

## Journal of the Hellenic Veterinary Medical Society

Vol 70, No 4 (2019)



### Effects of Indigenous Spore-Forming Probiotic as Feed Supplement on Performance and Safety in Broilers

N.G. HOSSEINI, M.H. MODARRESSI, S.N. MOUSAVI, M.T. EBRAHIMI

doi: [10.12681/jhvms.22234](https://doi.org/10.12681/jhvms.22234)

Copyright © 2020, N.G. HOSSEINI, M.H. MODARRESSI, S.N. MOUSAVI, M.T. EBRAHIMI



This work is licensed under a [Creative Commons Attribution-NonCommercial 4.0](https://creativecommons.org/licenses/by-nc/4.0/).

### To cite this article:

HOSSEINI, N., MODARRESSI, M., MOUSAVI, S., & EBRAHIMI, M. (2020). Effects of Indigenous Spore-Forming Probiotic as Feed Supplement on Performance and Safety in Broilers. *Journal of the Hellenic Veterinary Medical Society*, 70(4), 1841–1850. <https://doi.org/10.12681/jhvms.22234>

## Effects of Indigenous Spore-Forming Probiotic as Feed Supplement on Performance and Safety in Broilers

N.G. Hosseini<sup>1</sup>, M.H. Modarressi<sup>1</sup>, S.N. Mousavi<sup>2</sup>, M.T. Ebrahimi<sup>3\*</sup>

<sup>1</sup> Department of Biology, Science and Research Branch, Islamic Azad University, Tehran, Iran

<sup>2</sup> Departments of Animal Science, Varamin-Pishva Branch, Islamic Azad University, Varamin, Iran

<sup>3</sup> Department of Biology, Faculty of Sciences, Central Tehran Branch, Islamic Azad University, Tehran, Iran

**ABSTRACT.** Probiotics colonize the intestine of animals and birds and provide useful effects on their performance and immune status. This study describes a high throughput screening and characterization of spore-forming bacteria from Iranian poultry farms with the aim to identify potential probiotic native *Bacillus* spp. and determine its effects on growth performance, hemato-biochemical parameters, immunity, intestinal microflora, morphology and *MUC2* gene expression of broiler chickens. A total of 300 one-day-old female Ross 308 broilers ( $42.6 \pm 0.6$  g) were used in a 6-wk study. Broilers were randomly allotted to 1 of 3 dietary treatments consisting of 4 replicate cages with 25 broilers each: 1- Control (Corn-soy-based diet: C), 2- C + 200 g/ton of the GalliPro® (*Bacillus subtilis* DSM 17299,  $4 \times 10^9$  CFU/g, as positive control group: PC), 3- C + 200 g/ton of the native probiotic (*B. tequilensis* K03,  $4 \times 10^9$  CFU/g: NP) identified in this study. During the experiment parameters were measured weekly. The results revealed that birds of the NP and PC groups exhibited improved feed conversion ratio (FCR) and increased body weight (BW), carcass and breast meat yield compared with the birds of the C group ( $P < 0.05$ ). Also, lymphocytes level, antibody titers against Newcastle diseases virus (NDV) and infectious bronchitis virus (IBV) of vaccinated birds were increased, while serum triglycerides, total cholesterol levels and abdominal fat of birds fed NP and PC were decreased compared to birds of the C group ( $P < 0.05$ ). The villus height, the relative expression of *MUC2* gene and *Bacillus* spp. populations were increased, while *E. coli* was significantly decreased in the ileum content of treated groups ( $P < 0.05$ ). These results indicate that the identified native *B. tequilensis* K03 strain can improve immunity and broiler performance by modifying intestinal microflora and morphology. Studied native probiotic *Bacillus tequilensis* K03 has useful effects on health status and it can be used as poultry feed supplement.

**Keywords:** Broiler, Probiotic, *Bacillus*, Performance, Mucin

*Corresponding Author:*

Maryam Tajabadi Ebrahimi, Department of Biology, Faculty of Sciences, Central Tehran Branch, Islamic Azad University, Tehran, Iran  
Email address: m.tajabadi@iauctb.ac.ir

Date of initial submission: 19-04-2019  
Date of revised submission: 27-08-2019  
Date of acceptance: 05-09-2019

## INTRODUCTION

Antibiotics have been used in commercial poultry diet due to their growth-promoting and prophylactic effects for over 50 years (Coates *et al.*, 1963). Antibiotic intake of food animals, as well as the resulted antibiotic residue in food, has been noticed as one leading cause of the rapid spread of antimicrobial resistance in human populations. Reducing antibiotics in animal agriculture is one key in struggle against the spread of antibiotic resistance (Ghadban, 2002; Kabir, 2009). Increasing information on healthy food has led to increasing interests on natural food products such as probiotics. Probiotics have been demonstrated to improve intestinal microbial balance, provide protection against gut pathogens and modulate immune system. (Khaksefidi and Ghoorchi, 2006; Mingmongkolchai and Panbangred, 2018). These products have been identified as a safe feed additive in animal industry (Nawab *et al.*, 2019). Lactic acid bacteria (LAB), mainly from genus *Lactobacillus*, consist the most important microbial population in the intestine of broiler chickens that have been used as probiotics in poultry industry (Huang *et al.*, 2004). Encapsulation technologies are used to keep probiotic cell viable all over storage, commercialization and use in food products, so that these cells are active during their passage through the gastrointestinal tract (Tellez *et al.*, 2012). *Bacillus* spp. is a genus of Gram-positive, rod shaped, and spore-forming bacteria. The spores present in vegetative cells allow long-term storage, and survival at the harsh environmental and processing condition and low pH of the gastrointestinal tract (Cutting, 2011).

The *Bacillus* spp. have been known as probiotics for chickens feed because it secretes antimicrobials compounds and suppress the colonization of gut pathogens (Hong *et al.*, 2008; Knap *et al.*, 2011; Guyard-Nicodeme *et al.*, 2016). This probiotic with improve immunity (Melegy *et al.*, 2011) and changes in the intestine morphology of broilers (Sen *et al.*, 2012) lead to promote growth (Melegy *et al.*, 2011) and improves the quality of meat (Xu *et al.*, 2006; Yang *et al.*, 2016). Also, reported that *Bacillus* spp. decrease  $\text{NH}_3$  emission from poultry manure (Jeong and Kim, 2014). Nonetheless, a few of them such as *B. subtilis*, *B. cereus*, and *B. licheniformis* are currently used in poultry industry, and the probiotic potential of other *Bacillus* spp. has been less studied (Cutting, 2011; Mingmongkolchai and Panbangred, 2018). The potential and efficacy of probiotics depend on the bacterial species and host origin, as well as on the appli-

cation levels (Mountzouris *et al.*, 2007; Amerah *et al.*, 2013). Moreover, the antibiotic resistance of *Bacillus* spp. is another matter of concern. Therefore, exploring native or new probiotic strains is important to obtain very efficient probiotics for chicken feed. There is little information about the probiotic potential of *Bacillus tequilensis*, which biochemically is quite similar to *B. subtilis*, and can be differentiated by lysine decarboxylase, positive arginine hydrolases, ornithine decarboxylase and acid production from rhamnose (Gatson *et al.*, 2006). It is reported that *Bacillus tequilensis* K03 have the highest attachment ability to intestinal epithelium cells and inhibits the growth of *Salmonella* Typhimurium (Ghorban Hosseini *et al.*, 2019). Therefore, in the present study, we investigated the effects a selected native strain (*B. tequilensis* K03) on performance and carcass traits, hemato-biochemical parameters, immunity, and intestinal morphology, microflora and *MUC2* gene expression of broiler chickens.

## MATERIALS AND METHODS

### Bacterial isolation and characterization

Bacterial isolates were obtained from fecal samples (n=86) collected from poultry farms in Golestan province in the north-east of Iran. The samples were serially diluted and spread plated on nutrient agar (QueLab-393506) followed by incubation at 37°C for 48 h. Discrete bacterial colonies (n=34) were picked and characterized according to Wu *et al.*, (2011). Then, probiotic characteristics (acid and antibiotic resistance, bile salt, the ability to attach to intestinal epithelial cells, and inhibit *Salmonella enterica* serovar Typhimurium invasion), as well as ability of producing amylase and phytase of *Bacillus* spp. isolates were analyzed (Latorre *et al.*, 2016; Thirabunyanon and Thongwittaya, 2012). The 16S ribosomal typing was also performed for identification of the selected strain (Jeevana Lakshmi *et al.*, 2013). All isolates were catalase-positive, oxidase-positive and non-hemolytic. The K03 strain was the superior bacterium, and had desirable probiotic characteristics, with production of  $4.56 \pm 1.1$  U/ml phytase and  $36.7 \pm 1.3$  U/ml  $\alpha$ -amylase enzymes, and the highest adherence ability ( $1.9 \log \text{CFU/well}$ ) to intestinal epithelial cells. The strain had more inhibitory strength than the other isolates using exclusion assay to inhibit *Salmonella enterica* serovar Typhimurium attachment, up to 53% compared to control. The analysis of 16S rDNA gene sequences showed the highest similarity (% 99) of the K03 strain to *Bacillus tequilensis* KCTC 13622<sup>T</sup>, in-

dicating the auto probiotic (indigenous bacteria) potential of the strain for use in chicken diet (Ghorban Hosseini *et al.*, 2019).

### Birds and experimental design

Three hundred one-day old healthy female broilers (Ross 308) with the initial weight of  $42.6 \pm 0.6$  g were obtained from a local hatchery (Tehran, Iran), and randomly allocated to three dietary treatments ( $n=100$ ) with four replicates (25 birds/pen) and raised for 42 days. The broiler chickens were fed a basal diet (Control; C) as well as basal diet + 200 g/ton of the GalliPro® commercial probiotic (*B. subtilis* DSM

17299,  $4 \times 10^9$  CFU/g) as positive control group (PC). The birds in the native probiotic (NP) group were fed with basal diet + 200 g/ton of the native probiotic (*B. tequilensis* K03,  $4 \times 10^9$  CFU/g) isolate. In broiler diets  $8 \times 10^5$  viable spores/g was evaluated. Feed ingredients and nutrient composition of basal diet are shown in the Table 1. The environmental temperature was maintained at 32°C during the first week and gradually decreased (2°C per week) to 22°C, and then maintained constant until the end of the experiment. All guidelines for the ethical use and care of animal were followed, and approved by the Islamic Azad University Ethics Committee for Animal Experimentation.

**Table1.** Feed ingredients and nutrient composition of basal diet

| Ingredients (%)                      | Starter (1-10 d) | Grower (11-21d) | Finisher (22-42d) |
|--------------------------------------|------------------|-----------------|-------------------|
| Corn                                 | 54.91            | 56.80           | 60.54             |
| Soybean meal (44% CP)                | 38.00            | 36.22           | 32.03             |
| Soy oil                              | 2.51             | 3.00            | 3.83              |
| Limestone                            | 1.10             | 1.01            | 0.94              |
| Di-calcium phosphate                 | 1.93             | 1.65            | 1.42              |
| Vitamin and Mineral premix*          | 0.50             | 0.50            | 0.50              |
| DL-methionine                        | 0.30             | 0.26            | 0.24              |
| L-lysine HCl                         | 0.25             | 0.13            | 0.10              |
| L-threonine                          | 0.11             | 0.06            | 0.03              |
| Common Salt                          | 0.20             | 0.23            | 0.24              |
| Sodium bicarbonate                   | 0.19             | 0.14            | 0.13              |
| Nutrient composition                 |                  |                 |                   |
| Metabolizable energy (kcal / kg)     | 2950             | 3000            | 3100              |
| Crude protein (%)                    | 22.61            | 20.80           | 18.89             |
| Digestible lysine (%)                | 1.26             | 1.11            | 0.99              |
| Digestible methionine + cysteine (%) | 0.93             | 0.84            | 0.77              |
| Digestible threonine (%)             | 0.84             | 0.74            | 0.66              |
| Calcium (%)                          | 0.94             | 0.84            | 0.75              |
| Available Phosphorus (%)             | 0.47             | 0.42            | 0.38              |
| Sodium (%)                           | 0.16             | 0.15            | 0.15              |

\* The vitamin-mineral premix provided the following quantities per kg of diet: vitamin A, 9000 IU; vitamin D3, 2000 IU; vitamin E, 18 IU; vitamin K3, 2 mg; vitamin B1, 1.8 mg; vitamin B2, 6.6 mg; vitamin B3, 10 mg; vitamin B5, 30 mg; vitamin B6, 3 mg; vitamin B9, 1 mg; vitamin B12, 0.015 mg; biotin, 0.1 mg; choline chloride, 250 mg; antioxidant, 100 mg; Mn, 100 mg; Zn, 84.7 mg; Fe, 50 mg; Cu, 10 mg; I, 1 mg; Se, 0.2 mg.

### Growth performance

Growth performance parameters, including body weight gain (BWG) and feed intake (FI) were measured while feed conversion ratio (FCR) was calculated for starter (1-10 d), grower (11-21 d), finisher (22-42 d), and overall period (1-42 days).

### Carcass yield and relative weight of organs

On day 42, four birds from each replicates were randomly selected, weighed and slaughtered for carcass analysis, and determination of relative weight of organs. The weight of carcass, breast, thigh, gizzard, liver, heart, spleen and abdominal fat for each slaugh-

tered bird was calculated as a relative percentage of live body weight (Zaghari *et al.*, 2016).

### Hematological parameters

At the end of experiment, blood samples were collected from wing vein of four birds from each replicates, and divided into two aliquots. The first aliquot was transferred to a 2 ml heparinized tube containing EDTA to determine leukocytes, and other one in the same tube without anticoagulant and left to clot then serum was collected for humoral and biochemical analyses. Blood smears were prepared from each samples by Giemsa staining, and were examined un-

der a compound microscope for leukocyte differential count according to Beski and Al-Sardary (2015). Moreover, 100 cells from the slides were evaluated to determine the heterophil to lymphocyte ratio.

### Serum biochemical analysis

The collected blood samples (4 birds per replicate) in the 2 ml tube without anticoagulant left to clot, then serum was collected by centrifuging (1500 g for 15 min at 4°C), and stored at -20°C.

The concentration of serum total protein (TP), triglyceride (TG), glucose, total cholesterol, high-density lipoprotein (HDL) cholesterol, and low-density lipoprotein (LDL) cholesterol were measured by commercial kits (Parsazmon Co. Iran) according to the manufacturer protocols, using the Eppendorf Auto analyzer (Epos5060).

### Humoral immune parameters (Antibody titers)

The broilers were vaccinated against Newcastle, Influenza, and Infectious Bronchitis as described by Rahmani *et al.* (2005). On day 28 of the experiment, four birds from each replicate were bled by wing vein for serum antibody titer analysis (Rowghani *et al.*, 2007). The samples were tested for Newcastle and Influenza disease by HI test (Xu *et al.*, 1997), and were analyzed by an ELISA kit (Bronchitis, IDEXX Kit) for bronchitis diseases according to manufacturer's instruction.

### Determination of ileum microflora

On day 42, four birds from each replicate were randomly selected and slaughtered, and then their ileum contents (1 g) were removed to determine microflora. The samples were diluted from  $10^{-1}$  to  $10^{-7}$  in normal saline solution, and then to determine *Bacillus* spp., *Lactobacillus* spp., and *Escherichia coli* counts, the diluted samples were seeded on Nutrient agar (QueLab-393506), MRS agar (Merck, Germany), and MacConkey agar (Merck, Germany), respectively, and incubated at 37°C for 48 h. The numbers of colony-forming units (CFUs) were expressed as log<sub>10</sub> CFU per gram (Wu *et al.*, 2011).

### Ileum morphological examination

At the end of experiment, 4 birds per replicate were sampled, and ileum (5 cm after Meckel's diverticulum) was taken, and fixed in 10% formalin. The 5 µm sections were prepared and stained with hematoxylin and eosin (H&E) for light microscopic (E600; Nikon) examination. Morphological experiments were performed according to Iji *et al.* (2001) methods, using Image-J software (<http://rsb.info.nih.gov/ij/>).

### MUC2 gene expression

Total RNA was extracted from the 20 mg of the homogenized ileum intestinal samples (3 birds from each replicates) using the RNA Isolation Kit (QIAGEN, Cat. No. 74104), and then cDNA synthesis was performed in a total volume of 25 µl from 5 µl of extracted RNA using Quantifast Reverse-Transcriptase cDNA synthesis kit (QIAGEN, Cat. No. 205311) according to the manufacturer's recommendations. Relative expression of *MUC2* gene was quantified in duplicate for each cDNA sample on the Real-Time PCR detection system (Applied Biosystems) using Quanti Fast Syber Green PCR kit (QIAGEN, Cat. No. 204052), and specific primer pairs (BX930545; F: 5'-ATGCGATGTTAACACAGGACTC-3'; R: 5'-GTGGAGCACAGCAGACTTTG -3') with cycling parameters of 95°C for 10 min for 1 cycle, 95°C for 15 s, 60°C for 20 s, and 72°C for 40 s for 40 cycles, as described previously by Forder *et al.* (2012). The melting curve of each amplicon was examined, and the expression of the *MUC2* gene was corrected based on the endogenous control expression (*GAPDH* gene: NM\_204305; F: 5'-TGTGACTTCAATGGTGACAGC-3', R: 5'-GCTATATCCAACTCATTGTCATACC-3') and calculated as fold change according to the  $2^{-\Delta\Delta Ct}$  method (Livak and Schmittgen, 2001).

### Statistical analysis

The data were analyzed using the statistical package SAS software (SAS Institute, 2007) by one-way analysis of variance (ANOVA) followed by Tukey's pairwise multiple comparison test. Values of  $P < 0.05$  were considered statistically significant.

## RESULTS

### Growth performance

The results of growth performance of broilers fed with diets containing native strain (*B. tequilensis* K03) and commercial product (*B. subtilis* DSM 17299) of *Bacillus* spp. probiotic are presented in Table 2. The results showed that dietary supplementation of *Bacillus* spp. probiotics (both native strain and commercial product) significantly improved BW, FCR of birds compared to the control group ( $P < 0.05$ ) during the overall period, while there was no significant difference ( $P > 0.05$ ) for starter, grower, and finisher periods. Feed intake was not affected by treatments. No significant differences were found in growth performance parameters between birds fed native strain and commercial *Bacillus* spp. probiotic supplemented diets ( $P > 0.05$ ).



**Table 2.** Growth performance of broiler chickens fed *Bacillus* spp. probiotics at different periods of experiment

| Parameters          | C                | PC               | NP               | SEM  | P-value |
|---------------------|------------------|------------------|------------------|------|---------|
| <b>1 – 10 days</b>  |                  |                  |                  |      |         |
| BW (g)              | 238.3            | 243.7            | 244.8            | 2.0  | 0.4     |
| FI (g)              | 266.2            | 235.2            | 233.8            | 11.3 | 0.4     |
| FCR                 | 1.1              | 0.9              | 0.9              | 0.05 | 0.3     |
| <b>11 – 21 days</b> |                  |                  |                  |      |         |
| BW (g)              | 601.4            | 625.9            | 627.5            | 7.5  | 0.3     |
| FI (g)              | 852.1            | 835.2            | 834.4            | 16.3 | 0.9     |
| FCR                 | 1.4              | 1.33             | 1.3              | 0.02 | 0.2     |
| <b>22 – 42 days</b> |                  |                  |                  |      |         |
| BW (g)              | 1720.6           | 1763.7           | 1762.5           | 10.1 | 0.1     |
| FI (g)              | 3676.9           | 3663.8           | 3662.1           | 19.0 | 0.9     |
| FCR                 | 2.1              | 2.0              | 2.0              | 0.01 | 0.06    |
| <b>1 – 42 days</b>  |                  |                  |                  |      |         |
| BW (g)              | 2602.3           | 2675.4           | 2676.9           | 15.3 | 0.05    |
| FI (g)              | 4795.3           | 4734.3           | 4730.4           | 42.8 | 0.8     |
| FCR                 | 1.8 <sup>a</sup> | 1.7 <sup>b</sup> | 1.7 <sup>b</sup> | 0.01 | 0.04    |

Different letters indicate significant differences between groups at  $P < 0.05$ .

BW, Body weight; FI, Feed intake; FCR, Feed conversion ratio

C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

### Carcass yield and relative weight of organs

The results of carcass yield and relative weight of organs of broiler chickens are shown in Table 3. The relative weight of carcass, breast, thigh, and spleen were significantly increased and abdominal fat was decreased ( $P \leq 0.05$ ) in the birds fed with diets supplemented with *Bacillus* spp. probiotics (native strain and commercial product) as compared to the control

during the overall experimental period. However, dietary *Bacillus* spp. probiotics had no significant effects on relative weight of liver, gizzard, and heart of the birds ( $P > 0.05$ ). No significant differences in carcass yield and relative weight of organs were observed between birds fed dietary native strain and commercial *Bacillus* spp. probiotics ( $P > 0.05$ ).

**Table 3.** Carcass yield and relative organ weight in broiler chickens fed *Bacillus* spp. probiotic diets at 42 d of age

| Parameters (%) | C                 | PC                | NP                | SEM  | P-value |
|----------------|-------------------|-------------------|-------------------|------|---------|
| Carcass yield  | 66.2 <sup>a</sup> | 67.3 <sup>b</sup> | 67.4 <sup>b</sup> | 0.2  | 0.05    |
| Breast         | 22.4 <sup>a</sup> | 23.3 <sup>b</sup> | 23.4 <sup>b</sup> | 0.1  | 0.05    |
| Thigh          | 16.1 <sup>a</sup> | 16.8 <sup>b</sup> | 16.8 <sup>b</sup> | 0.1  | 0.04    |
| Liver          | 1.6               | 1.6               | 1.8               | 0.03 | 0.11    |
| Gizzard        | 1.6               | 1.7               | 1.8               | 0.03 | 0.17    |
| Spleen         | 0.1 <sup>a</sup>  | 0.2 <sup>b</sup>  | 0.2 <sup>b</sup>  | 0.01 | 0.04    |
| Heart          | 0.8               | 0.9               | 0.8               | 0.07 | 0.96    |
| Abdominal fat  | 1.6 <sup>a</sup>  | 1.4 <sup>b</sup>  | 1.3 <sup>b</sup>  | 0.04 | 0.04    |

Different letters indicate significant differences between groups at  $P < 0.05$ .

C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

### Hematological parameters (leukocytes)

The effects of dietary supplementation of native strain and commercial *Bacillus* spp. probiotics on leukocytes differential count of broiler chickens are shown in Table 4. Diets containing native strain and commercial *Bacillus* spp. probiotics (K03 and DSM 17299, respectively) significantly increased the percentage of lymphocytes compared to the control

group ( $P < 0.05$ ), however, no significant differences were found between K03 and DSM 17299 groups ( $P > 0.05$ ). There was no significant differences in the percentage of heterophile, eosinophil, basophile, monocyte, as well as heterophile/lymphocytes ratio of birds fed diets containing native strain and commercial *Bacillus* spp. probiotics compared to the control group ( $P > 0.05$ ).

**Table 4.** Hematological parameters of broiler chickens fed *Bacillus* spp. probiotics based diets at 42 d of age

| Parameters (%)          | C                 | PC                | NP                | SEM  | P-value |
|-------------------------|-------------------|-------------------|-------------------|------|---------|
| Heterophile             | 31.6              | 31.5              | 31.3              | 0.3  | 0.9     |
| Lymphocytes             | 51.8 <sup>a</sup> | 53.4 <sup>b</sup> | 53.9 <sup>b</sup> | 0.3  | 0.02    |
| Monocyte                | 7.7               | 7.2               | 7.3               | 0.1  | 0.52    |
| Eosinophil              | 2.6               | 2.7               | 2.7               | 0.05 | 0.74    |
| Basophile               | 2.5               | 2.5               | 2.6               | 0.03 | 0.69    |
| Heterophile/Lymphocytes | 0.6               | 0.5               | 0.5               | 0.01 | 0.56    |

Different letters indicate significant differences between groups at  $P < 0.05$ .

C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

### Serum biochemical parameters

The results of serum biochemical analysis of broilers fed with diets containing probiotic are shown in Table 5. The results revealed significant decrease in serum triglycerides and total cholesterol levels of birds fed dietary native strain and commercial *Bacillus* spp. probiotics (K03 and DSM 17299) compared

to the control group ( $P < 0.05$ ), however, no significant differences were found between K03 and DSM 17299 dietary groups ( $P > 0.05$ ). No significant differences were also found in serum glucose, total protein, High density lipoprotein (HDL), and Low density lipoprotein (LDL) levels among treatments ( $P > 0.05$ ).

**Table 5.** Serum biochemical parameters in broiler chickens fed *Bacillus* spp. probiotics based diets at 42 d of age.

| Parameters                               | C                  | PC                 | NP                 | SEM  | P-value |
|--|--------------------|--------------------|--------------------|------|---------|
| Glucose (mg dl <sup>-1</sup> )           | 261.0              | 235.9              | 246.9              | 12.6 | 0.75    |
| Total protein (g dl <sup>-1</sup> )      | 3.2                | 3.6                | 3.4                | 0.1  | 0.74    |
| Triglycerides (mg dl <sup>-1</sup> )     | 79.5 <sup>a</sup>  | 66.9 <sup>b</sup>  | 67.9 <sup>b</sup>  | 2.2  | 0.02    |
| Total Cholesterol (mg dl <sup>-1</sup> ) | 163.2 <sup>a</sup> | 147.9 <sup>b</sup> | 149.3 <sup>b</sup> | 2.7  | 0.01    |
| HDL (mg dl <sup>-1</sup> )               | 65.3               | 59.8               | 62.4               | 1.7  | 0.49    |
| LDL (mg dl <sup>-1</sup> )               | 54.2               | 49.6               | 52.2               | 2.3  | 0.76    |

Different letters indicate significant differences between groups at  $P < 0.05$

C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

### Humoral immune parameters (Antibody titers)

The results of humoral immune responses of birds are shown in Table 6. Results revealed a significant increase ( $P < 0.05$ ) in antibody titers against Newcastle diseases virus (NDV) and infectious bronchitis virus (IBV) of vaccinated birds fed with diets containing native strain and commercial *Bacillus* spp. probiot-

ics (K03 and DSM 17299) in comparison with the control group ( $P < 0.05$ ), however, no significant differences were seen between K03 and DSM 17299 dietary groups. Moreover, diets containing *Bacillus* spp. probiotics had no significant effects on antibody titer against Influenza.

**Table 6.** Effect of *Bacillus* spp. Probiotics on immune response (antibody body production) of broiler chickens at 28 d of age

| Parameters | C                   | PC                  | NP                  | SEM   | P-value |
|------------|---------------------|---------------------|---------------------|-------|---------|
| Bronchitis | 2676.2 <sup>a</sup> | 2772.7 <sup>b</sup> | 2784.5 <sup>b</sup> | 18.88 | 0.01    |
| Newcastle  | 3.6 <sup>a</sup>    | 4.6 <sup>b</sup>    | 4.6 <sup>b</sup>    | 0.19  | 0.03    |
| Influenza  | 1.3                 | 1.3                 | 1.4                 | 0.01  | 0.12    |

Different letters indicate significant differences between groups at  $P < 0.05$ .

C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

### Ileum microflora

The effect of treatments on ileum microflora of broilers (42 d) is shown in Table 7. The results revealed that the native strain and the commercial *Bacillus* spp. probiotics (K03 and DSM 17299) significantly increased the *Bacillus* spp. Populations. *E. coli* was significantly

decreased in the ileum content of birds fed with diets supplemented with probiotics as compared to control ( $P < 0.05$ ), however, no significant differences were found between the treated groups ( $P > 0.05$ ). Despite the slight increase in *Lactobacillus* spp. there were no significant differences between treated and control groups.

**Table 7.** Ileum bacterial counts [log (cfu/g)] of broiler chickens fed *Bacillus* spp. probiotic diets at 42 d of age

| Parameters                | C                | PC               | NP               | SEM | P-value |
|---------------------------|------------------|------------------|------------------|-----|---------|
| <i>Lactobacillus</i> spp. | 6.6              | 7.3              | 7.4              | 0.1 | 0.09    |
| <i>Bacillus</i> spp.      | 5.6 <sup>a</sup> | 6.1 <sup>b</sup> | 6.3 <sup>b</sup> | 0.1 | 0.03    |
| <i>Escherichia coli</i>   | 7.0 <sup>a</sup> | 6.2 <sup>b</sup> | 6.1 <sup>b</sup> | 0.1 | 0.04    |

Different letters indicate significant differences between groups at  $P < 0.05$ .

C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

### Ileum morphology

The result of morphological analysis of ileum is shown in Table 8. No histopathological changes were observed in the intestine tissue of any birds of all feeding groups (Fig. 1). Morphological analysis of ileum revealed significant increases ( $P < 0.05$ ) in the villus height in birds fed with dietary containing *Bacillus*

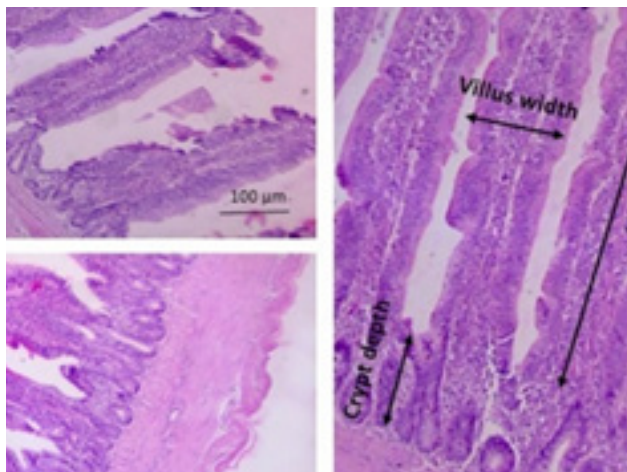
spp. probiotics (Native strain and commercial product) as compared to the control group, however, no significant differences were found between native and commercial probiotic dietary groups ( $P > 0.05$ ). There were no significant differences in the villus width, crypt depth, as well as villus height/crypt of ileum between experimental and control groups ( $P > 0.05$ ).

**Table 8.** Ileum morphology of broiler chickens fed *Bacillus* spp. probiotic diets at 42 d of age

| Parameters ( $\mu\text{m}$ ) | C                  | PC                 | NP                 | SEM  | P-value |
|------------------------------|--------------------|--------------------|--------------------|------|---------|
| Villus height                | 769.0 <sup>a</sup> | 859.3 <sup>b</sup> | 889.7 <sup>b</sup> | 17.8 | 0.01    |
| Villus width                 | 153.6              | 154.2              | 165.2              | 4.7  | 0.53    |
| Villus height/crypt          | 6.0                | 6.7                | 7.0                | 0.2  | 0.17    |
| Crypt depth                  | 133.1              | 134.5              | 132.6              | 3.9  | 0.97    |

Different letters indicate significant differences between groups at  $P < 0.05$ .

C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

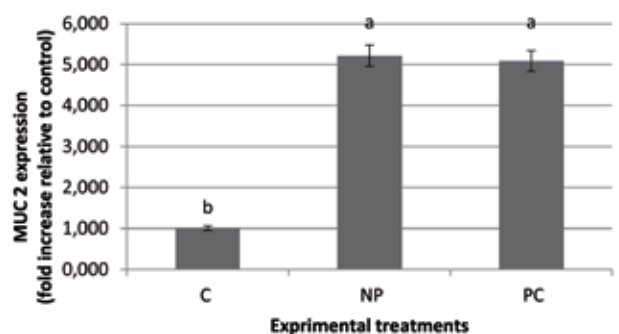


**Fig. 1.** Histological section (H&E) showing ileum morphology (Villus height, Crypt depth, and Villus width) of broiler chickens fed *Bacillus* spp. probiotics based diets at 42 d of age. C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); SEM, Standard error of means.

### Intestinal *MUC2* gene expression

The effects of probiotic treated diets on expression of the intestinal *MUC2* gene are shown in the Fig. 2. The expression of intestinal *MUC2* gene was quantified by qPCR assay, and expressed relative to expression of the *GAPDH* gene. The relative expres-

sion of *MUC2* gene was significantly increased in the dietary native strain and commercial probiotics (K03 and DSM 17299, respectively) compared to the control group ( $P < 0.05$ ). No significant differences were found in *MUC2* gene expression between birds fed with K03 and DSM 17299 probiotic supplemented diets ( $P > 0.05$ ).



**Fig. 2.** The relative expression of *muc2* gene in the intestine tissue of broiler chickens fed *Bacillus* spp. probiotics diets at 42 d of age. C, Control; NP, Native Probiotic (200 g/ton, *B. tequilensis* K03,  $4 \times 10^9$  CFU/g); PC, Positive Control (200g/ton, *B. subtilis* DSM 17299,  $4 \times 10^9$  CFU/g); Data were normalized based on endogenous *GAPDH* gene and presented as mean fold increase relative to the control ( $2^{-\Delta\Delta\text{Ct}}$  method). Different letters indicate significant differences between groups at  $P < 0.05$ .



## DISCUSSION

The present study showed that consumption of diets supplemented with NP and PC significantly improved FCR and increased BW. The beneficial effects of dietary *Bacillus* spp. probiotic supplementation on FCR and increased BW of broilers are well documented in many studies (Opalinski *et al.*, 2007; Melegy *et al.*, 2011; Yang *et al.*, 2016; Reis *et al.*, 2017). Spore-forming *Bacillus* spp. have been noticed as probiotic candidates due to their beneficial effects on animal health and growth, as well as their survivability under the harsh environment of the gastrointestinal tract, and stability during processing and long-term storage (Elshaghabee *et al.*, 2017). Probiotics can modulate intestinal microflora, change intestinal morphology or secretion of enzymes and produce antimicrobial compounds. They can regulate immune system, increase the digestibility and the absorption of dietary nutrients and consequently improve the broiler performance (Ghadban, 2002; Elshaghabee *et al.*, 2017). However, since the host origin microbes are quite familiar with the environment of gastrointestinal tract, the native and species-specific probiotic are highly preferred (Kabir, 2009). Similar studies showed that the improvement of broiler performance can be caused by beneficial changes of intestinal morphology and microflora (Ghadban, 2002; Elshaghabee *et al.*, 2017). In this investigation increased BW and decreased FCR could be attributed to the growth of beneficial bacteria in the digestive tract, digestive enzymes production by these bacteria and improved digestion and absorption processes. The lack of impact in the initial period may be explained by the fact that probiotic bacteria are required to longer time for localization in the digestive tract. Our results showed that supplementation with the *B. tequilensis* K03 strain and commercial *B. subtilis* DSM 17299 have no effect on feed intake of chickens. Several studies (Opalinski *et al.*, 2007; Melegy *et al.*, 2011) have shown that feed intake of chickens was not affected by supplementation of *Bacillus* spp., suggesting that these strains cannot affect their appetite (Ferket and Gernat, 2006).

In our present study, increase in spleen relative weight, carcass, thigh and breast meat yield and decrease in abdominal fat of broiler chicks have been found when compared with the control group. These results are in agreement with those of Hatab *et al.* (2016), who reported that dietary supplementation with *Bacillus* spp. probiotics (*B. tequilensis* K03 strain and *B. subtilis* DSM 17299) rose carcass and

relative organ weights due to increase of cell growth and turnover, while other researchers reported that (Afsharmanesh *et al.*, 2014; Park *et al.*, 2014; Reis *et al.*, 2017; Shokryazdan *et al.*, 2017), using the same or different probiotic species did not affect the relative organ weights of broilers. The reason for these contradictions may be due to differences in conditions of chickens, methods of administration, viability and concentrations of used bacteria, as well as the strain sources (Shokryazdan *et al.*, 2017). Therefore, it seems probably that increase in carcass, thigh and breast meat yield of broiler in our present study can be due to useful effect of probiotics in the growth of intestinal microbiota. In the report of Santoso *et al.* (2001) decrease synthesis and storage of fat in adipose tissue lead to decrease the percentage of abdominal fat.

Our results showed a significant increase in lymphocytes level, antibody titers against NDV and IBV of vaccinated birds. Lymphocytes play a crucial role in innate immune response, especially during stressful conditions, and participate in inflammation responses and phagocytosis. The increase in lymphocytes level indicates stimulation of the immune properties by *Bacillus* spp. probiotics that lead to increase in relative lymphoid organ weights (such as spleen). This assumption is supported by report of Neveling *et al.* (2017), who reported higher lymphocytes level in birds after dietary supplementation with probiotics.

It is strongly possible that probiotic microorganisms as an external organism stimulate the immune system, increase production the number of white blood cells and other immune compounds, the percentage of lymphocytes increased. Moreover, the ability of probiotics to promote humoral immunity in chickens vaccinated against Newcastle disease and infectious bronchitis reported by Rowghani *et al.* (2007), and in present study confirmed the immunostimulatory effects of the selected strain and the commercial *Bacillus* spp. probiotics. Probiotics control the balance of pro-inflammatory and anti-inflammatory cytokines. Cytokines have an important role in immune responses. IFN- $\gamma$  is a subset of the cytokine T-helper 1 that lead to killing organisms and protecting against all types of intracellular infections. Moreover interleukin-4 also can stimulate the differentiation of B cells and increase the production of antibodies to B cells (Belardelli, 1995). Therefore, the probable reason of increase in NDV and IBV of vaccinated birds is the stimulation of the immune system by probiotic native *Bacillus* spp. and probiotic Galpiro.

Our results showed a significant decrease in tri-glyceride and total cholesterol concentration in the serum of broilers fed with *B. tequilensis* K03 strain and *B. subtilis* DSM 17299 compared with the control group. Probiotics increase deconjugation of biliary acids excretion and since cholesterol is a substrate for the synthesis of bile acids, cholesterol molecules are used to produce bile acids (De Smet *et al.*, 1998). Therefore they decrease the lipids level of blood.

In our present study, *Bacillus* spp. populations increased in the intestine of broilers fed the *B. tequilensis* K03 strain and *B. subtilis* DSM 17299. Several studies have demonstrated that dietary supplementation with *Bacillus* spp. modulate the microflora of broilers (Knap *et al.*, 2011; Sen *et al.*, 2012; Guyard-Nicodeme *et al.*, 2016). Probiotics which increase the number of lactic acid bacteria in the gastrointestinal reduce its pH. Therefore, an unsuitable environment for the growth of harmful bacteria such as *E. coli* and *Salmonella* spp. is provided (Deniz *et al.*, 2011). Therefore, it seems probably that probiotic native *Bacillus* spp. and probiotic Galpiro by pH reduction, increase beneficial bacteria and decrease *E. coli* population.

Our results indicated that the *B. tequilensis* K03 strain and *B. subtilis* DSM 17299 significantly increased villus height in ileum of the chickens. The effect of dietary *Bacillus* spp. probiotics on intestinal morphology of broilers has been well documented. Sen *et al.* (2012) reported the increased villus height and villus height to crypt depth ratio in chicken fed *Bacillus* spp. dietary. Deng *et al.* (2012) also found that dietary *Bacillus licheniformis* increased villus height in the ileum under heat stress conditions. It

is showed that the digestive function of the intestine is related to villi structure and mucosal architecture, which influence absorptive capacity (Sen *et al.*, 2012; Neveling *et al.*, 2017). Moreover, probiotics by short-chain organic acids formation stimulate the proliferation of epithelial cells and lead to increased villus height (Ichikawa *et al.*, 1999).

The mucin secreted by goblet cells in the villi of the intestine is the main glycoprotein component of the mucus layer that it has role in modulation of intestinal microflora and health (Forder *et al.*, 2007). In this study, intestinal *MUC2* gene expression under influence of two types of *Bacillus* spp. probiotic was significantly increased, suggesting that the probiotics may bind to specific receptor sites on the enterocyte and stimulate *MUC2* gene expression (Mattar *et al.*, 2002).

## CONCLUSION

From this study, it can be concluded that the identified native *B. tequilensis* K03 strain can improve immunity, hemato-biochemical parameters, as well as broiler performance, which can be explained by the modified intestinal microflora, intestinal morphology changes and increase of *MUC2* gene expression. Since the effects of selected strain (*B. tequilensis* K03) were similar with the GalliPro® commercial probiotic (*Bacillus subtilis* DSM 17299) it can be used as probiotic potential for broilers feed.

## ACKNOWLEDGMENTS

This research did not receive any specific funding.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

- Afsharmanesh M, Sadaghi B, Silversides FG (2011) Influence of supplementation of prebiotic, probiotic, and antibiotic to wet-fed wheat-based diets on growth, ileal nutrient digestibility, blood parameters, and gastrointestinal characteristics of broiler chickens. *Comp Clin Path* 22:245-251.
- Amerah AM, Quiles A, Medel P, Sánchez J, Lehtinen MJ, Gracia MI (2013) Effect of pelleting temperature and probiotic supplementation on growth performance and immune function of broilers fed maize/soy-based diets. *Anim Feed Sci Tech* 180:55-63.
- Belardelli FI (1995) Role of interferons and other cytokines in the regulation of the immune response. *Apmis* 103:161-179.
- Beski SSM, Al-Sardary SYT (2015) Effects of dietary supplementation of probiotic and synbiotic on broiler chickens hematology and intestinal integrity. *Int J Poult Sci* 14:31-36.
- Coates ME, Fuller R, Harrison GF, Lev M, Suffolk SF (1963) A comparison of the growth of chicks in the Gustafsson germ-free apparatus and in a conventional environment, with and without dietary supplements of penicillin. *Br J Nutr* 17:141-150.
- Cutting SM (2011) *Bacillus* probiotics. *Food Microbiol* 28:214-220.
- De Smet I, De Boever P, Verstraete W (1998) Cholesterol lowering in pigs through enhanced bacterial bile salt hydrolase activity. *Br J Nutr* 79:185-194.
- Deng W, Dong XF, Tong JM, Zhang Q (2012) The probiotic *Bacillus licheniformis* ameliorates heat stress-induced impairment of egg production, gut morphology and intestinal mucosal immunity in laying hens. *Poult Sci* 91:575-582.
- Deniz G, Orman A, Cetinkaya F, Gencoglu H, Meral Y, Turkmen II (2011) Effects of probiotic (*Bacillus subtilis* DSM 17299) supplementation on the caecal microflora and performance in broiler chickens. *Revue Med Vet* 11:538-545.
- Elshaghabee FMF, Rokana N, Gulhane RD, Sharma C, Panwar H (2017) *Bacillus* as potential probiotics: status, concerns, and future perspectives.

- tives. *Front Microbiol* 8:1490.
- Ferket PR, Gernat AG (2006) Factors that affect feed intake of meat birds: A review. *Int J Poultry Sci* 5:905-911.
- Forder REA, Howarth GS, Tivey DR, Hughes RJ (2007) Bacterial modulation of small intestinal goblet cells and mucin composition during early posthatch development of poultry. *Poult Sci* 86:2396-2403.
- Forder RE, Natrass GS, Geier MS, Hughes RJ, Hynd PI (2012) Quantitative analyses of genes associated with mucin synthesis of broiler chickens with induced necrotic enteritis. *Poult Sci* 91:1335-1341.
- Gatson JW, Benz BF, Chandrasekaran C, Satomi M, Venkateswaran K, Hart ME (2006) *Bacillus tequilensis* sp. nov., isolated from a 2000-year-old Mexican shaft-tomb, is closely related to *Bacillus subtilis*. *Int J Syst Evol Microbiol* 56:1475-1484.
- Ghadban GS (2002) Probiotics in broiler production- a review. *Arch Geflügelkd* 66:49-58.
- Ghorban Hosseini N, Modarressi MH, Mousavi SN, Tajabadi Ebrahimi M (2019) Evaluation of novel probiotic *Bacillus* strains based on enzyme production and protective activity against salmonellosis. *J HELLENIC VET MED SOC* 69:1205-1212.
- Guyard-Nicodeme M, Keita A, Quesne S, Amelot M, Poezevara T, Le Berre B, Sánchez J, Vasseur P, Martín Á, Medel P, Chemaly M (2016) Efficacy of feed additives against *Campylobacter* in live broilers during the entire rearing period. *Poult Sci* 95:298-305.
- Hatab MH, Elsayed MA, Ibrahim NS (2016) Effect of some biological supplementation on productive performance, physiological and immunological response of layer chicks. *J Radiat Res Appl Sci* 9:185-192.
- Hong HA, Huang JM, Khaneja R, Hiep LV, Urdaci MC, Cutting SM (2008) The safety of *Bacillus subtilis* and *Bacillus indicus* as food probiotics. *J Appl Microbiol Biochem* 105:510-520.
- Huang MK, Choi YJ, Houde R, Lee JW, Lee B, Zhao X (2004) Effects of *Lactobacilli* and an acidophilic fungus on the production performance and immune responses in broiler chickens. *Poult Sci* 83:788-795.
- Ichikawa H, Kuroiwa T, Inagaki A, Shineha R, Nishihira T, Satomi S, Sakata T (1999) Probiotic bacteria stimulate gut epithelial cell proliferation in rat. *Dig Dis Sci* 44:2119-2123.
- Iji PA, Saki AA, Tivey DR (2001) Intestinal development and body growth of broiler chicks on diets supplemented with non-starch polysaccharides. *Anim Feed Sci Tech* 89:175-188.
- Jeevana Lakshmi P, Kumari Chitturi CM, Lakshmi VV (2013) Efficient degradation of feather by keratinase producing *Bacillus* sp. *Int J Microbiol* 7.
- Jeong JS, Kim IH (2014) Effect of *Bacillus subtilis* C-3102 spores as a probiotic feed supplement on growth performance, noxious gas emission, and intestinal microflora in broilers. *Poult Sci* 93:3097-3103.
- Kabir SM (2009) The role of probiotics in the poultry industry. *Int J Mol Sci* 10:3531-3546.
- Khaksefidi A, Ghoorchi T (2006) Effect of probiotic on performance and immunocompetence in broiler chicks. *Poult Sci* 43:296-300.
- Knap I, Kehlet AB, Bennedsen M, Mathis GF, Hofacre CL, Lumpkins BS, Jensen MM, Raun M, Lay A (2011) *Bacillus subtilis* (DSM17299) significantly reduces *Salmonella* in broilers. *Poult Sci* 90:1690-1694.
- Latorre JD, Hernandez-Velasco X, Wolfenden RE, Vicente JL, Wolfenden AD, Menconi A, Bielke LR, Hargis BM, Tellez G (2016) Evaluation and selection of *Bacillus* species based on enzyme production, antimicrobial activity, and biofilm synthesis as direct-fed microbial candidates for poultry. *Front Vet Sci* 3:95.
- Livak KJ, Schmittgen TD (2001) Analysis of relative gene expression data using real-time quantitative PCR and the 2<sup>-ΔΔC<sub>T</sub></sup> method. *Methods* 25:402-408.
- Mattar A, Teitelbaum DH, Drongowski R, Yongyi F, Harmon C, Coran A (2002) Probiotics up-regulate MUC-2 mucin gene expression in a Caco-2 cell-culture model. *Pediatr Surg Int* 18:586-590.
- Melegy T, Khaled NF, El-Bana R, Abdellatif H (2011) Effect of dietary supplementation of *Bacillus subtilis* PB6 (Clostat™) on performance, immunity, gut health and carcass traits in broilers. *AM SCI* 7:891-898.
- Mingmongkolchai S, Panbangred W (2018) *Bacillus* probiotics: an alternative to antibiotics for livestock production. *J Appl Microbiol Biochem* 124:1334-1346.
- Mountzouris KC, Tsirtsikos P, Kalamara E, Nitsch S, Schatzmayr G, Fegeros K (2007) Evaluation of the efficacy of a probiotic containing *Lactobacillus*, *Bifidobacterium*, *Enterococcus*, and *Pediococcus* strains in promoting broiler performance and modulating cecal microflora composition and metabolic activities. *Poult Sci* 86:309-317.
- Nawab A, Liu W, Li G, Ibtisham F, Fox DP, Zhao Y, Wo J, Xiao M, Nawab Y, An L (2018) The potential role of probiotics (nutraceuticals) in gut health of domestic animals; an alternative to antibiotic growth promoters. *J HELLENIC VET MED SOC* 69:1169-1188.
- Neveling DP, Van Emmenes L, Ahire JJ, Pieterse E, Smith C, Dicks LMT (2017) Safety assessment of antibiotic and probiotic feed additives for *Gallus gallus* domesticus. *Sci Rep* 7:12767.
- Opalinski K, Maiorka A, Dahlke F, Cunha F, Vargas FSC, Cardozo E (2007) On the use of a probiotic (*Bacillus subtilis* - strain DSM 17299) as growth promoter in broiler diets. *Braz J Poultry Sci* 9:99-103.
- Park JH, Kim IH (2014) Supplemental effect of probiotic *Bacillus subtilis* B2A on productivity, organ weight, intestinal *Salmonella* microflora, and breast meat quality of growing broiler chicks. *Poult Sci* 93:2054-2059.
- Rahmani HR, Speer W, Modirsanei M (2005) The Effect of Intestinal pH on Broiler Performance and Immunity. In: The 15th European Symposium on poultry nutrition, Balatonfüred, Hungary: pp 338-340.
- Reis MP, Fassani EJ, Júnior AG, Rodrigues PB, Bertechini AG, Barrett N, Persia ME, Schmidt CJ (2017) Effect of *Bacillus subtilis* (DSM 17299) on performance, digestibility, intestine morphology, and pH in broiler chickens. *J Appl Poultry Res* 26:573-583.
- Rowghani E, Arab M, Akbarian A (2007) Effects of a probiotic and other feed additives on performance and immune response of broiler chicks. *Int J Poultry Sci* 6:261-265.
- Santoso U, Tanaka K, Ohtani S, Sakaida M (2001) Effect of fermented product from *Bacillus subtilis* on feed conversion efficiency, lipid accumulation and ammonia production in broiler chicks. *Asian-Australas J Anim Sci* 14:333-337.
- Sen S, Ingale SL, Kim YW, Kim JS, Kim KH, Lohakare JD, Kim EK, Kim HS, Ryu MH, Kwon IK, Chae BJ (2012) Effect of supplementation of *Bacillus subtilis* LS 1-2 to broiler diets on growth performance, nutrient retention, caecal microbiology and small intestinal morphology. *Res Vet Sci* 93:264-268.
- Shokryazdan P, Jahromi MF, Liang JB, Ramasamy K, Sieo CC, Ho YW (2017) Effects of a *Lactobacillus salivarius* mixture on performance, intestinal health and serum lipids of broiler chickens. *PLoS one* 12:e0175959.
- Tellez G, Pixley C, Wolfenden RE, Layton SL, Hargis BM (2012) Probiotics/direct fed microbials for *Salmonella* control in poultry. *Food Res Int* 45:628-633.
- Thirabunyanon M, Thongwittaya N (2012) Protection activity of a novel probiotic strain of *Bacillus subtilis* against *Salmonella enteritidis* infection. *Res Vet Sci* 93:74-81.
- Wu BQ, Zhang T, Guo LQ, Lin JF (2011) Effects of *Bacillus subtilis* KD1 on broiler intestinal flora. *Poult Sci* 90:493-499.
- Xu CL, Ji C, Ma Q, Hao K, Jin ZY, Li K (2006) Effects of a dried *Bacillus subtilis* culture on egg quality. *Poult Sci* 85:364-368.
- Yang J, Qian K, Zhang W, Xu Y, Wu Y (2016) Effects of chromium-enriched *Bacillus subtilis* KT260179 supplementation on chicken growth performance, plasma lipid parameters, tissue chromium levels, cecal bacterial composition and breast meat quality. *Lipids Health Dis* 15:188.
- Zaghari M, Zahroojian N, Riahi M, Parhizkar S (2015) Effect of *Bacillus subtilis* spore (GalliPro®) nutrients equivalency value on broiler chicken performance. *Ital J Anim Sci* 14:3555.