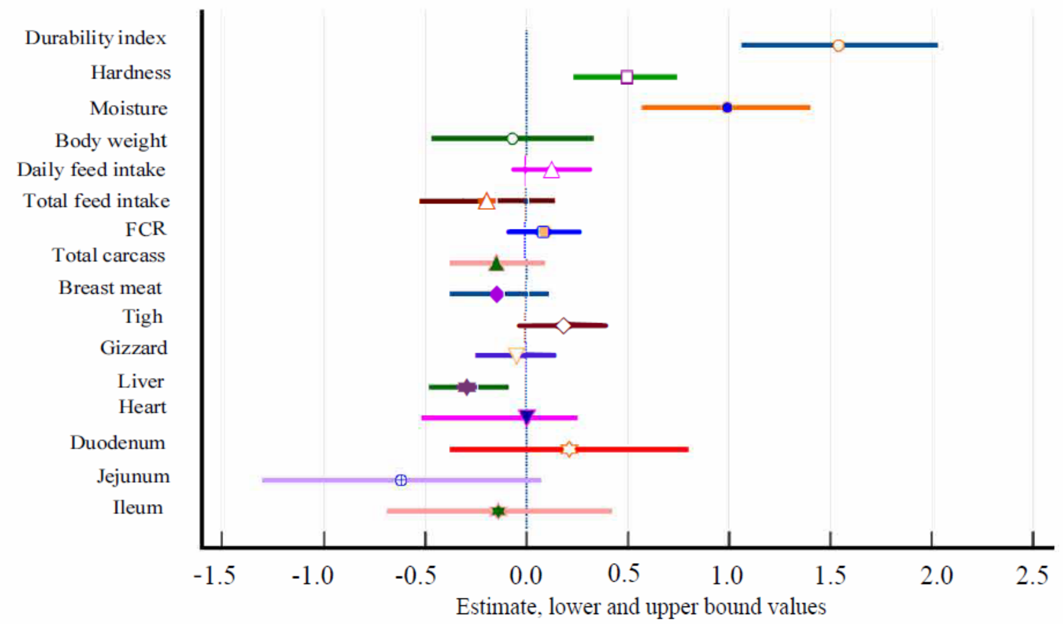

Figure 2 Forest plot of the effect of binders on pellet quality, moisture, broiler performance, carcass yield, and organ weight.

Meta-analysis results showed that adding binders significantly increased both PDI (pellet durability index) and hardness (P <0.01). These results are in agreement with Abadi et al. (2019a), who used 2% bentonite as a binder. Abdollahi et al. (2012) also reported that supplementing feed formulations with pellet binders can increase the PDI value, regardless of whether the feed is processed at 60° or 90°C. Other studies have also reported that adding and increasing the level of pellet binders in feed formulations can improve PDI and hardness of pellet feed (Wecker et al., 2018; Saleh et al., 2021; Dorrani and Rezvani, 2023). The increase in PDI and hardness value in broiler pellets with binder addition is due to the binding mechanisms and forces that bind the particles together (Ayoola, 2020).

Each type of binder exhibits distinct properties that enhance the cohesion of pellet particles. Binders such as lignosulfonate, bentonite, and sepiolite significantly improve PDI by dispersing and occupying the pore spaces between particles in the conditioning chamber (Corey et al., 2014; Yalcın et al., 2020; Zhao et al., 2022). Lignosulfonate is a water-soluble fiber derived from plants (Ruwoldt, 2020), while bentonite is a clay that can form fiber structures with other particles (Kawatra and Ripke, 2001), both of which have been shown to improve pellet quality for animal feed. In contrast, sepiolite is a hydrated magnesium silicate used as a binder and anti-caking agent in animal feeds at effective concentrations of up to 2%. Its use improves pellet durability and quality while minimizing dust (Yalcın et al., 2020). In addition, binders such as starch and protein sources improve pellet strength and durability through chemical reactions that alter the nature of the feed mix during the pelleting process, which involves the application of heat and moisture (Ayoola, 2020).

In general, the addition of pellet binders to broiler feed significantly enhances pellet strength, increases bulk density, and reduces dust during production and handling (Abadi et al., 2019a). This reduction in fine particles and dust results in cleaner feed and minimizes feed waste due to unconsumed particles. Moreover, binders contribute to a more uniform appearance and consistency of the pellets, increasing their appeal to broilers. This uniformity also ensures an even distribution of nutrients within each pellet, essential for a balanced diet. By maintaining the structural integrity of the pellets, binders ensure a consistent nutrient mix with each bite, potentially supporting uniform growth and development across the flock (Idan et al., 2023).

Some binders, particularly those containing antioxidants and anti-toxins, can protect the feed from oxidation, nutrient degradation, and harmful toxins (Lee et al., 2023). Oxidation can lead to the breakdown of essential nutrients such as fats, vitamins, and minerals, diminishing the overall nutritional quality of the feed (Boushehri et al., 2021). Anti-toxin binders help to neutralize or adsorb toxins, such as mycotoxins, that can contaminate feed ingredients and pose health risks to animals (Kihal et al., 2022). By incorporating antioxidant and anti-toxin-containing binders, the feed's nutritional integrity is preserved over time, ensuring that animals receive consistent and high-quality nutrition. This protection against nutrient degradation and toxins not only extends the shelf life of the feed but also enhances its effectiveness in supporting animal health and growth (Albarki et al., 2024).

Pellet moisture content

Pellet moisture content refers to the amount of water present in the pellets, expressed as a percentage of the total weight. It is a critical quality parameter in pellet production, especially for animal feed. Meta-analysis results indicated that pellet moisture content increased by binder treatment ($P<0.01$). This finding aligns with the report by Yalcin et al. (2019), which demonstrated that sepiolite supplementation as a pellet binder at a concentration of 1.5% increases the moisture content of concentrate feed. A linear relationship was observed between moisture content and sepiolite dosage, potentially attributable to the rise in steam temperature. In standard pellet production, water is typically introduced in steam form, playing a crucial role in the bonding process during pellet formation (Behnke and Gilpin, 2019). Bentonite exhibits remarkable hygroscopic and expandable properties. Notably, bentonite can absorb water ranging from 8 to 15 times its dry mass, which effectively retards the rate of evaporation from the pellets (Liu et al., 2017). However, not all binders have the capacity to increase the moisture content of pellets. Tabil et al. (1997) reported that the inclusion of the binder did not influence the amount of water steam adsorbed during conditioning.

Variations in the moisture content of feed occur at different stages of the pelleting process. Initially, the moisture content of the feed in mash form ranges from 11% to 13%, contingent on the feed formulation. This content increases from 16% to 17.5% during the conditioning phase (Behnke and Gilpin, 2019). Due to its gaseous state, steam from the boiler is evenly distributed through the feed mash, raising the feed's temperature to 93.3°C. Under these conditions, a thin film of water forms around the feed particles. This water film, combined with the elevated temperature, promotes the binding of particles through a process known as gelatinization (Lee et al., 2000; Cutlip et al., 2008; Zhu et al., 2016). In this state, starch within the feed serves as a binder, with additional binders enhancing the cohesion among pellet particles (Subwilawan et al., 2019).

Finally, moisture loss occurs during the pelleting process, particularly from the mash in the conditioning phase to the hot pellets after exiting the die. Furthermore, the feed experiences the most significant moisture loss during the cooling process in the cooler, which lasts approximately 8 minutes and 30 seconds (Fahrenholz, 2012). The target moisture content of the final product is 11% (Abadi et al., 2019b). Pellets with optimal moisture content exhibit extended shelf life and a reduced likelihood of spoilage during storage. This preservation of feed quality over time minimizes wastage (Peng et al., 2022). Insufficient moisture content can render pellets brittle and prone to crumbling, while excessive moisture can promote mold growth and spoilage, thereby diminishing the nutritional quality of the feed and posing health risks to animals. Maintaining optimal moisture content is crucial for preserving the nutritional integrity of the feed (Zainuddin et al., 2014). Additionally, moisture content influences the palatability of feed, as animals generally prefer feed with a certain level of moisture, which enhances its attractiveness and ease of consumption (Nejad et al., 2017).

Broiler performance

Critical parameters for assessing broiler performance include body weight (BW), feed intake (FI), feed conversion ratio (FCR), and mortality rate. BW, measured in grams at specific intervals such as 7, 14, or 21 days, or at harvest, serves as a primary indicator of growth. FI refers to the quantity of feed consumed by the broiler, typically determined by subtracting the leftover feed from the total provided under ad libitum feeding conditions. The FCR is a crucial metric, representing the efficiency of feed utilization by calculating the ratio of body weight gain to FI; a lower FCR signifies enhanced performance. Mortality rate, expressed as a percentage, indicates the proportion of broilers that do not survive until the end of the rearing period. This discussion focuses on the first three parameters, specifically on the application of binders during the pelleting process.

The meta-analysis indicates that pellet binders may not consistently impact broiler performance measures such as body weight (BW), feed intake (FI), and feed conversion ratio (FCR). These results are consistent with previous reports stating that pellet binders do not increase the body weight of broilers (Acar et al., 1990; El-Medany et al., 2021; Saleh et al., 2021). However, this finding contradicts several reports which mention that binders can increase the BW of broiler chickens (Abdollahi et al., 2012; Abdelaziz, 2021). The inability of pellet binders to increase poultry body weight is believed to be associated with the unchanged feed intake.

Several factors influence FI concerning feed. Firstly, the metabolic energy (ME) content in feed plays a significant role. Massuquetto et al. (2020) stated that the energy level of the diet appears to be related to feed consumption by chickens. The second factor is antinutrients. Commonly phytate is present in the feed due to the high level of feed ingredients coming from cereals origin (Walk and Rama Rao, 2020). The third factor is the bulk density of feed or ingredients. Taylor and Kyriazakis (2021) predicted that bulk characteristics potentially influence feed intake. Similarly, Taylor et al. (2021) provided evidence that the bulk density of feed limits feed intake and performance. Finally, the feed form also influences the FI of broiler chicken. It has been reported that feeding a pelleted diet to broiler chickens increases FI, and weight gain, and improves the feed-to-gain ratio compared to birds maintained on mash diets (Karimirad et al., 2020; Tavakolinasab et al., 2020).

On the other hand, the meta-analysis results indicate that the addition of pellet binders has no significant effect on the FCR of broilers. These results are in line with previous studies that added pellet binders to feed without influencing FCR (Abdollahi et al., 2012; El-Medany et al., 2021). This is likely because the addition of binders does not enhance the nutritional value of the feed, improve the physical characteristics, or alter the chemical structure of the feed in a manner that increases nutrient utilization efficiency.

Pelleting processes have been shown to enhance the feed conversion ratio (FCR), with comparable outcomes observed for both pellet and crumble sizes (El-Medany et al., 2021). Producing robust pellets with minimal fines and breakage reduces feed wastage, thereby improving overall feed efficiency (FE) and lowering feeding costs (Aguado-Giménez, 2020). Conversely, increasing the number of fines in pellets, and reducing whole pellets from 80% to 60%, has been linked to poorer FCR outcomes (McKinney and Teeter, 2004). High baseline pellet quality may mitigate the benefits of binders (Abdelaziz, 2021).

Improved feed conversion ratio (FCR) in broiler-fed pellets is often linked to pre-conditioning methods involving moist heat (steam). Typically, the feed industry employs conditioning temperatures ranging from 80 to 90°C, with a retention time of 25-30 seconds (Aftab et al., 2018). This process is known to enhance starch digestibility (Wang et al., 2023), which serves as a primary energy source in broiler diets (Zaefarian et al., 2015). Additionally, reduced maintenance energy required for broilers to consume a given amount of feed in a shorter period contributes to enhanced feed efficiency with pelleted diets (Aftab et al., 2018). This concept is supported by classical experiments conducted by Jensen et al. (1962) who observed that broilers fed pelleted diets spent significantly less time consuming the same amount of feed, resulting in a 67% reduction in energy expenditure.

However, there is a dearth of literature examining whether enhancements in pellet quality resulting from binder supplementation also lead to reduced feeding time for broilers. Moreover, the type and amount of binder used may not be tailored optimally for specific feed formulations, potentially limiting its efficacy. The overall nutritional composition of the feed, as dictated by its formulation, might exert a more significant influence on broiler performance than the physical quality of pellets influenced by binders (Barekatain et al., 2021). Environmental variables such as housing conditions, temperature fluctuations, and management practices have substantial impacts on broiler growth and could overshadow any subtle benefits derived from binders (Muharlien et al., 2020). Understanding these factors is crucial for accurately assessing the potential effects of pellet binders and for optimizing their application in broiler production.

Although the meta-analysis shows pellet binders did not directly enhance broiler performance, they offer significant economic benefits to the poultry industry. By improving pellet durability and reducing feed wastage, binders lead to cost savings and increased feed efficiency, contributing to overall cost-effectiveness (Supriadi et al., 2020; Abu et al., 2023; Jaelani et al., 2024). Enhanced pellet quality reduces the need for frequent production and distribution, lowering operational costs and potentially boosting profit margins (Abdollahi et al., 2013; Abdelaziz, 2021). Additionally, high-quality pellets that maintain integrity during transport can command a higher market value, giving feed producers a competitive edge and improving profitability in feed manufacturing, despite no direct impact on broiler growth rates (De Jong et al., 2014; Cardeal et al., 2014).

Broiler carcass yield

A meta-analysis has revealed an interesting fact: pellet binders, commonly used in broiler feed, may not significantly impact carcass yields. These binders are primarily additives that enhance the physical quality of the pellets (Peng et al., 2020). By making them more durable and reducing fines (small particles), binders improve feed handling and minimize waste during storage and consumption (Zdanowicz and Chojnacki, 2017). However, despite their benefit to the physical aspects of the feed, binders offer little to no nutritional value. They are inert, meaning they pass through the digestive system without being absorbed, and don't affect nutrient breakdown or absorption in broilers.

The primary purpose of including pellet binders in broiler feed is to improve feed efficiency and minimize waste, not to enhance broiler growth or carcass output (Abdelaziz, 2021). While binders contribute to better feed handling and consistent consumption, their lack of nutritional value means they don't affect the biological processes related to growth and carcass development. Therefore, the decision to use pellet binders should be based on their cost-effectiveness in improving feed quality and reducing waste, not on anticipated improvements in broiler performance or carcass yields (Abdelaziz, 2021).

Broiler relative organ weights

Meta-analysis found that broiler organ weights (including gizzard, heart, duodenum, jejunum, and ileum), remain unchanged due to binder treatment. These results follow the report of Abadi et al. (2019b) who found no differences in digestive tract parameters and intestinal morphology due to pellet binder treatment. The lack of effect of a pellet binder on broiler organ weights, such as the gizzard and small intestine, can be attributed to several potential reasons. Pellet binders are primarily used to improve pellet quality and durability rather than to contribute to the nutritional content of the feed (Zdanowicz and Chojnacki, 2017). If the nutritional composition and digestibility of the feed remain unchanged, the organ weights might not be significantly affected. Additionally, for changes in organ weights to occur, the pellet binder would need to have a metabolic impact on the broilers, which might not be the case.

The primary components of pellet binders, such as lignosulfonates and bentonite, are non-nutritive and do not contribute to intestinal development or health. Consequently, the intestines continue to perform their roles in digestion and nutrient absorption unaffected, as the primary influences on intestinal structure and function are the nutritional and bioactive components of the diet, which remain unchanged by the presence of pellet binders (Ravindran and Abdollahi, 2021).

Furthermore, the specific conditions and design of the experiment can influence the outcomes, including factors such as the duration of the study, the age of the broilers, the type of binder used, and the overall diet composition (Kaushal et al., 2019). There may also be inherent biological variation among individual broilers that can mask the subtle effects of the pellet binder. The gizzard has specific functions related to digestion and metabolism, and if the binder does not interfere with these functions, its weight may remain unchanged (Abadi et al., 2019b). Therefore, the absence of an effect of pellet binders on broiler organ weights could be due to the specific role and function of the binder not interacting significantly with the physiological processes that determine organ size and weight (Lv et al., 2015).

The effect of binders on reducing liver weight might be attributed to their ability to bind mycotoxins and other harmful substances in the feed, particularly when using binders derived from bentonite clay, thereby preventing their absorption in the digestive tract (El-Medany et al., 2021; Saleh et al., 2021;Albarki et al., 2024). This reduction in toxin load decreases the liver's detoxification workload, potentially leading to a smaller liver (Moradi, 2019; Pour et al., 2021; Qutaiba et al., 2021). Additionally, Deng et al. (2023) reported that by reducing the toxin burden, bentonite may contribute to a smaller liver size by lessening the liver's detoxification demands over time.

CONCLUSIONS

The meta-analysis revealed that although pellet binders significantly enhanced the physical attributes of feed, such as increased pellet durability, hardness, and moisture content, they did not impact broiler performance measures including feed intake, body weight, feed conversion ratio (FCR), carcass yield (total carcass, breast, and thighs), or the relative weights of organs such as the gizzard, liver, heart, and intestines (duodenum, jejunum, and ileum). Therefore, pellet binders did not improve efficiency in broiler production. Given these results, the justification for using pellet binders remains unclear, highlighting the need for further research to assess the cost-effectiveness of incorporating pellet binders in broiler diets.

AUTHOR CONTRIBUTIONS

All authors contributed equally.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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