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The Effect of Various Dietary Fibre Sources on Performance, Cecal and Ileal Nutrient Digestibility in Broiler Chickens

Research Article

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ABSTRACT

This experiment was conducted to investigate the effects of different sources of insoluble fiber on performance, gastrointestinal tract characteristics, and nutrient digestibility in the broiler's ileum, and cecum. A total of 380-day-old chickens of ross 308 unsexed were arranged into 5 treatments, 4 replicates, and 19 chickens in each, by completely randomized design (CRD). Experimental treatments included 1: control (corn-soybean meal) 2: arbocel (synthetic fiber) 1% in diet, 3: sunflower hulls (3% in diet), 4: soybean hull (3% in diet), 5: processed wheat straw (3%in diet). Observed parameter include: performance (feed intake, feed conversion ratio and body weight gain), gastrointestinal pH, gastrointestinal viscosity and digestibility of dry matter and protein in ileum and cecum and microbial population in ileum and cecum. The results have shown that the inclusion of 3% sunflower hulls in diets leads to the higher average feed intake from 1 to 10 days of age rather than control (P<0.05). In comparison between the ileum and cecum showed that the higher viscosity by Arbocel® in the cecum and the lowest viscosity showed by wheat straw in the ileum (P<0.05). On the other hand, the digestibility of protein and dry matter in the ileum was higher than the cecum (P<0.05). According to the results of this study, it could be noted that all fibers are considered insoluble fibers and their different behavior in the gastrointestinal tract. The diet Arbocel® has generally led to physicochemical changes (digesta pH and viscosity) and microbial populations. It could be the most important reason for these observations which is related to insoluble fiber particle size and their processing. In addition, reduced dry matter and protein digestibility in the cecum in comparison to the ileum status. Finally, digest pH, viscosity, dry matter and protein digestibility were reduced by insoluble fiber in cecum in comparison to ileum.

KEY WORDS gastrointestinal tract, insoluble fiber, microbial population, performance, viscosity.

INTRODUCTION

Dietary fiber in plants causes physiological, structural and functional changes in the gastrointestinal tract. Fiber is not digested in the small intestine and effected the absorption and metabolism of other nutrients in the gastrointestinal tract. It has been reported that the inclusion of insoluble fiber in the diet of broiler chickens has a positive effect on intestinal morphology, growth of digestive organs, nutrient absorption, growth performance and intestinal microbiota (Tejeda and Kim, 2021). In recent years, the beneficial effects of dietary fiber are attracted and central attention by many researchers, as well as recommendations have been made regarding the presence of insoluble fiber in humans, livestock, and poultry diets (Mc Burney, 2010). The beneficial effects of dietary fibers could reduce dietary energy density (Mossami, 2011), decline plasma lipids, and cardiovascular disease (Appleby *et al.* 1999). Stimulating the natural flow of feed in the gastrointestinal tract (Roma *et al*. 1999), helps to improve gastrointestinal development (Mateos *et al*. 2012).

Feed intake, gastrointestinal tract size at different parts, gastrointestinal motility, enzyme production, microbial growth, and even bird behaviors are affected by fiber sources (Choct, 2002). Fiber can be classified into two main categories: 1- water soluble fibers (viscous and fermentable fibers) such as pectin and 2- water-insoluble fibers (non-viscous and fermentable) such as lignin and cellulose (Graham and Aman, 1991; Choct, 2002). The anti-nutritional effects of fibers are related to soluble components in contrast insoluble fibers can play a positive role in gastrointestinal status and development (Hemmati Matin *et al*. 2016). As a result, these effects contribute to the growth and health of the animal, however, the potential benefits of the fiber depend to a large extent on the physicochemical properties and various sources (Mateos *et al*. 2012).

Abdollahi *et al*. (2021) reported that examining two levels of 2.5% and 5% fiber showed that the 2.5% level has beneficial effects on the gastrointestinal tract development and nutrient digestibility (Jiménez-Moreno *et al*. 2019). protein and ash digestibility were not influenced by the fiber source, but increased ileum dry matter digestibility by diets containing 3% Sugar beet pulp compared with the control diet and 6% wheat bran in diet.

Jangiaghdam *et al*. (2022) pointed that there are few systematic studies on the dietary fiber requirements of broilers in the late feeding stage, and there are not enough data to support this hypothesis and they are reported that 7–9% crude fiber (processed wheat straw, sunflower hulls, or soybean hulls) in diet may promote growth performance by improving the nutrient digestibility, immunity and intestinal morphology of broilers from day 22 to 42 days of age (Jangiaghdam *et al*. 2022). Poultry needs a certain amount of fiber for the growth and development of the gastrointestinal tract. Depending on the type and amount of dietary fiber could lead to the growth and development of the gastrointestinal tract in different ways (Jiménez-Moreno *et al*. 2010; Jiménez-Moreno *et al*. 2011). The present study was performed to investigate the effects of different sources of insoluble fiber (Arbocel®, soybean hulls, sunflower hulls, and processed wheat straw) on, gastrointestinal tract characteristics and function, nutrient digestibility in broilers ileum and cecum.

MATERIALS AND METHODS

Fiber sources and diets

Three hundred and eighty (380) day-old chickens Ross 308 male and female mixtures were arranged in a completely randomized design (CRD) with an average 43 + 3 grams' body weight from 40 weeks of broiler breeder age. Experimental treatments included 5 treatments (control treatment, processed wheat straw (3%), sunflower hulls (3%), soybean hulls (3%), and Arbocel®) (1%)) by 4 replications, and 19 chickens in each. The experimental diets were formulated by UFFDA software according to Ross 308, 2023 strain recommendations, which are presented in Table 1 and Table 2. First, a basic diet based on corn and soybean meal was formulated by UFFDA software, then, the base diet was diluted using different sources of insoluble fibers. The particle size of fiber sources in this diet was 1-2 mm. wheat straw was processed by 2% hydroxide (Guzman *et al*. 2015)

Diet composition

First, wheat straw was processed with 2% sodium hydroxide solution then chemical analysis of fiber sources including soybean hull, sunflower hull, processed wheat straw, and Arbocel® were performed. Dry matter, moisture, crude ash, crude fat, and crude protein in the diet were measured by AOAC (2000) methods, and crude fibers, Neutral detergent fibers (NDF), and Acid detergent fibers (ADF) in soybean hulls sunflower hulls, processed wheat straw, and Arbocel® were determined by Van Soset *et al*. (1991) method. The amino acid profile of corn and soybean meal was determined by infrared spectroscopy of Evonik Degussa, Tehran. After determining the approximate analyses, experimental diets were adjusted and then were measured performance (feed intake, feed conversion ratio and body weight gain), gastrointestinal pH, gastrointestinal viscosity and digestibility of dry matter and protein in ileum and cecum and microbial population in ileum and cecum.

Growth performance

Feed intake (FI) and body weight (BW) were measured weekly and performance was determined in starter, grower, and finisher; mortality as well as was recorded daily for each pen.

Hen-Day= the number of days in survival mortalities at the period + (the number of periods days'×the number of chickens alive in each replicate at the end of the period)

Average daily feed intake of each chicken in replicate= Hen-Day / feed intake in replicate of rearing period

Chicken average feed intake in rearing period= chicken daily feed intake × duration of rearing period

Increase pen weight= loss weight + (beginning period weight-finish period weight)

Chicken daily gain= hen-day / chicken period pen gain

Chicken period gain= duration period × chicken daily weight gain

Feed conversion ratio= period feed intake / weight gains in the period

Production index

In order to obtain the performance of chickens in different treatments, the production index was obtained for each replicate at the age of 21 and 42 days of age according to the following formula:

Production index= ((average body weight (kg)×livability)/(rearing days×feed conversion ratio)) ×100

Nutrient digestibility and PH status

The ileum, and cecum pH, were measured in two birds in each replicates (10 birds in each treatment) by a pH meter (Model SD 230, manufactured by Lutron Electronic Enterprise, Taiwan) at 42 days of age. In other to nutrient digestibility, 60 broilers (5 treatments, 3 replicates, and 4 broilers in each) were selected at 21 days of age, weighed, and transferred to a cage. Experimental diets included control treatment (corn-soybean meal) and dilution of control diet with 3% sunflower hulls, soybean hulls, and processed wheat straw, and dilution of control diet with 1% Arbocel® (synthetic fiber). Chromium oxide (Cr_2O_3) 0.5 g/kg was added to the experimental diets as an indigestible marker in the chicken's diet for one week. The samples of feces and feed were collected in the last three days after 4 days of adaption and they were dried in an oven at 60 ˚C for 72 hours, then weighed and ground. At 28 days of age, all chickens were slaughtered and their ileum and cecum contents were poured into sealed containers and dried in a freeze dryer. Crude protein in the feces and feed were measured by the Kjeldahl method. The concentration of chromium oxide was determined in feed and feces samples of the ileum and cecum by Fenton and Fenton's (1979) method whit following formula.

Apparent digestibility of nutrients (percentage)= [(diet nutrient×waste chromium oxide concentration) / (waste nutrient concentration×chromium oxide concentration in the diet] × 100

Microbial population

To measure the microbial population at the 42 days of age, one chick from each experimental unit was randomly selected and authorized. Then the contents of the ileum and cecum were emptied into sterile collection containers for microbial culture. The collected samples were immediately transferred to the laboratory in containers containing ice and prepared for microbial culture.

The microbial population was considered by Mathlouthi *et al.* (2002a). MRS agar Growth medium + 0.1% Tween 80, Mac Conkey agar Growth medium, and XLD Growth medium were used for culture of lactic acid bacteria, a culture of *Escherichia coli* (*E. coli*) producing bacteria, and Salmonella culture respectively.

Ileum and cecum viscosity

Two g of fresh ileum and cecum contents were immediately centrifuged for 10 minutes. The resulting supernatant (1 cc) was collected into a 2 cc microtube and stored in a freezer at -20 ˚C. Then, using a digital viscometer (Brookfield digital DV-II +, Brookfield Engineering Labs), viscosity was measured in centipoise at 40 ˚C (Baurhoo *et al.* 2011). Each sample was read twice and the average data was arranged for statistical analysis.

Data analysis

The experiment was performed in a completely randomized design (CRD). Data analysis was tested by SAS (2013) statistical software. Data were first tested for normality and uniformity of variance. The differences between the means were determined by Duncan's multiple range with a significant level of (P<0.05).

Statistical model for feed intake, body weight gain, feed convention ratio and Production index: $Y_{ij}= \mu + T_i + E_{ij}$ the statistical model used to comparison viscosity, pH, microbial population, and nutrient digestibility in ileum and cecum were completely randomized design in the form of a factorial experiment.

Statistical model for comparison data in ileum and cecum:

$$Y_{ijk}= \mu + A_i + B_j + AB_{ij} + E_{ijk}$$

Statistical model for other parameters:

$$Y_{ijk}= \mu + T_i + E_{ij} + S_{ijk}$$

Where:

Y_{ij}: amount of observation of treatment i in replicate j.

Y_{ijk}: amount of observation of treatment i in replicate j and k sample.

μ: mean effect.

T_i: effect of treatment i.

E_{ij}: effect of treatment i error in replicate j.

E_{ijk}: effect of treatment i error in replicate j and k sample.

S_{ijk}: sampling error of treatment I in replicate j and sample k.

A_i: effect of level i of A factor.

B_j: effect of level j of B factor.

AB_{ij}: interaction between A and B factors.

Table 1 Feed formulation and chemical composition of treatment diets (%, as is, starter period from 1 to 10 days of age)

Feed ingredient	T1	T2	T3	T4	T5
Corn	56.8	56.26	55.12	55.12	55.12
Soybean meal	34.24	33.9	33.21	33.21	33.21
Corn gluten	3	2.97	2.91	2.91	2.91
Arbocel	-	1	-	-	-
Sunflower hulls	-	-	3	-	-
Soybean hulls	-	-	-	3	-
Processed wheat straw	-	-	-	-	3
Soy bean oil	1.39	1.37	1.34	1.34	1.34
Di-calcium phosphate	1.86	1.84	1.81	1.81	1.81
Oyster shell	1.15	1.14	1.11	1.11	1.11
Salt	0.34	0.33	0.32	0.32	0.32
Mineral premix[1]	0.25	0.25	0.25	0.25	0.25
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25
DL-methionine	0.3	0.29	0.29	0.29	0.29
L-lysine-hydrochloride	0.34	0.33	0.32	0.32	0.32
Threonine	0.08	0.07	0.07	0.07	0.07
Total	100	100	100	100	100
Chemical analysis (calculated) (%)					
Metabolizable energy (kcal kg^{-1})	29.62	2934	2883	28.96	2878
Crude protein	22.13	21.92	21.65	21.77	21.61
Crude fiber	3.82	4.50	5.18	4.78	4.66
Calcium	0.94	0.93	0.91	0.91	0.91
Available phosphorus	0.47	0.46	0.45	0.45	0.45
Sodium	0.16	0.16	0.15	0.15	0.15
Potassium	0.86	0.85	0.84	0.84	0.84
Chlorine	0.30	0.30	0.29	0.29	0.29
Amino acids (digestible) (%)					
Lysine	1.33	1.32	1.30	1.30	1.30
Methionine	0.68	0.67	0.66	0.66	0.66
Methionine + cysteine	0.94	0.93	0.91	0.91	0.91
Threonine	0.88	0.87	0.86	0.86	0.86
Tryptophan	0.21	0.21	0.21	0.21	0.21
Analysis (measured) (%)					
Dry matter	92.68	92.16	93.05	92.48	92.73
Crude ash	6.20	6.33	6.06	6.00	5.80
Crude protein	22.09	21.43	21.34	21.39	21.29
Crude fiber	3.80	4.43	5.11	4.72	4.59

[1] Mineral supplements contain: Mn: 99200 mg; Zn: 84700 mg; Fe: 50000 mg; Cu: 10000 mg; I: 1000 mg; Se: 200 mg and Choline chloride: 250000 mg.
[2] Vitamin supplement contains: vitamin A: 900000 IU; vitamin D_3: 200000 IU; vitamin E: 18000 IU; vitamin K_3: 2000 mg; B_1: 1800 mg; B_2: 6600 mg; B_3: 10000 mg; B_5: 30000 mg; B_9: 3000 mg; B_{12}: 15 mg; Biotin: 100 mg; Choline chloride: 250000 mg and Antioxidant: 1000 mg.
T1: Control; T2: arbocel; T3: sunflower hulls; T4: soybean hulls and T5: processed wheat straw.

RESULTS AND DISCUSSION

The results of different treatments on the performance parameters of broiler chickens are shown in Table 3. The highest feed intake was observed in starter (1 to 10 days of age) by treatments 3 (sunflower hulls), 4 (soybean hulls), and 5 (processed wheat straw) and the lowest feed intake was shown by control diet in this case (P<0.05). The average feed intake was not affected in Grower (11 to 24 days of age), finisher (25 to 42 days of age), and total period (1 to 42 days of age) by experimental treatments. In the starter period, the average weight gains of chickens in treatment 3 (sunflower hulls) compared with control and treatment 2 (Arbocel®) showed a significant increase (P<0.05) but no response was found by other treatments in this respect this trend was also observed in the grower period. There were no significant differences in this trait (weight gain) in the finisher and in the whole period. No effected was found in the feed conversion ratio in any experimental periods. In addition, no significant differences were observed between the experimental treatments in terms of production index in the whole rearing period.Gizzard, crop, duodenum, and cecum pH were not affected by experimental treatments. But pH (ileum and cecum) was decreased by treatments 4 (soybean hulls) and 5 (processed wheat straw) in compared with other treatments (P<0.05) (Table 4).

Table 2 Feed formulation and chemical composition of treatment diets (%, as is, grower (11 to 24 days of age) and finisher (25 to 42 days of age)

Feed ingredient	Grower					Finisher				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Corn	60.53	59.84	58.61	58.62	58.62	62.5	61.82	60.57	60.57	60.57
Soybean meal	32.89	32.56	31.9	31.9	31.9	30.84	30.53	29.91	29.91	29.91
Corn gluten	1	0.99	0.97	0.97	0.97	-	-	-	-	-
Arbocel	-	1	-	-	-	-	1	-	-	-
Sunflower hulls	-	-	3	-	-	-	-	3	-	-
Soybean hulls	-	-	-	3	-	-	-	-	3	-
Processed wheat straw	-	-	-	-	3	-	-	-	-	3
Soy bean oil	1.84	1.822	1.785	1.781	1.781	3.06	3.031	2.973	2.973	2.973
Di-calcium phosphate	1.61	1.59	1.566	1.56	1.56	1.42	1.4	1.38	1.38	1.38
Oyster shell	1.04	1.029	1	1	1	0.96	0.95	0.93	0.93	0.93
Salt	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23
Mineral premix[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
DL-methionine	0.2	0.19	0.19	0.19	0.19	0.22	0.22	0.21	0.21	0.21
L-lysine-hydrochloride	0.13	0.12	0.12	0.12	0.12	0.1	0.099	0.097	0.097	0.097
Threonine	0.01	0.009	0.009	0.009	0.009	0.04	0.04	0.03	0.03	0.03
Sodium bicarbonate	0. 12	0.11	0.11	0.11	0.11	0.12	0.17	0.17	0.17	0.17
Total	100	100	100	100	100	100	100	100	100	100
Chemical analysis (calculated) (%)										
ME (kcal kg^{-1})	3004	2975	2924	2937	2919	3069	3069	3016	3030	3006
Crude protein	20.65	20.45	20.22	20.34	20.17	19.27	19.27	19.06	19.18	18.87
Crude fiber	3.75	4.43	5.05	4.66	4.60	3.66	4.34	5.03	4.63	4.5
Calcium	0.84	0.83	0.81	0.81	0.81	0.75	0.75	0.73	0.73	0.73
Available phosphorus	0.42	0.41	0.40	0.40	0.40	0.38	0.37	0.36	0.36	0.36
Sodium	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14
Potassium	0.85	0.84	0.82	0.82	0.82	0.81	0.80	0.79	0.79	0.79
Chlorine	0.21	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19
Amino acids (digestible)										
Lysine	1.06	1.04	1.02	1.02	1.02	1.06	1.05	1.02	1.02	1.02
Methionine	0.49	0.48	0.47	0.47	0.47	0.53	0.52	0.51	0.51	0.51
Methionine + cysteine	0.78	0.77	0.75	0.75	0.75	0.82	0.81	0.79	0.79	0.79
Threonine	0.68	0.67	0.65	0.65	0.65	0.74	0.72	0.72	0.72	0.72
Tryptophan	0.21	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19
Analysis (measured) (%)										
Dry matter	92.71	92.96	92.68	92.4	92.06	92.73	91.63	91.73	91.06	90.07
Crude ash	5.40	5.73	6.00	6.06	6.06	5.13	6.26	6.13	6.06	6.06
Crude protein	19.27	19.51	19.39	19.45	19.72	18.96	18.78	18.44	18.81	18.85
Crude fiber	3.75	4.43	5.05	4.66	4.60	3.66	4.24	5.02	4.63	4.50

[1] Mineral supplements contain: Mn: 99200 mg; Zn: 84700 mg; Fe: 50000 mg; Cu: 10000 mg; I: 1000 mg; Se: 200 mg and Choline chloride: 250000 mg.
[2] Vitamin supplement contains: vitamin A: 900000 IU; vitamin D_3: 200000 IU; vitamin E: 18000 IU; vitamin K_3: 2000 mg; B_1: 1800 mg; B_2: 6600 mg; B_3: 10000 mg; B_5: 30000 mg; B_9: 3000 mg; B_{12}: 15 mg; Biotin: 100 mg; Choline chloride: 250000 mg and Antioxidant: 1000 mg.
T1: Control; T2: arbocel; T3: sunflower hulls; T4: soybean hulls and T5: processed wheat straw.

Table 3 The effect of treatment diets on performance of broilers in different rearing periods

Treatments	1 to10 of days			11 to 24 days			25 to 42 days			1 to 42 days			PI
	FI (g/bird)	BWG (g/bird)	FCR	FI (g/bird)	BWG (g/bird)	FCR	FI (g/bird)	BWG (g/bird)	FCR	FI (g/bird)	BWG (g/bird)	FCR	
Control	205^{b}	139^{b}	1.46	745	465^{b}	1.61	2625	1352	1.49	3276	1864	1.76	292
Arbocel	213^{ab}	144^{b}	1.47	758	490^{ab}	1.54	2652	1277	2.09	3366	1849	1.83	289
Sunflower hulls	226^{a}	158^{a}	1.43	818	553^{a}	1.48	2700	1258	2.15	3400	1864	1.85	289
Soybean hulls	222^{a}	150^{ab}	1.48	759	490^{ab}	1.55	2732	1349	2.11	3416	1917	1.81	304
Processed wheat straw	219^{a}	150^{ab}	1.46	797	529^{ab}	1.50	2682	1286	2.13	3399	1874	1.83	303
SEM	4.117	4.021	0.032	23.618	22.414	0.047	108.477	93.579	0.167	90.832	115.542	0.085	0.972
P-value	0.0170	0.0435	0.8049	0.2037	0.0921	0.5022	0.9627	0.9283	0.9106	0.8154	0.9922	0.9639	21.1523

FI: feed intake; BWG: body weight gain; FCR: feed conversion ratio and PI: production index.
The means within the same column with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 4 The effect of treatment diets on the pH in various parts of the gastrointestinal tract at 42 days of age

Treatments	Crop	Proventriculus	Gizzard	Duodenum	Jejunum	Ileum	Cecum
Control	4.76	3.43a	3.16	5.84	5.87	5.63	6.41
Arbocel	4.97	3.53a	3.26	5.87	5.77	5.76	6.36
Sunflower hulls	5.03	3.42a	3.39	5.85	5.84	5.60	6.41
Soy bean hulls	4.68	2.86b	2.94	5.85	5.80	5.37	6.40
Processed wheat straw	4.68	2.86b	2.94	5.85	5.80	5.37	6.40
SEM	0.1404	0.1610	0.1718	0.0331	0.0325	0.1211	0.0971
P-value	0.2992	0.0172	0.2958	0.9769	0.2631	0.1418	0.9947

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 5 The effect of treatment diets on gastrointestinal viscosity (centipoise) and digestibility of dry matter and protein in ileum and cecum at 42 days of age (%)

Treatments	Viscosity		Ileum digestibility		Cecum digestibility	
	Ileum	Cecum	Dry matter	Protein	Dry matter	Protein
Control	1.69	2.01^{b}	74.36^{bc}	70.12	68.91^{b}	70.17
Arbocel	1.85	2.22^{a}	78.13^{a}	73.56	71.52^{ab}	68.80
Sunflower hulls	1.66	1.75^{c}	76.64^{ab}	71.22	70.95^{ab}	68.92
Soy bean hulls	1.81	1.92^{b}	78.05^{a}	71.50	75.94^{a}	68.22
Processed wheat straw	1.63	2.04^{b}	72.92^{c}	70.53	67.42^{b}	70.29
SEM	0.0324	0.0325	0.259	0.419	0.643	0.543
P-value	0.1159	< 0.0001	< 0.0001	0.1859	0.0097	0.0789

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 6 The effect of treatment diets on microbial population at 42 days of age (log 10 cfu/g)

Treatments	Ileum			Cecum		
	Lactobacillus	*Escherichia coli*	*Salmonella*	*Lactobacillus*	*Escherichia coli*	*Salmonella*
Control	7.41	6.41	6.39	8.95	10.12^{a}	6.73
Arbocel	7.81	5.14	6.04	965	8.53^{cd}	6.16
Sunflower hulls	7.44	6.55	6.63	9.8	9.20^{b}	6.36
Soy bean hulls	6.70	6.76	6.74	9.04	8.94^{bc}	6.02
Processed wheat straw	6.77	6.35	6.05	9.33	8.31^{c}	6.61
SEM	0.178	0.158	0.128	0.119	0.0530	0.1122
P-value	0.3744	0.2265	0.2778	0.1895	< 0.0001	0.1986

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

As shown in Table 5 the viscosity of cecum was significantly increased by 1% Arbusel® compared with other treatments (P<0.05). No significant differences were found by 3% soybean hulls and processed wheat straw in viscosity although different reaction was indicated in ileum in this case. On the other hand, the lowest viscosity in the cecum was related to the 3% sunflower hulls in the diet (P<0.05). The lowest amount of dry matter digestibility in the ileum was shown by treatment containing processed wheat straw (P<0.05). There were no statistically significant differences in protein digestibility. The highest dry matter digestibility was shown by soybean hulls in the cecum (P<0.05), although no significant response was found by Arbusel® and sunflower hulls in this respect. There were no statistically significant differences in protein digestibility in the cecum by different treatments (Table 5).

The results of the Microbial population have shown in Table 6. The population of lactic acid-producing bacteria and Salmonella in the ileum and cecum were not affected by experimental treatments. The population of *Escherichia coli* in the cecum was reduced by experimental treatments compared to the control treatment (P<0.05) But the *Escherichia coli* population in the ileum was not affected by experimental treatments (P>0.05).

The amount of pH and lactic acid in the ileum was lower than in the cecum (P<0.05). The effect of texture on other indicators was not significant. Interactions between the measuring site (tissue) and the treatments showed that the highest viscosity levels were by Arbocel® in the cecum and the lowest response was approved by processed wheat straw in the ileum. The highest population of *Escherichia coli* was found by control treatment in the cecum (P<0.05), but no reaction was observed by sunflower hull in the cecum as well as no significant differences was shown by interactions in other treatment (Table 7).

A comparison of nutrient digestibility in the ileum and cecum of broilers at 42 days of age are present in Table 8. The results showed that no significant protein digestibility was found differences by the effect of treatments, but dry matter digestibility was significantly lower in the control treatment with 3% processed wheat straw ($P<0.05$). Protein and dry matter digestibility were higher in the ileum than cecum by treatments ($P<0.05$). Although there were statistically significant differences in the interaction of tissue and dietary fibers in protein digestibility, the change in tissue location was not significant for each of the treatments. The lowest dry matter digestibility was obtained by processed wheat straw in the cecum and the highest amount was obtained by soybean hulls in the ileum ($P<0.05$).

Feed intake had no significant difference with Arbocel but was increased by other treatments in the (1 to 10 days of age). These results are consistent with Amerah *et al.* (2009). The researchers have observed that increased the amount of feed consumed and increased the body weight of broilers by wood shaving. On the other hand, the performance of broilers varies and depends on the particle size by the effects of insoluble fiber sources (Mateos *et al.* 2012). Hetland *et al.* (2003) have suggested that the passage rate depends on the particles size of fiber diet. In addition, increase in the passage rate by fine particles and a reduction in passage rate was found by large particles accumulating in the gizzard. Therefore, the increase in feed intake observed in treatments 3, 4, and 5 in 1to 10 days of age this could be due to the decrease in the viscosity of intestinal contents. When the energy of the diet is diluted by the addition of fiber, the reduction of the bird's energy leads to increases feed consumption to meet its need for nutrients and the amount of energy required thus increasing feed consumption. The obtained results have shown that no differences in body weight of broilers in the starter and grower period, by treatment 3 (sunflower hulls) compared with other treatments. Adding moderate amounts of insoluble fiber to low-fiber starter diets is beneficial for broiler performance (González-Alvarado *et al.* 2007). Sunflower hulls seem to have more insoluble fibers than other treatments and can leads to weight gain by increasing the permeability of nutrients and affecting the digestibility of nutrients. These results are consistent with the findings of Jiménez-Moreno *et al.* (2010). In the present study, no response was found in the feed conversion ratio by experimental treatments. This observation contradicts the reports of Jiménez-Moreno *et al.* (2016). One of the main reasons for this variation can be due to the differences in the levels and sources of fiber in the diet.

The degree of viscosity of fibers depends on the solubility, molecular weight, and bonds in their chemical structure (Choct, 2002). Viscosity could be affected by molecular size, spatial shape, and concentration of fibrous compounds in the environment (Campbell *et al.* 1983). Among the factors that can play a vital role in viscosity in the gastrointestinal tract by fibrous compounds can be related to their ability to create viscosity (Shakouri *et al.* 2006), their dissolution in the gastrointestinal tract, molecular weight, type, and some bonds which is existed in their chemical structure (Debon and Tester, 2001; Choct, 2002). The observed viscosity from the ileum to the cecum tends to increase, which is consistent with the results of other researchers (Saki *et al.* 2010).

Increased the viscosity in both ileum and cecum by Arbusel® as an insoluble fiber. However, the results can be related to higher water holding capacity and swelling, passage *rate* and duration of storage in the gastrointestinal tract and its spatial structure and shape, as well as the level of crude fiber and high amount of cellulose in the bird’s diet. The physicochemical properties of crude fiber depend on the fibers type fraction that builds it and affect bulk density, ferment ability, water absorption, pH and viscosity of digestive contents, passage rate of digestive contents in gastrointestinal tract, short-chain fatty acid production, and microflora status (Urban *et al.* 2024).

The physiological effects of dietary fiber are related to their physicochemical properties (Gómez Ordóñez *et al.* 2010). In this experiment, the crop, gizzard, and different parts of the intestine pH were not affected by the experimental treatments but the proventriculus pH reduced by the soybean hulls and processed wheat straw treatments in compared with the control treatment. No significant differences were observed in the duodenum pH by added fiber in the broiler diet (Jiménez-Moreno *et al.* 2009; Mossami, 2011). The secretion of bile acids and other alkaline compounds in the duodenum seems to have been sufficient to modulate the pH in this part.

The retention time in the upper gastrointestinal tract was increased by fiber sources in the diet (Jiménez-Moreno *et al.* 2009) which improves gizzard function, and production of hydrochloric acid and bile acids. Low pH in the upper gastrointestinal tract can be beneficial for better pepsin activity, solubility, and absorption of mineral salts (González-Alvarado *et al.* 2008).

It has been reported that anti-nutritional substances in cereals can inhibit the digestion of energy, protein, and fat (Choct, 1997). In addition, increasing the viscosity due to different fibers reduces the rate of digestion substances through the gastrointestinal tract it prevents the access of digestive enzymes to the substrate (Fengler and Marquardt, 1988), which could reduce the nutrient digestibility.

Table 7 The effect of treatment diets on viscosity, pH, and microbial population in ileum and cecum of broilers at 42 days of age

Treatments	Viscosity (Centipoise)	pH	Microbial population		
			Lactobacillus (log10cfu/g)	*Escherichia coli* (log10cfu/g)	*Salmonella* (log10cfu/g)
Control	1.85	6.03	8.18	8.27	6.56
Arbocel	2.04	6.06	8.73	6.84	6.11
Sunflower hulls	1.71	6.01	8.26	8.78	6.49
Soy bean hulls	1.87	5.89	7.87	7.85	6.38
Processed wheat straw	1.84	5.89	8.05	7.33	6.33
SEM	0.150	0.2654	0.2098	0.1411	0.1708
Tissue					
Ileum	1.73	5.55[b]	7.23[b]	6.24	6.37
Cecum	1.99	6.40[a]	9.21[a]	9.02	6.37
SEM	0.095	0.1553	0.1327	0.0892	0.1080
Combine treatments					
Ileum-control	1.69[cd]	5.64	7.41	6.41[c]	6.39
Cecum-control	2.01[abc]	6.42	8.96	10.12[a]	6.73
Arbocel-Ileum	1.85[bcd]	5.76	7.81	5.14[d]	6.05
Arbocel-Cecum	2.22[a]	6.36	9.65	8.53[b]	6.16
Sunflower hulls-Ileum	1.66[d]	5.60	7.44	6.55[c]	6.63
Sunflower hulls-Cecum	1.75[bcd]	6.41	9.08	9.20ab	6.36
Soybean hulls-Ileum	1.81[bcd]	5.37	6.70	6.76[c]	6.74
Soybean hulls-Cecum	1.92[abcd]	6.40	9.04	8.94[b]	6.02
Processed wheat straw -Ileum	1.63[d]	5.37	6.78	6.35[c]	6.06
Processed wheat straw -Cecum	2.04[ab]	6.60	9.33	8.31[b]	6.62
SEM	0.212	0.3474			
P-value					
Fiber	0.0008	0.3804	0.0772	0.0001	0.3950
Tissue	0.0001	0.0001	0.0001	0.0001	0.9663
Fiber × tissue	0.0124	0.1648	0.3676	0.0003	0.0920
Treatments	0.0001	0.0001	0.0001	0.0001	0.2115

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

In the present experiment, the greatest effect on protein digestibility was found by the treatment with processed wheat straw that was not significant. It seems that the effects of straw processing and without straw processing have more negative effects on dry matter digestibility than other treatments. Processed straw seems to inhibit the release of secreted enzymes and reduce digestion by limiting the hydrolysis of nutrients by the digestive enzyme.

Diet composition (Vander Hoven-Hangoor *et al.* 2013), type and level of fiber sources in the diet (Mateos *et al.* 2012), antibiotic dietary supplements prebiotics, and other factors related to the diet could affect the amount and type of intestinal microbial population in different parts of intestine (Torok *et al.* 2011).

Changes in diet can lead to modifications in microbial activity. In general, an increasing trend in colony formation from the ileum to the cecum was observed in all experimental treatments. These observations are consistent with the other researchers (Saki *et al.* 2010).

In this experiment no response was found in the bacteria population by treatments in ileum and cecum in compared with control diet. This observation is consistent with the results of Jiménez-Moreno *et al.* (2011), and it contradicts the results of Choct *et al.* (2006) these could be related to types of treatments and experimental diet. In the present experiment no affect was shown on the number of *E. coli* colonies by insoluble fiber source in ileum but reduced the population of this bacteria were indicated in the cecum. It has been reported that the use of different particle size and levels of barley hulls reduced the population of *E. coli* in the ileum, which these researchers reported could be due to the different mechanisms of cellulose and lignin in the intestinal, they suggested that mainly reason due to the prebiotic effect of fiber in the digestive tract (Afra *et al.* 2017). Also, JangiAghdam *et al.* (2017) have reported that reduced the population of *E. coli* in the cecum by 3% of processed wheat straw, which is consistent with the results of this study.

Table 8 The effect of treatment diets on of nutrient digestibility (%) of ileum and cecum of broilers at 28 days of age

Treatments	Protein	Dry matter
Control	70.15[a]	71.64[b]
Arbocel	71.19[a]	74.83[ab]
Sunflower hulls	70.09[a]	73.80[ab]
Soybean hulls	70.90[a]	76.99[a]
Processed wheat straw	67.88[b]	70.17[b]
SEM	1.0185	1.2203
Tissue		
Ileum	71.40[a]	70.64[a]
Cecum	67.68[b]	70.95[b]
SEM	0.6442	0.7718
Combine treatments		
Ileum-control	70.12[ab]	74.37[ab]
Cecum-control	70.18[ab]	68.92[bc]
Arbocel-Ileum	73.57[a]	78.14[a]
Arbocel-Cecum	68.80[ab]	71.52[bc]
Sunflower hulls-Ileum	71.25[ab]	76.65[ab]
Sunflower hulls-Cecum	68.92[ab]	70.95[bc]
Soybean hulls-Ileum	71.50[ab]	78.05[a]
Soybean hulls-Cecum	70.30[ab]	75.94[ab]
Processed wheat straw -Ileum	70.54[ab]	72.92[bc]
Processed wheat straw -Cecum	62.23[b]	67.43[c]
SEM	1.4403	1.7259
P-value		
Fiber	0.0194	< 0.0001
Tissue	0.0001	< 0.0001
Fiber × tissue	0.0495	0.0177
Treatments	0.0295	< 0.0001

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

The highest viscosity was found by Arbocel® in the cecum and the lowest was found by processed wheat straw in the ileum. On the other hand, the highest population of *Escherichia coli* was indicated in cecum by the control treatment. It is suggested that feed consumption as the most important factor may affect the microflora of the gastrointestinal tract. Intrinsic properties of different parts of the gastrointestinal tract, including aerobic or anaerobic conditions, pH, and physiological characteristics of various part cause a change in the microbial population, which is consistent with the present experiment (Smits *et al*. 1998; Engberg *et al*. 2000; Williams *et al*. 2001; Hubener *et al*. 2002; Mathlouthi *et al*. 2002b; Engberg *et al*. 2004; Bjerrum *et al*. 2005; Hemmati Matin *et al*. 2016). In comparison to results have shown that the lowest amount of dry matter digestibility in the ileum is related to the treatment containing processed wheat straw. Therefore, no significant differences were found with the control.

There were no significant differences in protein digestibility in both regions ileum and cecum. The highest dry matter digestibility in the cecum was shown by soybean hull treatment. However, no significant differences were observed by treatments containing Arbocel® and sunflower hulls. In this study protein and dry matter, digestibility was higher in the ileum than in the cecum. This was expected because the jejunum and ileum are the main sites for digestion and absorption of nutrients (Choct, 2002). On the other hand, the lowest amount of dry matter digestibility was observed in the ileum containing processed wheat straw in contrast there were no statistically significant differences in protein digestibility. It seems that processing wheat straw or only straw has more negative effects on diet digestibility.

CONCLUSION

It is concluded that some performance and gastrointestinal characteristics was influenced by treatments 3, 4 and 5 than other treatments in this study. Feed intake increased by treatments 3, 4 and 5 than other treatments. In contrast gastrointestinal pH were reduced by soy bean hulls and wheat straw than others options. On the other hand, no response was shown in a microbial population whit exception *E. coli* was reduced by treatments 3, 4 and 5 in a cecum than other reaction in this respect. Otherwise declined viscosity was indicated only by sunflower hulls in cecum than other reaction in this case. It is generally suggestion that more capacity was observed in ileum reaction in a comparison to cecum.

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