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Growth Performance, Nutrient Digestibility, Gastrointestinal Tract Traits in Response to Dietary Fiber Sources in Broiler Chickens

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Abstract

The effects of dietary insoluble fiber sources on growth performance, gastrointestinal tract (GIT) traits, nutrient digestibility and intestinal enzyme activity were studied in broilers from 1 to 42 d of age. A total of 480 one-day-old chicks (Ross 308), were allocated in four treatments, six replicates and 20 birds in each, based on a completely randomized design. Dietary treatments were including a corn-soybean meal basal diet (control diet) and other three diets formulated by the inclusion of 30 g/kg of processed wheat straw (WS), sunflower hulls (SFH), or soybean hulls (SBH) in the control diet. From 1 to 10 d of age, broiler chickens fed processed WS tended to have higher feed intake than broilers fed the control diet (P = 0.064) and had higher body weight gain than broilers fed the other treatments ($P < 0.05$). The relative weight of the GIT organs was not affected by treatments but SFH and SBH decreased the length of the small intestine at 42 d of age ($P < 0.05$). The pH of different segments of the GIT, carcass traits, dry matter, nitrogen digestibility, and apparent metabolizable energy corrected by nitrogen were not affected by treatments. The activity of amylase and aminopeptidase in the duodenum and jejunum was not affected by the insoluble fiber sources. In conclusion, the dilution of the control diet with the inclusion of 30 g/kg insoluble fiber did not have any negative effect on broiler chickens' performance and marketing weight. Moreover, improved performance was observed with processed WS, particularly during the starter period.

Introduction

Modifying the physical structure of feed ingredients, highly digestible feedstuffs, heat processing, and the addition of dietary fiber are of central attention in the poultry industry to improve gut health and nutrient availability without promoters agent (Kheravii *et al.*, 2017). Fiber inclusion in the diet has been intended as a diluent factor in monogastric animals (Mateos *et al.*, 2002). However, recent investigations have clarified in detail the insoluble fiber's beneficial effects on growth performance, intestinal microflora, gizzard activity, gut health, and animal welfare (Mateos and Jimenez-Moreno, 2014). Fiber sources have various physicochemical characteristics such as the soluble fraction of dietary fiber increases digesta viscosity, and passage rate of the digesta (Raninen *et al.*, 2011). In contrast, insoluble fiber increases gizzard weight and decreases feed passage rate, at least in the proximal part of the GIT (Mateos *et al.*, 2012). Lignocellulose products such as arbocel have been reported to show have a positive effect on excreta content, litter status, intestinal microflora, fermentation, and nitrogen retention in broilers (Boguslawska-Tryk *et al.*, 2015; Sozcu, 2019). It is well known that cereal by-products could be used instead of purified insoluble fiber sources regarding feed costs in broilers (Kheravii *et al.*, 2017). Straw is a by-product with uniform quality and needs to be further considered in broiler feeding (Guzman *et al.*, 2015b).

Rice and wheat are the largest crops production throughout the world (Asseng *et al.*, 2011). Cereal seeds are used by humans whereas non-seed parts are largely considered as by-products or some sources of environmental pollution in the particular case. Wheat straws tend to be more lignified than other small grain straws and could be an important feed resource

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for ruminants and monogastric animals such as geese if properly processed (Mateos *et al.,* 2012). For instance, straw processed with sodium hydroxide could lead to greater digestibility and promotes better animal performance (Males, 1987). Release nutrients in the cell could be available by breaking down the lignin-cellulose structure of cell wall (Severe and ZoBell, 2012). Therefore, many investigations have been conducted on the effects of feeding soybean hulls (SBH) (Gonzalez-Alvarado *et al.,* 2007) or sunflower hulls (SFH) (Kimiaeitalab *et al.,* 2018; Jimenez-Moreno *et al.,* 2019) in poultry production but comparison to wheat straw (WS) needs to further investigation. We hypothesized that processed WS would be an alternative for an insoluble fiber source in broiler chicken feeding. The objective of this study was to investigate the effect of including various insoluble fiber sources on growth performance, gastrointestinal tract traits, nutrient digestibility, and intestinal enzyme activity in broiler chickens from 1 to 42 days of age.

Materials and Methods

Fiber sources and experimental diets

Before trial commencement, Wheat Straw, Soybean hull, and, Sunflower hull were purchased from Hamedan province, Energy and protein Shayan company, and the Research center of Tabriz University, respectively. Wheat straw was processed with a 20 g/kg sodium hydroxide solution. Before incorporation into the diet, the insoluble fiber sources were ground by a hammer mill; a 2.5 mm screen (Model DFZC-635, Bühler AG, Uzwill, Switzerland). The control diet was based on corn and soybean meal and met or exceeded recommendations (Aviagen, 2014) for all nutrients. The other three experimental diets provided by the inclusion of 30 g processed WS, SFH, or SBH hulls in the control diet. The feeding program consisted of 3 periods: starter (1 to 10 d of age); grower (11 to 24 d of age) and finisher (25 to 42 d of age). Chromium oxide (Cr_2O_3) was added at 5 g/kg to the grower diet as an indigestible marker. Feed in mash form and water were offered *ad libitum*. The chemical analysis of the insoluble fiber sources is shown in Table 1. The ingredient composition, and chemical analysis of the starter, grower, and finisher experimental diets are shown in Tables 2, 3, and 4, respectively.

Table 1. Determined chemical analysis (g/kg as fed) and geometric mean diameter of the insoluble fiber sources

	Processed WS	Sunflower hulls	Soybean hulls
Chemical analysis			
Dry matter	964	955	940
AME_n[A] (kcal/kg)	198	339	800
Total ash	109	34	50
Crude protein	40	60	121
Crude fiber	303	485	352
Ether extract	15	30	25
Neutral detergent fiber	642	719	614
Acid detergent fiber	344	520	431
Acid detergent lignin	71	200	18
Total carbohydrate [B]	799	831	744
Cellulose [C]	273	320	413
Hemicellulose [D]	298	219	183
Non fiber carbohaydrate [E]	194	167	190
Amino acid profiles[F]			
Methionine	0.51	0.86	1.21
Methionine + Cystine	1.04	1.66	3.19
Lysine	1.28	2.19	7.34
Threonine	1.15	1.97	4.21
Arginine	1.30	2.55	5.89
Phenylalanine	1.25	2.00	4.46
GMD ± GSD[G] (μm)	610 ± 1.80	593 ± 1.60	578 ± 1.81

[A]According to FEDNA: Fundacion Espanola para el Desarrollo de la Nutricion Animal (2010).
[B] Total carbohydrate can be calculated by [100 - (protein + fat + moisture + ash)].
[C] Cellulose content was calculated by difference: ADF – ADL
[D] Hemicellulose content was calculated by difference: NDF - ADF
[E] NFC: (Non fiber carbohydrate) is calculated by the difference [100 - (%NDF + %CP + %fat + ash)].
[F]Amino acid profiles were measured by High-Performance Liquid Chromatography (HPLC).
[G]Geometric mean diameter ± log geometric standard deviation.

Table 2. Ingredient composition and chemical analysis (as fed) of starter diets (Days 1–10)

Ingredient	Control	Processed WS	Sunflower hulls	Soybean hulls
Corn	571.5	554.4	554.4	554.4
Soybean meal (CP=46.82%)	335.4	325.3	325.3	325.3
Corn gluten meal	30.00	29.1	29.1	29.1
Soy oil	17.1	16.6	16.6	16.6
Processed WS	-	30.0	-	-
Sunflower hulls	-	-	30.0	-
Soybean hulls	-	-	-	30.0
Dicalcium phosphate	18.8	18.2	18.2	18.2
Oyster shell	11.5	11.2	11.2	11.2
Sodium chloride	3.4	3.3	3.3	3.3
L-Lysine (780 g/kg)	3.4	3.3	3.3	3.3
DL-Methionine (990 g/kg)	3.1	3.0	3.0	3.0
L-Threonine (990 g/kg)	0.8	0.8	0.8	0.8
Vitamin premix[A]	2.5	2.4	2.4	2.4
Mineral premix[B]	2.5	2.4	2.4	2.4
Determined analysis				
Dry matter (g/kg)	918	917	915	912
Total Ash (g/kg)	55	56	58	61
Crude protein (g/kg)	211	207	206	202
Crude fiber (g/kg)	29	37	47	41
Neutral detergent fiber (g/kg)	103	122	124	121
Acid detergent fiber (g/kg)	44	49	54	52
GMD ± GSD[C] (µm)	1011 ± 2.01	956 ± 2.00	941 ± 2.00	960 ± 2.00
Calculated analysis				
AME_n (kcal/kg)	2951	2839	2841	2851
Crude protein (g/kg)	226	215	216	217
Ether extract (g/kg)	44.9	44.1	44.4	44.3
Total carbohydrate (g/kg) [D]	607.1	609.9	606.6	604.7
Non fiber carbohydrate (g/kg) [E]	586.1	570.9	567.6	571.7
Digestible amino acids				
Lysine (g/kg)	12.6	12.2	12.2	12.2
Methionine (g/kg)	6.2	6.0	6.0	6.0
Methionine + Cystine (g/kg)	9.3	9.0	9.0	9.0
Threonine (g/kg)	7.9	7.7	7.7	7.7
Tryptophan (g/kg)	2.2	2.1	2.1	2.1
Calcium (g/kg)	9.4	9.1	9.1	9.1
Available phosphorus (g/kg)	4.7	4.5	4.5	4.5

[A]Supplied per kg of diet: 3.1 mg all-trans-retinyl acetate, 0.05 mg cholecalciferol, 18 mg dl-α-tocopheryl acetate, 2 mg menadione nicotinamide, 1.8 mg thiamine hydrochloride, 6.6 mg riboflavin, 2.9 mg pyridoxine hydrochloride, 0.015 mg cyanocobalamin, 30 mg nicotinic acid, 25 mg pantothenic acid, 1 mg folic acid, 500 mg choline chloride, 1 mg ethoxyquin.
[B]Supplied per kg of diet: 50 mg Fe (FeSO4-7H2O), 84 mg Zn (ZnO), 99 mg Mn (MnSO4-H2O), 0.2 mg Se (Na2SeO3), 0.99 mg I (KI), 10 mg Cu (CuSO4-5H2O).
[C]Geometric mean diameter ± log geometric standard deviation.
[D]Total carbohydrate can be calculated by [100 - (protein + fat + moisture + ash)].
[E]NFC: (Non fiber carbohaydrate) is calculated by the difference [100 - (%NDF + %CP + %fat + ash)]

Table 3. Ingredient composition and chemical analysis (as fed) of grower diets (Days 11–24)

Ingredient	Control	Processed WS	Sunflower hulls	Soybean hulls
Corn	605.0	586.9	586.9	586.9
Soybean meal (CP=46.82%)	321.8	312.1	312.1	312.1
Corn gluten meal	10.0	9.7	9.7	9.7
Soy oil	24.5	23.8	23.8	23.8
Processed WS	-	30.0	-	-
Sunflower hulls	-	-	30.0	-
Soybean hulls	-	-	-	30.0
Dicalcium phosphate	16.2	15.7	15.7	15.7
Oyster shell	10.4	10.1	10.1	10.1
Sodium chloride	2.5	2.4	2.4	2.4
$NaHCo_3$	1.2	1.2	1.2	1.2
L-Lysine (780 g/kg)	1.3	1.3	1.3	1.3
DL-Methionine (990 g/kg)	2.0	1.9	1.9	1.9
L-Threonine (990 g/kg)	0.1	0.1	0.1	0.1
Vitamin premix[A]	2.5	2.4	2.4	2.4
Mineral premix[B]	2.5	2.4	2.4	2.4
Determined analysis				
Dry matter (g/kg)	911	912	913	911
Total Ash (g/kg)	51	53	47	49
Crude protein (g/kg)	200	196	197	193
Crude fiber (g/kg)	29	38	42	37
Neutral detergent fiber (g/kg)	105	123	126	123
Acid detergent fiber (g/kg)	43	48	54	51
GMD ± GSD[C] (µm)	1173 ± 2.14	1094 ± 2.04	1097 ± 2.10	1081 ± 2.26
Calculated analysis				
AME_n (kcal/kg)	3001	2903	2908	2915
Crude protein (g/kg)	208	200	201	203
Ether extract (g/kg)	52.7	51.6	52	51.9
Total carbohydrate (g/kg)[D]	607.3	611.4	617	617.1
Non fiber carbohydrate (g/kg)[E]	591.3	576.4	578	583.1
Digestible amino acids				
Lysine (g/kg)	10.6	10.3	10.3	10.3
Methionine (g/kg)	4.9	4.8	4.8	4.8
Methionine + Cystine (g/kg)	7.8	7.6	7.6	7.6
Threonine (g/kg)	6.8	6.6	6.6	6.6
Tryptophan (g/kg)	2.1	2.0	2.0	2.0
Calcium (g/kg)	8.4	8.1	8.1	8.1
Available phosphorus (g/kg)	4.2	4.0	4.0	4.0

[A]Supplied per kg of diet: 3.1 mg all-trans-retinyl acetate, 0.05 mg cholecalciferol, 18 mg dl-α-tocopheryl acetate, 2 mg menadione nicotinamide, 1,8 mg thiamine hydrochloride, 6.6 mg riboflavin, 2.9 mg pyridoxine hydrochloride, 0.015 mg cyanocobalamin, 30 mg nicotinic acid, 25 mg pantothenic acid, 1 mg folic acid, 500 mg choline chloride, 1 mg ethoxyquin.
[B]Supplied per kg of diet: 50 mg Fe (FeSO4-7H2O), 84 mg Zn (ZnO), 99 mg Mn (MnSO4-H2O), 0.2 mg Se (Na2SeO3), 0.99 mg I (KI), 10 mg Cu (CuSO4-5H2O).
[C]Geometric mean diameter ± log geometric standard deviation
[D]Total carbohydrate can be calculated by [100 - (protein + fat + moisture + ash)].
[E]NFC: (Non fiber carbohaydrate) is calculated by the difference [100 - (%NDF + %CP + %fat + ash)].

Table 4. Ingredient composition and chemical analysis (as fed) of finisher diets (Days 25-42)

Ingredient	Control	Processed WS	Sunflower hulls	Soybean hulls
Corn	615.7	597.3	597.3	597.3
Soybean meal (CP=46.82%)	309.3	300.0	300.0	300.0
Soy oil	38.5	37.3	37.3	37.3
Processed WS	-	30.0	-	-
Sunflower hulls	-	-	30.0	-
Soybean hulls	-	-	-	30.0
Dicalcium phosphate	14.2	13.8	13.8	13.8
Oyster shell	9.6	9.3	9.3	9.3
Sodium chloride	2.3	2.2	2.2	2.2
$NaHCo_3$	1.3	1.3	1.3	1.3
L-Lysine (780 g/kg)	1.3	1.3	1.3	1.3
DL-Methionine (990 g/kg)	2.3	2.2	2.2	2.2
L-Threonine (990 g/kg)	0.5	0.5	0.5	0.5
Vitamin premix[A]	2.5	2.4	2.4	2.4
Mineral premix[B]	2.5	2.4	2.4	2.4
Determined analysis				
Dry matter (g/kg)	916	916	916	914
Total ash (g/kg)	46	49	49	48
Crude protein (g/kg)	181	175	175	178
Crude fiber (g/kg)	27	35	42	37
Neutral detergent fiber (g/kg)	107	123	125	121
Acid detergent fiber (g/kg)	38	47	53	51
GMD ± GSD[C] (µm)	1254 ± 2.27	1173 ± 2.01	1173 ± 2.05	1128 ± 2.13
Calculated analysis				
AME_n (kcal/kg)	3102	2992	2997	3001
Crude protein (g/kg)	189	182	182	184
Ether extract (g/kg)	66.5	65	65.4	65.3
Total carbohydrate (g/kg)[D]	622.5	627	626.6	622.7
Non fiber carbohydrate (g/kg)[E]	599.5	588	585.6	587.7
Digestible amino acids				
Lysine (g/kg)	9.9	9.6	9.6	9.6
Methionine (g/kg)	5.0	4.9	4.9	4.9
Methionine + Cystine	7.7	7.5	7.5	7.5
Threonine (g/kg)	6.6	6.4	6.4	6.4
Tryptophan (g/kg)	1.9	1.8	1.8	1.8
Calcium (g/kg)	7.6	7.3	7.3	7.3
Available phosphorus (g/kg)	3.8	3.6	3.6	3.6

[A]Supplied per kg of diet: 3.1 mg all-trans-retinyl acetate, 0.05 mg cholecalciferol, 18 mg dl-α-tocopheryl acetate, 2 mg menadione nicotinamide, 1,8 mg thiamine hydrochloride, 6.6 mg riboflavin, 2.9 mg pyridoxine hydrochloride, 0.015 mg cyanocobalamin, 30 mg nicotinic acid, 25 mg pantothenic acid, 1 mg folic acid, 500 mg choline chloride, 1 mg ethoxyquin.
[B]Supplied per kg of diet: 50 mg Fe (FeSO4-7H2O), 84 mg Zn (ZnO), 99 mg Mn (MnSO4-H2O), 0.2 mg Se (Na2SeO3), 0.99 mg I (KI), 10 mg Cu (CuSO4-5H2O).
[C]Geometric mean diameter ± log geometric standard deviation.
[D]Total carbohydrate can be calculated by [100 - (protein + fat + moisture + ash)].
[E]NFC: (Non fiber carbohaydrate) is calculated by the difference [100 - (%NDF + %CP + %fat + ash)].

Laboratory analysis

All experimental samples were ground by a laboratory mill with a 1 mm screen (Retsch Model Z-I, Stuttgart, Germany) and analyzed for dry matter, ash and nitrogen by the Dumas method (Model FP-528, Leco Corporation. St. Joseph, MI) as explained by AOAC International (2000). Gross energy was determined by an adiabatic bomb calorimeter (model 1356, Parr Instrument Company, Moline, IL). Crude fiber (CF), acid detergent fiber (ADF), and neutral detergent fiber (NDF) of the fiber sources and experimental diets were measured sequentially using a filter bag system (Ankom Technology Corp. Macedon, NY) (Van Soest *et al.,* 1991). Dietary NDF was determined with the addition of heat-stable α-amylase without any sodium sulphite added. The amino acid contents of the fiber samples were determined by High-Performance Liquid Chromatography (Evonik-Degussa, Hanau, Germany)

(AOAC International, 1995). Chromium oxide content of the experimental diets and excreta was measured according to Saha and Gilbreath (1991). The geometric mean diameter (GMD) of the fiber sources and experimental diets were measured (in triplicate) using a Retsch shaker (Retsch, Stuttgart, Germany) as explained by the ASAE (1995).

Husbandry and experimental design

The research protocol was approved by Bu-Ali Sina University Animal Care and Use Committee. Four hundred and eighty day-old male chickens, Ross 308 chicks with 42.2 ± 2.7 g body weight (BW) were used in this trial. The temperature was set at 31ºC for chicks on d 1 and gradually decreased by 3ºC per week until a final temperature of 22ºC was obtained. The light program consisted of 23 h of light and 1 h of dark in the first 7 days, followed by 20 h light: and 4h darkness (42 days). The experiment was conducted as a completely randomized design with 4 treatments, 6 replicates per treatment, and 20 birds per experimental unit (a floor pen).

Growth performance, gastrointestinal tract traits, and carcass characteristics

Feed intake and BW of the chickens were recorded weekly by pen and at the end of each period. These data were used to calculate FI, body weight gain (BWG), and F: G ratio by period (1 to 10 d, 11 to 24 d, and 25 to 42 d of age) and cumulatively (1 to 42 d of age).

At 42 d of age, two birds per pen with a weight close to the average weight of the pen were selected, and euthanized by thiopental sodium (15 mg/kg of BW, Sandoz GmbH, Kundl, Austria). Full GIT, proventriculus, gizzard, pancreas, and cecum were weighed and expressed in relative (%BW) terms. In addition, the length (cm) of the small intestine segments (SI; in absolute), and the cecum length were measured by a flexible ruler with a precision of 1 mm.

In addition, the crop, gizzard, duodenum, jejunum, ileum, and cecum were clamped to avoid the mixing of the digesta, and the pH of all these segments was measured using a digital pH meter (WTW Multi 3420 set G, Germany). Gently, digesta was collected and pH was recorded twice for each segment (Pang and Applegate, 2007).

Breast and thigh weights were determined and expressed as the percentage of carcass weight. Carcass yield was calculated by dividing the carcass weight by live weight.

Nutrient digestibility and Intestinal enzyme activity

For the determination of nutrient digestibility at 19 d of age, three birds from each replicate of the corresponding pen were selected and transferred to metabolic cages. Birds in each cage were offered the corresponding experimental diet (3 days for the adaptation period) and afterward, excreta samples were collected for two days, oven dried for 72 h at 60 °C, and ground with a laboratory mill fitted with a 1 mm screen. The digestibility of DM, N, and the AME_n of the diets were determined (Houshmand *et al.*, 2011). Moreover, the energy conversion ratio (ECR; kJ AME_n ingested/ g BWG) was calculated for each period.

The activity of amylase (EC 3.2.1.1) and aminopeptidase (EC 3.4.11.2) was considered homogenized in the duodenum and jejunum tissue (Silent Crusher M, Heidolph Instruments, GmbH & Co., Schwabach, Germany) (Shirazi-Beechey *et al.* 1991). Briefly, the homogenate was centrifuged at 3,500 × g for 30 min at 4 ºC, then the supernatant was collected, and the activities of the digestive enzymes were detected. Amylase activity was determined by soluble starch as a substrate as explained by Bernfeld (1955). The reaction was stopped by 3, 5 - dinitrosalicylicacid (Sigma Chemical Co., St. Louis, MO). Maltose was assayed by staining and color intensity was determined by a double-beam spectrophotometer (UV 4802, Zhejiang Scientific Instruments and Materials, Hangzhou, China) at 530 nm. One unit of α-amylase activity was recognized by producing 1 mg of maltose per min at 40ºC. Aminopeptidase activity was measured as explained by Gal-Garber and Uni (2000) using L-leucine-p-nitroanilide (L-9125, Sigma Chemical Co.) as a substrate. Briefly, the substrate was hydrolyzed to p-nitroaniline and L-leucine. The 30 min at 39ºC was managed as a reaction time and temperature, respectively. The 4-nitroaniline was assayed by staining, and the intensity of the color was recognized spectrophotometrically at 410 nm. One unit of aminopeptidase activity was described as 1 Mmol production of 4-nitroaniline per min from the L-leucine-p-nitroanilide substrate.

Statistical analysis

Data were analyzed as a completely randomized design with four treatments using the GLM procedure of SAS (2013) and differences were considered significant at $P \leq 0.05$ and tended towards significance ($0.10 > P > 0.05$).

Results

The processed WS, SFH, and SBH contained by analysis of 40, 60, and 121 g CP/kg and 642, 719, and 614 g NDF/kg, and had a Geometric mean diameter of 610, 593, and 578 μm, respectively.

Growth performance, gastrointestinal tract traits and carcass characteristics

Low mortality (1.0%) was found and no response to treatments occurred (data not shown). In comparison to the control group, processed WS tended to increase FI ($P = 0.064$) and significantly increased BWG than other treatments ($P < 0.05$) from 0 to 10 d of age, although, the F: G ratio was not significant (Table 5).

Table 5. Influence of insoluble fiber sources on growth performance and energy conversion ratio (ECR, KJ AME_n ingested/g BWG) of the broilers

	Control	Processed WS	Sunflower hulls	Soybean hulls	*SEM*[A]	*P*-value	
						Treatment	Contrast[B]
Days 0-10							
FI[C] (g)	199.18 [b]	222.35[a]	204.27[ab]	213.25[ab]	5.721	0.064	0.055
BWG[D] (g)	144 .50[b]	169.07[a]	147.12[b]	150.05[b]	5.561	0.030	0.107
F:G[E]	1.38	1.31	1.39	1.42	0.048	0.456	0.920
ECR[F]	17.01	15.66	16.52	17.08	0.592	0.299	0.325
Days 11-24							
FI (g)	920.56	920.22	925.37	923.61	30.422	0.999	0.951
BWG (g)	571.39	554.54	552.40	533.52	16.345	0.463	0.208
F:G	1.61[b]	1.66[ab]	1.67[ab]	1.73[a]	0.027	0.070	0.037
ECR	20.21	20.22	20.40	21.11	0.342	0.249	0.461
Days 25-42							
FI (g)	2,747.41	2,797.50	2,680.71	2,749.66	68.125	0.685	0.948
BWG (g)	1,629.72	1,598.40	1,588.31	1,581.68	36.122	0.799	0.361
F:G	1.68	1.75	1.69	1.74	0.035	0.467	0.344
ECR	21.90	21.91	21.22	21.83	0.451	0.606	0.658
Days 1-42							
FI (g)	3,867.10	3,940.42	3,809.31	3,885.55	84.981	0.753	0.911
BWG (g)	2,344.59	2,321.00	2,288.05	2,265.19	42.855	0.583	0.303
F:G	1.64	1.69	1.66	1.71	0.022	0.192	0.107
ECR	20.81	20.78	20.32	20.95	0.282	0.425	0.644

[A]*SEM*: Standard error of the mean.
[B]Contrast of control vs. fiber sources.
[C]Feed intake.
[D]Body weight gain.
[E]Feed to gain ratio.
[F]Energy conversion ratio.
[a-b] Means within each row with different superscripts are significantly different ($P < 0.05$).

Feed intake and BWG were not affected by dietary treatments from 11 to 24 d of age, but F: G ratio tended to be better for the control than for the SBH diet ($P = 0.070$). Broiler performance was not affected with insoluble fiber sources from 25 to 42 d and 1 to 42 d of age. The energy conversion ratio was not affected by diet at any age.

No effects were found on the relative weight of the GIT organs by the inclusion of fiber sources at 42 d of age (Table 6). But, SFH and SBH decreased the length of the SI ($P < 0.05$) than processed WS (Table 7). The pH of different segments of the GIT was not affected by fiber inclusion in the diet (Table 8). At 42 d of age, the inclusion of fiber sources in the diet did not affect carcass characteristics (breast, thigh, and carcass yield) (Table 9).

Table 6. Influence of insoluble fiber sources on the relative weight (g/kg BW) of the gastrointestinal tract organs of the broilers at day 42

	GIT[A]	Proventriculus[B]	Gizzard[C]	Pancreas	Cecum[D]
Control	122	3.91	14.71	2.32	6.08
Processed WS	126	3.93	14.86	2.24	6.07
Sunflower hulls	126	4.00	14.57	2.44	5.92
Soybean hulls	121	4.17	14.67	2.40	5.77
SEM [E]	4.0	0.208	0.606	0.105	0.355
P-Value					
Treatment	0.685	0.808	0.988	0.584	0.909
Contrast[F]	0.588	0.622	0.984	0.768	0.697

[A]Full gastrointestinal tract.
[B]Empty proventriculus.
[C]Empty gizzard.
[D]Cecum with digesta.
[E]*SEM*: Standard error of the mean.
[F]Contrast of control vs. fiber sources.
A same letter in each column indicates a non-significant difference of means at 0.05 level.

Table 7. Influence of insoluble fiber sources on the absolute length (cm) of the small intestine and the cecum of the broilers at day 42

	SI[A]	Duodenum	Jejunum	Ileum	Cecum[B]
Control	183.1[ab]	31.5	74.6	77.0	19.0
Processed WS	190.7[a]	30.2	79.2	81.2	19.5
Sunflower hulls	177.8[b]	31.4	73.6	73.0	19.0
Soybean hulls	177.5[b]	29.2	73.7	74.5	19.0
SEM [C]	3.34	0.76	1.91	2.52	0.55
P-Value					
Treatment	0.043	0.182	0.140	0.155	0.866
Contrast[D]	0.776	0.197	0.666	0.790	0.782

[A]Small intestine (duodenum, jejunum, and ileum).
[B]Length of the 2 cecum.
[C]*SEM*: Standard error of the mean.
[D]Contrast of control vs. fiber sources.
A same letter in each column indicates a non-significant difference of means at 0.05 level.

Table 8. Influence of insoluble fiber sources on the pH of different segments of the gastrointestinal tract of broilers at day 42

	Crop	Gizzard	Duodenum	Jejunum	Ileum	Cecum
Control	5.91	4.04	6.29	6.53	6.77	7.36
Processed WS	5.83	3.71	6.48	6.60	6.71	7.41
Sunflower hulls	5.81	3.76	6.33	6.51	6.42	7.36
Soybean hulls	5.87	3.88	6.55	6.62	6.65	7.42
SEM [A]	0.214	0.187	0.094	0.068	0.224	0.143
P-Value						
Treatment	0.989	0.607	0.221	0.112	0.245	0.987
Contrast [B]	0.797	0.253	0.152	0.494	0.265	0814

[A] *SEM*: Standard error of the mean. The experimental unit was formed by 2 birds per replicate at Day 42.
[B]Contrast of control vs. fiber sources.
A same letter in each column indicates a non-significant difference of means at 0.05 level.

Table 9. Influence of insoluble fiber sources on carcass characteristics of the broilers at day 42

	Breast[A] (%)	Thigh[A] (%)	Carcass yield[B] (%)
Control	38.3	28.0	60.6
Processed WS	38.1	28.7	60.1
Sunflower hulls	38.7	28.2	60.1
Soybean hulls	38.9	28.5	60.6
SEM [C]	0.96	0.48	0.47
P-Value			
Treatment	0.945	0.726	0.802
Contrast [D]	0.799	0.420	0.546

[A]Breast and thigh are calculated as the percentage of carcass weight.
[B]Carcass yield is calculated by dividing the carcass weight by live weight.
[C]*SEM*: Standard error of the mean.
[D]Contrast of control vs. fiber sources.
A same letter in each column indicates a non-significant difference of means at 0.05 level.

Table 10. Influence of insoluble fiber sources on nutrient digestibility and AME_n content of the diets

	Dry matter (%)	Nitrogen (%)	AME_n (MJ/Kg)
Control	0.735	0.721	12.91
Processed WS	0.747	0.735	12.96
Sunflower hulls	0.744	0.726	12.94
Soybean hulls	0.745	0.724	12.95
SEM [A]	0.0034	0.0044	0.0190
P-Value			
Treatment	0.245	0.234	0.444
Contrast [B]	0.063	0.220	0.147

[A] *SEM*: Standard error of the mean.
[B]Contrast of control vs. fiber sources.
A same letter in each column indicates a non-significant difference of means at 0.05 level.

Nutrient digestibility, and intestinal enzyme activity

Insoluble fiber sources did not affect the DM and N digestibility and AME_n of the diets (Table 10). Amylase and aminopeptidase activity in the duodenum and jejunum was not affected by treatments (Table 11).

Table 11. Influence of insoluble fiber sources on intestinal enzyme activity (Units/mg of intestinal tissue)

	Amylase		Aminopeptidase	
	Duodenum	Jejunum	Duodenum	Jejunum
Control	63.94	64.66	26.80	27.05
Processed WS	64.81	65.15	27.20	27.29
Sunflower hulls	64.68	68.98	27.12	28.06
Soybean hulls	66.20	69.75	29.62	29.24
SEM [A]	3.062	2.765	1.062	1.079
P-Value				
Treatment	0.960	0.489	0.289	0.513
Contrast [B]	0.723	0.332	0.365	0.385

[A]*SEM*: Standard error of the mean.

[B]Contrast of control vs. fiber sources.

A same letter in each column indicates a non-significant difference of means at 0.05

Discussion

The analytical values of the insoluble fiber sources used in the current research were within the range reported by SBH: Chee *et al.,* (2005) and Gonzalez-Alvarado *et al.,* (2007); WS: Guzman *et al.,* (2015*a*); and SFH: Kimiaeitalab *et al.,* (2017) and Moradi *et al.,* (2020). The chemical composition of the experimental diets was close to expected values, indicating that the diets were mixed correctly.

Growth performance, gastrointestinal tract traits, and carcass characteristics

The dilution of the control diet with processed WS increased FI and BWG from 1 to 10 d of age. Dietary insoluble fiber had no effect on FI and BWG from 11 to 24 d and 25 to 42 d of age, but the F: G ratio tended to be better for the control than for the SBH diet. Most of the benefits of fiber inclusion, especially processed WS, were observed at the first week of life, and not at an older age. When considering the later periods, no effects were shown in ADFI and BWG through addition of fiber sources (Jimenez-Moreno *et al.,* 2010). The authors have not found any research on the effects of processed WS on the growth of broilers. Shirzadegan and Taheri (2017) indicated that lower FI in broilers fed low fiber diet in comparison to chickens fed diets containing 30 or 60 g/kg of rice bran and wood shavings. Moradi *et al.* (2020) reported that SFH inclusion improved BWG and feed conversion ratio compared to oat hull and lignocellulose. The dietary inclusion of 3% SFH improves growth performance through improved weight and reduced pH of gizzard and can be practically used in the broiler industry. Guzman *et al.* (2015*b*) observed that FI was higher with the inclusion of 40 g/kg straw in the diet of pullets from 5 to 10 wk of age. In the current research, the inclusion of processed WS in the diet increased FI by around 11.6% and improved BWG by 17.4% compared to the control diet. Also, compared to SFH and SBH, processed WS increased BWG by around 15 and 13%, respectively. It has been indicated that the birds can keep their BW because of diet dilution with insoluble fiber by the capacity enhancement of GIT or faster passing rate of digesta through the digestive tract (Hetland *et al.,* 2004). Sozcu (2019) reported that the supplementation of processed lignocellulose as an insoluble fiber stimulated BW and F: G ratio in birds at 35 d of age. The higher BWG observed in broilers fed processed WS may be due to the higher FI that leads to improved performance of birds. Processing WS imparts appealing flavors, thereby contributing to the increase in FI. The addition of alkali increases straw pH causing lignin-carbohydrate complexes to disassociate and exogenous fibrolytic enzymes can act on the disassociated carbohydrate remnants creating monosaccharides or other shorter chain carbohydrates. Salarinia *et al.* (2018) reported that broilers fed 60 g/kg Rice Hull had higher BWG, Feed intake and lower feed: gain than the control group. Masoudi and Bajarpour (2020) reported that soybean hulls can be used up to 50 g/kg in broiler diets due to the positive impact on conversion ratio and production efficiency factor.

In relative terms, no effects of fiber inclusion were detected for any of the organs studied. Rezaei *et al.* (2011) reported that the relative weight of the gizzard, cecum, and small intestine was not affected with the inclusion of up to 5 g/kg of micronized insoluble fiber that consistent with the results reported herein. The small intestine length was lower in SFH and SBH than in processed WS at 42 d of age. Amerah *et al.* (2009) reported that the relative length of the SI was reduced with the inclusion of cellulose or wood shavings as compared to the control diet. The shorter small intestine may be explained by the lower nutrient density, which decreases the surface area needed for absorption. However, Santos *et al.* (2006) did not observe any effects of insoluble fiber inclusion (wood shavings) in the diet on intestinal

length in turkeys. The inclusion of insoluble fiber sources in the diet did not affect the pH of the crop, gizzard, duodenum, jejunum, ileum, and cecum. Most available research by Jimenez-Moreno *et al.* (2013*b*) for OH, Sacranie *et al.* (2012) for a mixture of oats and barley hulls in broilers, and Guzman *et al.* (2015*b*) for straw in pullets reported a reduction of gizzard pH with the inclusion of insoluble fiber sources in the diet. Recently, Kimiaeitalab *et al.* (2017) reported that the inclusion of 30 g/kg SFH in a low fiber diet reduced the gizzard pH of broilers and pullets at 7 and 21 d of age. However, these authors did not observe any reduction in gizzard pH when 30 g/kg SFH was included in the high fiber diet. The dietary insoluble fiber can reduce the growth of pathogenic microorganisms and improve litter quality depending on insoluble fiber fractions. In the current experiment, lactic acid bacteria increased while *Escherichia coli* tended to decrease in the ceca of birds receiving insoluble fiber sources compared to the control diet (data are not shown).

In the present study, carcass characteristics were not affected by the inclusion of the insoluble fiber sources at 42 d of age. Little information is available on the effect of insoluble fiber sources on carcass traits, especially at the weight of marketing. Sadeghi *et al.* (2015) indicated that higher carcass yield of birds fed a mixture of sugar beet pulp and rice hulls compared to those receiving sugar beet pulps at 42 d of age. This might account for decreased deposition of fat in the abdomen area of broiler. Gonzalez-Alvarado *et al.* (2010) reported that the inclusion of OH improved growth performance, but that primal parts yield (breast and leg quarters) was not affected, results that are consistent with the data reported herein.

Nutrient digestibility, and intestinal enzyme activity

The inclusion of insoluble fiber sources in the diet improved DM retention, which is in agreement with data reported by Kimiaeitalab *et al.* (2017) in broilers and pullets fed a diet that contained 30 g/kg of SFH. Jimenez-Moreno *et al.* (2013*a*) and Gonzalez-Alvarado *et al.* (2010) noted an improvement in the AME_n of the diet by the inclusion of 25 and 30 g/kg OH in the diet, respectively. The beneficial effects of dietary fiber on nutrient retention depend on basal diet composition and source and level of fiber (Mateos *et al.*, 2012).

Information related to the effects of insoluble fiber sources, especially processed WS, on intestinal enzyme activity in broilers is scarce. In the current study, amylase and aminopeptidase activity in the duodenum and jejunum was not affected by the inclusion of insoluble fiber sources in the diet. Yokhana *et al.* (2016) reported that intestinal aminopeptidase activity was not affected by inclusion of 10 g/kg of Arbocel (650 g/kg crude fiber and 200 g/kg acid detergent lignin) in the diet in 8-week-old Hy-Line pullets. In contrast, Hetland *et al.* (2003) pointed out that OH inclusion (100 g/kg) increased starch digestibility, amylase activity, and bile acid concentration in the jejunum of broilers which might be related to a higher level of inclusion of OH in the diet.

Conclusion

The dilution of the control diet with 30 g/kg insoluble fiber sources did not have any negative effect on performance, pH or organ weight of the GIT, nutrient digestibility, and intestinal enzyme activity but reduced the absolute length of the small intestine. An improvement in the growth performance of birds was more pronounced by processed WS at the first weeks of age. The processed WS can reduce the cost of feed and is practically used in the broiler industry. Further investigations are needed on the effects of higher levels of insoluble fiber sources in the broilers diet, especially processed wheat straw to use to maximize benefits on physiological parameters.

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