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Changes in performance, cecal microflora counts and intestinal histology of Japanese quails fed diets containing different fibre sources

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ABSTRACT

The purpose of this experiment was to investigate how various fiber sources impact the performance, microbial population, and intestinal histology of Japanese quail that was performed in a completely randomized design for 42 days. The dietary treatments involved a fiber-free corn-soybean meal-based diet (control, CTL), and CTL with added levels of sunflower hulls (SFH) and sugar beet pulp (SBP) (20 and 40 g kg^{-1}). Body weight gain (BWG) and feed intake (FI) were recorded weekly. Carcass characteristics, cecal microbial population, blood variables and intestinal histology were measured on the 42 day of age. Adding 40 g kg^{-1} of SBP led to a significant decrease in body weight gain and an increase in the feed conversion ratio of birds from 1 to 21 days ($P < 0.05$). The relative weight of the gastrointestinal tract and gizzard increased significantly in birds that consumed SFH. Blood triglyceride concentration decreased with the inclusion of fiber in the diet. However, there was a notable increase in blood cholesterol concentration in the birds that were fed SBP (20 and 40 g kg^{-1}) in comparison to those fed SFH ($P < 0.05$). The population of *E. Coli* in the cecum increased significantly in the birds that were fed 4 g kg^{-1} of SBP as opposed to those fed 20 and 40 g kg^{-1} of SFH ($P < 0.05$). The villus height of the jejunum in birds that were fed 20 g kg^{-1} and 40 g kg^{-1} of SFH demonstrated a significant increase in comparison to the other treatments ($P < 0.05$). In general, the findings of this research indicated that the inclusion of 40 g kg^{-1} of SBP in the diet had a negative impact on performance and other physiological parameters. However, the use of SFH and 20 g kg^{-1} of SBP yielded similar results to birds in the CTL, and in some cases, even better outcomes.

1. Introduction

Dietary fiber plays a crucial role in poultry diets and has a beneficial impact on the digestive tract's physiological function (Wenk, 2001). Research findings indicate that adding moderate levels of fibrous materials to feeds can improve gizzard function (Svihus, 2011), enhance the digestibility of non-fibre nutrients (Jimenez-Moreno et al., 2009b; Gonzalez-Alvarado et al., 2010), promote gastrointestinal tract (GIT) health (Kalmendal & Bessei, 2012; Mateos et al., 2013), and boost growth performance (Gonzalez-Alvarado et al., 2007; Jimenez-Moreno et al., 2013a) in broilers. Furthermore, the low pH in the upper part of the digestive tract was found to increase pepsin activity through the dietary inclusion of fiber. Specifically, soluble fiber sources like SBP were observed to elevate intestinal viscosity and microbial activity, which is linked to gastrointestinal hypertrophy and decreased the digestibility of nutrients and the performance of broiler (Sadeghi et al., 2015). Studies have demonstrated that broiler chickens' performance and digestion are improved when oat hulls and SFH are included in the diet (Gonzalez-Alvarado et al., 2008; Svihus, 2011; Sacranie et al., 2012). Gonzalez-Alvarado et al. (2007) determined that incorporating 3% OH or soybean hulls (SH) into the feed of broiler chickens enhances their performance from 1 to 21 days of age and improves nutrient digestibility at 18 days of age. In general, studies have highlighted the impact of both soluble and insoluble fiber on the digestive organs (Banfield et al., 2002; Jimenez-Moreno et al., 2009a) and intestinal morphology (Iji et al., 2001; Jimenez-Moreno et al., 2013b) in broilers. It has been stated that water-soluble fiber contributes to the growth of harmful bacteria such as *Clostridium perfringens* and *coliforms*. Besides, the toxins produced by these bacteria in the intestine cause the secretion of water and electrolytes from the crypt into the lumen space and cause diarrhea, destruction of the intestinal mucosa, and the destruction of the germ cells in the depth of the crypt (Montagne et al., 2003).

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Additionally, Rezaie et al. (2011) documented that incorporating insoluble fiber in the diet resulted in an elongation of villi in broiler chickens. While moderate levels of fiber have been reported to benefit poultry, exceeding 3 % in the diet could negatively impact performance. Jimenez-Moreno et al. (2013a) showed that augmenting SBP from 2.5 % to 7.5 % of diet had a negative impact on the daily growth rate of broiler chickens aged 1 to 6 days.

There is a close relationship between Japanese quail and broiler chickens from a phylogenetic perspective (Stock & Bunch, 1982), and both are classified under the order Galliformes and the family Phasianidae (Shibusawa et al., 2001). Japanese quail has been proposed as a model species for poultry (Mills et al., 1997), and it is reasonable to anticipate that dietary interventions would produce comparable effects in Japanese quail and other poultry species. Nevertheless, there is still a lack of scientific data comparing the effects of soluble and insoluble fiber in Japanese quail nutrition. The study aimed to investigate the effects of including higher levels of SBP and SFH in the quail diet on performance, small intestine structure, digestive organ weights, cecal microflora counts, and blood metabolites.

2. Materials and methods

2.1. Animal ethics

The study's procedures were approved by the Animal Ethics Committee at the Agricultural Sciences and Natural Resources University of Khuzestan, Ahvaz, Iran (Approval no 40,131,215).

2.2. Chemical analysis of sunflower hulls and sugar beet pulp

The SFH and SBP were acquired from Maz Maz factory in Isfahan, Iran, and Khuzestan sugarcane industry in Iran, respectively. They were then ground using a hammer mill equipped with a 3 mm screen. The chemical composition of SFH and SBP was analyzed using AOAC (2000) methods (refer to Table 1). Crude fiber (CF) was measured using the sequential extraction method with diluted acid and alkali (method 978.10; AOAC, 2000). Dry matter (DM) and crude protein (CP) were determined using methods 930.15 and 990.03, respectively (AOAC, 2000). Ether extract (EE) was analyzed as ether extract using the Soxhlet method after acid hydrolysis (method 954.02; AOAC, 2000). The neutral (NDF) and acid detergent fiber (ADF) of the samples were determined sequentially following the method described by Van Soest et al. (1991) and expressed on an ash-free basis. The moisture and ash contents were determined using methods reported by Debon and Tester (2001). Nitrogen-free extract (NFE) was calculated using the following formula:

$$NFE = 100 - (CP + ash + CF + EE)$$

2.3. Birds, diets, and management

450 male Japanese quail chicks, all one day old, were obtained from a commercial hatchery in Iran. The birds were assigned at random to 5 treatments, with 6 replicate pens each containing 15 birds, following a design that is entirely randomized. The chicks were raised in floor pens that covered with approximately 2 in (5.08 cm) of clean softwood shavings, and the bird density was approximately 0.06 m^2 per bird. The lighting programme was 24 hr a day for the first 5 days and then reduced to 23 hr of light afterwards. The temperature of the room was maintained at 35 °C for the first 5 days and decreased to 25 °C until the end of the experiment. Ventilation was provided by negative pressure with fans. The experiment lasted for 6 week (from day 0 to 42), and birds had ad libitum access to water and feed during this period. The dietary treatments included a fiber-free diet based on corn and soybean meal (control, CTL), and the CTL supplemented with SFH and SBP at 2 levels (20 and 40 g kg^{-1} of the diet). The basal diet contained 40 g kg^{-1} of washed sand, which was substituted with 20 and 40 g kg^{-1} of fiber ingredients in the treatment diets. The CTL diet was designed to fulfill the nutrient needs of quails as per NRC (1994) and was provided in mash form (see Table 2).

2.4. Growth performance

Weekly records were maintained for BWG and FI for each pen. The FCR was calculated by dividing the FI by the BWG for each experimental period (1 to 21 days and 22 to 42 days), as well as for the entire 42-day period. Mortality was minimal, and there were no variations between the groups.

2.5. Size of different organs

To assess the weight (relative to BW) of the breast, thigh, gastrointestinal tract (including contents, from the end of the crop to the cloaca), gizzard and proventriculus (with contents), and liver, two birds were randomly chosen from each replicate and euthanized by cervical dislocation at the conclusion of the study (42 d of age).

2.6. Gut microflora

On day 42, for the assessment of caecal microflora, one caecum from two birds in each replicate, which had been euthanized by cervical dislocation were utilized. The contents of the ceca were collected in separate sterile culture tubes using aseptic techniques, then promptly placed on ice and transported to the microbiological laboratory. Caecal digesta (1 g) from each bird were aseptically transferred into 9 ml of sterile saline solution and serially diluted. *Lactobacilli* was enumerated on de Man–Rogosa–Sharpe agar and *E. coli* and *coliformes* were counted on MacConkey agar after incubation at 37 °C for 48 h in an anaerobic chamber and for 24 h in an aerobic chamber, respectively. All samples were plated in duplicate (Masouri et al., 2017).

2.7. Intestinal morphology

Upon completion of the 42-day study, segments of the duodenum, jejunum and ileum were gathered and examined using the methodology outlined by Liu et al. (2022). Specifically, 1 cm sections from the middle region of the duodenum, jejunum and ileum tissues were washed with 0.1 M phosphate buffered saline, fixed in 10 % formaldehyde phosphate buffer, and subsequently processed, dehydrated, and embedded in paraffin wax. These sections were then sliced into 5 mm sections and stained with hematoxylin-eosin for analysis. Histological sections were analyzed for villus height (VH) and crypt depth (CD) using a digital camera microscope (BA400 Digital, McAudi Industrial Group Co., Ltd., Xiamen, China) and the Motic Advanced 3.2 digital image analysis system. The ratio of villus height to crypt depth (VH/CD) was then determined based on 10 well-oriented villi.

2.8. Statistical analysis

The data were analyzed using a completely randomized design with 5 treatments, employing the PROC GLM of SAS (SAS Institute, 2008). The pen was considered the experimental unit for all traits. Microbiological counts underwent base-10 logarithm transformation prior to analysis. The study evaluated significant differences between the treatments using Tukey's test with a significance level of $P < 0.05$.

3. Results

3.1. Growth performance

In contrast to the control group, the inclusion of 40 g kg^{-1} SBP did not significantly impact FI but led to a notable decrease in BWG at 1 to 21 days of age and 1 to 42 days of age (Table 3, $P < 0.05$). Quails that were

Table 1
Chemical composition (g kg^{-1}) of sunflower hulls and sugar beet pulp.

Fiber Source	DM[3]	Ash	CP[4]	EE[5]	CF[6]	ADF[7]	NDF[8]	NFE[9]
SBP[1]	947.8	62.5	101.0	19.8	89.8	250.0	400.0	674.7
SFH[2]	945.3	35.4	52.5	50.0	460.0	495.4	712.2	347.4

NFE = 100- (CP+Ash+ CF+EE).
[1] Sugar beet pulp.
[2] Sunflower hull.
[3] Dry matter.
[4] Crude protein.
[5] Ether extract.
[6] Crude fiber.
[7] Acid detergent fiber.
[8] Neutral detergent fiber.
[9] Nitrogen free extract.

Table 2
Ingredients and chemical composition of the experimental diets (as fed on basis).

Ingredients (g kg^{-1}, unless stated otherwise)	1–42 d
Maize	408.3
Soybean meal, 410 g CP/kg	400.0
Corn gluten meal, 600 g CP/kg	70.0
Vegetable oil	50.0
Limestone	13.1
Dicalcium phosphate	8.5
DL- Methionine	0.8
Common salt	3.3
Vitamin and mineral premix[1]	3.0
Washed sand[2]	40.0
Calculated composition	
ME (MJ/kg)	12.26
Crude protein	241.2
Ether extract	71.3
Crude fiber	42.4
Methionine	5.0
Methionine + Cysteine	9.0
Lysine	12.5
Arginine	15.4
Available phosphorus	3.0
Sodium	1.5
Calcium	8.0
Determined analysis	
Dry matter	900.0
Crude protein	242.5
Crude fibre	41.2
Ether extract	70.3

[1] Supplied the following per kilogram of diet: retinyl acetate, 2.7 mg; cholecalciferol, 0.05 mg; DL-α-tocopheryl acetate, 11.25 mg; menadione sodium bisulphite, 1.76 mg; biotin, 0.12 mg; thiamine, 1.2 mg; riboflavin, 3.2 mg; calcium D-pantothenate, 6.4 mg; pyridoxine, 1.97 mg; nicotinic acid, 28 mg; cyanocobalamine, 0.01 mg; choline chloride, 320 mg; folic acid, 0.38 mg; MnSO4·H2O, 60 mg; FeSO4·7H2O, 80 mg; ZnO, 51.74 mg; CuSO4·5H2O, 8 mg; iodised NaCl, 0.8 mg; Na2SeO3, 0.2 mg.
[2] Washed sand was replaced by 20 g kg^{-1} or 40 g kg^{-1} sunflower hulls or sugar beet pulp.

fed a diet supplemented with 40 g kg^{-1} SBP exhibited impaired FCR at 1 to 21 days of age ($P < 0.05$).

3.2. Organ weights

Table 4 presents the findings for organ weights and gut segments at the conclusion of the rearing period. The relative weight of the thigh, breast, and proventriculus was not influenced by the diet ($P > 0.05$). However, the relative weight of the gastrointestinal tract (GIT) was notably higher in quail fed diets containing SFH compared to those fed SBP ($P < 0.05$). Additionally, the relative weight of the gizzard was significantly higher in quail fed diets containing SFH in comparison to the other treatments ($P < 0.05$). Furthermore, the inclusion of 40 g kg^{-1} SBP in the diet resulted in increased relative liver weight in quail compared to other treatments ($P < 0.05$).

3.3. Blood lipid metabolites

Table 5 displays that the plasma concentration of glucose was not significantly impacted by the treatments ($P > 0.05$). Quails that were fed diets containing SFH and SBP exhibited significantly lower ($P < 0.05$) concentrations of triglycerides compared to the CTL group. The inclusion of SFH in the diet led to a reduction in cholesterol concentration compared to the other treatments ($P < 0.05$). However, HDL concentration increased in birds fed 20 and 40 g kg^{-1} of SBP, and LDL concentration increased in quails fed 40 g kg^{-1} of SBP ($P < 0.05$).

3.4. Microbial population

In Table 6, it is observed that the cecal populations of *E. coli* decreased significantly in quails fed SFH compared to the birds fed 4 % SBP ($P < 0.05$). However, the cecal populations of *Lactobacillus* and *Coliform* were not affected by the treatments ($P < 0.05$).

3.5. Small intestine morphology

In the morphology of the duodenum and ileum, there were no significant differences between treatments ($P > 0.05$). However, in the jejunum, the villus height of the birds fed 20 and 40 g kg^{-1} SFH was significantly higher than in the other treatments ($P < 0.05$).

4. Discussion

In this study, while SBP did not affect FI, its negative impact on BWG and FCR may be partly due to its pectin content (Langhout et al. 1999). Pectin enhances the viscosity in the gastrointestinal tract. Additionally, the presence of viscous non-starch polysaccharides (NSP) decreases the rate at which digestive enzymes diffuse into the digesta, hindering their interaction at the mucosal surfaces and decreasing nutrient utilization (Annison 1993). However, consistent with the current findings, Sadeghi et al. (2015) observed that SBP had no significant impact on FI, but it decreased BWG at 14 to 28 days of age and increased FCR compared to rice hull (RH) at 14 to 28 days of age and 28 to 42 days of age. Similarly, chicks that were given a diet with a greater pectin to cellulose ratio in their initial 21 days of life showed reduced BWG and FCR (Saki et al. 2011b). In contrast, González-Alvarado et al. (2010) found that the use of 30 g kg^{-1} of SBP, compared to 30 g kg^{-1} of oat hulls, reduced FI in broiler chickens.

There is limited available data on the effects of various fiber sources on carcass components. The relative weights of thigh, breast, and proventriculus were not influenced by diet. However, Pourazadi et al. (2020) discovered that incorporating SFH, sugarcane bagasse (SB), or wheat bran (WB) into the diet led to improved relative weights of breast and thigh in broilers compared to the control group at 42 days of age. In

Table 3
. Effect of different sources of fiber on growth performance of Japanese quails.

Treatments	Feed intake (g/bird)			Body weight gain(g/bird)			Feed conversion ratio		
	1–21 d	22–42 d	1–42 d	1–21 d	22–42 d	1–42 d	1–21 d	22–42 d	1–42 d
CTL[1]	307.19	617.16	924.35	115.93[a]	138.58	254.52[a]	2.66[b]	4.48	3.64
20 g kg-1 SFH[2]	397.89	625.94	933.83	116.16[a]	132.75	248.92[ab]	2.66[b]	4.71	3.75
40 g kg-1 SFH	315.96	620.78	936.74	122.87[a]	137.53	260.40[a]	2.57[b]	4.54	3.61
20 g kg-1 SBP[3]	311.28	658.01	969.28	118.21[a]	140.72	258.93[a]	2.64[b]	4.68	3.75
40 g kg-1 SBP	297.01	635.93	932.94	93.96[b]	139.89	233.85[b]	2.16[a]	4.55	4.00
P Value	0.461	0.134	0.150	0.0001	0.595	0.023	0.0007	0.774	0.077
SEM	7.24	11.75	12.71	3.72	3.71	5.83	0.090	0.146	0.099

[a–b] Means with different letters within the same column differ significantly ($P < 0.05$).
[1] Control.
[2] Sunflower hull.
[3] Sugar beet pulp.

Table 4
Effect of different sources of fiber on carcass traits of Japanese quails on d 42 (g/100 g BW).

Treatment	Thigh	Breast	Gastrointestinal tract[4]	Gizzard	Proventriculus	Liver
CTL[1]	14.15	24.19	11.02[a,b]	1.94[c]	0.431	2.08[b]
20 g kg-1 SFH[2]	15.00	24.04	13.01[a]	2.56[a]	0.406	2.03[b]
40 g kg-1 SFH	15.03	25.50	12.67[a]	2.63[a]	0.346	2.06[b]
20 g kg-1 SBP[3]	14.86	25.41	10.02[b]	2.16[b,c]	0.403	2.09[b]
40 g kg-1 SBP	15.51	22.68	10.36[b]	2.15[b,c]	0.371	2.42[a]
P-Value	0.391	0.379	0.016	0.021	0.552	0.016
SEM	0.474	0.794	0.700	0.147	0.370	0.104

[a–c] Means with different letters within the same column differ significantly ($P < 0.05$).
[1] Control.
[2] Sunflower hull.
[3] Sugar beet pulp.
[4] The gastrointestinal tract, including contents, from the end of the crop to the cloaca.

Table 5
Effect of different sources of fiber on serum blood metabolites (mg/dl) of Japanese quails on d 42.

Treatments	Glucose	Triglyceride	Cholesterol	HDL	LDL
CTL[1]	209.83	271.47[a]	193.33[a]	91.66[ab]	34.00[c]
20 g kg-1 SFH[2]	178.83	161.82[bc]	159.00[b]	93.00[ab]	33.33[c]
40 g kg-1 SFH	200.33	167.46[b]	160.83[b]	76.16[b]	39.66[bc]
20 g kg-1 SBP[3]	237.83	127.50[d]	217.00[a]	105.00[a]	44.83[b]
40 g kg-1 SBP	210.50	133.83[cd]	192.17[a]	106.66[a]	53.50[a]
P Value	0.093	<0.0001	0..002	0.019	<0.0001
SEM	14.20	10.98	10.26	6.51	2.57

[a–c] Means with different letters within the same column differ significantly ($P < 0.05$).
[1] Control.
[2] Sunflower hull.
[3] Sugar beet pulp.

the current study, the addition of SFH led to an elevated gizzard weight at 42 days of age. Likewise, Hetland and Svihus (2001) noted that the inclusion of 40 g kg^{-1} oat hulls resulted in an increase in the fresh contents of the gizzard in chicks. This finding aligns with previous research on younger chicks fed similar diets (González-Alvarado et al. 2007; Jiménez-Moreno et al. 2009c).Yet, the degree of the response was contingent on the type of fiber source utilized. In 42-day-old broilers, the inclusion of SFH resulted in a greater increase in gizzard weight compared to SBP. Jiménez-Moreno et al. (2009c) found a 30 % improvement with OH and a 21 % improvement with SBP in 5-day-old chicks. Similarly, González-Alvarado et al. (2007) reported a 35 % increase in the relative weight of the gizzard when 30 g kg^{-1} OH was included in the diet of 21-day-old broilers. The higher gizzard weight with SFH compared to SBP may be due to the greater hardness of the SFH particles, attributed to its high degree of lignification, which was more effective in enlarging the organ than the higher water-holding capacity and swelling capacity of the SBP particles. In this study, the proportional weight of the gastrointestinal tract (GIT) was increased by the dietary inclusion of SFH. Research has shown that insoluble fiber particles absorb water into their structure and expand to varying degrees as they pass through the gastrointestinal tract (GIT), leading to larger digesta. Thus, the expansion of the GIT in birds fed insoluble fibers may be a result of physical distension caused by the swelling of the hulls and the simultaneous increase in digesta bulk (Knudsen 2001). Incorporating 40 g kg^{-1} SBP into the diet led to a greater relative weight of the liver compared to other treatments in quail. In contrast, Jiménez-Moreno et al. (2009b) discovered that liver weight was not influenced by fiber inclusion. The observed effect of SBP in increasing liver weight may be attributed to the high pectin content of SBP, which can increase digesta viscosity (Iji et al. 2001). It has been demonstrated that non-starch polysaccharides (NSP) can increase the de-conjugation of bile acids, potentially impairing liver activity (Smits & Annison 1996).

In this study, the plasma glucose concentration was not influenced by the treatments. Quails that were fed diets containing SFH and SBP showed lower triglyceride concentrations compared to the control group. The inclusion of SFH in the diet led to a reduction in cholesterol concentration compared to the other treatments. However, HDL

Table 6
Effect of different sources of fiber on the cecal microbial population (log cfu g^{-1}) of Japanese quails on d 42.

Fiber source	*Lactobacilli*	*Coliforms*	*E. Coli*
CTL[1]	8.17	7.02	7.34[a,b]
20 g kg^{-1} SFH[2]	8.29	6.92	7.01[b]
40 g kg^{-1} SFH	8.53	6.32	7.10[b]
20 g kg^{-1} SBP[3]	9.04	6.70	7.42[a,b]
40 g kg^{-1} SBP	8.26	7.08	8.02[a]
P Value	0.435	0.116	0.048
SEM	0.184	0.207	0.224

[a–b] Means with different letters within the same column differ significantly ($P < 0.05$).
[1] Control.
[2] Sunflower hull.
[3] Sugar beet pulp.

Table 7
Effects of different sources of fiber on small intestine morphology of quails at 42 d (μm).

Item	CTL[1]	20 g kg^{-1} SFH[2]	40 g kg^{-1} SFH	20 g kg^{-1} SBP[3]	40 g kg^{-1} SBP	P Value	SEM
Duodenum							
Villus height	927.5	982.6	905.0	989.6	970.1	0.912	75.51
Crypt depth	96.97	103.54	91.66	96.14	95.47	0.680	5.64
Villus thickness	118.33	123.23	137.50	125.83	123.69	0.906	14.32
Villus height/ Crypt depth ratio	9.58	9.72	9.88	10.37	10.20	0.969	0.912
Jejunum							
Villus height	321.07[b]	406.67[a]	410.82[a]	336.25[b]	295.83[b]	0.001	18.14
Crypt depth	70.10	75.42	76.83	81.67	71.23	0.834	7.74
Villus thickness	41.72	47.52	52.49	5541	46.66	0.481	5˙.57
Villus height/ Crypt depth ratio	5.23	4.70	5.28	5.06	4.27	0.856	0.741
Ileum							
Villus height	328.33	247.91	316.66	334.06	267.08	0.142	26.00
Crypt depth	62.58	57.60	65.62	77.60	61.96	0.439	7.57
Villus thickness	39.99	41.24	39.16	36.96	44.16	0.095	6.58
Villus height/ Crypt depth ratio	5.49	4.42	4.81	4.43	4.44	0.376	0.431

[a–b] Means with different letters within the same row differ significantly ($P < 0.05$).
[1] Control.
[2] Sunflower hull.
[3] Sugar beet pulp.

concentration increased in birds fed 20 and 40 g kg^{-1} of SBP, and LDL concentration increased in quails fed 40 g kg^{-1} of SBP. Boazar et al. (2021) found that including SBP, SFH, and wheat bran in the diet decreased glucose, cholesterol, and triglyceride concentrations compared to the control in broiler chickens. Likewise, Rahmatnejad and Saki (2016) documented that incorporating 10 or 20 g kg^{-1} of CEL as insoluble fiber decreased the concentration of cholesterol in blood plasma, aligning with our results. Furthermore, Mohiti-Asli et al. (2012) demonstrated that a 30 g kg^{-1} of cellulose inclusion led to a reduction in plasma cholesterol concentration in broiler breeders. The drop in serum triglyceride levels in broilers given different fiber sources in our experiments could be credited to the influence of fiber, as dietary fiber is recognized for reducing fat utilization by deconjugating bile salts. In studies conducted by Rama Rao et al. (2004; 2006), a similar pattern was noted, with a decrease in serum concentrations of LDL and triglycerides observed in birds fed high-fiber diets. Conversely, Shirzadegan and Taheri (2017) documented elevated concentrations of serum LDL in chickens fed 30 g kg^{-1} of wood shavings at 40 days of age.

In this study, the cecal populations of *E. coli* decreased in quails fed SFH compared to those fed 40 g kg^{-1} SBP. However, the cecal populations of *Lactobacillus* and *Coliform* were not impacted by the treatments. Similarly, Rezaei et al. (2018) found no notable variances in *Lactobacilli* spp., coliforms, and total aerobic counts in the small intestine of quail fed diets with or lacking micronized wheat fiber. The elements of dietary fiber resist digestion by internal digestive enzymes, leading to bacterial fermentation in the lower part of the gut (Montagne et al. 2003). The primary products of this fermentation are short-chain fatty acids (SCFAs), which can hinder the proliferation of intestinal bacterial pathogens like *E. coli* and *Clostridium spp*. (Montagne et al. 2003).The bacterial composition of the small intestine varies based on age, physiological state, gut region, diet composition, and the presence and nature of fiber. Jiménez Moreno et al. (2011) conducted a study to investigate the effects of incorporating 50 g kg^{-1} oat hulls or sugar beet pulp in the diets of broilers, and they found that dietary fiber did not affect the cecal population of *Lactobacilli spp*. In contrast, the presence of oat hulls led to a significant decline in the counts of *C. perfringens* and *Enterobacteriaceae* spp. in the caeca, while SBP did not have an impact, consistent with the findings of the present study. Incorporating insoluble fiber in this research did not alter the levels of *Lactobacilli* spp. and *coliforms* in the cecal contents of quail, but it did decrease the total number of *E. coli*. In this study, the villus height of the jejunum in birds fed 20 and 40 g kg^{-1} SFH was higher than in other treatments. However, there were no differences between treatments in the morphology of the duodenum and ileum. In contrast, Sadeghi et al. (2015) stated that sugar beet pulp decreased villus height in the duodenum and ileum compared with the control, whereas no influence of rice hull was detected in broiler chickens. The height of the villi in the intestine reflects its capacity for absorption (Teirlynck et al. 2009). Birds that have a larger villus surface area in the gut experience increased nutrient absorption. Due to the reduced crypt cell proliferation and increased absorptive villus surface area, the nutrients conserved in birds that received SFH supplementation led to higher body weight gain (BWG) and lower feed conversion ratio (FCR). Supporting this, Sarikhan et al. (2010) found that adding 5 and 7.5 g kg^{-1} of insoluble fiber to the diet led to a rise in the height of villi in broilers. Additionally, Rezaei et al. (2011) stated that commercially processed fiber (Vitacel) increased the height of the villi and the ratio of villus length to crypt depth in broiler chickens. Modifications in intestinal morphology, such as reduced villi length and deeper crypts, have been linked to increased tissue turnover (Miles et al. 2006). The impact of dietary fiber on epithelial morphology and cell turnover is diverse and is influenced by factors such as the physicochemical characteristics of the fibers, their dietary inclusion level, duration of consumption, animal species and age, and the specific location in the intestinal tract (Montagne et al. 2003) (Table 7).

5. Conclusion

In this experiment, it was observed that incorporating 40 g kg^{-1} of SBP into the Japanese quail diet had adverse effects on the bird's performance and other physiological parameters. However, the use of SFH and 20 g kg^{-1} of SBP yielded similar or even improved results compared to the control group in some cases.

Ethical statement

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to and the appropriate ethical review committee approval has been received. The authors confirm that they have followed EU standards for the protection of animals used for scientific purposes.

CRediT authorship contribution statement

Azra Bamedi: Investigation, Data curation. **Somayyeh Salari:** Writing – review & editing, Supervision, Investigation, Conceptualization. **Farshad Baghban:** Software, Methodology.

Declaration of competing interest

The authors declare no conflict of interest.

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