Effects of Bacillus megaterium on Growth Performance, Slaughter Performance, Organ Indices, and Serum Biochemical Indices of 1-70-Day-Old Yangzhou Geese (Postprint)

Authors: Zhongmei Cai, Wang Zhiyue, Yang Haiming, Ding Wenjun, Jin Shilei, Zhang Yanyun

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Abstract

This study aimed to investigate the effects of Bacillus megaterium on growth performance, slaughter performance, organ indices, and serum biochemical indices of Yangzhou geese aged 1 to 70 days. A total of 260 healthy 1-day-old male Yangzhou goslings with similar body weight were selected and randomly divided into 4 groups, with 5 replicates per group and 13 goslings per replicate. The control group (Group) was fed a basal diet, while the experimental groups (Groups , , and) were fed experimental diets supplemented with 20, 40, and 60 mg/kg of Bacillus megaterium, respectively. The experimental period lasted 70 days. The results showed that: 1) The body weight of goslings in Group at 14 and 56 days of age was significantly greater than that of the control group ($P<0.05$), and the body weight at 28 and 42 days of age was extremely significantly greater than that of the control group ($P<0.01$); the average daily gain of goslings in Group during 1-28 days of age was extremely significantly higher than that of the control group ($P<0.01$) and significantly higher than that of Group ($P<0.05$); the feed-to-gain ratio of goslings in Group during 1-28 days of age was significantly lower than that of Group ($P<0.05$) and extremely significantly lower than that of Group ($P<0.01$); the average daily feed intake of goslings in Groups and during 29-70 days of age was significantly higher than that of the control group ($P<0.05$). 2) The eviscerated yield and semi-eviscerated yield of Group were significantly higher than those of the control group ($P<0.05$), while there were no significant differences among groups in breast muscle percentage, leg muscle percentage, and abdominal fat percentage ($P>0.05$). 3) The gizzard index and jejunum index of Group were significantly higher than those of the control group ($P<0.05$). 4) The high-density lipoprotein cholesterol content of Group was significantly higher than that of Group

(P<0.05), and the low-density lipoprotein cholesterol content was significantly lower than that of the control group (P<0.05). In conclusion, supplementation with Bacillus megaterium can improve the growth performance of goslings and has certain effects on their eviscerated yield, semi-eviscerated yield, intestinal development, and serum high-density lipoprotein and low-density lipoprotein contents, with the dosage of 60 mg/kg showing better results.

Full Text

Effects of Bacillus Megaterium on Growth Performance, Slaughter Performance, Visceral Indices and Serum Biochemical Parameters of Geese from 1 to 70 Days of Age

CAI Zhongmei, WANG Zhiyue*, YANG Haiming, DING Wenjun, JIN Shilei, ZHANG Yanyun

College of Animal Science and Technology, Yangzhou University, Yangzhou 225009, China

*Corresponding author, professor, E-mail: dkwzy@263.net

Abstract

This study was conducted to investigate the effects of *Bacillus megaterium* on growth performance, slaughter performance, visceral indices and serum biochemical parameters of geese from 1 to 70 days of age. Two hundred and sixty 1-day-old healthy male Yangzhou geese with similar body weight were randomly divided into 4 groups with 5 replicates per group and 13 geese per replicate. The control group (group I) was fed a basal diet, while the experimental groups (groups II, III and IV) were fed the basal diet supplemented with 20, 40 and 60 mg/kg *B. megaterium*, respectively. The experiment lasted for 70 days. The results showed that: 1) The body weight of geese at 14 and 56 days of age in group IV was significantly higher than that in the control group (P<0.05), and the body weight at 28 and 42 days of age was extremely significantly higher (P<0.01). The average daily gain (ADG) of geese at 1-28 days of age in group IV was extremely significantly higher than that in the control group (P<0.01) and significantly higher than that in group II (P<0.05). The feed to gain ratio (F/G) of geese at 1-28 days of age in group IV was significantly lower than that in group II (P<0.05) and extremely significantly lower than that in group III (P<0.01). The average daily feed intake (ADFI) of geese at 29-70 days of age in groups III and IV was significantly higher than that in the control group (P<0.05). 2) The eviscerated rate and semi-eviscerated rate in group IV were significantly higher than those in the control group (P<0.05). There were no significant differences in breast muscle rate, leg muscle rate and abdominal fat rate among all groups (P>0.05). 3) The gizzard index and jejunum index in group IV were significantly higher than those in the control group (P<0.05). 4) The serum high-density lipoprotein cholesterol content in group II was significantly higher than that in group IV (P<0.05), while the low-density lipoprotein cholesterol content was significantly lower than that in the control group (P<0.05). In conclusion, dietary supplementation with *B. megaterium* can improve the growth performance of goslings, and has certain effects on eviscerated rate, semi-eviscerated rate, intestinal development, serum high-density lipoprotein content and low-density lipoprotein content, with 60 mg/kg supplementation showing the best effects.

Keywords: *Bacillus megaterium*; goslings; growth performance; slaughter performance; visceral indices; serum biochemical parameters

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Introduction

As an aerobic Gram-positive bacillus, *Bacillus* exhibits characteristics such as acid and heat resistance. When *Bacillus* enters the animal intestinal tract, it can consume oxygen, making it difficult for aerobic harmful bacteria such as *Escherichia coli* and *Salmonella* to survive, thereby promoting healthy animal growth [1]. Studies have indicated that *Bacillus* can produce highly active lipase, amylase and protease after entering the animal intestine, demonstrating strong degradation capacity for carbohydrates and improving the digestion and utilization efficiency of nutrients [2]. *Bacillus megaterium* 1259 (BM1259) is a strain isolated and extracted from soil with unique functions such as odor removal. Dai [3] reported that dietary supplementation with *B. megaterium* is not only highly stable and safe, but also possesses the functions of other feed-grade *Bacillus*. Currently, there have been some studies on *B. megaterium* in reducing the volatilization of malodorous gases from excreta of laying hens and pigs [4], but few studies have investigated its effects on animal growth performance, especially in geese. This experiment was conducted to study the effects of dietary *B. megaterium* supplementation on growth performance, slaughter performance, visceral indices and serum biochemical parameters of goslings, and to accumulate experimental data for the rational utilization of *B. megaterium* in goose diets.

Materials and Methods

1.1 Experimental Materials

The *Bacillus megaterium* 1259 preparation was a microecological agent developed by the research group "Development of Novel Biological Feed Additive BM1259" from the Animal Nutrition Teaching and Research Section of the College of Animal Science and Technology, Yangzhou University. Its main component was BM1259 (Patent No. ZL200510091277.0) with a viable count of

1×10^{10} CFU/g. The experimental animals were 1-day-old male Yangzhou geese, purchased from the Yangzhou Goose Breeding Farm in Yangzhou City.

1.2 Experimental Design and Diets

Two hundred and sixty 1-day-old healthy male Yangzhou geese with similar body weight were selected and randomly divided into 4 groups using a single-factor experimental design, with 5 replicates per group and 13 geese per replicate. The control group (group I) was fed a basal diet, while the experimental groups (groups II, III and IV) were fed the basal diet supplemented with 20, 40 and 60 mg/kg *B. megaterium* preparation (containing 2×10^{5}, 4×10^{5} and 6×10^{5} CFU viable bacteria per gram of diet, respectively). The experimental period lasted for 70 days. The geese were raised on net floors indoors with ad libitum access to feed and water under natural lighting.

The experimental diets were formulated primarily based on previous research results of our research group, using corn and soybean meal as basal ingredients. The metabolic energy, crude protein and crude fiber contents of the raw materials were determined before diet preparation. The composition and nutrient levels of the basal diet are shown in Table 1 .

Table 1 Composition and nutrient levels of basal diets (air-dry basis) %

Items	Content	
	1 to 28 days of age	29 to 70 days of age
Ingredients		
Corn		
Soybean meal		
Corn gluten meal		
Rice hull		
Limestone		
$CaHPO_4$		
Met		
NaCl		
Premix[1]		
Total		
Nutrient levels[2]		
ME (MJ/kg)		
CP		
CF		
Lys		
Met		
Ca		
TP		

[1]The premix was provided by the Yangzhou University Feed Company, per kg

of premix contained: VA 1,200 IU, VD_3 400 IU, VE 1,208 mg, VK 400 mg, VB_1 2.2 mg, VB_2 5.5 mg, VB_6 380 mg, VB_{12} 1 mg, nicotinic acid 3 g, D-pantothenic acid 12 mg, folic acid 500 mg, biotin 0.4 mg, choline 1,500 mg, Fe (as ferrous sulfate) 6 g, Cu (as copper sulfate) 5 g, Mn (as manganese sulfate) 9.5 g, Zn (as zinc sulfate) 9 g, I (as potassium sulfate) 50 mg, Se (as sodium sulfate) 30 mg. [2]Nutrient levels were calculated values.

1.3.1 Growth Performance

At 08:00 on days 14, 28, 42, 56 and 70 of age, the experimental geese were weighed after fasting (feed withdrawal for 6 h). Feed intake and leftover feed were recorded accurately to calculate the average daily gain (ADG), average daily feed intake (ADFI) and feed to gain ratio (F/G) for each group.

1.3.2 Slaughter Performance

On day 70 of the experiment, 2 geese with body weight close to the average were selected from each replicate for slaughter performance evaluation. The measured parameters included semi-eviscerated rate, eviscerated rate, leg muscle rate, breast muscle rate and abdominal fat rate. The measurement methods followed the standard "Poultry Production Performance Terminology and Measurement Statistics Methods" (NY/T823-2004).

1.3.3 Visceral Indices

The heart, liver, spleen, thymus, bursa of Fabricius, proventriculus, gizzard (with surrounding fat removed, and contents and cuticle removed) and intestinal segments (with contents removed) were rapidly weighed separately to calculate the visceral indices using the following formula: Visceral index (%) = 100 × visceral organ weight / live weight.

1.3.4 Serum Biochemical Parameters

At 08:00 on day 70 of the experiment, 2 geese with body weight close to the average were selected from each replicate, and 5 mL of blood was collected from the wing vein after fasting. Serum was obtained after centrifugation using a high-speed centrifuge. The serum contents of triglycerides (TG), cholesterol (TC), glucose (GLU), high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C) were determined using a UniCel DxC-800 Synchron automatic biochemical analysis system (Beckman Coulter, USA).

1.4 Statistical Analysis

Experimental data were analyzed using one-way ANOVA in SPSS 17.0. Results were expressed as "mean ± standard error". LSD multiple comparisons were performed when significant differences were detected. $P<0.01$ was considered as extremely significant difference and $P<0.05$ as significant difference.

Results

2.1 Effects of Bacillus megaterium on Body Weight and Growth Performance of Goslings from 1 to 70 Days of Age

As shown in Table 2 , dietary supplementation with *B. megaterium* had varying degrees of influence on the body weight of goslings at 14, 28, 42 and 56 days of age. Compared with the control group, the body weight of goslings at 14 and 56 days of age in group IV was significantly increased (P<0.05), and the body weight at 28 and 42 days of age was extremely significantly increased (P<0.01). The body weight of goslings at 28 and 42 days of age in group II was significantly different from that in group IV (P<0.05), and the body weight at 42 days of age in group III was significantly different from that in group IV (P<0.05). *B. megaterium* had no significant effect on body weight at 70 days of age (P>0.05), but groups II, III and IV showed an increasing trend compared with the control group.

Table 2 Effects of *Bacillus megatherium* on body weight of geese from 1 to 70 days of age (g)

Groups	Day of age				
	14	28	42	56	70
I	105.93$±1.15	623.96 ± 11.79^{a}	$1,520.78\pm26.13^{Aa}$	$2,582.59\pm48.93^{Aa}$	$3,395.45\pm61.48^{a}$
II	106				

In the same row, values with the same or no letter superscripts mean no significant difference (P>0.05), while with different small letter superscripts mean significant difference (P<0.05), and with different capital letter superscripts mean extremely significant difference (P<0.01). The same as below.

As shown in Table 3 , the ADG of goslings at 1-28 days of age in group IV was extremely significantly increased compared with the control group (P<0.01) and significantly increased compared with group II (P<0.05). The F/G of goslings at 1-28 days of age in group IV showed no significant difference compared with the control group (P>0.05), but was significantly lower than that in group II (P<0.05) and extremely significantly lower than that in group III (P<0.01). The ADFI of goslings at 29-70 days of age in groups III and IV was significantly higher than that in the control group (P<0.05). *B. megaterium* had no significant effect on the overall growth performance from 1 to 70 days of age (P>0.05), but ADFI and ADG showed an increasing trend compared with the control group.

Table 3 Effects of *Bacillus megaterium* on growth performance of geese from 1 to 70 days of age

Groups	Day of age	Items		
		ADFI (g)	ADG (g)	
I	1-28	105.41±0.99	50.43±0.93^{Aa}	2.09±0.01^{ABab}
II	1-28	108.29±1.38	51.44±0.89^{ABa}	2.11±0.03^{ABa}
III	1-28	112.93±1.63	52.43±0.89^{ABab}	2.15±0.03^{Aa}
IV	1-28	109.03±4.61	54.36±0.87^{Bb}	2.00±0.03^{Bb}
I	29-70	232.57±3.73^{a}	53.93±1.31	4.31±0.09
II	29-70	236.10±3.65^{ab}	53.17±1.33	4.44±0.09
III	29-70	243.95±4.52^{b}	53.39±1.31	4.57±0.11
IV	29-70	246.10±3.06^{b}	54.33±1.19	4.53±0.11
I	1-70	205.97±5.73	52.50±1.09	3.92±0.04
II	1-70	206.62±3.00	52.55±0.97	3.93±0.04
III	1-70	211.32±4.66	52.93±0.96	3.99±0.08
IV	1-70	212.07±3.85	54.58±0.82	3.89±0.04

2.2 Effects of Bacillus megaterium on Slaughter Performance of 70-Day-Old Goslings

As shown in Table 4 , the eviscerated rate and semi-eviscerated rate of 70-day-old goslings in group IV were significantly higher than those in the control group (P<0.05). The leg muscle rate in groups II, III and IV was increased by 1.35%, 3.05% and 5.67% compared with the control group, respectively, but the difference was not significant (P>0.05). *B. megaterium* had no significant effect on abdominal fat rate among groups (P>0.05), but the abdominal fat rate in groups II, III and IV was increased by 13.86%, 14.19% and 16.83% compared with the control group, respectively.

Table 4 Effects of *Bacillus megaterium* on slaughter performance of geese at 70 days of age

Items	Groups			
	I	II	III	IV
Live weight (g)	3,628.20±73.05^{a}	3,709.82±37.18^{ab}	3,683.84±65.11^{ab}	3,857.86±65.71^{b}
Eviscerated rat				
eviscerated rate (	±1.95^{a}	79.55±1.14^{ab}	80.72±0.62^{ab}	82.32±1.34^{b}
Breast muscle rate (	±0.			

2.3 Effects of Bacillus megaterium on Visceral Indices of 70-Day-Old Goslings

As shown in Table 5 , dietary supplementation with *B. megaterium* had certain effects on the gizzard index and jejunum index of 70-day-old goslings. The gizzard index in group IV was significantly higher than that in the control group (P<0.05). The proventriculus index in groups II and III showed no significant difference compared with the control group (P>0.05), but exhibited an increasing trend. The jejunum index in group IV was significantly higher than that in groups I, II and III (P<0.05). *B. megaterium* had no significant effect on other visceral indices (P>0.05).

Table 5 Effects of *Bacillus megaterium* on visceral indices of geese at 70 days of age (%)

Items	Groups			
	I	II	III	IV
Heart index	0.60±0.02	0.60±0.01	0.60±0.01	0.63±0.03
Hepatic index	2.03±0.09	1.97±0.08	1.96±0.	

2.4 Effects of Bacillus megaterium on Serum Biochemical Parameters of 70-Day-Old Goslings

As shown in Table 6 , the high-density lipoprotein cholesterol content in group IV was reduced by 16.46% compared with that in group II, with a significant difference (P<0.05). Meanwhile, the low-density lipoprotein cholesterol content in group II was reduced by 42.76% compared with that in the control group, with a significant difference (P<0.05). In addition, there were no significant differences in triglyceride, glucose and total cholesterol contents compared with the control group (P>0.05).

Table 6 Effects of *Bacillus megaterium* on serum biochemical parameters of geese at 70 days of age

Items	Groups			
	I	II	III	IV
Triglycerides (mmol/L)	11.88±0.31	12.11±0.48	12.02±0.21	12.06±0.36
Glucose (mmol/L)	0.93±0.14	1.33±0.1		
[illegible]C (mmol/L)	1.75±0.08^{ab}	1.91±0.09^{a}	1.84±0.10^{ab}	1.64±0.08^{b}
LDL-C (mmol/L)	1.45±0.34^{a}	0.83±0.05^{b}	1.03±0.13^{ab}	1.15±0.21

Discussion

3.1 Effects of Bacillus megaterium on Growth Performance of Goslings from 1 to 70 Days of Age

Microecological agents primarily regulate the gastrointestinal microbiota through competitive exclusion. During the early growth stage of animals, the gastrointestinal microbiota is not fully established and remains in a dynamic state. Therefore, early administration of microecological agents can promote the establishment of a healthier intestinal microbial community, thereby benefiting animal growth [5-6]. *Bacillus* is an aerobic bacterium that can consume large amounts of free oxygen in the intestine, inhibiting aerobic harmful bacteria due to oxygen deficiency. Additionally, *Bacillus* can produce antimicrobial proteins during growth and reproduction, which exhibit resistance against certain pathogens [7]. In this feeding trial, goslings in all *B. megaterium*-supplemented groups showed good health status, with no obvious abnormal symptoms indicative of intestinal microbiota imbalance or pathogenic infection, such as diarrhea, feed passage, watery feces or tomato-like feces.

Regarding ADG, this study found that *B. megaterium* significantly affected the early growth performance of goslings. Group IV (60 mg/kg *B. megaterium*) showed significant effects on ADG of goslings at 1-28 days of age, being extremely significantly higher than the control group and significantly higher than group II (20 mg/kg *B. megaterium*). These results indicate that *B. megaterium* significantly promotes early growth rate of goslings, and higher concentrations exhibit better growth-promoting effects than lower concentrations within the 20-60 mg/kg supplementation range. Similar to our results, Lü et al. [8] also found that *Bacillus* (*Bacillus coagulans* and *Bacillus licheniformis*) could significantly increase the ADG of broilers at 1-3 weeks of age (by 4.9%). Chen et al. [5] fed early-stage broilers with *B. licheniformis* and found that 50 mg/kg supplementation was optimal, significantly increasing ADG by 17.86% compared with the control group. Although *B. megaterium* supplementation significantly affected early ADG in this experiment, it had no significant effect on overall ADG (1-70 days of age), which is similar to the findings of Tan et al. [9] in broilers. The results of this study demonstrate that supplementation with 60 mg/kg *B. megaterium* in the early diet of Yangzhou geese can significantly improve ADG.

Regarding feed conversion efficiency, there were no significant differences between the experimental groups and the control group. The results suggest that since the 60 mg/kg *B. megaterium* group showed significant weight gain at 1-28 days of age with no significant difference in F/G compared with the control group, *B. megaterium* can promote rapid growth in goslings, potentially advancing market time, reducing management costs and improving economic benefits. The F/G of goslings at 1-28 days of age in group IV was significantly lower than that in group II and extremely significantly lower than that in group III (40 mg/kg *B. megaterium*), indicating that higher concentrations of *B. megaterium* supplementation can improve feed conversion efficiency in goslings. These results differ from those of Liu et al. [7], who added different doses of *Bacillus coagulans* to broiler diets and found that 100 mg/kg supplementation had no significant effect on F/G at 1-3 weeks. In this experiment, *B. megaterium* supplementation had no significant effect on F/G in the later stage (29-70 days of age), which is similar to the findings of Liu et al. [7]. However, Chen et al. [5] found that 50 mg/kg *B. licheniformis* significantly reduced F/G by 10.98%, which is inconsistent with our results. These discrepancies may be related to differences in proliferation ability and metabolic activity among different *Bacillus* strains, as well as different animal species. No relevant studies on geese have been reported, and the mechanism by which *B. megaterium* affects F/G in goslings at 1-28 days of age requires further investigation.

Regarding ADFI, supplementation with 40 and 60 mg/kg *B. megaterium* significantly increased the ADFI of goslings at 29-70 days of age, which differs from the results of Lu et al. [10]. The reason may be that *B. megaterium* caused differences in body weight, requiring increased feed intake to meet growth requirements, or it may be related to different bacterial strains. The specific mechanism requires further investigation.

Furthermore, although *B. megaterium* had no significant effect on overall growth performance, it significantly affected body weight from 1 to 56 days of age, indicating that *B. megaterium* has certain growth-promoting effects on goslings. The lack of significant difference in body weight among groups at 70 days of age may be attributed to the hot and rainy summer conditions during the last 2 weeks of the feeding period, with temperatures between 31-35°C, which affected feed intake during the final 2 weeks and consequently hindered growth and development of the geese.

The main reason for *Bacillus* to improve growth performance may be its ability to produce various nutrients and enzymes during growth and reproduction in the animal intestine, thereby improving the hydrolysis and utilization efficiency of protein, energy and fat in the intestine [11]. Li [12] added *B. megaterium* to laying hen diets and found that supplementation at 40 mg/kg could significantly improve the metabolic rates of dietary energy, calcium, crude protein and various amino acids, which also verifies the growth-promoting mechanism of *B. megaterium*.

3.2 Effects of Bacillus megaterium on Slaughter Performance of 70-Day-Old Goslings

Slaughter performance is an important indicator for evaluating the growth performance of meat-producing animals, reflecting differences in nutrient deposition among different tissues and within the same tissue. The results of this study showed that when *B. megaterium* supplementation reached 60 mg/kg, the eviscerated rate and semi-eviscerated rate of 70-day-old goslings were significantly increased. Cui et al. [13] added *Bacillus subtilis* to broiler diets and found that the eviscerated rate and semi-eviscerated rate were significantly increased by 3.38% and 1.83%, respectively, which is similar to our results. Additionally, although there was no significant difference in leg muscle rate among groups in this experiment, it showed a gradually increasing trend, which is consistent with the results of Lu et al. [10].

The results of this experiment demonstrate that *B. megaterium* supplementation can significantly improve the meat production performance of Yangzhou geese. The reason may be that *B. megaterium* can secrete digestive enzymes such as protease and amylase, thereby degrading dietary protein and polypeptides to produce free amino acids, improving protein utilization efficiency and promoting protein synthesis in animals [12]. Protein is the material basis for muscle growth, with protein content in muscle exceeding 80% [14]. Zhou et al. [15] found that supplementation with 0.15 g/kg *B. subtilis* could extremely significantly improve the absorption and utilization rate of crude protein. Studies have indicated that improved protein level or utilization efficiency can enhance meat production performance and significantly increase eviscerated rate and semi-eviscerated rate [16-18].

In this experiment, there was no significant difference in abdominal fat rate, but it showed a gradually increasing trend. The reason may be that probiotic supplementation improved dietary energy utilization efficiency, leading to increased abdominal fat deposition and higher abdominal fat rate. Sen et al. [19] reported that supplementation with 0.3% *B. subtilis* in broiler diets significantly improved the utilization efficiency of total dietary energy. Li [12] pointed out that when *B. megaterium* supplementation reached 40 mg/kg, the metabolic rate of total dietary energy was significantly improved. Sun [20] added three different types of *Bacillus* preparations to broiler pellet diets and found that energy utilization efficiency was significantly increased by 6.61%, 5.99% and 9.45%, respectively. Liu et al. [21] found that when dietary metabolic energy level increased from 12.122 MJ/kg to 13.376 MJ/kg, the abdominal fat rate of Beijing fatty chickens increased significantly from 0.21% to 0.56%. Numerous studies have shown that abdominal fat deposition increases significantly with increased energy level or improved energy utilization efficiency. The increased abdominal fat rate with increasing *B. megaterium* supplementation in this study may imply that *B. megaterium* improved dietary energy utilization efficiency. The different effects of *Bacillus* on slaughter performance may be related to animal species, probiotic type, supplementation level and active component content.

3.3 Effects of Bacillus megaterium on Visceral Indices of 70-Day-Old Goslings

Visceral index is the ratio of visceral organ weight to live body weight, commonly used to indicate the growth and development status of internal organs. Adequate development of visceral organs ensures effective nutrient deposition. Visceral indices are mainly affected by factors such as breed and nutrition. In this experiment, supplementation with 60 mg/kg *B. megaterium* significantly increased the gizzard index and jejunum index. Ren et al. [22] reported that compound *Bacillus* preparations promoted intestinal development in meat rabbits, particularly affecting the ratio of villus height to crypt depth in the duodenum, jejunum and ileum. Zhang [23] investigated the effects of feed-grade *Bacillus* on intestinal development in chickens and found that *Bacillus* promoted the growth and development of intestinal mucosa and enhanced nutrient absorption function of the small intestine. These results suggest that after probiotics enter the animal digestive tract, they continuously stimulate the intestinal mucosa, promote mucosal development, increase intestinal villus height and epithelial cell number. Meanwhile, probiotics inhibit the colonization of harmful bacteria in the gastrointestinal tract through competitive inhibition and production of metabolites, thereby indirectly promoting gastrointestinal development [24].

3.4 Effects of Bacillus megaterium on Serum Biochemical Parameters of 70-Day-Old Goslings

During lipid metabolism in animals, high-density lipoprotein (HDL) is a class of lipoproteins with heterogeneous particle size, function and composition that gradually matures through the metabolic processes of pre-β-HDL, HDL3 and HDL2 [25]. Its function is to transport cholesterol from extrahepatic tissues to the liver for metabolism, while low-density lipoprotein transports endogenous cholesterol synthesized in the liver to extrahepatic tissues for utilization. Increased HDL helps remove excess cholesterol from blood vessels and benefits cardiovascular health [26]. Elevated serum low-density lipoprotein content is a major risk factor for atherosclerotic cardiovascular and cerebrovascular diseases [27]. In this experiment, supplementation with 20 mg/kg *B. megaterium* significantly reduced serum low-density lipoprotein cholesterol content. The 20 mg/kg *B. megaterium* group had significantly higher high-density lipoprotein cholesterol content than the 60 mg/kg group, indicating that higher *B. megaterium* supplementation levels reduced serum high-density lipoprotein cholesterol content. The reason may be that *B. megaterium* supplementation caused increased blood triglyceride levels. When triglyceride levels increase, serum HDL2 content decreases [28]. Yan et al. [29] found that HDL2 content is significantly positively correlated with high-density lipoprotein cholesterol content. When HDL2 content decreases, high-density lipoprotein cholesterol content also decreases, but the specific reason requires further investigation.

Experimental results showed that the 20 mg/kg *B. megaterium* group had the highest total cholesterol content, which decreased with increasing supplementation levels. Xin et al. [30] found that *Bacillus* had no significant effect on serum cholesterol content in laying hens, but reduced cholesterol content by 11.29%, which is similar to our results. Studies have reported that serum cholesterol content is affected by the activity of the key enzyme hydroxymethylglutaryl-CoA, and probiotics can inhibit the activity of key enzymes in cholesterol synthesis. Therefore, supplementation with certain amounts of *Bacillus* can reduce serum cholesterol content.

In this experiment, *B. megaterium* supplementation had significant effects on serum low-density lipoprotein cholesterol content, which is similar to the results of Fukushima et al. [31]. The reason for these results may be that *B. megaterium* can reduce serum uric acid content [12], and Gouri et al. [32] reported that reduced serum uric acid content leads to decreased low-density lipoprotein cholesterol content, but the specific mechanism requires further investigation.

Conclusion

1. Supplementation with 60 mg/kg *Bacillus megaterium* significantly affected the growth performance of Yangzhou geese at 1-28 days of age, significantly

increased body weight at 56 days of age, and may advance market time, thereby improving economic benefits.

2. Supplementation with 60 mg/kg *Bacillus megaterium* significantly affected the slaughter performance of 70-day-old Yangzhou geese.
3. Supplementation with 20 mg/kg *Bacillus megaterium* significantly increased serum high-density lipoprotein cholesterol content and significantly decreased low-density lipoprotein cholesterol content in 70-day-old Yangzhou geese, but the specific mechanism of action requires further investigation.

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Note: Figure translations are in progress. See original paper for figures.