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A Meta-analysis of Fiber Ratio Effects on Growth Performance, Gastrointestinal Traits, and Nutrient Digestibility of Broiler Chickens

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ABSTRACT

Fiber is one of the essential nutrients for broiler chickens. This meta-analysis was carried out to investigate the impacts of fiber fraction ratio on broiler chickens growth performance, digestive characteristics, and nutritional digestibility. The database was compiled from 15 publications reports on the addition of fiber sources in broilers feed. To analyze the effect of acid detergent fiber (ADF) / neutral detergent fiber (NDF) ratio, the mixed model technique was utilized, with ADF/NDF ratio in the feed as a fixed effect and the experiment as a random effect. The ADF/NDF ratio in the feed had no effect on average daily gain, average daily feed intake, and feed per gain ratio in this research. Moreover, a decrease in ADF/NDF ratio in broiler chicken feed increased the relative weight of the gizzard. The relative weight and length of the small intestine and cecum were not affected by the ADF/NDF ratio in the feed. The ADF/NDF ratio in feed enhanced ileal digestibility and total tract apparent retention of most nutrients. The ADF/NDF ratio in the feed had no effect on the jejunal morphology. The minimum ADF/NDF ratio of 0.37 in the feed led to the maximum growth performance, digestive tract development, and optimal nutrient digestibility. In conclusion, controlling the ratio of fiber fraction in broiler chickens feed can improve broiler performance in the non-antibiotic growth promoters era.

Keywords: Broilers chickens, Fiber fraction, Meta-analysis, Performances

INTRODUCTION

The prohibition of antibiotics growth promoters (AGP) in animal feed and antimicrobial resistance has become a global problem over the last three decades. Probiotics, prebiotics, symbiotics, organic acids, enzymes, phytogenics, antimicrobial peptides, hyperimmune egg antibodies, bacteriophages, clay, and minerals are examples of natural ingredients that can be used to replace AGP in broiler chicken feeds (Gadde et al., 2017; Stefanello et al., 2022). Apart from using a natural AGP alternative, Mateos et al. (2012) proposed that using whole grains, manipulating feed particle size, and increasing fiber in the feed could be effective ways to improve broiler chicken performance in the non-AGP era.

Broiler chickens need fiber to improve the function and development of the digestive system (Mateos et al., 2012). The capacity to promote development in broilers is influenced by the physicochemical characteristics and particle size of the used fiber source. The use of fiber sources in broiler feed has been shown to improve the development of digestive organs, enzyme production, and performance, as well as encouraging the formation of beneficial bacteria (Gonzalez-Alvarado et al., 2007; Jimenez-Moreno et al., 2013a; Sacranie et al., 2012). The use of 2-3% fiber sources in broiler feed can help the growth of the gizzards (Mateos et al., 2012; Shivus, 2011). Fiber can increase the digestibility of amino acids in feed by stimulating the synthesis of hydrochloric acid in the proventriculus, which acts as a precursor for the formation of pepsinogen (Svihus, 2014).

The investigation of methods to improve broiler chicken performance in the era of the AGP ban is still ongoing. Optimizing the development of the digestive tract of broiler chickens by including fiber sources in feed has the potential to improve the performance of broiler

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chickens. The purpose of this study was to determine the effect of fiber fraction ratio in broiler chickens' feed and investigate the effect of using fiber on performance, development of the digestive tracts, and nutrient digestibility of broiler chickens.

MATERIALS AND METHODS

Database development

The database was created based on several types of literature that reported the effects of adding fiber sources on the growth performance of broiler chickens, gastrointestinal properties, and nutrient digestibility. Publication types were found using keywords such as "hull", "fiber", "broiler", and "performance" in Science Direct and Google Scholar. A total of 33 journal papers were included. After checking the suitability of the titles and abstracts, 15 articles were entered into the database (Table 1). The inclusion criteria were the English language of the article, the addition of fiber source, and the measured neutral detergent fiber (NDF) and acid detergent fiber (ADF) in the broiler feed. The Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) were followed in this meta-analysis investigation (Moher et al., 2009).

Cellulose, oat hulls, pea hulls, rice hulls, soy hulls, sugar beet pulp, sunflower hulls, wheat bran, and wood were some of the used fiber sources (Table 1). The amount of fiber sources added to the diet varied from 0 (control) to 9%. The assessed variables were growth performance (average daily gain [ADG], average daily feed intake [ADFI], and feed to gain ratio [FG]), gastrointestinal traits (relative organ weight, relative organ length, and pH), and nutrient digestibility (apparent ileal digestibility [AID] and total tract apparent retention [TTAR]).

Data with suitable units of measurement were handled statistically for meta-analysis using a mixed-procedure model (Jayanegara et al., 2019; Hidayat et al., 2021). The PROC MIXED technique was used to execute the analyses in *SAS*® OnDemand for Academics. The ADF/NDF ratio was assigned a fixed impact, whereas the study was assigned a random effect; hence, the analysis contained a random statement. The statistical significance level was set at $p < 0.05$, while the trend level was established at p = 0.05-0.10. The ADF/NDF ratio was regarded as a continuous predictor, and the response variables were regressed using the following mathematical model:

$$Y_{ij}=B_0+B_1X_{ij}+s_i+b_iX_{ij}+e_{ij},$$

Where, Y_{ij} is the dependent variable, B_0 denotes the overall intercept across all studies (fixed effect), B_1 refers to the linear regression coefficient of Y on X (fixed effect), X_{ij} signals ADF/NDF ratio as a continuous predictor, s_i stands for the value of research random effect i, b_i is the effect of random research on the regression coefficient of Y on X in research I, and e_{ij} signals the unexplained residual error.

Table 1. Literature included in the meta-analysis of fiber ratio effects on growth performance, gastrointestinal traits, and nutrient digestibility in broiler chickens

Fiber sources	Inclusion	Reference
Oat hulls	0-3%	Barekatain et al. (2017)
Oat hulls, Soy hulls	0-3%	Gonzalez-Alvarado et al. (2007)
Oat hulls, Soy hulls	0-3%	Gonzalez-Alvarado et al. (2008)
Oat hulls, Sugar beet pulp	0-3%	Gonzalez-Alvarado et al. (2010)
Oat hulls, Sugar beet pulp, Cellulose	0-3%	Jimenez-Moreno et al. (2009)
Oat hulls, Sugar beet pulp, Cellulose	0-3%	Jimenez-Moreno et al. (2010)
Pea hulls	0-7.5%	Jimenez-Moreno et al. (2011)
Oat hulls, Sugar beet pulp	0-7.5%	Jimenez-Moreno et al. (2013ab)
Oat hulls, Rice hulls, Sunflower hulls	0-5%	Jimenez-Moreno et al. (2015, 2019)
Wood	0-1%	Monika et al. (2019)
Oat hulls	0-9%	Scholey et al. (2020)
Wheat bran	0-3%	Shang et al. (2020)

RESULTS AND DISCUSSIONS

The effect of the ADF/NDF ratio on broiler chicken performance

Broiler chickens had 40.59±15.97 g/day ADG, 57.38±27.19 g/day ADFI, and 1.38±0.1 FG in this meta-analysis (Table 2). According to the results of the meta-analysis, the ADF/NDF ratio in broilers feed did not have a negative effect on ADG, ADFI, and FG (Table 3). As the ADF/NDF ratio in the feed reveals the proportion of fiber fraction in the broiler feed; the greater value of the ADF/NDF ratio, and the higher fraction of insoluble fiber (cellulose and lignin). Acid detergent fiber consists of cellulose and lignin, which are the two main components of insoluble fiber (Choct, 2009; Choct, 2015a; Choct, 2015b).

Fiber sources are high in insoluble fiber fractions and may resist enzymatic digestion processes in the digestive system and so they cannot be fermented by bacteria in the digestive tract (Mateos et al., 2012). A soluble fiber fraction is a form of fiber that is quickly fermented and has the potential to increase feed viscosity in the digestive system (Sozcu, 2019). Insoluble fiber promotes the development of the upper part of the digestive systems, such as the gizzard, while soluble fiber may be fermented into organic acid, both of which are advantageous to broiler chicken performance (Svihus, 2014; Shang et al., 2020).

Table 2. Descriptive statistics of the studies included in the meta-analysis of fiber ratio effects on growth performance, gastrointestinal traits, and nutrient digestibility in broiler chickens

Parameter		N	Mean	SD	Minimum	Maximum
Performance	ADG (g/bird/day)	49	40.59	15.97	28.60	95.84
	ADFI (g/bird/day)	46	57.38	27.19	39.30	142.40
	FG	46	1.38	0.10	1.25	1.60
Relative organ weight (g/kg BW)	Proventriculus	39	4.73	0.65	3.20	6.10
	Gizzard	47	17.47	5.95	9.50	32.90
	Liver	42	30.02	5.33	21.2	42.3
	Pancreas	14	3.20	0.31	2.70	3.80
	Small intestine	10	47.97	24.61	21.30	77.60
	Caeca	30	5.01	1.79	3.30	10.40
Relative organ length (cm/kg BW)	Small intestine	33	162.78	46.98	78.80	226.00
	Caeca	24	23.52	2.60	20.10	29.20
pH	Proventriculus	27	4.23	0.50	3.37	5.19
	Gizzard	33	3.28	0.58	2.38	4.78
	Duodenum	11	6.13	0.09	5.96	6.23
Apparent Ileal Digestibility (%)	DM	23	71.27	2.31	66.90	75.30
	OM	21	74.76	2.43	70.70	79.30
	CP	23	76.72	3.08	71.30	83.90
	Ash	10	48.65	4.08	42.30	55.60
	Starch	21	94.39	2.36	90.20	98.00
Total Tract Apparent Retention (%)	DM	33	77.59	2.14	73.50	81.60
	OM	33	82.20	2.11	77.80	86.20
	Soluble Ash	33	41.19	6.70	23.40	53.40
	Nitrogen	33	66.90	2.91	61.30	71.60
	EE	33	88.40	3.45	79.80	93.50
AMEn (Kcal)		33	3177.95	80.79	2974.00	3298.46
Jejunal Morphology	Villus Height (µm)	15	929.53	210.27	719.00	1449.00
	Crypt Depth (µm)	15	11.93	21.53	98.00	186.00
	Villus Height/Crypt Depth	15	8.24	1.87	6.72	14.49

N: Number of the sample, SD: Standart Deviation, ADG: Average Daily Gain, ADFI: Average Daily Feed Intake, FG: Feed to Gain ratio, DM: Dry Matter, OM: Organic Matter, CP: Crude Protein, EE: Ether Extract, AMEn: Apparent Metabolish Energy.

The effect of the ADF/NDF ratio on the digestive system of broiler chicken

The ADF/NDF ratio in feed affects each digestive organ differently (Table 3). An increase in the ADF/NDF ratio had a negative effect on the proventriculus and gizzard relative weight but had no effect on the liver and pancreas relative weights. According to the model, the ideal ADF/NDF ratio for obtaining the best relative weight of the gizzard is 0.41. According to Svihus (2011), proventriculus produces mucous, hydrochloric acid, pepsinogen, and lipases, on the other hand, the main functions of gizzard include increasing digestibility through feed particle size reduction, mechanical-chemical nutrient degradation of feed ingredients, and regulating the flow rate of feed in the digestive tract.

The physicochemical properties of the fiber source added to the feed are thought to stimulate an increase in the relative weight of the gizzard. According to Jimenez-Moreno et al. (2010), broilers fed oat hulls with particle sizes of 386 µm and 462 µm had relative gizzard weights of 2.73% and 3.3%, respectively. Fiber sources are high in lignin and can linger in the gizzard longer, causing the gizzard muscles to work harder to digest it, thereby stimulating better development of the gizzard (Gonzalez-Alvarado et al., 2008).

The ADF/NDF ratio in the feed had no effect on the relative weight or length of the small intestine. These findings contradict those of Kimiaetalab et al. (2018), who found that the fiber supplementation in broiler feed affects the weight and relative length of the small intestine. Dietary fiber helps the maintenance of small and large intestine integrity by strengthening mucosal structure and functions and increasing the population and diversity of commensal bacteria in the gastrointestinal tract (Jha and Mishra, 2021). Maintaining a balance of soluble and insoluble fiber in the small intestine is of utmost importance; in case there is too much soluble fiber, the viscosity will increase and the flow rate of feed in the small intestine will decrease; the addition of non-starch polysaccharide enzymes is expected to reduce the negative effects of this issue. Broiler chickens need some insoluble fiber for fermentation, in this regard, short-chain fatty acid can be utilized by broiler chickens as an energy source.

The weight and relative length of cecum had no effect on the ADF/NDF ratio in the feed. Through the help of bacteria in the cecum, the cecum aids in water and salt reabsorption as well as the fermentation of uric acid and carbohydrates into ammonia and volatile fatty acid (Svihus et al., 2013a; Svihus et al., 2013b). According to Shang et al. (2020), the addition of 3% wheat bran can enhance the population of *Lachnoclostridium* and *Butyricicoccus*, which can have a role in the production of butyric acid in broiler chicken. The proportion of soluble fiber is directly connected to the ratio of ADF/NDF to cecum function since bacteria in the cecum require a particular quantity of soluble fiber for effective fermentation.

The ratio of ADF/NDF in the feed altered the pH of the proventriculus and gizzard, while the ratio of the fiber fraction in the feed did not affect the pH of the duodenum (Table 3). To create a low pH gizzard, the minimal ADF/NDF ratio in the feed is 0.37. Changes in pH are closely related to the proventriculus and gizzards' increased ability to produce hydrochloric acid, which acts as a precursor for the enzyme pepsinogen (Svihus, 2011) and increases the reflux mechanism between the proventriculus-gizzard and gizzard duodenum resulting in a more optimal level of nutrient digestibility (Hetland et al., 2004).

Jejunal morphology (villus height, crypt depth, and villus height/crypt depth ratio) was unaffected by the ADF/NDF ratio in the feed (Table 3). Monika et al. (2019) reported that increasing the lignocellulose content in the feed causes shortness of jejunal crypt. The use of pea hull as a fiber source up to 7.5% in the feed can minimize the villus height and crypt depth (Jimenez-Moreno et al., 2011). This finding suggests that each organ requires a distinct type of fiber than the others. It is hypothesized that broiler chickens require a suitable composition of soluble fiber, which can function as a prebiotic to support improved intestinal health, in order to produce better jejunal morphology.

The effect of the ADF/NDF ratio on the nutrient digestibility of broiler chickens

The apparent ileal digestibility (AID) of dry matter (DM), organic matter (OM), and Ash, as well as the total tract apparent retention (TTAR) of DM, soluble ash, nitrogen (N), and ether extract (EE), were affected by the ADF/NDF ratio in feed (Table 3). The maximal ADF/NDF ratio values for producing AID DM, OM, and Ash were 0.44, 0.43, and 0.49, respectively, whereas TTAR DM, soluble ash, N, and EE were 0.46, 0.45, 0.44, and 0.51, respectively. The amount of digesta viscosity in the digestive system is related to the fiber ratio in feed. The higher the soluble fiber fraction in the diet, the higher the viscosity, and the lower the amount of nutritional digestibility. Maintaining a balance between the quantity of insoluble fiber and soluble fiber in the feed reduces viscosity, allowing the feed to be digested more easily (Nursiam et al., 2021).

Apparent metabolizable energy (AMEn) was unaffected by the ADF/NDF ratio in the feed (Table 3). The improved DM and nitrogen digestibility in broilers given more fiber in the feed was strongly tied to proventriculus and gizzard's capacity to produce hydrochloric acid, which functions as a precursor for the enzyme pepsinogen (Svihus, 2011). According to Hetland et al. (2003), adding fiber sources, such as oat hulls can boost bile acid production and amylase enzyme activity. Jimenez-Moreno et al. (2019) reported that the increased levels of fat digestibility in broiler chickens fed oat hulls, sunflower hulls, and rice hulls as a source of fiber in the feed were 89.4%, 89.35%, and 89.9%, respectively, compared to 87% in the control groups.

Table 3. The effect of fiber fraction ratio on growth performance, gastrointestinal traits, and nutrient digestibility in broiler chickens

Respon Parameter	N	Model	Intercept	SE intercept	Slope	SE slope	p-value	RMSE	R^2	AIC
Performance										
ADG (g/bird/day)	49	L	42.168	5.749	4.193	3.332	0.216	3.559	0.994	248
ADFI (g/bird/day)	46	L	61.684	10.028	4.729	3.995	0.245	4.265	0.997	252.4
Feed/Gain Ratio	46	L	1.415	0.042	-0.046	0.072	0.532	0.079	0.918	-135.2
Relative organ weight (g/Kg BW)										
Proventriculus	39	L	5.521	0.407	-1.878	0.802	0.026	0.751	0.825	48.5
Gizzard	47	Q	1.504	7.294	82.846 -100.11	32.851 37.090	0.011	9.512	0.701	260.3
Liver	42	Q	31.799	4.088	-11.678 12.216	16.129 16.822	0.473	3.145	0.954	171.2
Pancreas	14	Q	4.894	1.894	-8.691 10.383	9.916 12.658	0.433	0.524	0.519	-1.2
Small Intestine	10	L	31.163	17.112	21.286	14.034	0.18	8.424	0.985	56.7
Caeca	30	L	5.907	0.936	-1.777	1.14	0.134	0.882	0.968	60.1
Relative organ length (cm/Kg BW)										
Small Intestine	33	Q	151.34	22.592	43.492 -50.411	59.718 71.292	0.486	12.92	0.990	221.5
Caeca	24	L	24.697	2.011	-3.003	3.837	0.444	2.386	0.886	80
pH										
Proventriculus	27	L	3.744	0.374	1.263	0.618	0.054	0.472	0.877	10
Gizzard	33	Q	4.515	1.117	-7.127 9.513	4.994 4.978	0.098	0.883	0.697	38.3
Duodenum	11	Q	5.443	0.735	4.416 -6.255	3.906 4.978	0.249	0.228	0.148	-19.9
Apparent Ileal Digestibility (%)										
DM	23	Q	57.51	6.538	70.029 -79.696	28.3 30.243	0.018	5.253	0.335	86
OM	21	Q	63.664	7.187	58.331 -68.482	31.325 33.575	0.059	5.475	0.322	80
CP	23	Q	71.961	7.326	31.145 -39.25	30.125 31.559	0.232	4.381	0.74	91.2
Ash	10	Q	5.676	23.529	199.76 -204.34	90.326 80.125	0.044	8.45	0.445	32.5
Starch	21	Q	86.428	7.36	39.435 -44.171	31.986 34.23	0.216	5.146	0.364	80.8
Total Tract Apparent Retention (%)										

DM	33	Q	69.812	4.318	35.335	19.612	0.093	3.809	0.574	121.7
					-38.425	21.977				
OM	33	Q	80.205	4.209	9.79	19.104	0.57	3.461	0.64	120.3
					-12.34	21.406				
Soluble Ash	33	Q	5.268	12.901	168.2	58.184	0.009	12.153	0.541	188.2
					-186.54	65.125				
Nitrogen	33	Q	51.585	6.258	74.197	28.739	0.016	6.05	0.411	142.7
					-83.941	32.266				
EE	33	Q	74.383	3.76	59.715	16.434	0.004	3.457	0.856	116.8
					-59.002	18.353				
AMEN (Kcal)	33	Q	2901.79	168.76	1168.02	769.41	0.185	145.682	0.562	341.2
					-1178.38	862.74				
Jejunal Morphology										
Villus Height (μm)	15	L	845.2	269.49	261.8	538.36	0.636	250.816	0.814	167.4
Crypt Depth (μm)	15	L	145.06	34.931	-72.016	81.359	0.395	48.109	0.346	119.8
Villus Height/Crypt Depth	15	Q	-4.269	13.888	64.238	70.027	0.381	4.314	0.3	46.1
					-78.818	86.008				

N: Number of sample, SE: Standard error, RMSE: Root Mean Standard error; AIC: Akaike information criterion, ADG: Average Daily Gain, ADFI: Average Daily Feed Intake, FG: Feed to Gain ratio, DM: Dry Matter, OM: Organic Matter, CP: Crude Protein, EE: Ether Extract, AMEn: Apparent Metabolish Energy, L: Linear, Q: Quadratic.

CONCLUSION

In conclusion, broiler chickens require a certain amount of fiber to support optimal growth. The ADF/NDF ratio in the feed should be kept at a minimum of 0.37 to achieve high growth performance, digestive tract development, and optimal nutrient digestibility. Each fiber fraction has a unique impact on the function and growth of the digestive tract. Therefore, it is critical to consider the balance of each fiber fraction in order to promote health, nutritional digestibility, and welfare in broiler chickens.

DECLARATION

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Competing interest

The authors declare no conflict of interest.

Authors' contribution

Intan Nursiam contributed to data mining, building a database, data analysis, and preparing the manuscript. Muhammad Ridla, Nahrowi Nahrowi, Widya Hermana, and Anuraga Jayanegara contributed to the design and supervision of the research, the analysis of the results, and the writing of the manuscript. All authors read and approved the final version of the manuscript to publish in the present journal.

Ethical consideration

All authors have checked the ethical issues, including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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