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Effects of Xylanase Supplementation on the Performance, Nutrient Digestibility, and Digestive Organ Profiles of Broiler Chickens: A Meta-analysis

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ABSTRACT

Enzymes supplementation in broiler feeding is commonly applied to optimize animal feed utilization and reduce feed production costs. One of the enzymes widely used in the broiler industry is xylanase which breaks down complex fibrous compounds in feed, such as nonstarch polysaccharides, to simpler utilizable sugar molecules. However, the effects of xylanase enzymes on broiler growth performance, nutrient digestibility, and organ function in broiler chickens were variable and inconclusive. Therefore, the current study aimed to evaluate the effect of the xylanase enzyme in feed on the performance, nutrient digestibility, and digestive function of parrots using a meta-analysis approach. A dataset of 140 points obtained from 53 articles was analyzed using a mixed model methodology. The results showed that the xylanase enzyme supplementation increased the broiler's body weight gain and decreased feed consumption and feed conversion ratio. In addition, xylanase supplementation also increased nutrient digestibility, such as dry matter, crude protein, starch, gross energy, fat, phosphorus, and calcium. Concerning broiler organ weights, the xylanase supplementation in broiler feed significantly reduced the weight of the duodenum, small intestine, and relative length of the duodenum, jejunum, and ileum. Xylanase supplementation also tended to reduce the relative weight of the proventriculus. The results also showed a negative response to the crypt depth ileum of broiler due to xylanase supplementation. It can be concluded that xylanase supplementation improves the performance, nutrient digestibility, and digestive function of broiler chickens.

Keywords: Broiler chickens, Nonstarch polysaccharide, Performance, Xylanase enzyme

INTRODUCTION

The utilization and efficiency of feeds are critical factors for improving the performance and production rate in the livestock industry, including the broiler chicken (Masey-O'Neill et al., 2014). High fiber content in feedstuffs is a major issue in broiler chicken feeding that affects feed utilization and efficiency (Liu and Kim, 2017). Hence, it is difficult to optimize the expected result of broiler production due to the inability of broiler chickens to utilize feed compounds and increased production costs resulting from low feed efficiency (Liu and Kim, 2017).

Some dietary interventions have been applied to increase feed nutritional values and improve livestock production efficiently (Hidayat et al., 2021). Researchers' interests are currently focusing on enzyme utilization supplemented in the ration to increase feed nutritional values and reduce livestock production costs (Francesch et al., 2012). For instance, nonstarch polysaccharide (NSP), a complex fiber compound in feedstuff, is difficult to digest properly by monogastric animals, such as poultry (Craig et al., 2019). The insufficient ability of poultry to digest NSP compounds is due to the lack of specific enzymes in their digestive tract that can dissolve undigestible fiber bounds like NSP, especially in broiler chickens. Hence, some studies reported utilizing the xylanase enzyme in the broilers' ration to increase broiler chickens' feed nutritional values and digestibility (Gonzalez-Ortiz et al., 2017; Lee et al., 2019). Xylanase is an enzyme that can dissociate plant cell walls and reduce hemicellulose integrity and the viscosity of feed consumed in the broiler digestive system. Thus, the released feed nutrients may be optimally utilized and improve broilers' performance (Gonzalez-Ortiz et al., 2017).

Besides reducing the viscosity of intestinal contents, the xylanase enzyme is also known to possess the growth-promoting effect and appears to be partly related to the modulation of gut microflora (Craig et al., 2019). Such improvement may increase the feed efficiency of broiler chickens (Sarangi et al., 2016). However, studies concerning the effects of xylanase on broiler chickens' performance, nutrient digestibility, and digestive organs are varied and remain inconclusive (Olukosi et al., 2020). It is necessary to summarize the published data to determine the effects of xylanase on broiler chickens. Therefore, the current study evaluated the impact of dietary xylanase supplementation on broiler chickens' performance, internal organs, and nutrient digestibility by summarizing research data from various published articles.

MATERIALS AND METHODS

Database development

The database was built from published articles related to the study of the xylanase utilization on broiler chickens. Articles were obtained from Scopus, Google Scholar, NCBI, and Science Direct search engines using "xylanase", "performance", "fiber", and "broiler chicken" keywords. Articles that were included in the database must accede to the following criteria. They described experiments on broiler chickens, treatments were based on the levels of xylanase supplementation in basal feeds, and they must include data about broilers' growth performance (feed intake and daily gain), organ weight and/or internal organ morphometrics, and the articles were written in English. Data from these articles were rigorously selected to be included in the database following some selection stages (Figure 1).

A total of 140 data points representing treatments from 53 articles were included in the database (Table 1). Articles expressed the xylanase supplementation unit as the international unit (IU) values were homogenized and expressed as per 1000 IU (n / 1000 IU). The data included performance parameters (body weight gain, feed consumption, feed conversion ratio [FCR]), nutrient digestibility (dry matter [DM], gross energy, fat, starch, crude protein [CP], phosphorus, calcium digestibility), relative weight of internal organs and digestive tract (proventriculus, liver, pancreas, gizzard, duodenum, jejunum, ileum, small intestine, cecum), relative lengths of the duodenum, jejunum, ileum, cecum, and intestinal morphometrics (villus height [VH], crypt depth [CD], and VH: CD of the duodenum, jejunum, and ileum). Data expressed in different units were converted and adjusted into that of specified units to allow direct analysis within specified parameters. The statistical summary of the database included in the meta-analysis study is presented in Table 2.

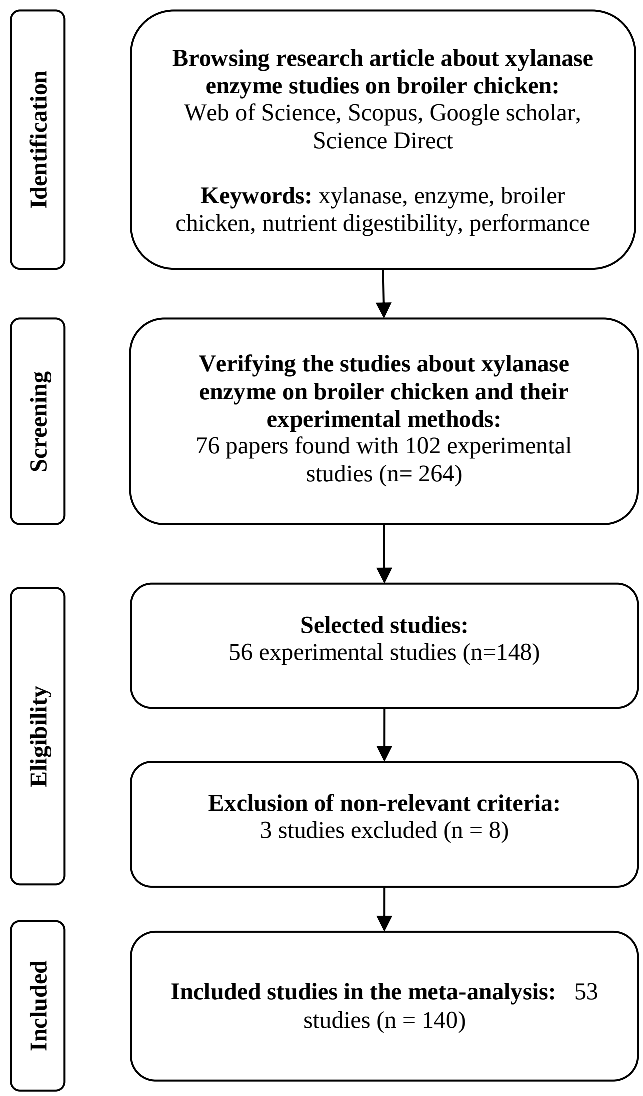

Figure 1. Selection of studies related to the effect of xylanase enzyme on broiler chickens

Table 1. The selected and used studies on the effects of dietary supplementation of xylanase on the performance, nutrient digestibility, and digestive organ profiles of broiler chickens

No.	References	Period (day)	Basal feed	Broiler sex	Xylanase dosage (10^3 IU/kg DM feed)		
1	Selle et al. (2003)	4-24	Wheat	Male	0	-	5.49
2	Wu and Ravindran (2004)	1-35	Wheat	Male	0	-	1.00
3	Wu et al. (2004)	1-21	Wheat	Male	0	-	1.00
4	Wu et al. (2004)	1-21	Wheat	Male	0	-	1.00
5	Olukosi et al. (2007b)	1-21	Wheat	-	0	-	32.0
6	Amerah et al. (2008)	1-21	Wheat	Male	0	-	1.00
7	Woyengo et al. (2008)	1-21	Wheat	Male	0	-	2.50
8	Yang et al. (2008)	8-21	Wheat	-	0	-	1.00
9	Amerah et al. (2009)	1-21	Wheat	Male	0	-	1.00
10	Lu et al. (2009)	1-35	Corn	Male	0	-	2.00
11	Luo et al. (2009)	1-22	Wheat	Male	0	-	5.00
12	Cowieson et al. (2010)	1-22	Corn	Male	0	-	16.0
13	Liu et al. (2011)	22-42	Corn	Mixed	0	-	3.60
14	Nian et al. (2011)	1-30	Wheat	Male	0	-	4.00
15	Walk et al. (2011)	1-18	Corn	Male	0	-	1.20
16	Amerah et al. (2012)	1-22	Wheat	Male	0	-	2.00
17	Esmaelipour et al. (2012)	1-24	Wheat	Male	0	-	1.00
18	Liu et al. (2012)	1-21	Wheat	Male	0	-	5.50
19	Masey-O'Neill et al. (2012)	1-18	Corn	Mixed	0	-	16.0
20	Singh et al. (2012)	1-22	Corn	Male	0	-	16.0
21	Barekatain et al. (2013a)	1-35	Corn	Male	0	-	1.00
22	Barekatain et al. (2013b)	1-21	Corn	Male	0	-	1.00
23	Cowieson and and Masey O'neill (2013)	1-49	Wheat	Male	0	-	16.0
24	Gehring et al. (2013)	1-25	Corn	Female	0	-	32.0
25	Kiarie et al. (2014)	1-22	Wheat	Male	0	-	1.25
26	Masey-O'Neill et al. (2014)	1-49	Corn	Male	0	-	32.0
27	Zhang et al. (2014)	7-21	Wheat	Male	0	-	3.20
28	Pirgozliev et al. (2015)	7-21	Soybean meal	Male	0	-	2.00
29	Gonzalez-Ortiz et al. (2016)	1-24	Wheat	Male	0	-	16.0
30	Kim et al. (2016)	14-35	Corn	Male	0	-	6.00
31	Amerah et al. (2017)	1-22	Corn	Male	0	-	2.00
32	dos Santos et al. (2017)	1-24	Sorghum	Mixed	0	-	16.0
33	Gonzalez-Ortiz et al. (2017)	1-22	Wheat	Male	0	-	16.0
34	Kiarie et al. (2017)	1-21	Wheat	Male	0	-	5.00
35	Liu and Kim (2017)	1-35	Wheat	Male	0	-	5.63
36	Mabelebele et al. (2017)	1-21	Sorghum	Female	0	-	1.60
37	Pakel et al. (2017)	7-21	Corn	Male	0	-	0.80
38	Tang et al. (2017)	1-22	Barley	Mixed	0	-	16.0
39	Ghayour-Najafabadi et al. (2018)	1-22	Wheat	Male	0	-	1.00
40	Lee et al. (2018)	1-22	Wheat	Male	0	-	16.0
41	Moss et al. (2018)	10-21	Canola	Male	0	-	2.00
42	Widodo et al. (2018)	1-21	Soybean meal	Male	0	-	16.0
43	Arczewska-Wlosek et al. (2019)	1-22	Corn	Male	0	-	1.00
44	Craig et al. (2019)	1-22	Wheat	Male	0	-	32.0
45	Gonzalez-Ortiz et al. (2019)	1-24	Wheat	Male	0	-	16.0
46	Lee et al. (2019)	1-32	Corn	Mixed	0	-	11.3
47	Olukosi and Bedford (2019)	1-28	Wheat	Male	0	-	16.0
48	Craig et al. (2020a)	1-21	Wheat	Male	0	-	16.0
49	Craig et al. (2020b)	1-28	Wheat	Male	0	-	32.0
50	Melo-Durán et al. (2020)	1-21	Corn	Male	0	-	16.0
51	Olukosi et al. (2020)	1-28	Wheat	Male	0	-	16.0
52	Pirgozlive et al. (2021)	7-21	Wheat	Female	0	-	0.10
53	Rabello et al. (2021)	1-49	Corn	Male	0	-	32.0

Table 2. Descriptive statistics of the observed parameters in broiler chickens by using xylanase supplementation in diet

Response Parameters	N	Mean	SEM	Min	Max
Performance and feed intake					
BWG (g/chick)	138	1558	88.5	285	4206
ADG (g/d/chick)	138	50.2	1.71	21.0	124
FI (g/chick)	138	2574	156	551	7502
ADFI (g/d/chick)	138	82.0	3.35	27.0	207
FCR (g/g)	138	1.60	0.02	1.03	2.29
Nutrient digestibility					
DM (%)	46	71.3	0.95	60.4	85.0
CP (%)	35	70.2	1.67	55.5	83.0
Starch (%)	19	77.8	6.64	0.92	98.1
Nitrogen (%)	24	79.0	1.50	64.0	90.0
Fat (%)	15	81.6	2.20	66.0	91.3
GE (%)	33	70.8	1.14	61.3	82.1
Phosphorus (%)	20	46.7	2.13	32.4	66.2
Calcium (%)	18	49.7	3.32	17.8	65.0
Relative weight					
Proventriculus (%)	12	0.40	0.03	0.28	0.59
Liver (%)	20	2.65	0.18	0.93	3.80
Pancreas (%)	22	0.29	0.02	0.14	0.46
Gizzard (%)	31	1.50	0.08	0.87	2.33
Duodenum (%)	30	0.67	0.05	0.42	1.17
Jejunum (%)	30	1.17	0.06	0.75	2.08
Ileum (%)	30	0.95	0.05	0.62	1.74
Small intestine (%)	36	3.40	0.26	1.93	6.90
Cecum (%)	26	0.34	0.03	0.12	0.70
Relative length					
Duodenum (cm/100g BW)	16	2.27	0.14	1.30	3.16
Jejunum (cm/100g BW)	16	6.07	0.37	3.63	7.87
Ileum (cm/100g BW)	16	6.08	0.37	3.71	7.85
Small intestine (cm/100g BW)	16	14	0.87	8.69	18.8
Cecum (cm/100g BW)	22	1.39	0.06	0.88	1.72
Villus Height (VH)					
Duodenum (µm)	22	1257	90.9	772	1949
Jejunum (µm)	30	809	41.5	354	1467
Ileum (µm)	22	626	48.4	355	1142
Crypt Depth (CD)					
Duodenum (µm)	22	249	33.6	56.8	480
Jejunum (µm)	30	204	23.0	38.6	402
Ileum (µm)	22	150	16.4	37.2	257
VH: CD					
Duodenum (µm)	16	5.61	1.51	0.08	18.0
Jejunum (µm)	24	5.68	1.34	0.12	25.5
Ileum (µm)	20	5.58	1.10	0.13	14.5

N: Number

Statistical analysis

The recorded database was processed statistically using the mixed model method with SAS software version 9.1 (St-Pierre, 2001; Sauvant et al., 2008). Different studies were assigned as random effects, and the dose of xylanase enzyme was assigned as a fixed effect following Hidayat et al. (2021) and Yanza et al. (2021b) modification methods, in which the effects of xylanase were assessed to have a relationship with factors, such as type of basal diets (barley, canola meal, corn, sorghum, soybean meal, and wheat) and sex (male and female). The mathematical model used in the present meta-analysis was accomplished as follows:

$$Y_{ij} = \mu + s_i + \tau_j + s\tau_{ij} + B_0 + B_1X_{ij} + B_2X_{2ij} + b_iX_{ij} + e_{ij}$$

Where, Y_{ij} is the dependent variable, µ denotes the average of all data,, s_i signifies the random effect of the i-th trial, τ_j is defined as the fixed effect of the jth-level factor, sτij is the random interaction between the i-th test and the jth-level factor, B_0 indicates the overall intercept in all experiments (fixed effect), B_1 refers to the linear regression coefficient Y on X (fixed effect), X_{ij} suggests the value of the continuous predictor variable (xylanase/1000 IU), b_i is the random effect of the study on the regression coefficient Y on X in the study -i, and e_{ij} show an unexplained residual error.

Due to the qualitative information, the class determination was based on the sex factor and the type of basal diet. Different studies were considered as random effects in the model. The number of replicates in the studies was determined based on the statement of weight available in the SAS as performed by Yanza et al. (2021a). The variables were considered significant at $p < 0.05$ and considered to have a tendency at $0.05 < p < 0.10$.

RESULTS

Supplementation of xylanase enzyme in ration positively affected broiler chickens' growth performance and nutrient digestibility (Tables 3 and 4). The total body weight gain (BWG) and average daily gain (ADG) of broiler chickens increased by a quadratic response ($p < 0.05$). However, xylanase supplementation reduced the broiler chickens' feed consumption when expressed as a total feed intake (FI; $p < 0.05$) and tended to reduce when linearly expressed as an average daily feed intake (ADFI; $p < 0.10$). Consequently, xylanase supplementation in broiler's ration reduced FCR. The effects of xylanase supplementation on FCR interacted with the type of diet ($p < 0.05$).

Xylanase supplementation enhanced nutrient digestibility, such as DM, CP, and starch by a quadratic response ($p < 0.05$). The xylanase supplementation, however, did not alter fat digestibility. Digestibility of phosphorus, calcium, and total gross energy digestibility (GED) were also elevated by xylanase supplementation by a linear response ($p < 0.05$). The effects of xylanase on phosphorus and calcium digestibility interacted with the type of diet ($p < 0.05$).

The present study showed that xylanase supplementation tended to negatively affect proventriculus ($p < 0.10$) in a quadratic manner, which had an interaction with the type of diet ($p < 0.05$; Table 5). Furthermore, the xylanase supplementation negatively affected the weight of the duodenum ($p < 0.05$) and small intestine ($p < 0.05$), in a quadratic and linear manner, respectively. The xylanase supplementation negatively influenced duodenum, jejunum, and ileum lengths in a quadratic manner ($p < 0.05$), while the small intestine length was reduced linearly ($p < 0.05$). The xylanase supplementation did not affect VH, VH: CD ratio of duodenum, jejunum, and ileum, and the CD of duodenum and jejunum (Table 6). However, xylanase supplementation lowered the CD of the ileum in a linear manner ($p < 0.05$).

DISCUSSION

Effects of xylanase on performance and nutrient digestibility of broiler chickens

The inclusion level of the feed ingredients with relatively high polysaccharide content, such as xylan and pentosan, may increase due to the availability of exogenous enzymes used in animal feed (Olukosi et al., 2007a). However, the effects of exogenous enzymes on livestock animals, such as broiler chickens, depend on utilizable nutrients contained in the dietary ration, species, age of the animal, level of antinutrients in feed ingredients, or a combination of these and other factors (Olukosi et al., 2007b). Nonstarch polysaccharide in broiler chicken feed is known to be hydrolyzed using the xylanase enzyme. In addition, it randomly cleaves the arabinoxylan backbone, generating unsubstituted or branched xylooligosaccharides, consequently increasing the polysaccharide substrate's bioavailability (Arczewska-Wlosek et al., 2019; Lee et al., 2017). Recently, results concerning the effects of xylanase on broiler chickens have been varied. Thus, it needs a systematic approach to obtain robust conclusions on several parameters. Hence, the present study was expected to determine the effects of the xylanase supplementation on the critical parameters in broiler chicken nutrition, such as performance (weight gain, feed consumption, and FCR), internal organs, and nutrient digestibility evaluated from published articles.

Xylanase is an exogenous degrading enzyme that can increase broiler chickens' bioavailability of dietary nutrients. The findings of the present study indicated an increased body weight of broiler chickens and decreased FCR, followed by increased levels of xylanase supplementation in feed ingredients. Therefore, it can be assumed that broiler chickens fed with ration supplemented xylanase may improve their performance (Liu and Kim, 2017). Previous studies reported positive effects of xylanase on broiler performance, such as body weight gain, feed intake, and FCR, which further positively increase the nutrient digestibility of broiler chickens (Cowieson, 2010; Kiarie et al., 2014). Xylanase degrades the polysaccharides structure of plant cell walls, especially NSP that is xylan, into xylose and releases other simple sugars or nutrients. Hence, the broiler chickens can readily utilize the released sugars or nutrients for further metabolism (Dornez e al., 2009).

Table 3. The effect of xylanase supplementation (per 1000 IU) on performance and feed intake in broiler chickens

Parameters	N	Model	Parameter estimate					Model statistics		Interaction		Trends
			Intercept	SE Intercept	Slope	SE Slope	P-value	RMSE	AIC	Enzyme × Diet	Enzyme × Sex	↑ / ↓
BWG (g/chick)	138	Q	1518	143	4.92	1.43	<0.001	33.02	1798	NS	NS	↑
					-0.12	0.05	0.022					
ADG (g/chick)	138	Q	49.6	2.77	0.15	0.046	0.001	1.05	820	NS	NS	↑
					-0.003	0.002	0.042					
FI (g/chick)	138	L	2525	253	-1.93	0.82	0.021	48.51	1917	NS	NS	↓
ADFI (g/d/chick)	138	L	81.3	5.47	-0.049	0.028	0.078	1.64	951	NS	NS	↓
FCR (g/g)	138	L	1.61	0.04	-0.003	0.0006	<0.001	0.04	-204	0.044	0.080	↓

BWG: Body weight gain, ADG: Average daily gain, FI: Feed intake, ADFI: Average daily feed intake, FCR: Feed conversion ratio, L: Linear, Q: Quadratic, SE, Standard error, RMSE: Root mean square of errors, AIC: Akaike information criterion, L: Linear response, ↑ / ↓: symbol to indicate increasing/decreasing effect of treatment, The model tends to be significant at $p < 0.1$, significant at $p < 0.05$, NS: Not significant, N: Number

Table 4. The effect of xylanase supplementation (per 1000 IU) on nutrient digestibility in broiler chickens

Parameters	N	Model	Parameter estimate					Model statistics		Interaction		Trends
			Intercept	SE Intercept	Slope	SE Slope	P-value	RMSE	AIC	Enzyme × Diet	Enzyme × Sex	↑ / ↓
DM (%)	46	Q	70.2	1.64	0.34	0.14	0.020	1.71	261	NS	NS	↑
					-0.011	0.004	0.025					
CP (%)	35	Q	69.4	3.11	0.67	0.17	<0.001	0.85	173.4	NS	NS	↑
					-0.026	0.012	0.049					
Starch (%)	19	Q	74.7	11.0	1.16	0.33	0.006	0.80	123	0.008	NS	↑
					-0.067	0.021	0.011					
Fat (%)	15	L	80.7	3.37	0.41	0.69	NS	2.36	94.4	0.019	0.001	↑
GE (%)	33	Q	70.1	1.83	0.44	0.10	<0.001	1.09	165	NS	NS	↑
Phosphorus (%)	20	L	45.2	3.64	0.44	0.12	0.003	1.87	119.7	0.025	NS	↑
Calcium (%)	18	L	46.6	6.29	0.55	0.16	0.005	2.51	117.3	NS	NS	↑

DM: Dry matter, CP: Crude protein, GE: Gross energy, L: Linear, Q: Quadratic, SE: Standard error, RMSE: Root mean square of errors, AIC: Akaike information criterion, ↑ / ↓: symbol to indicate increasing/decreasing effect of treatment. The model tends to be significant at $p < 0.1$, significant at $p < 0.05$, very significant at $p < 0.001$, NS: Not significant, N: Number

Table 5. The effect of xylanase supplementation (per 1000 IU) on relative weight and length of digestive organs in broiler chickens

Parameters	N	Model	Parameter estimate					Model statistics		Interaction		Trends
			Intercept	SE Intercept	Slope	SE Slope	P-value	RMSE	AIC	Enzyme × Diet	Enzyme × Sex	↑ / ↓
Relative Weight (%)												
Proventriculus	12	Q	0.4	0.05	-0.03	0.01	0.088	0.01	-9.7	0.003	NS	↓
					0.002	0.001	0.085					
Liver	20	L	2.59	0.33	0.006	0.007	NS	0.12	23.5	NS	NS	↑
Pancreas	22	L	0.3	0.03	0.00004	0.002	NS	0.02	-55.4	NS	NS	↑
Gizzard	31	L	1.53	0.13	-0.002	0.004	NS	0.11	15.5	NS	NS	↓
Duodenum	30	Q	0.74	0.08	-0.028	0.013	0.048	0.02	-40.1	NS	NS	↓
					0.0018	0.0008	0.044					
Jejunum	30	L	1.24	0.1	0.0006	0.003	NS	0.05	-17	NS	NS	↑
Ileum	30	L	0.99	0.09	0.0022	0.003	NS	0.05	-18.5	NS	NS	↑
Small intestine	30	L	3.48	0.51	-0.021	0.007	0.009	0.11	36.1	NS	NS	↓
Cecum	26	L	0.36	0.06	-0.0002	0.002	NS	0.02	-58.6	NS	0.09	↓
Relative Length (cm/100 g BW)												
Duodenum	16	Q	2.31	0.24	-0.2	0.08	0.042	0.1	25.5	NS	NS	↓
					0.013	0.005	0.04					
Jejunum	16	Q	6.04	0.61	-0.39	0.14	0.024	0.17	43.4	NS	NS	↓
					0.025	0.009	0.024					
Ileum	16	Q	6.07	0.62	-0.42	0.13	0.015	0.17	42.7	NS	NS	↓
					0.026	0.009	0.015					
Small intestine	14	L	15.5	1.4	-0.84	0.35	0.044	0.5	49.4	NS	NS	↓
Cecum	22	L	1.35	0.1	0.001	0.006	NS	0.05	-13.6	NS	NS	↑

BW: Body weight, L: Linear, Q: Quadratic, SE: Standard error, RMSE: Root mean square of errors, AIC: Akaike information criterion, NS: Not significant, N: Number, ↑ / ↓: symbol to indicate increasing/decreasing effect of treatment. The model tends to be significant at $p < 0.10$, significant at $p < 0.05$, very significant at $p < 0.001$, NS: Not significant.

Table 6. The effect of xylanase supplementation (per 1000 IU) on morphometric traits of broiler's digestive tract

Parameters	N	Model	Parameter estimate					Model statistics		Interaction		Trends
			Intercept	SE Intercept	Slope	SE Slope	P-value	RMSE	AIC	Enzyme × Diet	Enzyme × Sex	↑ / ↓
Villus height (VH)												
Duodenum (µm)	22	L	1357	159	3.27	3.58	NS	31.39	252	NS	NS	↑
Jejunum (µm)	30	L	805	79.4	6.06	6.29	NS	57.2	362	NS	NS	↑
Ileum (µm)	22	L	678	85	2.62	3.1	NS	37.78	254	NS	NS	↑
Crypt depth (CD)												
Duodenum (µm)	22	L	233	58.8	-0.25	0.69	NS	6.06	192	NS	NS	↓
Jejunum (µm)	30	L	189	40.8	-1.46	1.23	NS	11.09	283	NS	NS	↓
Ileum (µm)	22	L	144	28.5	-1.08	0.42	0.024	5.12	185.4	0.041	NS	↓
VH: CD												
Duodenum (µm)	16	L	5.08	3	0.03	0.11	NS	0.96	74.1	NS	NS	↑
Jejunum (µm)	24	L	5.69	2.66	-0.02	0.19	NS	1.7	127.4	NS	NS	↓
Ileum (µm)	20	L	5.68	1.99	0.05	0.09	NS	1.08	97.3	NS	NS	↑

L: Linear, Q: Quadratic, SE: Standard error, RMSE: Root mean square of errors, AIC: Akaike information criterion, N: Number; ↑ / ↓: symbol to indicate increasing/decreasing effect of treatment. The model tends to be significant at $p < 0.1$, significant at $p < 0.05$, very significant at $p < 0.001$, NS: Not significant;

However, the efficacy of xylanase to break down NSP structures are different, depending on the type of feed sources and NSP contained in feed materials. For example, poultry prefers to consume cereals that typically have high NSP. However, the polysaccharide composition and the solidness of NSP structural bounds of cereals are different and might influence animal nutrient digestibility (Gonzalez-Ortiz et al., 2017; Bryszak et al., 2020). For example, the corn diet contained 8.7% and 65.2% of NSP and starch, respectively, which is more rapidly digested by the broiler chicken, compared to wheat, which included 10.9% and 65.2% of NSP and starch, respectively (Peron and Amerah, 2012). Therefore, by adding xylanase to both types of feed, broiler chickens' digestibility might increase. However, xylanase seems more effective in dissociating NSP and fiber molecular structures in corn than in wheat. It was studied that broilers fed corn had a higher fiber and phosphorus digestibility than broilers fed with wheat in basal diets (Cowieson et al., 2010; Amerah et al., 2017; Kiarie et al., 2017; Liu and Kim, 2017). According to Bedford (2000), xylanase supplementation can reduce hemicellulose integrity and release previously encapsulated nutrients to improve digestive function and animal performance. However, broiler chicken's feed intake and FCR in the present meta-analysis were reduced by xylanase supplementation. Such xylanase mode of action may increase released nutrients and reduce hemicellulose integrity, and viscosity of feed consumed in the broiler chicken intestines (Kiarie et al., 2014; Khadem et al., 2016). Hence, available nutrients can be optimally absorbed in the broiler chicken hindgut. Nutrient utilization can improve broiler chickens' performance indicated by the increased weight gain and reduced feed intake or simplified by the FCR value (Kiarie et al., 2014).

Results also showed that xylanase supplementation interacted with FCR and fat digestibility in broiler chickens of different sexes. It was reported that the body weight gain, feed intake, and FCR of male chickens were higher than that of female chickens, indicating higher susceptibility of female chickens to disease than males (Ozkan et al., 2010; Quinteiro-Filho et al., 2010; Qurniawan et al., 2016).

The present study indicated that xylanase increased broiler chickens' nutrient digestibility, such as DM, CP, starch, fat, gross energy, phosphorus, and calcium. Kim et al. (2016) explained that adding xylanase to feed ration would increase the accessibility of encapsulated nutrients in the cell wall by demolishing plant cell wall structures through the arabinoxylan degradation. Therefore, it is assumed that xylanase is activated when consumed feed is delivered to the small intestine. Thus, undegraded nutrients in the previous digestive track, with the activated xylanase enzyme, degraded nutrients were readily absorbed in the hindgut. According to Francesch et al. (2012), the xylanase enzyme in poultry feed generally reduces digesta viscosity and increases the digestibility of nutrients. As reported, NSP in wheat may exacerbate endogenous amino acid secretion, suppressing amino acid digestibility (Angkanaporn et al., 1994; Liu and Kim, 2017). Accordingly, xylanase can reduce intestinal viscosity and endogenous amino acid secretion, release trapped nutrients, and increase cell wall permeability to absorb utilizable nutrients (Liu and Kim, 2017).

Effects of xylanase on weights and morphometrics of broiler chicken's digestive organs

In this study, Xylanase supplementation in broiler chicken feed showed no effect on the observed organ weights, such as pancreas, gizzard, jejunum, ileum, and cecum. However, the relative weight of the proventriculus, duodenum, and small intestine as well as the relative length of the duodenum, jejunum, ileum, and small intestine decreased with the xylanase supplementation. However, the present study results showed that high fibrous in feed ration can be digested properly due to exogenous enzymes, such as xylanase. Previous studies revealed that fiber or NSP components in poultry feed ration could influence intestinal development, especially the gizzard, and consequently digestibility (Hetland et al., 2004). Yasar and Forbes (2000) reported that the tissue lining the gizzard and the thickness of the gizzard glands of broiler chickens could be reduced by adding enzymes to the feed. On the contrary, Gonzalez-Ortiz et al. (2017) confirmed that no change in organ size was observed in any organs as measured by xylanase enzyme supplementation. Although gizzard weight slightly decreased due to the xylanase supplementation, it was still in the acceptable weight range.

The excessive fiber in feed ingredients may impact digestive organ size with the increased thickness of the apparent organ layer; thus, the weight of some digestive organs increases. In contrast, the current results found that xylanase may not interfere with liver activity in the detoxification process and negatively affect liver size (Septinar et al., 2021). This study revealed that xylanase positively affects metabolic processes so that the degraded nutrients can be well absorbed in the small intestine. Therefore, the cecum of broilers does not need to be burdened because of the workload of the digestive process, which can affect the size of the cecum. With xylanase supplementation, the indigestible fiber becomes more easily digested. Therefore, increasing digestive metabolism has no detrimental effect on organ function (Sharifi et al., 2012).

Additionally, most organs are believed to work properly even though the xylanase has a detrimental effect on weight and relative length of specified digestive organs as indicated by increased broiler performance and nutrient digestibility in the present study. The xylanase supplementation also reduced ileal CD and increased intestinal VH. According to Mathlouthi et al. (2002), enzyme supplementation increases the mean villi height in broiler chickens. The lack of evidence on organ histological morphometrics could probably be due to the physical and chemical characteristics of the digested fiber in broilers chickens' digestive tracks. Several studies found that xylanase had no effect on intestinal morphology. However, Montagne et al. (2003) and Mateos et al. (2012) stated when broiler chickens were fed a diet high in fiber, fiber molecules were left behind in digestive villi, depending on the physico-chemical characteristics of the fiber in the diet, level of feed consumed, type of animal, the age and health status of the poultry. The effect of xylanase on the weight of proventriculus and CD of ileum also depended on the consumed feed types. Gonzalez-Ortiz et al. (2017) stated that the size of broiler chickens' internal organs and digestive tract is influenced by the type of feed given. Therefore, supplementing broiler chickens' ration with the high amount of fiber compounds influences the weight and morphometric traits of digestive organs because fiber can stimulate the physiological process of digestive organs mechanically and enzymatically.

CONCLUSION

The present study reveals the positive effects of xylanase supplementation on the performance and nutrient digestibility of broiler chickens. Broilers' body weight gain was increased and FCR value was reduced with the xylanase supplementation. However, the xylanase enzyme had no effects on the relative weight of organs (pancreas, gizzard, jejunum, ileum, and cecum) and the relative length of the cecum. Otherwise, xylanase supplementation reduced ileal crypt depth and increased intestinal villus height. Xylanase also interacts with decreasing FCR, increasing the digestibility of nutrients, namely fat, nitrogen, and phosphorus. In addition, it also interacts with reducing proventriculus size based on the type of feed. Xylanase interacts with decreasing FCR, increasing fat digestibility, and decreasing cecum size based on the sex of broilers.

DECLARATION

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Authors' contribution

Sri Rahmani Inayah contributed to data collection, database creation, and preparation of the manuscript. Yulianri Rizki Yanza was also involved in preparing the manuscript and data analysis. Rita Mutia, Anuraga Jayanegara, and Sri Amnah guided the research, data analysis, and manuscript preparation. All authors read and approve the final manuscript for publication in the current journal.

Competing interests

The authors declared that there is no competing interest.

Ethical consideration

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

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