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Growth Performance, Intestinal Morphology, Cecal Microbiota Community and Ileal Nutrient Utilization of Broiler Chickens Fed Diet Containing Fermented Sesame Meal Using a Mixture of *Bacillus subtilis*, *Lactobacillus Plantarum* and *Aspergillus Niger*

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Abstract

This study aimed to investigate the efficacy of fermented sesame meal (FSM) utilizing a blend of *Bacillus subtilis*, *Lactobacillus plantarum* and *Aspergillus niger* compared to phytase supplementation on growth traits, jejunal morphology, cecal microbiota activity, and apparent digestibility of nutrients in broiler chickens. A total of 525-day-old male broiler chicks were randomly allocated to seven treatments. Each treatment had five replicate pens of 15 birds in each. The experimental treatments comprised a corn-soybean meal diet (control), a control diet supplemented with 6% or 12% of untreated sesame meal (USM), 6% or 12% of FSM, and 6% or 12% of USM with phytase supplementation. From 1 to 42 days of age, the feed conversion ratio improved in broilers fed diets containing 6 and 12% FSM and USM+phytase ($P < 0.05$). In the jejunum, morphological indices, the highest villus length, villus width, the ratio of villus length to crypt depth, and villus surface area were observed in broilers that received 6% FSM diet ($P < 0.05$). In terms of the cecal microbial population, the viable cell counts of *Lactobacillus* and aerobic total bacteria increased, and the population of *E. coli* decreased in broilers fed with a diet containing 6% FSM ($P < 0.05$). Ileal digestibility of ether extract decreased in broilers fed with a diet containing 12% USM, while crude protein digestibility increased in control and 12% FSM groups ($P < 0.05$). In summary, utilizing FSM or USM+phytase demonstrated improvement in the feed conversion ratio of broilers. Besides, jejunum villi enhancement, increased nutrient digestibility, and an improvement in the cecal microbiota activity were observed in broilers fed with diets containing FSM.

Introduction

Dietary protein stands as a pivotal factor influencing the feed efficiency of broiler chickens, with the protein content in their diets predominantly sourced from plant protein, particularly oilseed meals, whose compositions are influenced by oil extraction processes. Soybean meal is acknowledged as a standard protein source (Wiryawan and Dingle, 1998). However, the elevated cost of soybean meal, comprising 70 to 80 percent of the overall expenses in broiler husbandry, necessitates the exploration of alternative, economically viable protein sources of adequate quality (Khan, 2018). The quest for new sources of plant protein to replace soybean meal is imperative for nutritionists (Rahimian *et al.*, 2013). Sesame (*Sesamum indicum*) is one of the most important plants that is cultivated in tropical regions and parts of Iran (Rezaeipour *et al.*, 2016). This plant emerges as a resilient product, resistant to drought and adaptable to various soil types (Ram *et al.*, 1990). It has been reported that Sesame seeds contain 45 to 50% oil, 15 to 20% protein, and 10 to 15 % crude fiber (Yamauchi *et al.*, 2006). The sesame meal is a valuable byproduct after oil extraction from the seeds (Al Harthi and El Deek, 2009). It is well indicated that sesame meal contains essential amino acids, notably arginine, lysine, and methionine, with amino acid composition comparable to soybean meal (Rezaeipour *et al.*, 2016). Despite exhibiting higher levels of sulfuric amino acids such as methionine and cystine, it contains a lower quantity of lysine than soybean meal (Shanti *et al.*, 2012). In regions where

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sesame meal is economically viable and accessible, it represents a feasible alternative as a plant protein replacement for soybean meal in broiler chicken diets (Mamputu and Buhr, 1995).

However, the utilization of sesame meal faces constraints due to factors such as tannins and phytic acid, particularly in young birds (Rezaeipour *et al.,* 2016). Studies have demonstrated that the incorporation of processed sesame meal in the diet optimizes growth performance in broiler chickens (Al Harthi and El Deek, 2009; Hajimohammadi *et al.,* 2020). Microbial fermentation methods have been explored for producing high-quality protein products devoid of anti-nutritional compounds (Zengin *et al.,* 2022; Singhania *et al.,* 2009; Ashayerizadeh *et al.,* 2018). This method involves the utilization of bacterial species, including *Enterococcus fascium* and *Bacillus subtilis* (Mazaheri *et al.,* 2018), and fungal species such as *Aspergillus Niger* and *Aspergillus Oriza*, for fermentation purposes (Niba *et al.,* 2009). It has been demonstrated that the inclusion of sesame meal in the starter phase of broiler feeding is limited due to its high phytate and oxalate content (Ravindran, 1995). However, the reduction of anti-nutritional factors such as phytic acid, trypsin inhibitor or tannins in fermented sesame meal by Bacterial fermentation was observed (Hajimohammadi *et al.,* 2020). Addressing phosphorus utilization and reducing its excretion in feces is an important concern in the poultry industry, and the supplementation of phytase in feed emerges as an effective solution (Cowieson *et al.,* 2016). Research has indicated that the addition of phytase supplements to broiler chicken diets releases phosphorus bonds, thereby improving nutrient utilization, including energy, protein, and amino acids (Selle and Ravindran, 2007). On the other hand, the inclusion of phytase enzymes enhances the bioavailability of essential nutrients, including starch, protein, amino acids, and minerals.

The objective of this study was to investigate fermented sesame meal using a mixture of bacteria and fungi species in comparison with phytase supplementation concerning growth performance, intestinal morphology, microbial population, and nutrient intake in broiler chickens.

Materials and methods

The experiment was conducted at a research farm in the northern region of Iran, Sari city. All experimental procedures adhered to the guidelines of the Animal Care and Use Committee of the Department of Animal Science, Qaemshahr Branch, Islamic Azad University.

Table 1. Ingredients and chemical composition of experimental diets (1-10 d)

Feed ingredients (%)	Control	USM[1]	USM	FSM[2]	FSM	PSM[3]	PSM
Corn grain	53.94	53.57	54.15	53.63	54.19	53.52	54.10
Soybean meal (43.01%)	39.10	33.53	27.04	33.48	27.00	33.53	27.04
Sesame meal (42.31%)	-	6.00	12.00	-	-	6.00	12.00
Fermented Sesame meal (42.97%)	-	-	-	6.00	12.00	-	-
Phytase enzyme	-	-	-	-	-	0.05	0.05
Di calcium phosphate	1.77	1.76	1.76	1.75	1.75	1.76	1.76
Calcium carbonate	0.20	0.20	0.32	0.20	0.32	0.20	0.32
Oyster shells	1.21	0.95	0.67	0.95	0.67	0.95	0.67
Vitamin supplement[*]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral supplement[**]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.27	0.23	0.19	0.22	0.19	0.23	0.19
L-Lysine	0.37	0.46	0.58	0.46	0.58	0.46	0.58
L-Threonine	0.04	0.04	0.07	0.04	0.07	0.04	0.07
Common salt	0.38	0.38	0.30	0.38	0.30	0.38	0.30
Soybean oil	2.22	2.38	2.42	2.39	2.43	2.38	2.42
Chemical composition (calculated)							
AMEn (kcal/kg)	2980.0	2980.0	2980.0	2980.0	2980.0	2980.0	2980.0
Crude protein (%)	22.90	22.90	22.90	22.90	22.90	22.90	22.90
Calcium (%)	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Available phosphorus (%)	0.48	0.48	0.46	0.48	0.46	0.48	0.46
Sodium (%)	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Methionine (%)	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Threonine (%)	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Lysine (%)	1.43	1.43	1.43	1.43	1.43	1.43	1.43
DEB (mEq/kg)	247.69	231.85	224.58	231.85	224.58	231.85	224.58

[*]Provides per kilogram of diet: 9,000 IU vitamin A; 2,000 IU vitamin D_3; 18 IU vitamin E; 2 mg Menadion; 1.8 mg thiamine; 6.6 mg riboflavin; 30 mg niacin; 3 mg pyridoxine; 15 µg vitamin B_{12}; 100 mg D-pantothenic acid; 1 mg folic acid; 0.1 mg biotin; 500 mg choline chloride; and 100 mg antioxidant. [**]Provides per kilogram of diet: 100 mg Mn; 84.7 mg Zn; 50 mg Fe; 10 mg Cu; 1 mg I; and 0.2 mg Se. [1] USM = control diet+ untreated sesame meal, [2] FSM = control diet+ fermented sesame meal, [3] PSM = control diet+ (untreated sesame meal + Phytase)

Birds and diets

A total of 525 one-day-old male broiler chicks of the Ross strain were randomly distributed into seven treatments. Each treatment had five replicate pens of 15 broiler chickens per each. The dietary treatments were a corn-soybean meal diet (control), a control diet supplemented with 60 g/kg or 120 g/kg of untreated sesame meal (USM), 60 g/kg or 120 g/kg of fermented sesame meal (FSM), and 60 g/kg or 120 g/kg of USM with phytase supplementation.

The experimental diets were prepared for three periods: starter (1 to 10 days old, Table 1), grower (11 to 29 days old, Table 2), and finisher (25 to 42 days old, Table 3) according to the recommendations for the commercial strain of Ross 308 (Aviagen, 2019).

Table 2. Ingredients and chemical composition of experimental diets (11-24 d)

Feed ingredients (%)	Control	USM[1]	USM	FSM[2]	FSM	PSM[3]	PSM
Corn grain	57.29	56.48	57.87	56.56	57.93	56.43	57.82
Soybean meal (43.01%)	35.42	29.85	22.06	29.80	23.00	29.85	22.06
Sesame meal (42.31%)	-	6.00	12.00	-	-	6.00	12.00
Fermented Sesame meal (42.97%)	-	-	-	6.00	12.00	-	-
Phytase enzyme	-	-	-	-	-	0.05	0.05
Di calcium phosphate	1.54	1.52	1.52	1.51	1.51	1.52	1.52
Calcium carbonate	0.20	0.28	0.29	0.28	0.29	0.28	0.29
Oyster shells	1.12	1.10	0.58	1.10	0.58	1.10	0.58
Vitamin supplement*	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral supplement**	0.25	0.25	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.23	0.19	0.15	0.19	0.15	0.19	0.15
L-Lysine	0.29	0.38	0.51	0.38	0.51	0.38	0.51
L-Threonine	0.01	0.01	0.04	0.01	0.04	0.01	0.04
Common salt	0.36	0.30	0.30	0.30	0.30	0.30	0.30
Soybean oil	3.04	3.39	3.18	3.37	3.19	3.39	3.18
Chemical composition (calculated)							
AMEn (kcal/kg)	3070.0	3070.0	3070.0	3070.0	2980.0	3070.0	2980.0
Crude protein (%)	21.40	21.40	21.40	21.40	21.40	21.40	21.40
Calcium (%)	0.76	0.95	0.86	0.95	0.86	0.95	0.86
Available phosphorus (%)	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Sodium (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Methionine (%)	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Threonine (%)	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Lysine (%)	1.28	1.28	1.28	1.28	1.28	1.28	1.28
DEB (mEq/kg)	235.41	229.45	206.51	229.45	206.51	229.45	206.51

*Provides per kilogram of diet: 9,000 IU vitamin A; 2,000 IU vitamin D_3; 18 IU vitamin E; 2 mg Menadion; 1.8 mg thiamine; 6.6 mg riboflavin; 30 mg niacin; 3 mg pyridoxine; 15 µg vitamin B_{12}; 100 mg D-pantothenic acid; 1 mg folic acid; 0.1 mg biotin; 500 mg choline chloride; and 100 mg antioxidant. **Provides per kilogram of diet: 100 mg Mn; 84.7 mg Zn; 50 mg Fe; 10 mg Cu; 1 mg I; and 0.2 mg Se. [1] USM = control diet+ untreated sesame meal, [2] FSM = control diet+ fermented sesame meal, [3] PSM = control diet+ (untreated sesame meal + Phytase)

The sesame meal used in this experiment was obtained from an oiling factory located in Joybar Industrial Park in Mazandaran province, Iran. For sesame meal fermentation, two types of bacteria, including *Lactobacillus Plantarom* (PTCC1058) and *Bacillus Subtilis* (PTCC1156), in combination with *Aspergillus Niger* fungus (PTCC5010) in lyophilized vials were purchased from the Iran Industrial and Science Research Organization. These were activated using MRS-agar and Nutrient-agar environments at 37°C. Primer culture preparation for these bacteria and fungus was performed using MRS-broth and PDA environments at 37 and 25°C. Subsequently, 1200 mL of distilled water and primer culture (containing at least 10 colony formation units per ml) were added to each kg of sesame meal. The resulting mixture was fermented inside a specific tank (equipped with a one-way valve for gas release and air hindrance) for 25 days at a temperature of 30 °C. Finally, the fermented sesame meal was dried for 3 days at 50°C, following the method described by Ashayerizadeh *et al.* (2018). The phytase enzyme used in this trial was a commercial microbial phytase (Meriphyze 5000®, Meriden Animal Health, UK), 100 g/1000 kg of the diet.

Growth performance

To evaluate growth performance, the amount of feed intake and body weight gain of broiler chickens were recorded in each replicate at the starter (1-10 d), grower (11-24 d), finisher (24-42 d) and total (1-42 d) phases. The obtained data were corrected for mortality body weights in the experiment. In addition, to calculate the feed conversion ratio in each replicate pen, the feed intake was divided by the weight gain.

Table 3. Ingredients and chemical composition of experimental diets (25-42 d)

Feed ingredients (%)	Control	USM[1]	USM	FSM[2]	FSM	PSM[3]	PSM
Corn grain	62.24	62.60	62.75	62.65	62.79	62.55	62.70
Soybean meal (43.01%)	30.02	23.79	17.76	23.74	17.72	23.79	17.76
Sesame meal (42.31%)	-	6.00	12.00	-	-	6.00	12.00
Fermented Sesame meal (42.97%)	-	-	-	6.00	12.00	-	-
Phytase enzyme	-	-	-	-	-	0.05	0.05
Di calcium phosphate	1.42	1.41	1.40	1.40	1.39	1.41	1.40
Calcium carbonate	0.20	0.22	0.22	0.22	0.22	0.22	0.22
Oyster shells	1.01	0.74	0.47	0.74	0.47	0.74	0.47
Vitamin supplement*	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral supplement**	0.25	0.25	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.21	0.18	0.14	0.18	0.14	0.18	0.14
L-Lysine	0.29	0.40	0.50	0.40	0.50	0.40	0.50
L-Threonine	-	0.01	0.02	0.01	0.02	0.01	0.02
Common salt	0.31	0.30	0.30	0.30	0.30	0.30	0.30
Soybean oil	3.80	3.85	3.94	3.86	3.95	3.85	3.94
Chemical composition (calculated)							
AMEn (kcal/kg)	3170.0	3170.0	3170.0	3170.0	3170.0	3170.0	3170.0
Crude protein (%)	19.30	19.30	19.30	19.30	19.30	19.30	19.30
Calcium (%)	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Available phosphorus (%)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sodium (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Methionine (%)	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Threonine (%)	0.779	0.77	0.77	0.77	0.77	0.77	0.77
Lysine (%)	1.15	1.15	1.15	1.15	1.15	1.15	1.15
DEB (mEq/kg)	211.34	193.27	174.79	193.27	174.79	193.27	174.79

*Provides per kilogram of diet: 9,000 IU vitamin A; 2,000 IU vitamin D_3; 18 IU vitamin E; 2 mg Menadion; 1.8 mg thiamine; 6.6 mg riboflavin; 30 mg niacin; 3 mg pyridoxine; 15 µg vitamin B_{12}; 100 mg D-pantothenic acid; 1 mg folic acid; 0.1 mg biotin; 500 mg choline chloride; and 100 mg antioxidant. **Provides per kilogram of diet: 100 mg Mn; 84.7 mg Zn; 50 mg Fe; 10 mg Cu; 1 mg I; and 0.2 mg Se, [1] USM = control diet+ untreated sesame meal, [2] FSM = control diet+ fermented sesame meal, [3] PSM = control diet+ (untreated sesame meal + Phytase)

Jejunum morphology

At the end of the experiment, two broiler chickens per pen with weights close to the average of the experimental unit were weighed and then killed by cervical dislocation. To investigate jejunum morphology, approximately 3 cm of its middle part was selected, washed with distilled water, and fixed in a 10% (vol/vol) neutral buffered formalin solution. Cross sections were prepared with a thickness of 5 microns and stained using the Hematoxylin Eosin method. From each section, three tissue samples were prepared, and the villus width, villus length, crypt depth and the villus length to crypt depth ratio in each section of the jejunum were measured using an optical microscope (TE Nikon 300, Japan). In the present study, the villus surface area was also calculated using the following formula (Sakamoto *et al.*, 2000):

$$VSR = (2\pi) \times (VW/2) \times (VL)$$

Where:

VSR=villus surface area, VW=villus width and VL=villus length.

Microbial population

For the enumeration of cecal bacteria, two broiler chickens per pen were slaughtered at the end of the experiment. Caecal digesta (3 gr) from each broiler was collected in a sterile tube for the enumeration of the microbial population. Then, 1 gr per sample was transferred into 9 mL sterile physiological saline solution (NaCl 85%) and was serially diluted from 10^{-1} to 10^{-7}. Subsequently, 0.1 mL of each dilution suspension was plated onto the appropriate media. Mac Conkey agar (Merck, Darmstadt, Germany) was used for *E. coli* enumeration after incubation at 37°C for 24 h. *Lactobacilli* bacteria were cultured on de Man, Rogosa, and Sharpe agar (Merck, Darmstadt, Germany) after incubation for 48–72 h at 37°C. The number of colonies was measured and multiplied by the dilution factor. In the end, the logarithm of the colony count per unit weight was calculated.

Nutrient utilization

At the end of this experiment, the nutrient digestibility including dry matter, crude protein, and ether extract, were assessed using the sampling method from the ileal contents of broiler chickens. Briefly, on day 35, two broiler chickens were selected from each experimental unit (10 chickens per treatment), and they were transferred to the experimental cages for digestibility assessment. To determine the digestibility coefficients, a chromium oxide marker was used at a rate of 3 gr per kg in the experimental diets, and these diets were provided to the birds from day 35 to 42. At the end of this period, all birds were slaughtered using cervical dislocation.

In the next step, the contents of the ileum were gently collected in sterile containers and placed in an oven at 55 degrees Celsius for 48 hours for drying. The amount of dry matter, crude protein, and ether extract in feed and ileal samples was measured using AOAC (2002) methods. According to these methods, the amount of crude protein and ether extract in the samples were measured using the Kjeldahl method and the Soxhlet apparatus, respectively. The concentration of chromium oxide in ileal samples was measured using the Fenton and Fenton (1979) method. Apparent ileal digestibility coefficients were calculated using the following equation:

D (%) = 100 − (100 × (A⁄B) × (C⁄E))

where D = Digestibility, A = chromium oxide in feed (%), B=chromium oxide in ileal digesta (%), C = nutrient concentration in ileal digesta (%), E = nutrient concentration in feed (%).

Statistical analysis

Based on the completely randomized design, the data were statistically analyzed using the General Linear Model (GLM) procedure with SAS software (2003). The statistical model used was as follows:

$y_{ij}=\mu+A_i+e_{ij}$

Where Y_{ij} is the observation, μ is the overall mean, A_i is the treatment effect, and e_{ii} is the experimental error. Mean comparisons were conducted using the Tukey test at a significance level of 0.05.

Results

The dry matter content ranged from 91.2% in fermented sesame meal (FSM) to 93.55% in soybean meal (SBM), with untreated sesame meal (USM) at an intermediate value (Table 1). SBM exhibited the highest crude protein content at 43.01%, followed by FSM at 42.97% and USM at 38.03%. The pH levels varied, with SBM being slightly acidic (pH 5.98), USM neutral (pH 6.12), and FSM notably acidic (pH 4.15). In terms of fiber content, SBM showed the lowest crude fiber percentage at 4.79%, while both FSM and USM had higher values. Phytic acid content was highest in USM (3.58%) compared to SBM (0.47%) and FSM (2.53%). Microbial analysis revealed the absence of *Lactobacillus* in SBM and USM, while FSM exhibited a substantial count of 1×10^6cfu/g. Total bacterial counts were notably higher in FSM (1×10^8cfu/g) compared to SBM and USM (1×10^2cfu/g each). These findings highlight the variations in nutrient composition and microbial content among these ingredients, emphasizing the potential impact of fermentation on the nutritional profile of sesame meal.

Table 4. Nutrient composition of soybean meal (SBM), untreated sesame meal (USM) and fermented sesame meal (FSM)

Items	Treatments		
	SBM	USM	FSM
DM (%)	93.55	92.17	91.2
CP (%)	43.01	42.31	42.97
pH	5.98	6.12	4.15
CF (%)	4.79	6.89	5.92
EE (%)	2.73	8.13	8.96
Ash (%)	7.45	9.24	9.03
NFE (%)	42.02	33.43	33.12
AME_n (Kcal/kg)	2459	2136	2132
Phytic acid (%)	0.47	3.58	2.53
Lactobacillus (cfu/g)	-	-	1×10^6
Total bacteria (cfu/g)	1×10^2	1×10^2	1×10^8

DM: dry matter; CP: crude protein; CF: crude fiber; EE: ether extract; NFE: nitrogen-free extract; The apparent metabolizable energy corrected to zero N-retention (AMEn) of the samples was estimated according to the equation proposed by the World's Poultry Science Association.

The results of the efficacy of dietary treatments on the growth performance of broiler chickens are presented in Table 5. The findings indicated that the effect of experimental treatments on feed consumption during all raising periods was not statistically significant. However, the findings indicate a significant difference in body weight gain at the starter (1-10 days old) and grower (11-24 days old) phases ($P < 0.05$). During the starter phase, the treatment containing 6% USM + phytase enzyme exhibited the highest weight gain, while the treatment containing 6% USM showed the lowest value. In the grower phase, the treatment containing 12% FSM exhibited the highest weight gain, while the treatment containing 6% FSM showed the lowest value. The results of the feed conversion ratio indicated a significant difference during the starter (1-10 d), grower (11-24 d), and throughout the experiment (1-42 d) among the experimental treatments ($P < 0.05$). Using FSM and USM+phytase supplementation led to a lower feed conversion ratio than other treatments.

Table 5. Effects of experimental treatments on body weight gain (BWG), feed intake (FI) and feed conversion ratio (FCR) in broiler chickens

Treatment	1-10 d			11-24 d		
	BWG (g/bird)	FI (g/bird)	FCR	BWG (g/bird)	FI (g/bird)	FCR
Control	160.2^{ab}	219.4	1.37^{ab}	668.8^{ab}	996.2	1.49^{ab}
USM (6%)	156.8^{b}	222.0	1.42^{a}	688.4^{ab}	1035.0	1.50^{ab}
USM (12%)	160.6^{ab}	214.6	1.33^{b}	649.2^{b}	991.8	1.53^{a}
FSM (6%)	165.6^{b}	222.0	1.34^{b}	693.2^{ab}	1007.4	1.45^{b}
FSM (12%)	167.8^{ab}	221.2	1.32^{b}	718.8^{a}	1041.0	1.45^{b}
PSM (6%)	170.4^{a}	222.0	1.30^{b}	688.8^{ab}	1004.4	1.46^{b}
PSM (12%)	168.4^{ab}	227.0	1.35^{ab}	703.6^{ab}	1040.4	1.48^{ab}
P-value	0.02	0.39	0.001	0.06	0.34	0.003
SEM	2.51	3.01	0.01	12.85	16.77	0.01

Treatment	25-42 d			1-42 d		
	BWG (g/bird)	FI (g/bird)	FCR	BWG (g/bird)	FI (g/bird)	FCR
Control	1682.0	3168.8	1.89	2459.8	4384.4	1.79^{ab}
USM (6%)	1589.6	3037.0	1.91	2368.0	4294.0	1.81^{a}
USM (12%)	1620.4	3041.4	1.88	2349.8	4247.8	1.81^{a}
FSM (6%)	1675.6	3096.8	1.85	2484.0	4326.2	1.74^{b}
FSM (12%)	1611.8	2963.9	1.84	2419.0	4226.0	1.75^{b}
PSM (6%)	1706.4	3122.7	1.83	2502.0	4349.2	1.74^{b}
PSM (12%)	1647.6	3059.2	1.85	2410.0	4326.6	1.79^{ab}
P-value	0.39	0.31	0.10	0.09	0.70	0.0005
SEM	34.36	50.62	0.02	33.85	59.37	0.01

Means not sharing the same superscripts in each column are significantly different ($P < 0.05$). *SEM*: standard error of the means, USM = control diet+ untreated sesame meal, FSM = control diet+ fermented sesame meal, PSM = control diet+ (untreated sesame meal + Phytase), Data represent the mean of 5 replicate pens.

Jejunum morphology results among broiler chickens are presented in Table 6. The findings indicate a significant difference in villus length and width, the ratio of villus length to crypt depth, and villus area among the experimental treatments ($P < 0.05$). The treatment with 6% FSM showed higher values for length, width, area, and the ratio of villus length to crypt depth compared to other treatments.

Table 6. Effects of experimental treatments on jejunal morphometric indices in broiler chickens

Treatment	Jejunum morphology				
	VL (µm)	VW (µm)	CD (µm)	VL/CD	VSA (mm^2)
Control	1092.8^{abc}	154.00^{ab}	179.60	6.09^{ab}	0.528^{abc}
USM (6%)	983.6^{c}	149.99^{ab}	193.39	5.19^{b}	0.460^{bc}
USM (12%)	999.8^{bc}	133.04^{b}	185.62	5.39^{ab}	0.418^{c}
FSM (6%)	1147.4^{a}	176.22^{a}	176.30	6.52^{a}	0.636^{a}
FSM (12%)	1137.2^{ab}	154.40^{ab}	182.40	6.24^{ab}	0.548^{abc}
PSM (6%)	1116.8^{abc}	162.10^{ab}	181.92	6.14^{ab}	0.570^{ab}
PSM (12%)	1044.6^{abc}	150.68^{ab}	183.56	5.74^{ab}	0.492^{bc}
P-value	0.004	0.01	0.66	0.01	0.0003
SEM	27.55	6.12	5.51	0.23	0.02

Means not sharing the same superscripts in each column are significantly different ($P < 0.05$). *SEM*: standard error of the means, USM = control diet+ untreated sesame meal, FSM = control diet+ fermented sesame meal, PSM = control diet+ (untreated sesame meal + Phytase), VL: villus length; VW: villus width; CD: crypt depth; VSA: villus surface area.

Broiler chicken cecum microbial population results are presented in Table 7. The findings indicate a significant difference in *Escherichia coli* bacteria, *Lactobacillus*, and total aerobic bacteria among the experimental treatments ($P < 0.05$). The lowest population of *Escherichia coli* bacteria was observed in the treatment containing 6% FSM, while the highest population of *Lactobacillus* bacteria was in the treatment containing 12% FSM, and the highest population of total aerobic bacteria was in the treatment containing 6% fermented sesame meal.

Table 7. Effects of experimental treatments on caecal microbial counts (log CFU/g digesta) in broiler chickens

Treatment	Microbial population		
	Total count	*Lactobacillus*	*E. Coli*
Control	6.37^{ab}	4.19^{d}	3.23^{c}
USM (6%)	6.30^{ab}	4.10^{d}	3.56^{b}
USM (12%)	6.12^{ab}	4.03^{d}	3.82^{a}
FSM (6%)	6.43^{a}	5.98^{a}	3.07^{d}
FSM (12%)	6.29^{ab}	5.57^{b}	3.16^{cd}
PSM (6%)	6.32^{ab}	4.54^{c}	3.16^{cd}
PSM (12%)	6.08^{b}	4.14^{d}	3.22^{c}
P-value	0.02	<.0001	<.0001
SEM	0.06	0.04	0.03

Means not sharing the same superscripts in each column are significantly different ($P < 0.05$). *SEM*: standard error of the means, USM = control diet+ untreated sesame meal, FSM = control diet+ fermented sesame meal, PSM = control diet+ (untreated sesame meal + Phytase)

Nutrient digestibility results are presented in Table 8. The findings indicate a significant difference in ether extract and crude protein among the experimental treatments ($P < 0.05$). The control treatment and the treatment containing 6% and 12% FSM showed the highest digestibility of ether extract and crude protein, while the lowest digestibility was observed in the treatment containing 12% USM.

Table 8. Effects of experimental treatments on the ileal digestibility coefficients of dry matter (DM), ether extract (EE) and crude protein (CP) in broiler chickens.

Treatment	Items (%)		
	Dry matter	Ether extract	Crude protein
Control	74.15	75.58^{a}	67.70^{a}
USM (6%)	71.27	65.82^{bc}	62.31^{c}
USM (12%)	71.03	63.90c	62.24^{c}
FSM (6%)	73.43	73.61^{a}	65.79^{abc}
FSM (12%)	73.81	72.20^{a}	66.77^{a}
PSM (6%)	73.15	72.66^{a}	65.89^{ab}
PSM (12%)	71.06	70.54^{ab}	62.75^{bc}
P-value	0.02	<.0001	<.0001
SEM	0.68	0.98	0.65

Means not sharing the same superscripts in each column are significantly different ($P < 0.05$). *SEM*: standard error of the means, USM = control diet+ untreated sesame meal, FSM = control diet+ fermented sesame meal, PSM = control diet+ (untreated sesame meal + Phytase)

Discussion

The feed intake results in this study align with those reported by other researchers. No significant impact of sesame meal on broiler chicken feed intake has been noted (Barsalani and Rezaeipour, 2017), similar to the lack of effect observed with phytase enzyme in Japanese quail (Sacakli *et al.*, 2005). Another study on broiler chickens with different levels of FSM showed no significant difference in feed intake (Hajimohammadi *et al.*, 2020). Mamputu and Buhr (1995) reported no significant difference between chickens fed a soybean meal diet and those fed a diet with 38% sesame meal, consistent with the results of Rahimian *et al.* (2013).

The absence of a significant difference in feed intake across treatments throughout the raising period in this study may be attributed to the consistent energy, protein, and nutrient levels in the diets. The uniform energy intake by the birds may have played a crucial role, as feed intake is often unaffected when the energy supply is consistent across different treatments. In contrast to the present study, improved feed intake has been observed due to phytase enzyme consumption in Japanese quails (Rezaeipour *et al.*, 2016), indicating that the response to dietary factors can vary.

The body weight results suggested that adding phytase enzyme to the USM diet in the starter phase and using FSM in the grower phase contributed to improved body weight gain. These results are in parallel with the findings of Hajimohammadi *et al.* (2020), who reported higher body weights in broiler chickens consuming FSM during the grower and finishing periods. Feng *et al.* (2007a) reported improved broiler chicken weight gain by replacing fermented soybean with raw soybean meal. Similarly, the replacement of fermented cottonseed meal with soybean meal resulted in significant weight gain in broiler chickens compared to the control group (Sun *et al.*, 2012). The enhancement of broiler chicken

weight gain with sesame meal consumption, especially when supplemented with enzymes, may be attributed to the role of phytase in optimizing available phosphorus utilization, nutrient digestibility, and amino acid bioavailability (Sebastian *et al.,* 1996). Phytase supplementation has been shown to improve Japanese quail weight gain by increasing mineral diffusion from phytate and enhancing nutrient digestibility (Saima *et al.,* 2014). The varying responses observed in different studies may be influenced by factors such as sesame meal level and quality, processing methods, bird age, and feed-related variables, including the calcium-to-phosphorus ratio and enzyme source (Ravindran *et al.,* 1995; Angel *et al.,* 2002).

These results are consistent with previous studies reporting a lower feed conversion ratio in broiler chickens consuming diets containing FSM or phytase enzyme compared to those containing SBM (Hajimohammadi *et al.,* 2020). The increase in feed conversion ratio among chickens consuming untreated sesame meal may be attributed to the high fat and crude fiber content of USM, affecting digestion rate. On the other hand, the high fiber content may intensify the effects of these factors. The improvement in feed conversion ratio among chickens consuming sesame meal may be related to the role of methionine in sesame meal. In a study, fermented canola meal in broiler chicken diets significantly improved feed conversion coefficients (Chiang *et al.,* 2009). The increase in nutrient conversion ratio among broiler chickens fed FSM compared to USM may be due to the decrease in phytic acid levels during microbial fermentation, increased digestibility of essential amino acids and other beneficial nutrients (such as small peptides), and the richness of fermented meal in lactic acid bacteria, which decreases the pH of the digestive system (Olude *et al.,* 2016; Sun *et al.,* 2012; Paton *et al.,* 2006). Several studies demonstrated the beneficial effects of phytase enzyme on the nutrient digestibility in broiler chickens which received diets containing sesame meal (Saima *et al.,* 2014; Shanti *et al.,* 2012).

These results align with several studies demonstrating improved duodenal villus height and the ratio of villus height to crypt depth in broiler chickens fed fermented soybean meal (Feng *et al.,* 2007b) and fermented cotton meal (Sun *et al.,* 2013). Both studies reported positive effects of fermented canola meal on duodenal villus height increase and the ratio of villus height to crypt depth in broiler chickens (Chiang *et al.,* 2009; Hu *et al.,* 2016). Researchers have emphasized that villus height, crypt depth, and the ratio of villus height to crypt depth are crucial indices for studying the level of digestibility and intestinal utilization. An increase in villus height enhances the capacity for digestibility and nutrient supply to the crypt depth in line with broiler chicken requirements (Shamoto *et al.,* 1999). The improvement in intestine morphology observed in this study may be attributed to the increase in *Lactobacillus* population in the digestive system through the production of specific compounds, such as bacteriocins or short-chain fatty acids, during FSM intake (Jazi *et al.,* 2017). Additionally, the decrease in phytic acid levels and anti-nutritional compounds during the fermentation process of sesame meal may contribute to the observed improvement (Yamauchi *et al.,* 2006).

The study results demonstrate that the intake of fermented sesame meal led to an increase in the population of beneficial bacteria and a decrease in the level of harmful bacteria in the broiler chicken cecum. The replacement of fermented soybean meal with normal soybean meal has been shown to increase the population of lactic acid bacteria and decrease the total population of forms in the ileum. Jazi *et al.* (2017) reported a significant decrease in the total population of forms in the ileum with the replacement of 10% and 20% of fermented cottonseed meal with soybean in broiler chicken diets. Engberg *et al.* (2009) stated that feeding laying chickens with fermented meal increased lactic bacteria in layers and decreased the total population of form bacteria in the ileum. Fermented feed, with its unique features (high concentration of lactic acid and lactic acid bacteria), can create a balance in the digestive system and microbial flora. Such feeds acidify the upper part of the digestive system, maintaining health while providing a suitable environment for the growth and establishment of beneficial bacteria, such as lactic acid bacteria (Paton *et al.,* 2006).

Consistent with these findings, Shi *et al.* (2017) reported that dry matter and crude protein digestibility in pigs fed a diet containing fermented canola meal improved compared to the control group and the group fed with raw canola meal. They attributed this improvement to the decrease in anti-nutritional compounds during the fermentation period. Protein digestibility in diets containing fermented canola meal was higher than that in diets containing raw canola meal in broiler chickens (Ahmed *et al.,* 2014). Hong *et al.* (2004) showed that feed fermentation increased digestibility and facilitated protein dissipation by removing anti-nutritional factors, decomposing proteins, and forming peptides and amino acids. Chiang *et al.* (2009) stated that fermented feeds improved intestinal epithelium structure by decreasing the population of harmful microbes in the digestive system, leading to increased nutrient digestibility. Oilseed meal is a rich source of carbon and nitrogen, and their use as substrates and the bed for microbial fermentation promotes the growth of microorganisms and their

enzyme production. Therefore, the increase in nutrient digestibility may be attributed to the enzymes produced by microorganisms in the fermentation bed (Sun *et al.*, 2013). Feed fermentation has been shown to enhance microbial activity, increasing digestibility by reducing the level of dietary fibers during fermentation (Sugiharto and Ranjitikar, 2019).

Conclusion

In summary, the results of this study indicated that the inclusion of FSM and phytase enzyme in broiler chicken diets has positive effects on various performance indices, intestinal morphology, cecum microbial population, and nutrient digestibility. The findings contribute valuable insights into the potential benefits of incorporating FSM and enzyme supplementation in broiler chicken nutrition. Further research and exploration of specific mechanisms underlying these effects, as well as potential variations based on factors such as sesame meal quality and processing methods, are warranted for a comprehensive understanding of the implications for broiler nutrition.

Declaration and competing of interests

The authors declare that they have no conflict of interest.

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References

Ahmed A, Zulkifli I, Farjam AS, Abdullah N, Liang JB & Awad EA. 2014. Effect of solid-state fermentation on nutrient content and ileal amino acids digestibility of canola meal in broiler chickens. Italian Journal of Animal Science, 13(2): 3293. DOI: 10.4081/ijas.2014.3293

Al Harthi MA & El Deek AA. 2009. Evaluation of sesame meal replacement in broiler diets with phytase and probiotic supplementation. Egyptian Poultry Science Journal, 29: 99-125.

Angel R, Tamim NM, Applegate TJ, Dhandu AS & Ellestad LE. 2002. Phytic acid chemistry: influence on phytin-phosphorus availability and phytase efficacy. Journal of Applied Poultry Research, 11(4): 471-480. DOI: 10.1093/japr/11.4.471

Barsalani A & Rezaeipour V. 2017. Effects of different dietary protein and sesame meal levels supplemented with phytase on performance, carcass traits and blood parameters of Japanese quails. Animal Science Journal, 114: 157-168. DOI: 10.22092/asj.2017.111319

Ashayerizadeh A, Dastar B, Shargh MS, Mahoonak AS & Zerehdaran S. 2018. Effects of feeding fermented rapeseed meal on growth performance, gastrointestinal microflora population, blood metabolites, meat quality, and lipid metabolism in broiler chickens. Livestock Science, 216: 183-190. DOI: 10.1016/j.livsci.2018.08.012

Chiang G, Lu WQ, Piao XS, Hu JK, Gong LM & Thacker PA. 2009. Effects of feeding solid-state fermented rapeseed meal on performance, nutrient digestibility, intestinal ecology and intestinal morphology of broiler chickens. Asian-Australasian Journal of Animal Sciences, 23(2): 263-271. DOI: 10.5713/ajas.2010.90145

Cowieson AJ, Lu H, Ajuwon KM, Knap I & Adeola O. 2016. Interactive effects of dietary protein source and exogenous protease on growth performance, immune competence and jejunal health of broiler chickens. Animal Production Science, 57(2): 252-261. DOI: 10.1071/AN15523

Engberg RM, Hammersh j, Johansen NF, Abousekken MS, Steenfeldt S & Jensen BB. 2009. Fermented feed for laying hens: effects on egg production, egg quality, plumage condition and composition and activity of the intestinal microflora. British Poultry Science, 50(2): 228-239. DOI: 10.1080/00071660902736722

Feng J, Liu X, Xu ZR, Liu YY, &Lu YP. 2007a. Effects of Aspergillus oryzae fermented soybean meal on growth performance and plasma biochemical parameters in broilers. Animal Feed Science and Technology, 134(3-4): 235-242. DOI: 10.1016/j.anifeedsci.2006.08.018

Feng J, Liu X, Xu ZR, Liu YY, & Lu YP. 2007b. Effects of fermented soybean meal on digestive enzyme activities and intestinal morphology in broilers. Poultry Science, 86(6): 1149-1154. DOI: 10.1093/ps/86.6.1149

Fenton TW & Fenton M. 1979. An improved procedure for the determination of chromic oxide in feed and feces. Canadian Journal of Animal Science, 59(3): 631-634.

Hajimohammadi A, Mottaghitalab M & Hashemi M. 2020. Influence of microbial fermentation processing of sesame meal and enzyme supplementation on broiler performance. Italian Journal of Animal Science, 19(1): 712-722. DOI: 10.1080/1828051X.2020.1790045

Hong KJ, Lee CH & Kim SW. 2004. Aspergillus oryzae fermentation improves nutritional quality of food soybeans and feed soybean meals. Journal of Medicinal Food, 7(4): 430-435.

Hu Y, Wang Y, Li A, Wang Z, Zhang X, Yun T, Qiu L & Yin Y. 2016. Effects of fermented rapeseed meal on antioxidant functions, serum biochemical parameters and intestinal morphology in broilers.

Food and Agricultural Immunology, 27(2): 182-193. DOI: 10.1080/09540105.2015.1079592

Jazi V, Boldaji F, Dastar B, Hashemi SR & Ashayerizadeh A. 2017. Effects of fermented cottonseed meal on the growth performance, gastrointestinal microflora population and small intestinal morphology in broiler chickens. British Poultry Science, 58(4): 402-408. DOI: 10.1080/00071668.2017.1315051

Khan SH. 2018. Recent advances in role of insects as alternative protein source in poultry nutrition. Journal of Applied Animal Research, 46(1): 1144-1157. DOI: 10.1080/09712119.2018.1474743

Mamputu M & Buhr RJ. 1995. Effect of substituting sesame meal for soybean meal on layer and broiler performance. Poultry Science, 74(4): 672-684. DOI: 10.3382/ps.0740672

Mazaheri A, Shams Shargh M, Dastar B & Ashayerizadeh O. 2018. Comparison the effects of raw and fermented sesame meal by solid state fermentation on performance, carcass characteristic, and intestinal morphology in broiler chickens. Animal Sciences Journal, 31(120): 147-58. DOI: 10.22092/asj. 2018.115243.1533

Niba AT, Beal JD, Kudi AC & Brooks PH. 2009. Potential of bacterial fermentation as a biosafe method of improving feeds for pigs and poultry. African Journal of Biotechnology, 8(9).

Olude O, George F & Alegbeleye W. 2016. Utilization of autoclaved and fermented sesame (*Sesamum indicum* L.) seed meal in diets for Tilaqua natural male tilapia. Animal Nutrition, 2(4): 339-344. DOI: 10.1016/j.aninu.2016.09.001

Paton AW, Morona R & Paton JC. 2006. Designer probiotics for prevention of enteric infections. Nature Reviews Microbiology, 4(3): 193-200. DOI: 10.1038/nrmicro1349

Rahimian Y, Tabatabaie S, Valiollahi S, Toghyani M, Kheiri F, Zamani F, Rafiee A, Miri Y, Asgarian F, & Khajeali Y. 2013. Effect of use cumulative levels of sesame (*Sesamum indicum*) meal with phytase enzyme on performance of broiler chicks. Scientific Journal of Veterinary Advances, 2(12): 178-188. DOI: 10.14196/sjvs.v2i12.1047

Ram R, Catlin D, Romero J & Cowley C. 1990. Sesame: new approaches for crop improvement. In advances in new crops. Proceedings of the first national symposium 'New crops: research, development, economics', Indianapolis, Indiana, USA, 23-26 October 1988. (225-228). Timber Press.

Ravindran V. 1995. Phytates: occurrence, bioavailability and implications in poultry nutrition. Poultry and Avian Biology Reviews, 6: 125-143. DOI: 10.5555/19961401916

Rezaeipour V, Barsalani A & Abdullahpour R. 2016. Effects of phytase supplementation on growth performance, jejunum morphology, liver health, and serum metabolites of Japanese quails fed sesame (*Sesamum indicum*) meal-based diets containing graded levels of protein. Tropical Animal Health and Production, 48: 1141-1146. DOI: 10.1007/s11250-016-1066-x

Sacakli P, Sehu A, Genc B & Selcuk Z. 2005. The effect of phytase and organic acid on growth performance, carcass yield and tibia ash in quails fed diets with low levels of non-phytate phosphorus. Asian-Australasian Journal of Animal Sciences, 19(2): 198-202.DOI: 10.5713/ajas.2006.198

Saima M, Shad A, Pasha TN, Akram M, Ditta YA & Khan MZU. 2014. Effect of microbial phytase supplementation on growth performance of Japanese quails. The Journal Animal and Plant Sciences, 24: 19-23.

SAS. 2003. Statistical Analysis System User's Guide: Statistics. SAS Institute, Cary, NC.

Sebastian S, Touchburn SP, Chavez ER & Lagu PC. 1996. The effects of supplemental microbial phytase on the performance and utilization of dietary calcium, phosphorus, copper, and zinc in broiler chickens fed corn-soybean diets. Poultry Science, 75(6): 729-736. DOI: 10.3382/ps. 0750729

Selle PH & Ravindran V. 2007. Microbial phytase in poultry nutrition. Animal Feed Science and Technology, 135(1-2): 1-41. DOI: 10.1016/j. anifeedsci.2006.06.010

Shamoto K, Yamauchi KE & Kamisoyama H. 1999. Morphological alterations of the duodenal villi in chicks refer rice bran or grower mash after fasting. Japanese Poultry Science, 36(1): 38-46. DOI: 10.2141/jpsa.36.38

Shanti H, Abo Omar J, Al-Shakhrit K & Ghany AA. 2012. Performance and some blood constituents of broilers fed sesame meal supplemented with microbial phytase. Asian Pacific Journal of Tropical Biomedicine. 1: 1-8.

Shi C, Zhang Y, Lu Z & Wang Y. 2017. Solid-state fermentation of corn-soybean meal mixed feed with *Bacillus subtilis* and *Enterococcus faecium* for degrading anti-nutritional factors and enhancing nutritional value. Journal of Animal Science and Biotechnology, 8(1): 1-9. DOI: 10.1186/s40104-017-0184-2

Singhania RR, Patel AK, Soccol CR & Pandey A. 2009. Recent advances in solid-state fermentation. Biochemical Engineering Journal, 44(1): 13-18. DOI: 10.1016/j.bej.2008.10.019

Sugiharto S & Ranjitkar S. 2019. Recent advances in fermented feeds towards improved broiler chicken performance, gastrointestinal tract microecology and immune responses: A review. Animal Nutrition, 5(1): 1-10. DOI: 10.1016/j. aninu.2018.11.001

Sun H, Tang JW, Yao XH, Wu YF, Wang X & Feng J. 2012. Improvement of the nutritional quality of cottonseed meal by *Bacillus subtilis* and the addition of papain. International Journal of Agriculture and Biology, 14(4).

Sun H, Tang JW, Yao XH, Wu YF, Wang X & Feng J. 2013. Effects of dietary inclusion of fermented cottonseed meal on growth, cecal microbial population, small intestinal morphology, and digestive enzyme activity of broilers. Tropical Animal Health and Production, 45: 987-993. DOI: 10.1007/s11250-012-0322-y

Wiryawan KG & Dingle JG. 1999. Recent research on improving the. quality of grain legumes for chicken growth. Animal Feed Science and Technology, 76(3-4): 185-193. DOI: 10.1016/S0377-8401(98)00218-1

Yamauchi K, Samanya M, Seki K, Ijiri N & Thongwittaya N. 2006. Influence of dietary sesame meal level on histological alterations of the intestinal mucosa and growth performance of chickens. Journal of Applied Poultry Research, 15(2): 266-273. DOI: 10.1093/japr/15.2.266

Zengin M, Sur A, İlhan Z, Azman MA, Tavşanl H, Esen S & Demir E. 2022. Effects of fermented distillers grains with solubles, partially replaced with soybean meal, on performance, blood parameters, meat quality, intestinal flora, and immune response in broiler. Research in Veterinary Science, 150: 58-64. DOI: 10.1016/j.rvsc.2022.06.027