Pakistan Veterinary Journal

ISSN: 0253-8318 (PRINT), 2074-7764 (ONLINE)
DOI: 10.29261/pakvetj/2026.244

RESEARCH ARTICLE

Effects of Different Fiber Sources on Growth Performance, Gut Health, Nutrient Digestibility, Digesta Characteristics and Cecal Microbial Population in Broilers

CH Ahsan Akram[1,3], Shafqat Nawaz Qaisrani*[1], Saima[1] and Sohail Ahmad[2]

[1]Department of Animal Nutrition, [2]Department of Poultry Production, University of Veterinary and Animal Sciences, 54000, Lahore, Pakistan; [3]Department of Livestock and Poultry Production, Faculty of Veterinary Sciences, Bahauddin Zakariya University, 60800, Multan, Pakistan.
*Corresponding author: shafqat.qaisrani@uvas.edu.pk

ARTICLE HISTORY (26-833)

Received: July 11, 2026
Revised: October 07, 2026
Accepted: October 11, 2026
Published online: November 03, 2026

Key words:
Broiler
Growth performance
Maize bran
Soybean hulls
Sugar beet pulp
Wheat bran

ABSTRACT

The trial evaluated the effects of different fiber sources on growth performance, gut health, nutrient digestibility, digesta attributes and microbial counts in broilers. A total of 600 Ross 308 broiler chicks (day old) were allotted to five groups with six replicates (20 birds/replicate). The control diet (CON) contained a 3% filler, which was replaced with 3% of either soybean hulls (SH), wheat bran (WB), maize bran (MB), or sugar beet pulp (SBP) in the other four treatments. Growth performance was monitored phase wise, whereas development of gastrointestinal tract and pH, digesta attributes, gut health, nutrient digestibility and microbial population were assessed on day 35 of the experiment. The SBP significantly reduced ($P<0.05$) growth performance across all the phases. Conversely, during grower phases, WB and SH groups exhibited greater average daily gain (ADG) and better FCR ($P<0.05$). Overall, WB and SH had the highest ($P<0.05$) ADG, average daily feed intake (ADFI) and FCR, whereas SH was similar ($P>0.05$) to CON. The SH group had the greatest gizzard weight ($P<0.05$) than all the groups. The SBP significantly increased ($P<0.05$) digesta viscosity, small intestinal weight, duodenal crypt depth and cecal *E. coli* counts. In contrast, WB improved ($P<0.05$) the villus height and villus height to crypt depth ratio, ileal digestibility of CP and ether extract than the MB and SBP, whereas remained comparable to the SH and CON. The WB and SH increased ($P<0.05$) the cecal *Lactobacillus* spp. counts. In conclusion, 3% WB and SH supported growth, gut development and CP digestibility, whereas SBP reduced growth, worsened duodenal morphology and nutrient digestibility, increased digesta viscosity and cecal *E. coli*, in broilers.

To Cite This Article: Akram CA, Qaisrani SN, Saima and Ahmad S, 2026. Effects of different fiber sources on growth performance, gut health, nutrient digestibility, digesta characteristics and cecal microbial population in broilers. Pak Vet J. http://dx.doi.org/10.29261/pakvetj/2026.244

INTRODUCTION

Modern broilers have been selected for rapid growth and high feed efficiency (Aylward *et al.,* 2024). To fully exploit their genetic potential, broilers are fed nutrient-dense pelleted diets, which are low in fiber and lack physical texture necessary for physical stimulation of the digestive tract, particularly the gizzard. The absence of structural elements impairs the gut development and health ultimately affecting the nutrient digestibility (Svihus, 2011; Mateos *et al.,* 2012; Abdollahi *et al.,* 2018). However, coarse cereal particles, whole grains and insoluble dietary fiber have been reported to potentially improve feed texture, which enhances the digestive functioning and feed efficiency in broilers (Soltan *et al.,* 2024).

The dietary fiber (DF), historically regarded as a nutrient diluent and an anti-nutrient (Donadelli *et al.,* 2019), has recently gained attention in poultry nutrition due to its functional benefits. It primarily comprises a heterogeneous group of carbohydrate polymers like cellulose, hemicelluloses, pectin, mucilage, gums, β- glucans, oligosaccharides, resistant starch and lignin that are resistant to enzymatic breakdown and are fermented by the microbes (Kurul *et al.,* 2020). The DF is further classified either as soluble dietary (SDF) containing pectin, gums, β-glucans and hemicellulose, and insoluble dietary fiber (IDF), containing lignin and cellulose. These two types of DF stimulate contrasting physiological responses in the avian gut (Okrathok and Khempaka, 2020). The higher concentration of SDF impairs the broiler performance by

increasing the intestinal viscosity leading to hypertrophy of the GIT, reducing the nutrient digestibility by encapsulating nutrients and compromises the gut health by promoting the proliferation of detrimental microbes like *Clostridium perfringens* and coliforms (Sadeghi *et al.,* 2015; Kurul *et al.,* 2020; Bamedi *et al.,* 2024). Conversely, IDF provides essential structural elements and stimulates HCl secretion and gizzard function resulting in greater acidity, longer retention time, better mechanical grinding and increased digesta reflux (Rodrigues and Choct, 2018; Kiarie and Mills, 2019; Liebl *et al.,* 2022). Consequently, supplementing moderate IDF has been shown to enhance growth, gut development, intestinal functioning and nutrient utilization in broilers (Shang *et al.,* 2020; Rasool *et al.,* 2023).

A growing competition among humans and animals necessitates the use of agro-industrial byproducts that are not fit for humans (Garçon *et al.,* 2023). Fibrous dietary ingredients are inexpensive and sustainable in agro-industrial countries (Babatunde *et al.,* 2021). These fibrous byproducts, however, differ widely in their chemical and physicochemical properties, which has historically limited their use in poultry diets (Lindberg, 2023). Soybean hulls (SH, an oil-extraction byproduct) and maize bran (MB, a starch-manufacturing byproduct) are predominantly rich in highly lignified IDF fractions, with variable proportions of cellulose, hemicellulose and lignin (Raza *et al.,* 2022; Faryadi *et al.,* 2023). Wheat bran (WB) as an IDF is abundant in arabinoxylans (Veluri *et al.,* 2024). In contrast, sugar beet pulp (SBP) is rich in soluble pectin (21 to 30%), which increases water-binding capacity and digesta viscosity, whereas serving as a highly fermentable substrate in the ceca (Berrocoso *et al.,* 2020).

Reported responses to DF in broilers are inconsistent ranging from improved growth performance (Tejeda and Kim, 2020; Abdel Magied *et al.,* 2021; Rasool *et al.,* 2023) to reduced growth (Saadatmand *et al.,* 2019; Kakhki *et al.,* 2024) or no effect (Faryadi *et al.,* 2023). These differences are mainly attributed to composition and physicochemical properties of the DF source (Kakhki *et al.,* 2024). The response also depends on the inclusion level, solubility, hydration capacity and particle size of the DF as well as basal diet and bird age (Mateos *et al.,* 2012; Berrocoso *et al.,* 2020; Rybicka *et al.,* 2024). Differences in these factors among the studies make direct comparison of DFR sources difficult. Maize bran has received little attention as a source of DF in broilers, and to our knowledge, no study has compared it with SH, WB and SBP under identical conditions, although these fibers differ widely in lignification, arabinoxylan and pectin contents. This information is required to explore the suitable agro-industrial byproducts for broiler feeds. The present trial, therefore, examined the impacts of different DF sources included at 3% on growth performance, gut developments and health, nutrients utilization, digesta attributes and cecal bacterial counts in broilers. It was hypothesized that supplementing a modest level (3%) of these DF sources would improve gut development and health, enhance nutrient utilization and ultimately growth performance in broilers.

MATERIALS AND METHODS

All the processes followed during the research were permitted by the Animal Care and Use Committee, UVAS, Lahore, Pakistan (No. DR/426, dated 19/09/2023).

Experimental design, diets and bird management: The DF sources including SH, MB, SBP and WB were sourced from the local market and ground using a 1mm sieve to standardize their particle size. A total of 600 Ross 308 mixed sex broiler chicks (day old) were acquired and randomly allotted to five dietary treatments with six replicates (20 birds/replicate) in a completely randomized design. The five experimental diets were tested including a standard control (CON) diet containing 3% filler (acid insoluble ash). The four experimental feeds were formulated by substituting the filler with 3% of either SH, MB, SBP or WB (w/w) into the CON (Table 1) so that the diets differ mainly in crude fiber and crude ash. The feeds were prepared to satisfy the nutrient needs of the broilers as indicated by Aviagen (2022). Additionally, 1% Celite® was supplemented for the digestibility parameters. All the treatments were offered as pellets in starter (0 to10 day), grower (11 to 24 day) and finisher (25 to 35 day) phases. The broilers were vaccinated for Infectious Bursal Disease on first day and further vaccinated against Newcastle Disease and Infectious Bronchitis on fifth and 15th day of the trial. The broilers were provided feed and water *ad libitum*. The Ross 308 management guidelines were followed for management practices, including the temperature, relative humidity and lighting (Aviagen, 2018).

Table 1: Dietary ingredients and nutrient composition (% as-fed) of the basal experimental diets.

Ingredients (%)	Starter	Grower	Finisher
Maize	56.95	63.67	64.68
Soybean meal	26.00	20.00	19.00
Poultry by product meal	6.00	6.00	5.00
Maize gluten (60)	2.00	2.00	3.00
Vegetable oil	2.00	2.00	2.51
Limestone	1.01	0.94	0.87
DCP	0.97	0.65	0.52
Lysine Sulphate	0.83	0.67	0.52
L-Methionine	0.33	0.22	0.20
L-Threonine	0.18	0.11	0.01
L-Valine	0.01	0.02	0.01
L-Isoleucine	0.01	0.02	0.01
L-Arginine	0.12	0.13	0.10
Vit-Min Premix[1]	0.10	0.10	0.10
Na Bicarbonate	0.18	0.17	0.17
Salt	0.21	0.20	0.20
Choline	0.10	0.10	0.10
Filler	3.00	3.00	3.00
Nutrient Composition (%, unless otherwise mentioned)			
ME (Kcal/kg)	2980	3100	3150
CP	22.00	21.00	20.00
CF	2.74	2.45	2.55
Ca	0.96	0.87	0.80
Av.P	0.48	0.43	0.40
Dig Lys	1.28	1.15	1.03
Dig M+C	0.95	0.87	0.80
Dig Thr	0.86	0.77	0.69
Dig Tryp	0.20	0.18	0.16
Dig Leu	1.41	1.27	1.13
Dig Isoleu	0.86	0.79	0.71
Dig Valine	0.96	0.88	0.78
Dig Arginine	1.37	1.23	1.10

[1]Vit-Min premix composition (per kg of diet) 13000 I.U vitamin A, 5000 I.U vitamin D3, 30mg vitamin E, 2mg vitamin K3, 3mg vitamin B1, 6mg vitamin B2, 4mg vitamin B6, 0.01mcg vitamin B12, 40mg nicotinamide, 0.02mcg biotin, 1mg folic acid, 10mg Ca d-panthothenate, 80mg manganese, 65 mg zinc, 48mg iron, 10mg copper, 0.2mg selenium.

In Press

Parameters studied

Growth performance: The body weight (BW) and feed intake (FI) were measured phase wise. The mortality BW were noted to correct the FCR. The data on BW and FI were employed to calculate average daily gain (ADG), average daily feed intake (ADFI) and FCR for each feeding phase and cumulatively for entire duration of the experiment (Yu *et al.,* 2024).

Organ weights and pH: On day 35 of the experiment, two broilers from every pen were chosen, humanely euthanized and necropsy was performed to collect the samples. The visceral organs were excised and separated. The proventriculus, gizzard, duodenum, jejunum, ileum and ceca were weighed (% of LW) and the lengths (cm) of the mentioned intestinal segments were also recorded as stated by Rasool *et al.* (2023). The pH in these organs was recorded using a standardized pH meter (model 507, Crison instruments) following a procedure described by Moradi *et al.* (2021).

Gut health: For intestinal morphometric examination, 2cm mid duodenal tissues from the selected broilers were collected and preserved as recommended by Rasool *et al.* (2023). The preserved duodenal tissues were processed using the standard hematoxylin and eosin procedure (Bancroft and Gamble, 2008; Gul *et al.,* 2025). The sample slides were scanned for villus height (VH) and crypt depth (CD) using a light microscope (Olympus CX31, Olympus USA) equipped with a digital imaging system from 5 intact villi and crypts per bird. The VH:CD (VCR) was calculated from VH and CD data.

Nutrient digestibility: The ileal digesta was collected from the euthanized birds during necropsy examination as suggested by Rasool *et al.* (2023). The samples within a pen were combined and preserved at -20°C. The AID of CP and ether extract (EE) was calculated using acid insoluble ash (AIA), CP and EE data of the feed and digesta as stated by Moradi *et al.* (2021);

$$AID\ (\%) = [(nut/AIA)d - (nut/AIA)I] / [(nut/AIA)\ d] \times 100$$

Where, (nut/AIA)d represents the dietary proportion of CP and EE and AIA in the feed and (nut/AIA)I shows the digesta proportion of CP and EE and AIA.

Digesta characteristics: The digesta transit time was recorded following a procedure used by Moradi *et al.* (2021) using the chromic oxide (1g/kg) as a marker. The digesta was collected from the euthanized birds during necropsy examination and used for analyzing digesta viscosity using a procedure described by Anwar *et al.* (2023).

Cecal microbes: The cecal digesta was used to measure cultivable *E.coli*, *Salmonella* spp. and *Lactobacillus* spp. population as described by Yang *et al.* (2012). Briefly, the cecal contents were diluted with 2ml isotonic saline and three 10 folds' dilutions were prepared using the already diluted cecal contents. A 0.1ml of the dilutions was spread on selective media. *Escherichia coli* spp. were incubated on MacConkey agar at 37°C for 24 h. *Salmonella* spp. were incubated on *Salmonella Shigella* agar at 37°C for 24h. *Lactobacillus* spp. were incubated on de Man, Rogosa and Sharpe agar for 48h at 37°C. All the cultured plates with presumptive countable growth were enumerated and reported as a log CFU /g of cecal contents.

Chemical analysis: The feed and digesta samples were passed through a 0.5mm screen. The proximate composition contents of the ground feed samples and neutral detergent fiber and acid detergent fiber contents in the fiber samples (Table 2) were analyzed using the standard procedures (AOAC, 2005). The AIA contents in the sampled digesta and feed were evaluated as stated by Siriwan *et al.* (1993).

Table 2: Nutrient composition of the dietary fiber sources.

	Fiber sources[1]			
Nutrient (%- as such basis)	SH	MB	SBP	WB
Dry matter	90.05	95.35	93.62	90.42
Crude ash	2.58	0.73	7.88	4.52
Crude protein	10.05	10.38	6.96	13.87
Ether extract	0.40	5.64	0.41	3.60
Crude fiber	43.80	9.11	18.67	10.20
Neutral detergent fiber	72.66	55.84	48.92	43.78
Acid detergent fiber	57.63	11.51	28.91	11.04

[1]SH; Soybean hulls, MB; Maize bran, SBP; Sugar beet pulp, WB; Wheat bran.

Statistical analysis: The pen was considered an experimental unit and data from euthanized birds (2 birds per pen) were averaged prior to statistical analysis. The collected data were analyzed as one-way analysis of variance (ANOVA) through PROC GLM in SAS (9.1; SAS Inst. Inc., Cary, NC). Tukey's test was used to distinct the significant means when P-value was smaller than 0.05. The use of six replicates per treatment (20 birds/ pen) were consistent with previously published studies evaluating the effects of DF in broilers (Tejeda and Kim 2020; Rasool *et al.,* 2023).

RESULTS

Growth performance: Throughout the trial, the dietary treatments significantly influenced ($P<0.05$) growth (Table 3). During all the phases, the SBP supplementation reduced ADG, lowered FI and worsened FCR among all the treatment groups. During the starter period, the CON, SH and WB groups, however, had greater ADG and an improved FCR than the SBP and MB. The broilers in SBP group had the lowest ADG and ADFI (25.10 and 29.80g/d). During the grower period, the WB and SH groups had the highest ADG (61.2 and 60.5g/d) and improved FCR (1.39 and 1.42), whereas SH was similar to the CON. The broilers fed MB diets, however, showed a better ADG and a superior FCR than the SBP group. The CON diet fed broilers, however, showed a better ADG than those fed MB and SBP based diets. The SBP group had the lowest ADG and ADFI (55.50 and 84.01g/d) and the highest FCR (1.51) among all the groups.

During the finisher phase, the WB group yielded a greater ADG than the CON, MB and SBP treatments,

In Press

whereas at par with the SH. The WB group showed a greater ADFI than the SBP and statistically at par with the CON, MB and SH groups. WB supplementation to the broilers improved the FCR than the MB and SBP and statistically similar to the SH and CON groups. The SH group, similarly, had a better ADG than SBP and MB, however, at par with CON and WB groups. The WB group showed more ADFI than the SBP and similar to the CON, MB and SH. Overall, the broilers fed WB supplemented diets yielded a greater ADG (60.30 g/d) and an improved FCR (1.47) than the CON (58.70 and 1.51), MB (57.02 and 1.55) and SBP (54.51 and 1.59) and similar to SH (59.77 and 1.48). The SH group, similarly had a greater ADG and a better FCR than the MB and SBP groups, whereas at par with the WB and CON treatments. Overall, the SBP group had the lowest ADG and ADFI (54.51 and 86.77 g/d) and the highest FCR (1.59).

Organ weights and pH: Table 4 represents the influence of different DF on relative weights of the visceral organs. The relative weight of proventriculus did not respond to the experimental treatments (P>0.05). The gizzard, conversely, responded (P<0.05) to the supplemented fibers. The broilers in CON group had the lowest gizzard weight (1.30% of LW) among the experimental groups. Among the fiber supplemented treatments, feeding the SH yielded highest gizzard weight (1.66%) than the SBP treatments. The gizzard weight remained statistically comparable (P>0.05) in WB, SBP and MB groups. Supplementing the FS impacted (P<0.05) the intestinal weights in the broilers compared with the CON treatment. The broilers fed CON diets had the lowest weights (% of LW) of duodenum (0.84), jejunum (1.43), ileum (1.52) and ceca (0.73) than those fed the fiber supplemented groups. Among the fiber supplemented treatments, the broilers fed SBP had the highest weights of duodenum and jejunum (1.13 and 1.77% of LW, respectively). The broilers in SH, MB and WB groups had statistically comparable (P>0.05) duodenal and jejunal weights. The broilers in SBP, WB and MB groups had the highest ileal weights than those in the SH and CON groups. The SBP addition yielded the highest cecal weight than the SH and MB, however, similar to the WB treatment. The SH and MB groups, likewise had similar Ileal and cecal weights. The dietary treatments, however, had no effect on the lengths of different GIT segments of the broilers (Table 4).

Table 4 represents the effects of the dietary treatments on organ pH in broilers. The CON diet fed broilers exhibited the highest (P<0.05) pH in proventriculus (3.39) and gizzard (3.50) among all the treatments. The broilers in SH group showed the lowest (more acidic) pH in proventriculus (3.04). The SH and WB groups showed the lowest pH in gizzard (3.24 and 3.27). The WB group showed a lower pH in proventriculus compared with the MB and SBP groups. However, the broilers in SH group had a lower pH compared to the CON, MB and SBP fed diets, whereas similar to those fed WB diet. The WB and MB groups had a similar gizzard pH, however, less than the SBP treatment. The broilers in CON and fiber supplemented treatments had statistically similar (P>0.05) pH in duodenum, jejunum and ileum. The broilers in CON, however, showed the highest (P<0.05) cecal pH (6.97) among all the treatments. The SBP fed broilers had a lowest (6.79) cecal pH than those in the MB and SH groups (P<0.05) and similar to those in the WB groups.

Gut health: The effects of various dietary FS on gut health in the broilers are documented in Table 5. Feeding WB diets increased (P<0.05) VH in broilers than the MB and SBP groups, whereas similar (P>0.05) to the SH and CON groups. The SH and CON treatments yielded longer (P<0.05) villi than the SBP and similar to the MB treatments. The MB and SBP groups had similar (P>0.05) VH. The SBP supplementation yielded the lowest (P<0.05) VH (1810.50 µm) than the other groups. The CD was affected (P<0.05) in reaction to the treatments. The broilers in SBP and MB treatments had deeper crypts (267.03 and 260.61 µm) than the CON (229.90 µm), WB (223.85 µm) and SH (234.20 µm) treatments. The broilers fed CON, WB and SH diets, however, had similar (P>0.05) CD. The broilers in CON, WB and SH groups had statistically comparable (P>0.05) VCR, whereas greater (P<0.05) than MB and SBP groups. The MB and SBP groups had comparable (P>0.05) VCR. The broilers on SBP diets, however, yielded the lowest VCR (6.84) than all the treatments.

Nutrient digestibility: The impacts of supplementing various FS on AID of CP and EE are shown in Table 5. The WB group showed higher (P<0.05) AID of CP than the CON, MB and SBP, whereas similar (P>0.05) to the SH group. The SH and CON had a greater AID of CP than the MB and SBP. The highest AID of CP was recorded in WB (73.97%) and SH (72.96%) groups, whereas The SBP had the lowest AID of CP (66.71%) among all the treatment groups. The broilers in CON, WB and SH groups had comparable (P>0.05) AID of EE. The CON and MB fed broilers did not differ (P>0.05) in AID of EE. The broilers in SBP group had the lowest AID of EE (77.26%) among all the other dietary treatments.

Table 3: Influence of different fiber source on average daily gain (g/b/d), average daily feed intake (g/b/d) and FCR (g/g) in the broilers[1].

Age (d) →	Starter (1-10)			Grower (11-24)			Finisher (25-35)			Overall (1-35)		
Effects[2]	ADG	ADFI	FCR	ADG	ADFI	FCR	ADG	ADFI	FCR	ADG	ADFI	FCR
CON	27.33^{a}	30.97^{a}	1.13^{a}	59.22^{b}	85.08^{ab}	1.44^{b}	86.41^{ab}	144.86^{ab}	1.68^{a}	58.70^{b}	88.41^{a}	1.51^{b}
SH	27.85^{a}	31.16^{a}	1.12^{a}	60.51^{a}	85.67^{a}	1.42^{ab}	87.83^{a}	144.89^{ab}	1.65^{a}	59.77^{ab}	88.71^{a}	1.48^{ab}
MB	26.21^{b}	30.79^{a}	1.17^{b}	57.88^{c}	85.34^{a}	1.47^{c}	83.94^{b}	144.91^{ab}	1.73^{b}	57.02^{c}	88.50^{a}	1.55^{c}
SBP	25.1^{c}	29.82^{b}	1.19^{b}	55.50^{d}	84.01^{b}	1.51^{d}	80.11^{c}	142.05^{b}	1.77^{c}	54.51^{d}	86.77^{b}	1.59^{d}
WB	28.2^{a}	31.21^{a}	1.11^{a}	61.15^{a}	85.20^{ab}	1.39^{a}	88.40^{a}	145.90^{a}	1.65^{a}	60.30^{a}	88.84^{a}	1.47^{a}
SEM	0.211	0.216	0.010	0.322	0.294	0.010	0.600	0.779	0.010	0.311	0.335	0.010
P-value	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	0.023	<0.001	<0.001	0.012	<0.001

$^{a-d}$Means with dissimilar superscripts in a column vary significantly (P<0.05). [1]Each value indicates the mean of 6 replicate pens (20 broilers per pen). [2]CON; Control, SH; Soybean hulls, MB; Maize bran, SBP; Sugar beet pulp, WB; Wheat bran.

Table 4: Impacts of different fiber source on organ weights (% of LW), intestinal lengths and organ pH in the broilers[1]

	Treatments[2]						
Observations	CON	SH	MB	SBP	WB	*SEM*	*P-Value*
Organ weights (% of LW)							
Proventriculus	0.42	0.46	0.44	0.43	0.45	0.013	0.273
Gizzard	1.30^{c}	1.66^{a}	1.60^{ab}	1.57^{b}	1.63^{ab}	0.018	<0.001
Duodenum	0.84^{c}	0.97^{b}	0.95^{b}	1.13^{a}	0.95^{b}	0.021	<0.001
Jejunum	1.43^{c}	1.55^{b}	1.58^{b}	1.77^{a}	1.58^{b}	0.027	<0.001
Ileum	1.52^{c}	1.71^{b}	1.74^{ab}	1.83^{a}	1.80^{ab}	0.024	<0.001
Ceca[3]	0.73^{c}	0.82^{b}	0.83^{b}	0.91^{a}	0.86^{ab}	0.014	<0.001
Intestinal length (cm)							
Duodenum	29.83	29.05	27.75	27.92	28.17	0.888	0.390
Jejunum	80.00	80.92	81.25	81.42	80.08	1.270	0.904
Ileum	86.50	86.17	87.75	85.92	87.25	1.200	0.804
Ceca[3]	17.17	17.92	17.08	17.26	18.25	0.686	0.685
Organ pH							
Proventriculus	3.39^{a}	3.04^{d}	3.21^{bc}	3.25^{b}	3.14^{c}	0.019	<0.001
Gizzard	3.50^{a}	3.24^{c}	3.32^{bc}	3.41^{b}	3.27^{c}	0.021	<0.001
Duodenum	5.99	6.03	5.96	6.05	5.99	0.054	0.791
Jejunum	6.32	6.31	6.28	6.39	6.31	0.035	0.280
Ileum	6.88	6.92	6.91	6.95	6.91	0.030	0.690
Ceca	6.97^{a}	6.88^{b}	6.89^{b}	6.79^{c}	6.83^{bc}	0.019	<0.001

$^{a-c}$Means not sharing same superscript in a row vary significantly (P<0.05). [1]Each value indicates the mean of 6 replicate pens (average of 2 birds/pen). [2]CON; Control, SH; Soybean hulls, MB; Maize bran, SBP; Sugar beet pulp, WB; Wheat bran. [3]single ceca.

Table 5: Effects of different fiber source on ileal digestibility of nutrients, duodenal morphology and digesta characteristics in the broilers[1].

	Treatments[2]						
Observations	CON	SH	MB	SBP	WB	*SEM*	*P-Value*
AID of nutrients (%)[3]							
CP	71.61^{b}	72.96^{ab}	69.19^{c}	66.71^{d}	73.97^{a}	0.554	<0.001
EE	81.40^{ab}	83.66^{a}	80.44^{b}	72.26^{c}	83.99^{a}	0.642	<0.001
Duodenal morphology(µm)[4]							
VH	1932.40^{ab}	1995.80^{ab}	1898.71^{bc}	1810.50^{c}	2034.88^{a}	27.60	<0.001
CD	299.90^{b}	234.20^{b}	260.61^{a}	267.03^{a}	223.85^{b}	5.880	<0.001
VCR	8.53^{a}	8.62^{a}	7.40^{b}	6.84^{b}	9.17^{a}	0.167	<0.001
Digesta characteristics							
Digesta Transit Time (min)	249.50	257.50	283.83	278.00	265.50	8.490	0.144
Digesta Viscosity (cps)	4.65^{b}	4.53^{b}	4.79^{b}	7.53^{a}	4.48^{b}	0.187	<0.001

$^{a-d}$Means having dissimilar superscript in a row vary significantly (P<0.05). [1]Each value denotes the mean of 6 replicate pens. [2]CON; Control, SH; Soybean hulls, MB; Maize bran, SBP; Sugar beet pulp, WB; Wheat bran. [3]CP; crude protein, EE; Ether extract. [4]VH; Villus height, CD; crypt depth, VCR; VH: CD.

Digesta characteristics: The results of various FS on digesta transit time and its viscosity in the broilers are reported in Table 5. The digesta transit time did not differ significantly (P>0.05) among all the experimental treatments. However, the dietary treatments significantly affected (P<0.05) the digesta viscosity. The broilers in SBP group showed the highest digesta viscosity (7.53 cps) than those fed the other dietary treatments, which had statistically similar (P>0.05) digesta viscosity.

Cecal microbes: Impacts of various dietary FS on cecal bacterial counts in the broilers are presented in Fig. 1. The counts of *E. coli* and *Lactobacillus* spp. population in the ceca significantly differed (P<0.05) by the dietary treatments. The SBP supplemented broilers exhibited the greatest *E.coli* counts (7.06 $\log_{10}$ CFU/g) among all the treatments with MB and CON groups having similar *E.coli* counts, but greater than the SH and WB fed groups. The WB fed group had the lowest *E.coli* counts (6.59 $\log_{10}$ CFU/g) among all the treatments. The highest *Lactobacillus* spp. counts were recorded in WB (6.98) and SH (6.91 $\log_{10}$ CFU/g) fed groups. The CON diet fed broilers had greater *Lactobacillus* spp. counts than the MB and SBP treatments. The SBP fed group had the lowest *Lactobacillus* spp. counts (6.53 $\log_{10}$ CFU/g) among all the dietary treatments. The cecal *Salmonella* spp. population remained unchanged (P>0.05) in response to the treatments.

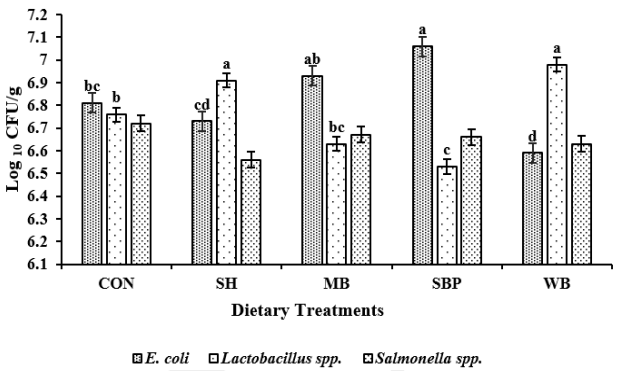


Fig. 1: Effects of fiber source on cecal microbial counts (Log_{10} CFU/g) in broilers. CON; Control, SH; soybean hulls, MB; maize bran, SBP; sugar beet pulp, WB; wheat bran. Error bars represent the pooled SEM (n=6). Bars with different letters within a bacterial group differ significantly (P<0.05).

DISCUSSION

This study explored the impacts of different DF sources on growth indices, gut health, nutrient utilization, digesta attributes and cecal microbial counts in broilers. It was hypothesized that dietary supplementation of a moderate amount of fiber may improve gut development and its health, nutrient digestibility leading to better growth performance in broilers. Nutrient utilization, gut health and organ weights and their pH, and cecal microbial counts were evaluated as explanatory variables. Longer villi with reduced crypt depths, greater VCR in duodenum and modulated cecal microbes were used as markers of a healthy intestine in the broilers.

The improved overall growth performance recorded in WB and SH groups during all phases is in line with the earlier research showing that moderate supplementation of IDF enhances growth rather than diluting the nutrients (Abdel Magied *et al.,* 2021; Idan *et al.,* 2023). Consistent with the current results, Shang *et al.* (2020a) and Pourazadi *et al.* (2020) reported that 3% WB improved ADG by 6.6 and 7.4% and FCR by 9.8 and 10%, respectively, in broilers. Likewise, Tejeda and Kim (2020) and Liebl *et al.* (2022), reported 5.1 and 4.3% greater BWG in broilers fed SH diets than those in the CON, correspondingly. Rather than acting as a nutrient diluent, these structurally intact fibers potentially stimulate upper gastrointestinal development, which improve the birds' capacity to assimilate nutrients. Poorer growth performance in broilers fed MB supplemented diets than those fed the WB, SH and CON diets is in agreement with findings reported by Sharifi and Masoudi (2024). These latter authors reported 8.3% lower ADG and 7.7% lower FI with 5% dietary MB supplemented diets compared with the CON group. Adedokun and Adeola (2020)

reported that type of fiber may influence the GIT in different manners by increasing the digesta viscosity and abrasion of the intestinal walls. The latter authors concluded that feeding the corn bran to broilers enhanced the endogenous secretion of various amino acids. In the present study, MB fed broilers had lower VH and VCR with deeper crypts than CON, WB and SH fed groups, which may be related to abrasive nature of the MB. Their lower digestibility of CP and EE may have contributed to poorer growth performance and lower CP digestibility may be due to higher endogenous amino acid losses as suggested by Adedokun and Adeola (2020). The SBP supplementation reduced the ADG and FI and worsened the FCR throughout the trial. Comparable to the current findings, Saadatmand *et al.* (2019) reported that feeding SBP (3-4%) to broilers resulted in 5.9% reduced BW and 6.1% poor FCR. Kakhki *et al.* (2024) reported that 3% SBP addition to broiler diets reduced the BWG (2.5 and 2.4%) and FI (3.2 and 3.7%) than the WB and SH groups, respectively. These latter authors suggested that the reduced FI in addition to the higher digesta viscosity may resulted in the reduced growth performance. Bamedi *et al*. (2024), likewise, reported that feeding 4% SBP decreased the BWG by 8.1% and increased FCR by 9.9% than the CON in quails. The poor gut health and reduced nutrient digestibility may have contributed to the worsened growth in the SBP fed broilers.

The gizzard serves as pacemaker of the avian digestive tract (Ravindran and Abdollahi, 2021). In the present trial, addition of IDF sources, mainly SH and WB, resulted in significantly increased gizzard weight compared to the CON probably due to the physical features of these fiber sources. The IDF are selectively retained within the gizzard to go through severe mechanical grinding (Sharifi and Masoudi, 2024), which may lead to muscular hypertrophy of the gizzard that is supported by previous research where WB or SH supplementation enhanced the gizzard weight (Shang *et al.,* 2020a; Tejeda and Kim, 2020). This greater gizzard weight has been suggested to enhance the pancreatic activity, digesta holding time and interaction of HCl and digesta leading to improved nutrient digestion (Sharifi and Masoudi, 2024). In contrast, it was stated that supplementing the DF fails to affect the visceral organ weights (Kurul *et al.,* 2020; Jangiaghdam *et al.,* 2022). Kakhki *et al.* (2024), similarly, described that supplementing various FS did not affect the gizzard weights in broilers at the end of the trial. Our findings, however, suggest that the type of the FS influences the structural changes in the GIT.

The activity of digestive enzymes is influenced by intestinal pH and any alteration in the pH influences digestibility of nutrients (Ravindran and Abdollahi, 2021). Supplementation of WB and SH led to a significant lower pH of both the proventriculus and the gizzard, with the lowest reduction recorded in the SH treatment. This lower pH may be resulted from the prolonged digesta retention in the gizzard that encourages greater endogenous hydrochloric acid (HCl) secretion from the proventriculus (Rasool *et al.,* 2023; Rybicka *et al.,* 2024). The lower pH in the upper GIT may be beneficial since it enhances the activation of pepsinogen to active pepsin, thus improving the protein digestibility (Ravindran and Abdollahi, 2021).

The fiber supplementation significantly increased the relative weights of duodenum, jejunum, ileum and ceca than the CON. SBP supplementation yielded the highest duodenal and jejunal weights. This increase may be due to the greater viscosity and bulk of digesta caused by pectin and rapid adaption of the GIT (Sadeghi *et al.,* 2015; Faryadi *et al.,* 2023). In agreement with Kurul *et al.* (2020) and Sharifi and Masoudi (2024), the relative lengths of the intestinal segments remained unchanged in response to the treatments. This suggests that broilers adapt to moderate DF addition through structural alterations rather than lengthening the GIT.

The broilers in WB and SH groups showed greater VH and improved VCR. Liebl *et al.* (2022) and Shang *et al.* (2020b) similarly described that moderate IDF supplementation stimulates mucosal development. In contrast, SBP supplementation resulted in the lowest VH and a worsened VCR. Reduced VH has been reported in broilers fed SDF high in pectin, whereas IDF has been reported to improve the villus development (Singh and Kim, 2021). The higher CD in SBP groups may indicates increased cellular proliferations. Consistent with our results, Sadeghi *et al.* (2015) and Kardel *et al.* (2025), stated that supplementing 3% SBP to broilers resulted in 28.7% lower VH in duodenum and 27% lower VH in ileum than the CON.

The structural and physiological improvements recorded in the GIT were reflected to our nutrient digestibility results. The broilers in WB and SH treatments had greater AID of CP and EE. González-Alvarado *et al.* (2010) similarly reported improvements in nitrogen retention and EE digestibility in broilers supplemented with dietary fibers. These authors suggested that these improvements in nutrient digestibility were related to greater HCl production and pepsin activity together with increased bile acid and pancreatic secretions. The reduced gastric pH recorded in the groups with improved gut health may have contributed to greater nutrient utilization (Pourazadi *et al.,* 2020; Zhang *et al.,* 2023). In contrast the SBP group showed lowest CP and EE digestibility. The SBP is abundant in uronic acid and pectic arabinose, making it rich in SDF (Kakhki *et al.,* 2024). Pectin may increase digesta viscosity which could reduce the diffusion of digestive enzymes into the digesta and limiting the digestion and absorption of the nutrients (Berrocoso *et al.,* 2020). In addition, the viscous gel network formed by SDF may increase the thickness of the unstirred water layer over the mucosa, which has been suggested to reduce the efficiency of nutrient absorption in poultry (Sing and Kim, 2021). In this trial, the SBP supplementation resulted in 65% increase in digesta viscosity than the CON, whereas the IDF resulted in lower digesta viscosity comparable to the CON. Furthermore, the viscous digesta associated with SDF can bind bile acids and fats, which may reduce EE absorption (Sing and Kim, 2021) and the greater digesta viscosity in SBP group (65% higher than the CON) may have further reduced lipid digestion. These mechanisms may partially explain the lower EE digestibility observed in this group, although bile acids and micelle formation were not measured in the present trial.

In the present study, the digesta transit time was not influenced by the DF sources. Comparable to our results,

In Press

it has been reported that digesta holding time did not differ in response to various DF sources (Abdollahi *et al.,* 2019; Kakhki *et al.,* 2024). In dissimilarity, the previous literature reports that high-fiber diets (5.19%) shorten transit times (Krás *et al.,* 2013) or that certain fibers (OH, LC, RH and SFH) enhance gizzard retention (Moradi *et al.,* 2021; Garcon *et al.,* 2023). A likely explanation for these opposing findings may be the fine particle size of the chromium oxide that was used as a marker to record the digesta holding time. Similar to our study, these latter authors also used chromic oxide as a marker to record the digesta holding time. Garcon *et al.* (2023), further, concluded that the fine particles (<0.1mm) of insoluble marker like chromium oxide are promptly excreted from the gizzard, hence, did not precisely determine the holding time of coarse particles.

The composition of the cecal microbiota is a key indicator of gut health. In the present study, dietary treatments significantly modulated cecal counts of cultivable *Lactobacillus* spp. and *E. coli*. The higher *Lactobacillus* spp. counts were reported in WB and SH groups and the WB group achieving the lowest *E. coli* counts. The structural carbohydrates particularly in WB are slowly fermented by the cecal microflora, which may favor the proliferation of saccharolytic bacteria such as *Lactobacillus* spp. (Vermeulen *et al.,* 2018). These bacteria produce acetate, propionate and butyrate, which could lower the pH and may suppress *E. coli* through competitive exclusion. However, the SCFA production was not measured directly in the trial, therefore this mechanism should be considered as a possible explanation of the observed effects. Despite the lower cecal pH than the CON, the lowest *Lactobacillus* spp. and the highest *E. coli* counts were recorded in the SBP group. This microbial profile is consistent with Bamedi *et al.* (2024), who reported that feeding 4% SBP as DF increased the counts of *E. coli* in quails by 8.5 and 12.6% than in the CON and RH, respectively. A possible explanation is that the rapid fermentation of highly soluble pectin together with an increased digesta viscosity may create a fermentation profile favoring the proliferation of *E. coli* (Berrocoso *et al.,* 2020). This altered microbial balance may have contributed to the poor overall productivity in the SBP group, although a causal relationship cannot be established from the data.

Conclusions: The effects of 3% DF supplementation were source-dependent. The WB and SH supported growth comparable to or better than the CON, with the WB group showing the highest overall ADG and an improved FCR compared with the CON, MB and SBP. The WB and SH increased gizzard weight and lowered pH of the proventriculus and gizzard than the CON. The SH and WB resulted in greater VCR, improved AID of CP and the highest cultivable cecal *Lactobacillus spp.* counts compared with the MB and SBP groups. The MB supplementation did not improve performance and resulted in deeper crypts, a lower VCR and lower AID of CP than the WB and SH. The SBP group exhibited the lowest ADG and the highest FCR with the highest digesta viscosity and cecal *E. coli* counts, deeper crypts with the lowest VH and VCR, the lowest AID of CP and EE, and the lowest *Lactobacillus spp*. counts.

Funding: The authors extend their gratitude to the Higher Education Commission of Pakistan for funding this research through "Faculty Development Program for Pakistani Universities (batch III, No: FVS3-001)", granted to Mr. CH Ahsan Akram.

Conflict of interest: The authors hereby declare no conflict of interest.

Author contributions: CAA, SNQ, S and SA planned and designed the study. CAA and SNQ executed the trial and analyzed the samples. CAA and SA analyzed and interpreted the data. CAA, SNQ, S and SA prepared, drafted, revised and approved the manuscript.

REFERENCES

Abdel Magied HA, Mostafa MA and ElMenawey M, 2021. Evaluation of different sources and levels of diet diluents on broilers performance and carcass quality. Egyptian Journal of Nutrition and Feeds 24:247-60. https://doi.org/10.21608/ejnf.2021.192892

Abdollahi MR, Zaefarian F, Ravindran V, *et al.,* 2018. The interactive influence of dietary nutrient density and feed form on the performance of broiler chickens. Animal Feed Science and Technology 239:33-43. https://doi.org/10.1016/j.anifeedsci.2018.03.005

Abdollahi MR, Zaefarian F, Hunt H, *et al.,* 2019. Wheat particle size, insoluble fibre sources and whole wheat feeding influence gizzard musculature and nutrient utilisation to different extents in broiler chickens. Journal of Animal Physiology and Animal Nutrition 103:146-61. https://doi.org/10.1111/jpn.13019

Adedokun SA and Adeola O, 2020. Regression-derived ileal endogenous amino acid losses in broiler chickens and cannulated pigs fed corn fiber, wheat bran and pectin. Animals 10:2145. https://doi.org/10.3390/ani10112145

Anwar U, El-kott AF, Bilal MQ, *et al.,* 2023. Supplementation of xylanase levels in lower energy diets on digesta viscosity, blood metabolites and gut health of broiler. Pakistan Veterinary Journal 43:351-55. https://doi.org/10.29261/pakvetj/2023.033

AOAC International, 2005. Official Methods of Analysis, 18th ed. Rev, Gaithersburg, MD, USA.

Aviagen, 2018. Ross Broiler Management Handbook. Aviagen, Huntsville, AL, USA.

Aviagen, 2022. Ross Broiler: Nutrition Specifications. Aviagen, Huntsville, AL, USA.

Aylward BA, Johnson CN, Perry F, *et al.,* 2024. Modern broiler chickens exhibit a differential gastrointestinal immune and metabolic response to repeated CpG injection relative to a 1950s heritage broiler breed. Frontiers in Physiology 15:1473202. https://doi.org/10.3389/fphys.2024.1473202

Babatunde OO, Park CS and Adeola O, 2021. Nutritional potentials of atypical feed ingredients for broiler chickens and pigs. Animals 11:1196. https://doi.org/10.3390/ani11051196

Bamedi A, Salari S and Baghban F, 2024. Changes in performance, cecal microflora counts and intestinal histology of Japanese quails fed diets containing different fibre sources. Veterinary and Animal Science 25:100386. https://doi.org/10.1016/j.vas.2024.100386

Bancroft JD and Gamble M (Eds), 2008. Theory and practice of histological techniques. 6th ed, Churchill Livingstone: London, pp: 80–186.

Berrocoso J, García-Ruiz A, Page G, *et al.,* 2020. The effect of added oat hulls or sugar beet pulp to diets containing rapidly or slowly digestible protein sources on broiler growth performance from 0 to 36 days of age. Poultry Science 99:6859-866. https://doi.org/10.1016/j.psj.2020.09.004

Donadelli R, Stone D, Aldrich C, *et al.,* 2019. Effect of fiber source and particle size on chick performance and nutrient utilization. Poultry Science 98:5820-830. https://doi.org/10.3382/ps/pez382

Faryadi S, Lashkari S, Ndou SP, *et al.,* 2023. Nutrient digestibility in broiler chickens fed diets containing high levels of soybean oil is affected by the source of fiber. Canadian Journal of Animal Science 103:134-42. https://doi.org/10.1139/cjas-2022-0064

Garçon C, Ellis J, Powell C, *et al.,* 2023. A dynamic model to measure retention of solid and liquid digesta fractions in chickens fed diets

with differing fibre sources. Animal 17:100867. https://doi.org/10.1016/j.animal.2023.100867

González-Alvarado J, Jiménez-Moreno E, González-Sánchez D, *et al.,* 2010. Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. Animal Feed Science and Technology 162:37-46. https://doi.org/10.1016/j.anifeedsci.2010.08.010

Gul ST, Tahir MZ, Ahmad L, *et al.*, 2025. Fipronil in sub-lethal doses leads to immuno-toxicological effects in broiler birds. PLOS ONE 20:e0315915. https://doi.org/10.1371/journal.pone.0315915

Idan F, Paulk CB, Pokoo-Aikins A, *et al.,* 2023. Growth performance, intestinal morphometry and blood serum parameters of broiler chickens fed diets containing increasing levels of wheat bran with or without exogenous multi-enzyme supplementation during the grower and finisher phases. Livestock Science 275:105296. https://doi.org/10.1016/j.livsci.2023.105296

Jangiaghdam S, Mirzaie GS, Saki AA, *et al.,* 2022. Growth performance, nutrient digestibility, gastrointestinal tract traits in response to dietary fiber sources in broiler chickens. Poultry Science Journal 10:185-96. https://doi.org/10.22069/psj.2022.19889.1773

Kakhki RAM, Navarro-Villa A, de Los Mozos J, *et al.*, 2024. Evaluation of fibrous feed ingredients alternatives to oat hulls as a source of feed structure in broiler diets. Poultry Science 103:104297. https://doi.org/10.1016/j.psj.2024.104297

Kardel AA, Kazemifard M, Rezaei M, *et al.,* 2025. Broiler responses to dietary fibre sources at different ages: Effects on growth performance, nutrient digestibility, blood parameters and intestinal morphology. Veterinary Medicine and Science 11:e70471. https://doi.org/10.1002/vms3.70471

Kiarie EG and Mills A, 2019. Role of feed processing on gut health and function in pigs and poultry: Conundrum of optimal particle size and hydrothermal regimens. Frontiers in Veterinary Science 6:19. https://doi.org/10.3389/fvets.2019.00019

Krás RV, Kessler AdM, Ribeiro AML, *et al.,* 2013. Effect of dietary fiber, genetic strain and age on the digestive metabolism of broiler chickens. Brazilian Journal of Poultry Science 15:83-90. https://doi.org/10.1590/S1516-635X2013000200003

Kurul A, Cengiz Ö and Pekel A, 2020. Live performance, digestive tract features and ileal nutrient digestibility in broilers fed diets containing soy hulls. Italian Journal of Animal Science 19:1577-582. https://doi.org/10.1080/1828051X.2020.1857312

Liebl M, Gierus M, Potthast C, *et al.,* 2022. Influence of insoluble dietary fibre on expression of pro-inflammatory marker genes in caecum, ileal morphology, performance and foot pad dermatitis in broiler. Animals 12:2069. https://doi.org/10.3390/ani12162069

Lindberg J, 2023. Nutrient and energy supply in monogastric food producing animals with reduced environmental and climatic footprint and improved gut health. Animal 17:100832. https://doi.org/10.1016/j.animal.2023.100832

Mateos GG, Jiménez-Moreno E, Serrano MP, *et al.,* 2012. Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. Journal of Applied Poultry Research 21:156-74. https://doi.org/10.3382/japr.2011-00477

Moradi S, Moradi A, Atabaigi Elmi V, *et al.,* 2021. Interactive effect of corn particle size and insoluble fiber source on performance, nutrient utilization and intestine morphology in broilers fed pelleted diets. Journal of Animal Physiology and Animal Nutrition 105:1113-126. https://doi.org/10.1111/jpn.13532

Okrathok S and Khempaka S, 2020. Modified-dietary fiber from cassava pulp reduces abdominal fat and meat cholesterol contents without affecting growth performance of broiler chickens. Journal of Applied Poultry Reseach 29:229-39. https://doi.org/10.1016/j.japr.2019.10.009

Pourazadi Z, Salari S, Tabandeh M, *et al.,* 2020. Effect of particle size of insoluble fibre on growth performance, apparent ileal digestibility and caecal microbial population in broiler chickens fed barley-containing diets. British Poultry Science 61:734-45. https://doi.org/10.1080/00071668.2020.1799329

Rasool A, Qaisrani SN, Khalique A, *et al.,* 2023. Insoluble fiber source influences performance, nutrients digestibility, gut development and carcass traits of broilers. Pakistan Journal of Agriculture Sciences 60:355-65. https://doi.org/10.21162/PAKJAS/23.220

Ravindran V and Abdollahi MR, 2021. Nutrition and digestive physiology of the broiler chick: State of the art and outlook. Animals 11:2795. https://doi.org/10.3390/ani11102795

Raza MA, Saeed F, Afzaal M, *et al.,* 2022. Comparative study of cross-and uncross-linked arabinoxylans extracted from maize bran with special reference to their structural and antioxidant potential. International Journal of Food Properties 25:2495-504. https://doi.org/10.1080/10942912.2022.2143524

Rodrigues I and Choct M, 2018. The foregut and its manipulation via feeding practices in the chicken. Poultry Science 97:3188-206. https://doi.org/10.3382/ps/pey191

Rybicka A, Del Pozo R, Carro D, et al., 2024. Effect of type of fiber and its physicochemical properties on performance, digestive transit time and cecal fermentation in broilers from 1 to 23 d of age. Poultry Science 103:103192. https://doi.org/10.1016/j.psj.2023.103192

Saadatmand N, Toghyani M and Gheisari A, 2019. Effects of dietary fiber and threonine on performance, intestinal morphology and immune responses in broiler chickens. Animal Nutrition 5:248-55. https://doi.org/10.1016/j.aninu.2019.06.001

Sadeghi A, Toghyani M and Gheisari A, 2015. Effect of various fiber types and choice feeding of fiber on performance, gut development, humoral immunity and fiber preference in broiler chicks. Poultry Science 94:2734-743. https://doi.org/10.3382/ps/pev292

Shang Q, Liu S, He T, *et al.,* 2020a. Effects of wheat bran in comparison to antibiotics on growth performance, intestinal immunity, barrier function and microbial composition in broiler chickens. Poultry Science 99:4929-938. https://doi.org/10.1016/j.psj.2020.06.031

Shang Q, Wu D, Liu H, *et al.,* 2020b. The impact of wheat bran on the morphology and physiology of the gastrointestinal tract in broiler chickens. Animals 10:1831. https://doi.org/10.3390/ani10101831

Sharifi MR and Masoudi A, 2024. Impact of dietary corn fiber on growth performance, digestive organs, intestinal morphology and nutrient digestibility in broiler chickens. Poultry Science Journal 12:87-93. https://doi.org/10.22069/psj.2023.21097.1904

Singh AK and Kim WK, 2021. Effects of dietary fiber on nutrients utilization and gut health of poultry: a review of challenges and opportunities. Animals 11:181. https://doi.org/10.3390/ani11010181

Siriwan P, Bryden WL, Mollah Y, *et al.,* 1993. Measurement of endogenous amino acid losses in poultry. British Poultry Science 34:939-949. https://doi.org/10.1080/00071669308417654

Soltan MA, Shewita RS, Matroud OA, *et al.,* 2024. Lignocellulose and probiotic supplementation in broiler chicken diet: Effect on growth performance, digestive health, litter quality and genes expression. Poultry Science 103:103735. https://doi.org/10.1016/j.psj.2024.103735

Svihus B. 2011. The gizzard: Function, influence of diet structure and effects on nutrient availability. World's Poultry Science Journal 67:207-24. https://doi.org/10.1017/S0043933911000249

Tejeda O and Kim W, 2020. The effects of cellulose and soybean hulls as sources of dietary fiber on the growth performance, organ growth, gut histomorphology and nutrient digestibility of broiler chickens. Poultry Science 99:6828-836. https://doi.org/10.1016/j.psj.2020.08.081

Veluri S, Bedford MR, Gonzalez-Ortiz G, *et al.,* 2024. Interaction of wheat bran particle size and stimbiotic supplementation on growth performance and gut health parameters in broilers. Animals 14:2685. https://doi.org/10.3390/ani14182685

Vermeulen K, Verspreet J, Courtin CM, *et al.,* 2018. Reduced-particle-size wheat bran is efficiently colonized by a lactic acid-producing community and reduces levels of enterobacteriaceae in the cecal microbiota of broilers. Applied and Environmental Microbiology 84:e1343-18. https://doi.org/10.1128/AEM.01343-18

Yang CM, Cao GT, Ferket PR, et al., 2012. Effects of probiotic, Clostridium butyricum, on growth performance, immune function, and cecal microflora in broiler chickens. Poultry Science 91:2121-129. https://doi.org/10.3382/ps.2011-02131

Yu H, Rahman A, Umer F, *et al.,* 2024. Effect of supplementing a blend of essential oils on the growth performance, carcass characteristics, meat quality, serological parameters and gut health in broiler chickens. Pakistan Veterinary Journal 44:1329-337. https://doi.org/10.29261/pakvetj/2024.301

Zhang C, Hao E, Chen X, *et al.,* 2023. Dietary fiber level improve growth performance, nutrient digestibility, immune and intestinal morphology of broilers from day 22 to 42. Animals 13:1227. https://doi.org/10.3390/ani13071227