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Insoluble fiber source influences performance, nutrients digestibility, gut development and carcass traits of broilers

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The research was conducted to examine the dietary influence of insoluble fiber sources, on performance, gut development, nutrients digestibility and carcass characteristics of the broilers. For this purpose, a total of 180-day old mixed sex, broiler (Ross 308) were randomly divided into 5 treatment groups of 6 replicates each. The broilers in first treatment group were fed basal diet, whereas broilers in other experimental groups were fed rations containing insoluble fiber from oat, rice hulls, sugarcane bagasse and wood shavings in such a way that the level of ingredients of each fibre source was 3%. All the diets were offered to the broilers in mash form during the entire experimental duration. The oat hulls-based diet improved ($P < 0.05$) the growth performance compared to those fed other experimental diets. The oat hulls-based diets increased the villus height by 15%, reduced the crypt depth by 11% and improved the villus height to crypt depth ratio upto 34% relative to those fed the rice hulls or wood shaving, while those fed sugarcane bagasse or control being intermediate. Apparent illeal digestibility of nutrients including dry matter, crude protein and amino acids was increased ($P < 0.05$) by feeding oat hulls-based ration to the broilers. Carcass traits such as dressed weight with and without giblets, breast and leg quarter yields were higher ($P < 0.05$) by the addition of oat hulls compared to other dietary treatment groups. The broiler fed oat hulls and sugarcane bagasse-based rations improved ($P < 0.05$) the relative weight of the gizzard compared to other treatment groups. In conclusion, dietary inclusion of 3% sugarcane bagasse and oat hulls resulted in an improved production, better duodenal histo-morphology, increased digestibility of various nutrients and carcass parameters in the broilers.
Keywords: Insoluble fibre Hulls, Digestibility, Intestine, Growth, Broilers.

INTRODUCTION

The inclusion of finely ground feed ingredients in broiler diets during early days of age is necessary due to inability of gastrointestinal tract to digest and absorb feed ingredients of varying particles size (Uni *et al.,* 1999). The primary disadvantage, however, associated with the higher proportion of the fines in the feed is reduced gizzard development (Abdollahi *et al.,* 2013). It has been reported that the reduced gizzard development enhanced the passage of undigested nutrients from fore to hind gut, which in turn, negatively affects the feed efficiency (Wiernusz *et al.,* 1995; Drozd *et al.*, 2022). In addition, the undigested proteins that reach in hind gut are fermented by microbes and are responsible for synthesis of various compounds of secondary nature such as ammonia, indoles, phenols and amines, which further exert negative impacts on production traits and intestinal histo-morphology in the broilers (Qaisrani *et al.,* 2015).

Various approaches including the inclusion of coarsely ground feed ingredients such as insoluble dietary fiber (IDF) and whole grains are used to stimulate the foregut development (Hetland *et al.,* 2005). The previous study has explored that the IDF in broiler diets, reduces the protein fermentation in hindgut, increases the digesta retention time, stimulates the gizzard development and enhances the production of HCl from the proventriculus (Kim *et al.,* 2008). The higher HCl production is responsible to reduce the intestinal tract pH which, in turn, improves the activity of digestive enzymes and enhances the digestibility of nutrients in the broilers (Guinotte *et al.,* 1995; Alshamiri *et al*., 2021).
The IDF, derived from plant cell wall, is mainly of three types including soluble high molecular weight polysaccharides and oligosaccharides and non-viscous IDF (Koca *et al.,* 2015). Nutritional properties of all these fiber types vary depending on various factors such as carbohydrate contents, ways of interaction with other similar compounds and molecular weight (Abdollahi *et al.,* 2021; Ikeogu *et al*., 2022). An

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increased dietary concentration of soluble polysaccharides, decreased the digesta passage rate and with increased viscosity which, hinders the absorption of nutrients, leading to poor growth performance of broilers (Gonzalez-Alvarado *et al.,* 2010). However, it has also been reported the increased dietary level of IDF source positively affect the growth performance of the broilers by enhancing digesta retention time, improving bile acids and pancreatic enzymes secretions and modifying microbial patterns (Amerah *et al.,* 2009).

The IDF efficacy in the intestinal region is influenced by numerous factors including type of IDF source, inclusion level and physio-chemical features (Hetland *et al.,* 2003). The type of IDF source, among those, is a primary factor that influences the gastro-intestinal tract development and finally the growth of broilers. Different IDF sources, due to differences in their nature, affects the digesta properties such as pH, passage rate, viscosity, microflora colonization and fermentation capabilities (Mateos *et al.,* 2012). Various fiber sources like wood shavings (WS), sugar beet pulp, sugarcane bagasse (SCB) and rice, oat and pea hulls can be used in the ration of broilers (Jha and Mishra, 2021).

In the current study, oat hulls (OH), rice hulls (RS), WS and SCB were used as IDF in broiler diet. The material left after the milling of oat grains is termed OH and is being used most commonly as IDF source in broilers diets due to its beneficial effects on gizzard development, nutrients digestibility and ultimately on feed conversion ratio (FCR) (Adewole *et al.,* 2020). It has also been reported that higher lignin concentrations of OH stimulates the synthesis of short chain fatty acids that reduces the GIT pH and modifies the intestinal microbiota population by decreasing the harmful gut microbiota proliferation that ultimately leads to an improved gut health in broilers (Cherrington *et al.,* 1991; Ndou *et al.,* 2018). In addition, OH has also been reported to enhance the digestive enzymes secretion and improves the digesta retention time in the gizzard, that lead to higher digestibility of nutrients (Gonzalez-Alvarado *et al.,* 2008; Sari *et al*., 2022). Furthermore, OH inclusion in broiler diet enhances the surface area of jejunum, that further improve the growth performance of broilers (Kheravii *et al.,* 2018). While, RH is by product of rice milling industries, left after the separation of grain from husk and RH shares about 20% of total production of the crop (Feng *et al.,* 2004). Similar to OH, RH can be used as IDF source in broiler diets due to its comparatively better nutritional profile (Rezaei *et al.,* 2014). Previous study has reported crude protein (CP), soluble and insoluble fiber in the RH as 2.4, 2 and 74%, respectively (Feng *et al.,* 2004). Dietary inclusion of RH has been documented to improve the broiler's production performance (Jimenez-Moreno *et al.,* 2016).

In addition to OH and RH, WS can also be used as an IDF source in broilers diets due to its higher cellulose, lignin and hemicellulose concentrations (Shirzadegan and Taheri, 2017). Wood shavings improve the nutrient utilization by enhancing the enzymatic activity and increasing the relative proventriculus and gizzard weight (Mateos *et al.,* 2012). Higher concentrations of WS, however, negatively influence the growth performance of broilers by increasing the abdominal fat and low density lipoprotein synthesis and decreasing the relative intestinal weight (Amerah *et al.,* 2009). During the extraction of sugar from sugarcane juice, a by-product SCB is produced (Zhang *et al.,* 2018), which contains significant amount of cellulose and hemicellulose. The SCB enhances the production performance of broilers by improving FI and FCR and promoting the multiplication of the microbes that are beneficial for the health of gastro-intestinal tract (Kheravii *et al.,* 2017).

The influence of inclusion of various IDF sources in the diet had variable results on nutrient digestibility, intestinal morphology and growth performance of broilers (Mateos *et al.,* 2012). For example, it has been reported that the IDF based rations, reduced the FI and BWG in the broilers (Sklan *et al.,* 2003) while, the study of Mateos *et al.* (2012) reported that the dietary IDF exerts positive influence on BWG, FCR and intestinal health in broilers. Keeping in view these variations, the present study was planned to evaluate the influence of different IDF sources on production performance, gut health, foregut development, carcass traits and apparent nutrients digestibility in the broilers.

MATERIALS AND METHODS

***Experimental design, diets and managemental procedure*:** Current experiment was approved by Animal Ethics Committee of University of Veterinary and Animal Sciences, Lahore, Pakistan (No. DR/168, Dated: 5 April 2020). A total of 180, day old mixed sexed broiler chicks (Ross 308) were procured from a local hatchery and divided randomly into 5 treatment groups of 6 replicates each. The broilers were kept in pens (0.8 × 0.6 × 0.5; L × W × H). The feed and water supply were ensured *ad libitum* during the complete experimental period of 35 d. The temperature of the experimental facility was initially maintained 33°C during first seven days of the experiment and then gradually decreased to 22°C till the completion of the trial phase. The lightening arrangements were maintained as 23 hour light and 1 hour dark period for first 3 days of the trail, thereafter minimized upto 16 hour light and 8 hour dark period with 20 lux intensity throughout the trail. All the other experimental procedures were adopted in accordance with strain recommendations.

For the experimental diets, different IDF sources including RH, WS, SCB and OH were purchased from a local market. The RH, WS, SCB and OH were ground to fine particle size with the help of a hammer mill (Wiley Mill, Model No. 2, Thomas Scientific) by using a sieve of 2 mm. The first treatment group was fed basal diet (control), whereas rest of the groups were fed rations containing RH, WS, SCB and OH, in such a way that the level of ingredients of each fibre source was 3%. The basal diets were formulated for all the phases including starter (0 to 10 d), grower (11 to 20 d) and finisher (21 to 35 d) in mash form (Aviagen International, 2017). Furthermore, celite (2%) was added in the finisher diets as an inert marker for estimation of nutrients digestibility (dry matter (DM), CP and amino acids (AA).

Table 1. Composition of dietary ingredients of the test diets

Ingredient (%)	Starter	Grower	Finisher
Maize	57.70	61.80	63.20
Soybean meal (47%)	31.05	24.05	21.80
Canola meal (37%)	1.60	3.04	3.91
PBM (58%)	1.90	1.95	0.95
Vegetable oil	2.77	4.50	5.00
Calcium carbonate	0.95	1.10	1.00
Di-calcium phosphate	2.00	2.10	2.15
Lysine-HCl	0.40	0.43	0.46
DL-Methionine	0.45	0.38	0.34
Thr-HCl	0.20	0.18	0.14
Tryptophan	0.03	0.03	0.03
Sodium chloride	0.19	0.19	0.21
Sodium bicarbonate	0.24	0.34	0.31
Premixes[1]	0.52	0.51	0.50
Total	100.00	100.00	100.00
Analyzed nutrients[2] composition (%)			
DM	87.95	88.98	88.93
CP	21.50	18.90	18.30
ME	3002.00	3150.00	3200.00
CF	3.65	3.52	3.68
Calcium	0.98	0.93	0.85
Available phosphorous	0.47	0.42	0.37
Lysine (digestible)	1.25	1.18	1.07
Threonine (Digestible)	0.85	0.76	0.70
Tryptophan (Digestible)	0.19	0.20	0.17
Methionine + Cystein	0.95	0.84	0.83
Arginine (digestible)	1.35	1.26	1.12
Valine (digestible)	0.94	0.89	0.75
Isoleucine (digestible)	0.88	0.76	0.75
Leucine (digestible)	1.39	1.30	1.15

[1]Mineral premix = Manganese = 120, Zinc = 100, Iron= 60, Iodine = 0.46, Copper = 10. Vitamin premix = Pantothenic acid= 11mg, Vitamin A= 5500IU, Vitamin B12= 0.006mg, Vitamin E= 11IU, Thiamine= 2.2mg, Vitamin D3= 1100IU, Choline chloride= 220mg, Riboflavin= 4.4mg, Pyridoxine= 2.2mg, Folic acid= 0.55mg, Biotin= 0.11mg. [2]CF = Crude fiber, DM = Dry matter, ME = Metabolizable energy, CP = Crude protein.

***Proximate analysis of the test diets and fiber sources*:** Proximate analysis (DM, CF, EE, CP and crude ash) of both fiber sources and experimental diets was performed by following the standards procedure of AOAC, 2006. Table 2 and 3 represents the analyzed concentration of nutrients of all IDF sources and the test diets.

Table 2. Nutrient analysis of insoluble fiber sources on dry matter basis (%)

Parameter[1]	Fiber source			
	Oat hulls	Rice hulls	Wood shavings	Sugarcane bagasse
DM	95.95	95.96	96.5	70.8
CP	4.85	2.10	1.80	1.79
EE	1.60	1.15	0.95	0.78
CF	33.00	25.10	28.5	45.0
NDF[2]	59.90	67.00	77.0	85.9
ADF[3]	28.00	48.90	63.1	58.0
ADL[4]	16.00	26.50	20.8	22.0

[1]CF = Crude fiber, DM = Dry matter, NDF = Neutral detergent fiber CP = Crude protein, EE = Ether extract, ADF = Acid detergent fiber, ADL = Acid detergent lignin.

***Production performance and carcass traits and intestinal tract measurements*:** Data regarding performance parameters (FI, BWG, and FCR) were taken at the completion of starter, grower and finisher phases. Mortality was recorded at the time of its occurrence.

At d 35 of the trial, three broilers were selected on random basis from each replicate and slaughtered by adopting the halal procedure (Yaseen *et al.,* 2021). After slaughtering, internal organs such as liver, pancreas, crop, gizzard and proventriculus were separated and weighed by using weighing balance (ADAM, Model No. 254). The above mentioned relative organ weight was measured as percentage of BW. After slaughtering, weighing balance was used to measure the carcass parameter including dressed weight (with and without giblets), breast yield (BY) and leg quarter yields (LQY).

Gut measurements including length and relative empty weights of duodenum, jejunum, ilium and ceacum were taken by initially removing a portion of intestine (duodenum) from the slaughtered broiler and then emptying it.

***Nutrients digestibility*:** Apparent ileal nutrients digestibility was determined by taking ileal digesta samples through gentle squeezing the region between the yolk sac and terminal ilium, at least 20 mm above ileo-caecal joint. These samples were then poured into plastic containers and stored at freezing temperature (-20°C) until further analysis. The acid insoluble ash (AIA) and CP contents of both digesta samples and test diets were measured by adopting the standards suggested by (AOAC, 2006). The analyzer (Biochrom 30+, Biochrom Limited. Cambridge, UK) was used to determine the AA contents in both digesta samples and test diets as documented by Ahmad *et al.* (2019). Before analysis, the samples of both ileal digesta and test diets were prepared by initially grounding them up to 500 microns and then oxidizing them by using performic acid for conversion of cysteine and methionine into cys-cystic acid and met-methionine sulphone, respectively. Hydrolysis was performed, after oxidation, for 24 h by using hydrochloric acid or phenol solution (6M), until the pH was sustained at 2.2. These samples were filtered, afterwards, moved to sample vials and placed in Biochrome for AA analysis with the help of ion exchange chromatography.

The formula used for calculation of AID of nutrients was as follows (Ravindran *et al.,* 2005);

$$\text{AID (\%)} = \frac{\text{CPd/AiAd} - \text{CPi/AiAi}}{\text{CPd/AiAd}} \times 100$$

***Morphology of the intestinal tract*:** For evaluation of morphology of the duodenum, sample (2cm) was taken from the middle portion of the duodenum, fixed in normal saline (0.9%), transferred into plastic container containing formalin solution (10%) for storage and sent to laboratory for further processing. For laboratory analysis, these samples were removed from plastic containers and transferred to ethanol solution (70%). Duodenal samples were picked from ethanol solution. These sample, thereafter were put in paraffin for blocks formation. These paraffin blocks were fixed in microtome to cut into segments of 5-μm thickness for each samples. Afterwards, six cross sections for each sample were processed for histological measurements (Anwar *et al.,* 2023 a,b). Morphological parameters of the gut including villus height (VH), crypt depth (CD), and villus height to crypt depth ration (VCR) were measured afterwards on 10 intact villi per bird by using camera fitted compound microscope (Nazir *et al.,* 2022; Shoaib *et al.,* 2021). The software used for these measurements was ImageJ software.

***pH of the digestive organs*:** The abdominal cavity of the slaughtered bird from each replicate was opened aseptically to measure the pH of the digestive organs including upper (Crop, proventriculus, gizzard) and lower digestive organs (duodenum, jejunum, ileum and ceacum) as the method reported by Singh *et al.* (2014). Briefly, above mentioned organs were opened with the help of aseptic sharp blade from the middle and immediately pH was noted by positioning the probe of a digital pH meter (Model-507, Crison. Instrument) directly into the digesta.

Statistical analysis: Following statistical model was used to analyse the data by using one-way ANOVA technique with the help of SAS software (version 9.1)

$$Y_{ijk} = \mu + ES\, i + e_{ijk}$$

Where, Y ijk = Dependant Variables, μ = Mean of the population, ES i = Effects of different IDF sources, e ijk = Residual effect.

A probability level was set at ($p < 0.05$). Duncan's Multiple Range Test (DMR) was used to compare the means

RESULTS

***Growth performance*:** The influence of IDF from different sources on various performance parameters of the broilers is represented in Table 4. The growth performance was decreased ($P > 0.01$) by inclusion of IDF sources compared to control during starter phase in the broilers. The OH supplementation in broiler diets, during grower period as well

Table 3. Analysed nutrient contents of the experimental diets (on DM basis)

Items	Starter[1] (%)					Grower[1] (%)					Finisher[1] (%)				
	CTL	OH	RH	WS	SCB	CTL	OH	RH	WS	SCB	CTL	OH	RH	WS	SCB
Dry matter	88.96	90.0	89.54	88.98	89.0	88.34	88.80	89.18	88.50	89.33	89.13	88.98	89.15	89.31	89.24
Crude protein	20.96	21.40	21.43	21.44	21.87	19.85	19.80	19.20	19.10	19.30	18.38	18.36	18.70	18.0	18.40
Ether extract	4.10	3.66	3.46	3.20	2.96	2.53	3.13	3.03	3.32	2.71	3.79	3.34	3.48	3.32	3.45
Crude fiber	4.08	5.23	5.51	5.67	5.80	4.12	5.08	5.53	5.85	7.19	4.12	5.20	5.56	5.83	6.50
Ash	5.71	4.32	5.15	4.62	4.28	6.05	4.02	6.28	3.83	3.81	5.12	5.12	6.37	5.14	5.36
Lysine	1.44	1.47	1.48	1.49	1.48	1.29	1.28	1.27	1.26	1.29	1.17	1.18	1.16	1.15	1.18
Methionine	0.63	0.62	0.61	0.61	0.63	0.57	0.58	0.59	0.57	0.60	0.61	0.61	0.59	0.65	0.60
M+C[2]	1.07	1.07	1.06	1.05	1.07	0.99	0.97	0.96	0.98	0.97	0.92	0.91	0.90	0.90	0.93
Threonine	0.97	0.98	0.96	0.97	0.98	0.89	0.88	0.88	0.90	0.88	0.78	0.78	0.77	0.76	0.79
Valine	1.10	1.11	1.09	1.08	1.10	1.00	1.05	0.99	0.95	1.00	0.90	0.95	0.87	0.90	0.90
Arginine	1.53	1.52	1.49	1.50	1.53	1.38	1.38	1.37	1.35	1.36	1.23	1.22	1.24	1.22	1.24

[1]CTL = Control, WS = Wood shaving, OH = Oat hulls, SCB = Sugarcane bagasse, RH = Rice hulls. [2]Cysteine and Methionine.

Table 4. Effects of insoluble dietary fiber source on production performance of broilers at 35[th] day of age[1].

Treatment	Observations[2]											
	Feed intake (grams)				Body weight gain (grams)				Feed conversion ratio (FI/BWG)			
Age →	0-10	11-20	21-35	1-35	0-10	11-20	21-35	1-35	0-10	11-20	21-35	1-35
Control	233.5[a]	1107.9[c]	1564.6[c]	2906.1[b]	204.1[a]	776.2[c]	1086.3[c]	2066.6[b]	1.14	1.43[c]	1.44	1.40[b]
Oat hulls	222.0[b]	1133.3[a]	1588.2[a]	2943.5[a]	192.2[b]	818.4[a]	1107.0[a]	2117.6[a]	1.15	1.38[a]	1.43	1.39[a]
Rice hulls	216.8[c]	1093.9[d]	1548.4[d]	2859.1[c]	184.4[c]	765.8[d]	1073.9[d]	2024.0[c]	1.80	1.43[c]	1.44	1.41[b]
Wood shavings	208.5[d]	1083.4[e]	1529.0[e]	2820.9[d]	180.5[d]	754.3[e]	1061.3[e]	1996.1[d]	1.55	1.44[c]	1.44	1.41[b]
Sugarcane bagasse	217.5[c]	1122.6[b]	1569.9[b]	2909.9[b]	186.8[c]	793.2[b]	1092.1[b]	2072.1[b]	1.16	1.41[b]	1.44	1.40[b]
Standard error of mean	1.61	3.43	3.79	8.03	1.59	4.23	2.93	7.87	0.004	0.004	0.001	0.002
p-value	0.001	0.001	0.001	0.001	0.02	0.01	0.01	0.01	0.096	0.01	0.13	0.01

Different superscripts (a-e) represent significant differences at $P < 0.05$. [1]The values of each treatment group is the mean of 6 replicates

Table 5. Effects of dietary insoluble fiber sources on nutrients digestibility in broilers at 35d of age[1].

Items (%)[3]	Fiber sources[2]						
	CTL	**OH**	**RH**	**WS**	**SCB**	**SE of Mean**	***p-value***
Dry matter	71.0^{c}	73.9^{a}	69.0^{d}	68.0^{d}	73.0^{b}	0.69	0.01
Crude protein	79.0^{c}	81.0^{a}	77.50^{cd}	76.4^{d}	80.0^{b}	0.54	0.01
Essential amino acids							
Methionine	83.3^{c}	89.8^{a}	82.2^{c}	80.4^{d}	86.2^{b}	0.89	0.01
Lysine	85.9^{c}	90.1^{a}	84.7^{cd}	83.2^{d}	87.9^{b}	0.65	0.01
Leucine	81.7^{c}	85.1^{a}	80.8^{c}	79.4^{d}	83.4^{b}	0.54	0.01
Isoleucine	74.0^{b}	77.9^{a}	73.2^{bc}	72.2^{c}	76.7^{a}	0.59	0.01
Threonine	65.9^{c}	70.0^{a}	63.9^{d}	62.7^{d}	67.5^{b}	0.69	0.01
Valine	61.0^{c}	64.0^{a}	59.0^{d}	58.5^{d}	62.2^{b}	0.50	0.01
Histidine	81.0^{c}	84.0^{a}	79.0^{d}	78.6^{e}	82.9^{b}	0.56	0.01
Arginine	86.9^{c}	89.9^{a}	85.9^{c}	83.9^{d}	88.8^{b}	0.56	0.01
Phenylalanine	76.4^{c}	80.7^{a}	75.0^{d}	74.0^{e}	78.5^{b}	0.66	0.01
Non- Essential amino acids							
Glycine	64.3^{c}	68.0^{a}	62.4^{d}	61.2^{d}	66.0^{b}	0.64	0.01
Alanine	72.9^{b}	76.0^{a}	71.5^{c}	69.9^{d}	74.0^{b}	0.55	0.01
Cystine	78.9^{c}	85.5^{a}	77.6^{d}	76.4^{d}	83.0^{b}	0.95	0.01
Serine	74.3^{c}	73.2^{a}	73.7^{cd}	72.3^{d}	77.1^{b}	0.68	0.01
Glutamine	84.4^{b}	85.7^{a}	83.1^{c}	82.0^{d}	84.6^{ab}	0.34	0.01
Aspartic Acid	71.3^{c}	75.2^{a}	69.2^{d}	67.8^{e}	73.8^{b}	0.74	0.01
Tyrosine	79.0^{c}	85.2^{a}	77.2^{d}	76.2^{e}	82.8^{b}	0.91	0.01
Ornithine	76.3^{a}	74.6^{ab}	72.7^{b}	74.3^{ab}	75.0^{3ab}	0.42	0.01
Proline	75.7^{c}	80.9^{a}	74.2^{d}	72.6^{e}	78.0^{b}	0.78	0.01

Different alphabets (a and e) on means represent significant differences at $P < 0.05$. [1]The values of each treatment group is the mean of 6 replicates each containing 3 birds. [2]CTL = Control, RH= Rice hulls, OH= Oat hulls, SCB= Sugarcane bagasse and WS= Wood shavings.

Table 6. Effects of dietary insoluble fiber source on relative empty weight and length of the intestinal segments in boilers at 35th day of age.[1]

Treatment	Relative weight (% of Body weight)				Length (cm)			
	Duodenum	**Jejunum**	**Ileum**	**Ceaca**	**Duodenum**	**Jejunum**	**Ileum**	**Ceaca**
Control	0.78	1.83	1.73	0.81	35.20	72.48	89.70	15.50
Oat hull	0.71	1.79	1.80	0.76	34.77	74.50	85.80	17.60
Rice hull	0.72	1.80	1.79	0.71	33.27	77.81	90.40	15.70
Wood shaving	0.81	1.77	1.77	0.77	32.87	74.75	83.70	16.90
Sugarcane bagasse	0.77	1.73	1.83	0.79	35.71	75.19	87.30	18.30
Standard error of mean	0.01	0.03	0.04	0.02	0.33	0.32	0.14	0.08
p-value	0.175	0.590	0.623	0.615	0.728	0.313	0.425	0.565

[1]The values of each treatment group is the mean of 6 replicates each containing 3 birds.

as finisher phase, increased ($P < 0.01$) the FI and BWG relative to the CTL and RH based diet, while SCB being intermediate. Moreover, the FCR remained unchanged ($P = 0.13$) by the addition of IDF in the broiler diet during finisher phase. During the entire experimental period of 35 d, dietary addition of OH has resulted in higher ($P < 0.01$) FI, BWG as well as FCR, compared to broilers fed the RH and CTL diets, whereas SCB remained intermediate.

***Apparent ileal nutrients digestibility*:** The results indicating the influence of IDF in broilers diet on apparent ileal nutrients digestibility are represented in the Table 5. The broilers consuming OH based diets indicated increased ($P < 0.05$) AID of CP and DM than those fed the CTL and other IDF sources. The OH and SCB based diets resulted in an improved ($P < 0.05$) AID of isoleucine relative to the other diets. The broiler consuming OH diets exhibited improved ($P < 0.05$) AID of almost all AA including lysine, methionine, valine, arginine, serine, histidine, threonine and proline than those fed the CTL, RH and WS diets, compared the broilers consuming SCB diets that remained intermediate.

Absolute length and Relative weight of intestinal segments: The results indicating the influence of IDF from different sources on empty relative weight and length of intestinal segments in the broilers are summarized in Table 6. The dietary treatment did not influence ($P > 0.05$) the empty absolute length and relative weight of different intestinal portions including ilium, ceaca, duodenum and jejunum in the broilers.

***Morphological measurements of the duodenum*:** The morphological measurement of the duodenum was affected (P < 0.05) by the experimental diets (Table 7). The OH containing diets increased the VH by 15%, VCR upto 34%, whereas the CD was reduced upto 11% than those fed the RH or WS based diets. Moreover, the broilers fed the SCB or CTL based diets were being intermediate.

Table 7. Effects of insoluble fiber source on duodenal histo-morphological parameters of the broilers at 35th day of age[1].

Treatment	Villus height (μm)	Crypt depth (μm)	VH:CD[2]
Control	1633^{b}	266^{c}	6.14^{c}
Oat hulls	1820^{a}	234^{a}	7.78^{a}
Rice hulls	1597^{b}	268^{cd}	5.96^{cd}
Wood shavings	1580^{b}	273^{d}	5.79^{d}
Sugarcane bagasse	1803^{a}	251^{b}	7.18^{b}
Standard error of mean	28.41	3.82	0.22
p-value	0.01	0.01	0.01

Different alphabets (a-d) represent significant differences at $P < 0.05$. [1]The values of each treatment group are the mean of 6 replicates each containing 3 birds. [2] Villus height to Crypt depth ratio.

***pH of the digestive organs*:** The results representing the effects of IDF on pH of the internal organs of the broilers are summarized in Table 8. The IDF supplementation, regardless of the fiber source, reduced ($P < 0.05$) the pH of gizzard and proventriculus relative to the control diet in broilers. The pH of the crop, ceacum, ileum, jejunum and duodenum and various segments of the intestinal tract, however, remained unaffected ($P > 0.05$) by the IDF sources.

***Carcass traits and organs weight measurements*:** The results indicating the influence of IDF from different sources on organs weight and carcass traits of the broilers are presented in Table 9. The dietary treatment influenced ($P < 0.05$) the carcass traits. The broilers diets containing OH increased the DWG, DWWG, BY up to 5% and 15% LQY, compared to those fed the CTL, RH and WS based diets, while SCB diets remained intermediate.

The IDF, irrespective of the source, increased ($P < 0.05$) the relative gizzard weights compared to the control in broilers. The addition of IDF sources in broilers diet, however, did not affect ($P > 0.05$) the empty relative weights of the crop, proventriculus, liver and pancreas in the broilers.

DISCUSSION

The current trial was carried out to evaluate the effects of IDF from different sources on production and carcass parameters, duodenal histo-morphology, foregut development and

Table 8. Effects of insoluble fiber source on the pH of various digestive organs in the broilers at 35th day of age.[1]

Treatment	pH[2]						
	Crop	Provent.	Gizzard	Duodenum	Jejunum	Ileum	Ceacum
Control	4.99	3.60^{a}	3.58^{a}	6.00	6.30	6.90	6.95
Oat hulls	5.02	3.20^{b}	3.21^{b}	5.98	6.25	6.79	6.94
Rice hulls	5.04	3.15^{b}	3.20^{b}	5.96	6.36	6.85	6.97
Wood shavings	5.11	3.24^{b}	3.23^{b}	6.10	6.40	6.89	6.93
Sugarcane bagasse	5.12	3.23^{b}	3.24^{b}	6.12	6.30	6.85	6.94
SEM[3]	0.007	0.034	0.03	0.025	0.028	0.13	0.013
p-value	0.80	0.001	0.001	0.60	0.49	0.81	0.23

Different alphabets (a - b) on means represent significant differences at $P < 0.05$. [1]The values of each treatment group is the mean of 6 replicates each containing 3 birds. [2]Proventriculus. [3]SEM = Standard error of mean.

Table 9. Effects of insoluble fiber source on carcass traits and relative empty organs weight in the broilers at 35th day of age[1].

Treatment	Observations (% BW)								
	Carcass traits[2]				Relative organ weight				
	DWG	DWWG	BY	LQY	Crop	Proventriculus	Gizzard	Liver	Pancreas
Control	62.0^{b}	58.0^{c}	23.0^{c}	8.8^{c}	0.25	0.36	1.30^{b}	1.98	0.17
Oat hulls	64.0^{a}	60.0^{a}	24.0^{a}	9.8^{a}	0.27	0.35	1.32^{a}	2.01	0.17
Rice hulls	61.0^{d}	57.0^{d}	23.0^{c}	8.5^{d}	0.25	0.34	1.31^{b}	2.11	0.16
Wood shavings	60.0^{e}	55.9^{e}	21.0^{d}	7.9^{e}	0.26	0.37	1.28^{b}	1.99	0.18
Sugarcane bagasse	61.2^{c}	58.6^{b}	23.2^{b}	9.4^{b}	0.27	0.35	1.29^{a}	1.98	0.17
Standard error of mean	0.18	0.19	0.11	0.08	0.004	0.003	0.004	0.021	0.003
p-value	0.001	0.001	0.001	0.001	0.27	0.216	0.021	0.34	0.24

Different alphabets (a-e) on means represent significant differences at $P < 0.05$. [1]The values of each treatment group is the mean of 6 replicates each containing 3 birds. [2]DWG= Dressed weight with giblet, DWWG= Dressed weight without giblet, BY= Breast yield, LQY= Leg Quarter yield nutrients digestibility in the broilers. It was hypothesized that the IDF addition in broiler diets may impose positive effects on nutrients digestibility, gut morphology and foregut development, leading to an improved performance in terms of growth. An increased VH and decreased CD were chosen as indicators of healthy intestinal tract.

The better production performance of the broilers, obtained in the current study, by the dietary addition of OH, is in accordance with the findings of published literature (Moradi *et al.,* 2021). These later authors reported that the addition of 3% OH in the diet of broilers increased the FI and BWG and improved the feed conversion ratio. These findings are in line with Adewole *et al.* (2020), who found 3% improved FI and BWG by the addition of 3% OH in the diet of broilers during the finisher phase. The better production performance in the current study may be correlated with OH potential to enhance gizzard development and function, leading to excessive digestive enzyme secretions in broilers (Engberg *et al.,* 2004). Moreover, inclusion of IDF may result in a prolonged retention of digesta in the gut, which leads to greater exposure of nutrients to the digestive enzyme secretions (Kheravi *et al.,* 2017b). This extended exposure, sequentially improves the utilization of nutrients in the digestive tract and ultimately better performance of broilers (Sacranie *et al.,* 2012). Similarly, Jimenez-Moreno *et al.* (2008) also reported 5% higher FI and 2% improved FCR in the broilers fed 5% oat and rice hulls-based ration. In contrast to the findings of the present study, Abdollahi *et al.* (2018) documented that the use of 3% OH resulted in 3% reduced FI and 8% decreased BWG in the broilers. These variations among studies may possible be due differences in feed form and physical properties of the fiber sources including water holding capacity and solubility.

The present findings regarding the influence of dietary addition of IDF from different sources on digestibility of various nutrients are in line with the literature in the broilers (Moradi *et al.,* 2021). These later authors found an improved AID of CP and DM by using 3% OH in the broiler's diets. The addition of OH lowers the gizzard pH and enhances the activity of digestive enzymes that leads to better utilization of protein and amino acids (Pourazadi *et al.,* 2020). Abdollahi *et al.* (2018), however, did not find significant influence of dietary inclusion of OH on nutrients digestibility in the broilers. Various factors are responsible for these variations among the results of various studies including fiber type, particle size and composition and feed form.

The influence of IDF from different sources on relative weights and lengths of the intestinal segments in the study, are in line with published literature (Pourazadi *et al.,* 2020). These later authors found non-significant influence of dietary use of IDF on the relative intestinal weight and length in broilers. Solubility of fiber source, among others, is the primary factor that influences the length and weight of the intestinal segment (Iji *et al.,* 2001). Dietary inclusion of highly soluble fiber sources, for instance, has resulted in an improved length and weight of the intestine, whereas IDF sources exert little or no effects on these parameters in the broilers. This negligible effect is associated with low digesta retention time in the intestinal tract, because of higher degradation of nutrients in the gizzard (Scholey *et al.,* 2020). Amerah *et al.* (2009), in opposition to the findings of the present study, found significant decreased length and weights of the intestinal segments in the broilers fed OH based ration. Similarly, Moradi *et al.* (2021) reported an increased intestinal length and weight by 9.4 and 11.3%, respectively, in the broilers fed RH and sunflower hulls based ration. The possible reason behind these discrepancies in the results of various studies may be due to the variations in the particle size of the IDF and its physio-chemical properties (Mateos *et al.,* 2012).

The primary factor that indicates the overall health of gastrointestinal tract is its morphology. An increased VH, for instance, is responsible for an enhanced surface area of the intestine that leads to higher nutrients absorption (Xu *et al.,* 2003). The improved CD, on the other hand, is an indicator of higher tissue turnover rate, which in turn, require more nutrients for maintenance that exert negative effects on growth performance of the broilers (Geyra *et al.,* 2001). Hetland *et al.* (2004) reported that there is a significant variation regarding the effects of IDF from different sources on the morphology of duodenum and depend on various properties including texture and coarseness. The improved intestinal morphology by the addition of IDF source in the current study is in line with expectations (Sittiya *et al.,* 2020). These later authors found beneficial effects of addition of SCB, OH and whole wheat in broilers diet on various morphological parameters including VH and villus height to crypt depth ratio. The current findings are in accordance with Moradi *et al.* (2021), who reported that the use of 3% OH in broilers diet resulted in significant improved VH and decreased crypt depth. The OH stimulates the development of intestinal mucosa and in turn, nutrients absorption that led to an increased VH in the broilers (Moradi *et al.,* 2021). Similar to the current findings, Jimenez-Moreno *et al.* (2011) found a greater VH by dietary addition of 2.5% RH in the broiler diet. Abdollahi *et al.* (2018), however, observed non-significant influence of dietary WS, OH and lignocellulose on the VH of jejunum and duodenum in the broilers. These variations between the findings of different studies may be associated with variations in properties including coarseness and texture of the fiber sources (Amerah *et al.,* 2009).

The present findings regarding the influence of IDF from different sources on pH of various digestive organs are in agreement with those reported by Jimenez-Moreno *et al.* (2009), who documented significant reduced pH of the gizzard in the broilers fed sugar beet pulp and OH based ration. These findings are inconsistent with those observed by Moradi *et al.* (2021), who found that the dietary inclusion of 3% oat and rice hulls resulted in significant reduced gizzard pH in broilers. The OH enhances the secretion of HCl from the proventriculus, which in turn, is responsible for an increased activity of the proteolytic enzymes, ultimately leading to lowered gizzard pH and better nutrients utilization in the broilers (Jimenez-Moreno *et al.*, 2019). Similar to the current findings, Yokhana *et al.* (2016) found lowered pH of gizzard in the broilers fed ration containing 2.5% OH. Gonzalez-Alvarado *et al.* (2010), in accordance with the results of present study, documented reduced gizzard pH by OH fed broilers.

The improved carcass traits of the broilers fed diets containing IDF are in agreement with the previous findings (Shahin and Abd El Azeem 2006; Adewole *et al.*, 2020), who documented an improved dressed weight and higher breast and leg quarter yield by the dietary addition of SCB and OH (3%) in broilers. Similar to the results of the present study, Pourazadi *et al.* (2020) found that 3% SCB addition in the diet of broilers resulted in an improved carcass weight and breast yield by 2 and 11%, respectively. This improved carcass traits in response to SCB containing diets may be correlated with the ability of IDF sources to bind cholesterol, produced from bile salts, which in turn reduces the abdominal fat deposition resulting in improved carcass characters (Kritchevsky and Story, 1974). Sittiya *et al.* (2020), in contrast to the findings of the present study, reported significantly decreased carcass weight and reduced BY and LQY by the dietary inclusion of 3% oat and rice hulls in broilers. These disparities among the findings of various studies may be due to variations in fiber type, its lignin and crude ash concentration (Pourazadi *et al.*, 2020).

The higher gizzard weight of the broilers fed IDF based ration in the current study is in agreement with the previous studies in the broilers (Hetland *et al.*, 2003; Kheravi *et al.*, 2017). Hetland *et al.* (2003) reported higher gizzard weight of the broilers fed OH based diet. These results are inconsistent with those documented by Scholey *et al.* (2020), who found 15% increased gizzard weight by the graded (7, 17 and 27%) use of OH in the broilers diet. The OH and other IDF source increase the digesta staying time in the gizzard, which in turn, is responsible for its better grinding ability and muscular development, leading to an improved weight of the gizzard in the broilers (Jones and Taylor, 2001). Svihus (2011), however, found non- significant effects on gizzard weight by the dietary use of OH in the broilers. The influence of IDF from various sources, in this trail, on liver, pancreas, crop and proventriculus weight, reported is in accordance with the published literature (Abdollahi *et al.*, 2018; Adewole *et al.*, 2020).

***Conclusions*:** The addition of OH and SCB as IDF sources in broiler diet resulted in an improved production performance and carcass traits, better duodenal morphology and higher nutrients utilization in the broilers, whereas the addition of RH and SCB exerted negative effects on various production parameters. In conclusion, 3% OH and SCB can potentially be used in broilers diets to enhance foregut development, gut health, nutrients digestibility and ultimately production performance.

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