

EFFECTS OF DIETARY BANANA PEEL MEAL SUPPLEMENTATION ON HEMATOLOGICAL TRAITS, IMMUNE ORGAN DEVELOPMENT, SERUM BIOCHEMISTRY, AND INTESTINAL MORPHOLOGY OF BROILER CHICKENS

Arooj Sohail¹, Zubair Azhar Nomi¹, Muhammad Farhan Anwar³, Baseer Ahmad⁴,
Muhammad Hamza Muneer⁵, Rana Muhammad Shahbakht⁶, Kashif Hussain⁷,
Rana Waseem Akhtar⁸, Atif Rehman⁹, Shahid Ali Rajput^{*10}

^{1,2,4,5,6,7, *9}Faculty of Veterinary and Animal Sciences, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan.

³Department. Veterinary Pathology, University of Veterinary and Animal Sciences, Lahore, Pakistan.

⁸Department of Animal Breeding and Genetics, Faculty of Veterinary and Animal Sciences, The Islamia University of Bahawalpur, Bahawalpur, Pakistan

⁹atif.rehman@mnsuam.edu.pk, ^{*10}shahid.ali@mnsuam.edu.pk

DOI: <https://doi.org/10.5281/zenodo.23357850>

Keywords

Banana peel meal; Broiler chickens; Immune organs; Serum biochemistry; Intestinal morphology; Functional feed ingredient; Poultry nutrition; Agricultural by-products

Article History

Received: 29 June 2026

Accepted: 20 September 2026

Published: 14 October 2026

Copyright @Author

Corresponding Author: *

Atif Rehman

Shahid Ali Rajput

Abstract

With the high cost of traditional feed ingredients, and the potential for problems with using antibiotics in the feed, functional feed resources are becoming more important in poultry production. The present study aimed to assess the effect of dietary banana peel meal (BPM) supplementation on haematological indices, humoral immune response, relative immune-organ weights, serum biochemical parameters and morphology of intestine in broiler chickens. The 240 one-day-old broiler chicks were randomly distributed to four dietary treatments of 0%, 10%, 20% and 30% BPM with six replicates of 10 chicks each and fed and raised under the standard broiler rearing conditions for 7 weeks. Blood, immune organs, and intestinal tissues were collected at the end of the experimental period for laboratory analyses. There were no significant difference between the dietary treatments for levels of white blood cells, red blood cells, hemoglobin, hematocrit, or levels of antibody to Newcastle disease virus, avian influenza H9 virus or infectious bronchitis virus ($P > 0.05$). The relative weight of the bursa of Fabricius, thymus and spleen showed significant effect ($P < 0.05$) with the 20% BPM group having the highest values. These variables, which were all lipid or liver enzymes, showed significant reductions with increases in BPM inclusion ($P < 0.05$). The villus height, villus width and crypt depth increased with increasing BPM inclusion while intestinal pH decreased with BPM inclusion ($P < 0.05$). Overall, BPM inclusion influenced immune-organ weights, as well as serum biochemical parameters and the morphology of the intestine but did not have a negative impact on the other measured hematological or humoral immune responses. Results indicated that BPM can be used as a suitable sustainable functional feed ingredient for broiler chickens. Further investigation should be

conducted to assess growth performance, nutrient digestibility, gut microbiota, long-term health effects and viability for commercial production.

1. Introduction

Broiler production is a key production sector to meet the global demand for cheap animal protein. Poultry meat is a relatively inexpensive and readily accepted source of high-quality protein, polyunsaturated fatty acids, essential amino acids, and vitamins in many developing countries like Pakistan. The cost of producing conventional feed ingredients, especially maize kernels and soybean meal, which make up the bulk of feed costs, is, however, driving increased costs and decreased profitability of broiler production. As a result, identification of alternative feed ingredients in the local context which are nutritionally valuable, health-friendly, and economically viable is one of the key research priorities for poultry production (Getahun et al., 2025; Nassar, 2026). Further tightening of the use of antibiotic growth promoters has made the search for natural additives in feed for supporting the health of the gut, immune competence, and metabolic efficiency even more urgent without the risk of promoting antimicrobial resistance. Plant feed ingredients and agro-industrial by-products have been given much attention as they are rich in bioactive compounds with antioxidant, antimicrobial, anti-inflammatory, and immunomodulatory properties (Enciso-Martínez et al., 2024; Saini et al., 2025). Within these, fruit by-products are of specific interest due to their high nutrient content, as well as high dietary fiber content, minerals, and phytochemicals, and their abundance, often wasted, in fruit processing (Sorrenti et al., 2023; Teshome et al., 2023). Banana peel is one of the most abundant by-products of fruit processing, accounting for around 30-40% of the fruit weight. Banana peel is very prone to microbial degradation and high in moisture, and is usually discarded, burned, or dumped into the environment, which raises issues related to waste management and pollution (Rajib & Suborna, 2022; Hikal et al., 2022). The utilization of banana peel for animal feeding can thus be beneficial in two ways: reducing waste in

the environment and providing an alternative animal feed with low cost for poultry farming. Carbohydrates, dietary fibre, resistant starch, minerals, essential amino acids, fatty acids, and bioactive compounds including phenolics, flavonoids, tannins, carotenoids, dopamine and gallic acid are found in banana peel meal (Ansari et al., 2023; Rawat et al., 2024; Khaskheli et al., 2026). These constituents have beneficial effects on intestinal function, lipid metabolism, antioxidant function, and the suppression of pathogenic microorganisms. The inclusion of banana peels in broiler ration has been shown to yield varying results in previous studies. Some investigations indicated that banana peel meal could increase the body weight growth, feed efficiency and serum lipid profile while high inclusion level could decrease the performance due to the presence of high fiber content and antinutrient factors like tannins, phytates, oxalates and cyanogenic compounds in it (Nuriyasa et al., 2022; Alshehri et al., 2024; Viana et al., 2025). These conflicting results suggest that the biological response to banana peel meal could be influenced by the processing method, its level, nutrient composition, the age of the birds and the response variables measured. Hence, it is necessary to make further studies to assess the potential of banana peel meal as functional feed ingredient instead of energy substitution. Apart from growth performance, blood biochemical indices, hematological parameters, development of immune organs and gut morphology are sensitive indicators of physiological health and nutrient utilization in broilers. The hematological parameters are indicative of general health and metabolic adaptation, and serum levels of glucose, cholesterol, triglycerides, ALT and AST are significant markers of energy metabolism, lipid regulation, and hepatic function (Mbah et al., 2024). In turn, immune organs like the bursa of Fabricius, thymus and spleen are crucial for the maturation of lymphocytes and immune responses. The structure of the villi in the intestine

is directly related to nutrient absorption, gut integrity and microbial balance, as well as the pH of the intestinal lumen. Thus, the present study was carried out to assess the effect of supplementation of different levels of banana peel meal on haematological parameters, humoral immunoglobulin response, relative weights of immune organs, serum biochemical parameters and intestinal morphology in broiler chickens. Hypothesis: The nutritional composition of banana peel meal (fiber and bioactive phytochemicals) would promote metabolic health, development of immune organs and intestinal architecture without compromising hematological parameters.

2. Materials and Methods

2.1. Experimental Site and Ethical Approval

The experiment was carried out at Poultry Research Facility, C-Block Experimental Sheds, Faculty of Veterinary and Animal Sciences at Muhammad Nawaz Sharif University of Agriculture (MNSUA) Multan, Pakistan. All experimental procedures on animals were carried out following the guidelines of institutional care and use of experimental animals and approved by the Institutional Animal Ethics Committee of MNSUA, Multan.

2.2. Experimental Birds, Housing, and Management

A total of 240 one-day-old commercial broiler chicks (Ross 308) were obtained from a commercial hatchery. Upon arrival, the chicks were randomly assigned in a completely randomized design (CRD) into 4 dietary treatment groups. The dietary treatments were replicated 10 birds/replicate for 6 replications per dietary treatment and a total of 240 birds comprised. The feeding treatments were a basal diet without BPM (G1, basal diet) and diets supplemented with 10% (G2), 20% (G3) and 30% (G4) BPM. Experimental feeding trial was carried out for a period of 7 weeks. Feed and drinking water was offered freely during the entire experimental period. Birds were kept on deep litter system where rice husk was utilized as the litter material.

The poultry house, feeders and drinkers were completely cleaned and disinfected prior to chick placement. The brooding temperature was held at about 35°C for the first week then decreased at the rate of 2-3°C per week till it reached about 21-24°C, the relative humidity was kept at 55-65% and a lighting schedule of 22 h light: 2 h dark was used. Birds were checked every day for health and all normal commercial broiler management procedures were applied during the experimental period.

2.3. Preparation of Banana Peel Meal

Banana peels were freshly picked from the local fruit markets of Multan, Pakistan. Peelings were hand-sorted, foreign materials were removed, and the peels were well washed with clean water to get rid of dirt and contaminants. The cleaned peels were spread out evenly on clean jute sheets and were sun-dried for 4-5 days until they were significantly dried. These peeled and partially dried tubers were then put into a cabinet tray dryer to get a dry and stable product after thermal drying at 125°C for 25 min. A dried powder was obtained by grinding dried peels in a hammer mill and stored in airtight polyethylene bags until it was mixed into the experimental diets, which was described as banana peel meal (BPM).

2.4. Chemical Composition of Banana Peel Meal

The proximate analysis of the processed BPM was conducted prior to formulation of the experimental diets. The moisture, crude protein, crude fiber, ether extract, and ash contents were measured by standard methods of the Association of Official Analytical Chemists (AOAC). The final moisture content of the BPM was kept to less than 10% to ensure storage stability and reduce microbial deterioration.

2.5. Experimental Diets

The experimental diets were designed to meet the nutritional needs of broiler chickens according to the NRC (1994). The amount of BPM added to the basal diet was 0%, 10%, 20% and 30%, respectively, corresponding to T1, T2, T3 and T4. The feeding conditions and the feeding of the

diets were the same throughout the experimental period, and the diets were fed as a mash. The nutrient composition of the experimental diets

was calculated, and the ingredient composition is shown in Table 1.

Table 1. Ingredient and calculated nutrient composition of experimental diets containing graded levels of banana peel meal (BPM)

Ingredient/nutrient	Control (0% BPM)	10% BPM	20% BPM	30% BPM
Maize (%)	55.00	48.00	40.00	32.00
Soybean meal (44% CP) (%)	32.00	31.00	30.00	29.00
Banana peel meal (%)	0.00	10.00	20.00	30.00
Vegetable oil (%)	5.50	5.80	6.20	6.80
Dicalcium phosphate (%)	1.80	1.80	1.80	1.80
Limestone (%)	1.20	1.20	1.20	1.20
Salt (NaCl) (%)	0.30	0.30	0.30	0.30
Vitamin–mineral premix (%)	0.50	0.50	0.50	0.50
DL-Methionine (%)	0.25	0.30	0.35	0.40
L-Lysine HCl (%)	0.15	0.20	0.25	0.30
Total (%)	100.00	100.00	100.00	100.00
Calculated nutrient composition				
Metabolizable energy (kcal/kg)	3100	3075	3050	3025
Crude protein (%)	21.5	21.3	21.0	20.8
Crude fiber (%)	3.5	5.2	7.0	8.8
Ether extract (%)	5.5	5.8	6.0	6.3
Calcium (%)	1.00	1.00	1.00	1.00
Available phosphorus (%)	0.45	0.45	0.45	0.45
Lysine (%)	1.15	1.15	1.15	1.15
Methionine (%)	0.50	0.50	0.50	0.50

CP = crude protein; BPM = banana peel meal. The vitamin–mineral premix was supplied per kilogram of diet as follows: vitamin A, 12,000 IU; vitamin D₃, 2,500 IU; vitamin E, 30 mg; vitamin K₃, 3 mg; vitamin B₁, 2 mg; vitamin B₂, 6 mg; vitamin B₆, 4 mg; vitamin B₁₂, 0.015 mg; niacin, 40 mg; pantothenic acid, 10 mg; folic acid, 1 mg; biotin, 0.05 mg; Fe, 80 mg; Cu, 8 mg; Zn, 60 mg; Mn, 80 mg; I, 0.5 mg; and Se, 0.2 mg/kg diet.

2.6. Blood Collection and Hematological Analysis

One bird was randomly selected from each replicate at the end of the experimental period, resulting in six sampled birds per treatment. Blood samples were collected with sterile syringes. Samples for hematological examination were placed in EDTA tubes. White blood cell (WBC)

count, red blood cell (RBC) count, hemoglobin concentration (Hb) and hematocrit percentage (HCT) were measured with standard laboratory methods.

2.7. Determination of Humoral Immune Response

Blood samples were centrifuged at 3,000 × g for 10 min and the serum was collected and stored at –20°C for analysis. Commercially available enzyme-linked immunosorbent assay (ELISA) kits were used to measure serum antibody levels to Newcastle disease virus (NDV), avian influenza H9 virus (H9), and infectious bronchitis virus (IBV) following their respective manufacturers' instructions.

2.8. Measurement of Relative Immune Organ Weights

At the end of the experimental period, one bird from each replicate was humanely euthanized, and the bursa of Fabricius, thymus, and spleen were carefully removed, cleaned of adherent tissues, and weighed with a digital balance. The relative organ weight was calculated with the equation: Relative organ weight = organ weight/body weight*100.

Relative organ weight (%) = [Organ weight (g) / Body weight (g)] × 100.

2.9. Serum Biochemical Analysis

Commercial diagnostic kits and an automated biochemical analyzer were used to determine the serum glucose, cholesterol, triglycerides, and ALT and AST concentrations as per the respective manufacturers' instructions.

2.10. Intestinal Morphology and pH Measurement

During slaughter, small intestines were excised and washed in physiological saline solution. The tissue samples were processed, embedded in paraffin, sectioned into 5 µm pieces, and stained with hematoxylin and eosin (H&E). The villus height, villus width, and crypt depth were measured by a calibrated light microscope with image analysis software. Immediately after slaughter, the pH level of the intestine was measured by a portable digital pH meter.

2.11. Statistical Analysis

The IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA) software was used to analyze data. Normality of data was checked by the Shapiro-Wilk test, and homogeneity of variances was determined by Levene's test. One-way analysis of variance (ANOVA) was used to determine the effect of dietary BPM supplementation. The replicate pen was considered the experimental unit for statistical analysis. Treatment means were compared to determine significant treatment effects, where treatment was detected, by Duncan's multiple range test. Data were expressed as mean ± SEM, and significance (P < 0.05) was assumed when the differences were observed.

3. Results

3.1. Hematological Responses

The banana peel meal meal (BPM) had no significant effect on the hematological profile of broiler chicken (Table 2). WBC counts were 115.01, 115.03, 114.20, and 115.50 × 10³/µL in G1 (control), G2 (10% BPM), G3 (20% BPM), and G4 (30% BPM), respectively, with no significant treatment effect (P > 0.05). Similarly, RBC counts were 2.65, 2.89, 2.67, and 3.19 × 10⁶/µL in G1-G4, respectively, and did not differ significantly among treatments (P > 0.05). Hemoglobin concentrations were 19.58, 20.59, 18.70, and 20.16 g/100 mL in G1-G4, respectively, with no significant treatment effect (P > 0.05). Hematocrit was not significantly different (P > 0.05) between dietary treatments and was 32.26, 31.02, 30.92, and 31.52% for each, respectively.

Table 2 Hematological profile of broiler chickens fed graded levels of banana peel meal (BPM).

Parameter	G1 (Control)	G2 (10% BPM)	G3 (20% BPM)	G4 (30% BPM)
WBC count (×10 ³ /µL)	115.01 ± 0.75 ^a	115.03 ± 0.57 ^a	114.20 ± 0.14 ^a	115.50 ± 0.84 ^a
RBC count (×10 ⁶ /µL)	2.65 ± 0.036 ^a	2.89 ± 0.244 ^a	2.67 ± 0.145 ^a	3.19 ± 0.081 ^a
Hemoglobin (g/100 mL)	19.58 ± 0.71 ^a	20.59 ± 0.19 ^a	18.70 ± 0.40 ^a	20.16 ± 0.38 ^a
Hematocrit (%)	32.26 ± 2.363 ^a	31.02 ± 0.223 ^a	30.92 ± 0.223 ^a	31.52 ± 0.733 ^a

Values are presented as mean ± SEM. Means within a row sharing the same superscript letter are not significantly different (P > 0.05). WBC = white blood cell count; RBC = red blood cell count;

BPM = banana peel meal. G1 = control (0% BPM), G2 = 10% BPM, G3 = 20% BPM, and G4 = 30% BPM.

3.2. Humoral Immune Response

The results of graded dietary inclusion of banana peel meal (BPM) on antibody against Newcastle disease virus (NDV), avian influenza H9 virus (H9) and infectious bronchitis virus (IBV) are shown in Figure 1A, 1B and 1C, respectively. There was no significant difference ($P > 0.05$) in antibody levels against NDV, H9 or IBV between treatment groups when dietary BPM was included. For NDV,

the mean antibody titers were 7.00, 8.30, 8.45, and 8.00 in the control, 10%, 20%, and 30% BPM groups, respectively. Similarly, H9 antibody titers were 8.65, 9.20, 9.00, and 8.10, respectively. The corresponding IBV antibody titers were 13,185.00, 13,930.33, 15,058.33, and 12,396.67, respectively. There was variation between dietary treatments but this was not statistically significant.

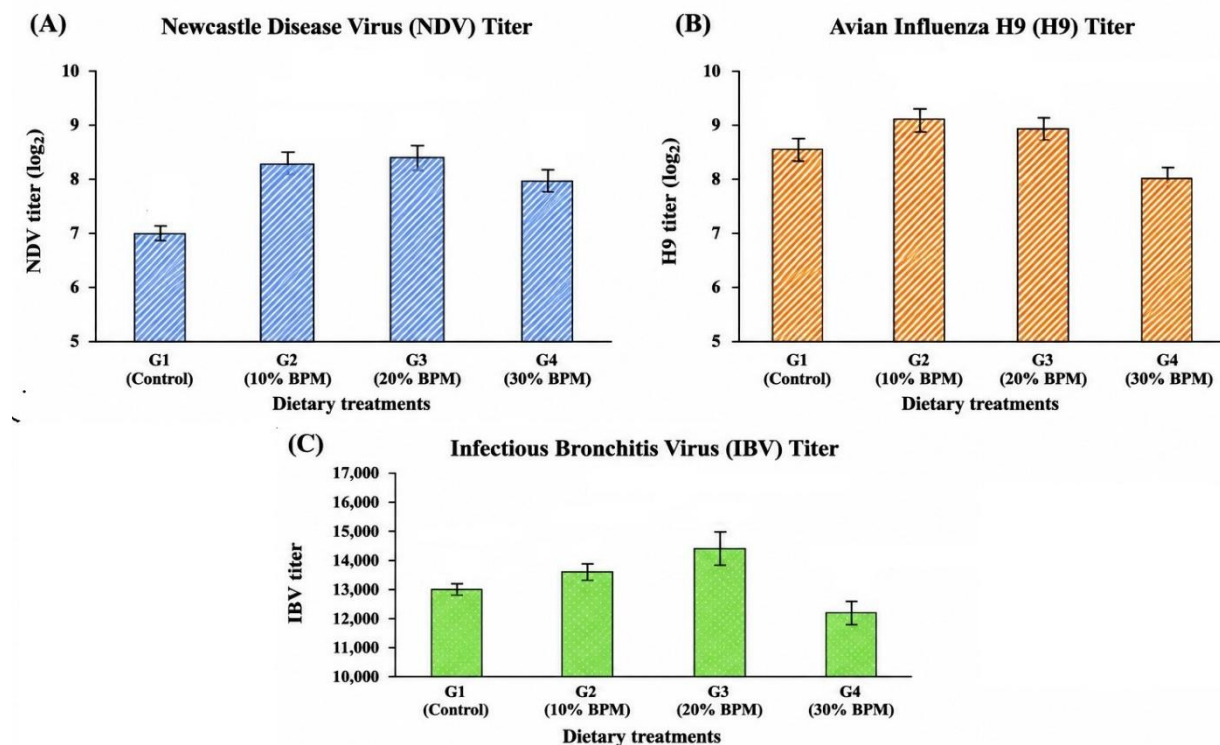


Figure 1. Antibody titers against (A) Newcastle disease virus (NDV), (B) avian influenza H9 virus (H9), and (C) infectious bronchitis virus (IBV) in broiler chickens fed graded levels of banana peel meal (BPM). Bars represent mean $\pm$ SEM ($n = 6$ replicates per treatment). No significant differences were detected among dietary treatments for NDV, H9, or IBV antibody titers ($P > 0.05$). G1 = control (0% BPM), G2 = 10% BPM, G3 = 20% BPM, and G4 = 30% BPM.

3.3. The Development of Immune Organs

Dietary inclusion of banana peel meal (BPM) significantly affected the relative weights of the bursa of Fabricius, thymus, and spleen (Table 3; $P < 0.05$). For the bursa of Fabricius, relative weight increased from $0.71 \pm 0.01\%$ in the control group to $0.74 \pm 0.01\%$ and $0.81 \pm 0.01\%$ in the 10% and 20% BPM groups, respectively, before decreasing to $0.65 \pm 0.01\%$ in the 30% BPM group. The highest relative bursa weight was obtained from the 20% BPM group while the lowest was obtained

from the group with 30% BPM. A similar reaction occurred for the thymus. Relative thymus weight was $0.62 \pm 0.01\%$, $0.68 \pm 0.01\%$, $0.76 \pm 0.01\%$, and $0.55 \pm 0.01\%$ in the control, 10%, 20%, and 30% BPM groups, respectively. The relative thymus weight was the highest in the 20% BPM group and the lowest in the 30% BPM group. Relative spleen weight was $0.15 \pm 0.01\%$, $0.13 \pm 0.01\%$, $0.18 \pm 0.01\%$, and $0.11 \pm 0.01\%$ in the control, 10%, 20%, and 30% BPM groups, respectively. The relative spleen weight was

greatest in the 20% BPM group, and least in the 30% BPM group. In general, the relative weight of the immune organs of bursa of Fabricius, thymus and spleen were the highest in 20% BPM

treatment while the lowest relative weight was recorded in the 30% BPM treatment. Means with different superscript letters are significantly different ($P < 0.05$).

Table 3. Relative weights of immune organs in broiler chickens fed graded levels of banana peel meal (BPM).

Immune organ	G1 Control	G2 10% BPM	G3 20% BPM	G4 30% BPM
Bursa of Fabricius (%)	0.71 ± 0.01 ^b	0.74 ± 0.01 ^{ab}	0.81 ± 0.01 ^a	0.65 ± 0.01 ^c
Thymus (%)	0.62 ± 0.01 ^b	0.68 ± 0.01 ^{ab}	0.76 ± 0.01 ^a	0.55 ± 0.01 ^c
Spleen (%)	0.15 ± 0.01 ^{ab}	0.13 ± 0.01 ^b	0.18 ± 0.01 ^a	0.11 ± 0.01 ^c

Values are presented as mean ± SEM. Different superscript letters within a row indicate significant differences among dietary treatments ($P < 0.05$). G1 = control (0% BPM), G2 = 10% BPM, G3 = 20% BPM, and G4 = 30% BPM.

3.4. Blood Biochemical Profile

Broiler chickens showed significant differences in blood biochemical parameters when fed diets containing different levels of banana peel meal (BPM) (Figure 2A-E). Some serum variables were significantly influenced by dietary treatments, such as the concentration or activity of glucose, cholesterol, triglycerides, alanine aminotransferase (ALT) and aspartate aminotransferase (AST) ($P < 0.05$). The serum glucose concentration (mg/dL) was reduced from 100 ± 5 in the control group to 95 ± 4, 90 ± 3 and 85 ± 2 in the 10% BPM, 20% BPM and 30% BPM groups, respectively, as the dietary BPM inclusion increased (Figure 2A). The control and 10% BPM group did not show any significant difference while the glucose concentration in 20% BPM and 30% BPM groups was significantly lower. Likewise, serum cholesterol level (Figure 2B) was reduced from 180 ± 10 mg/dL in the control group to 170 ± 8, 160 ± 7 and 150 ± 6 mg/dL in the 10%, 20% and 30% BPM groups, respectively. The differences between control and 10% BPM were not significant, but the 20% and 30% BPM groups were significantly

different in terms of cholesterol concentration. In the next step, with increasing dietary BPM (increasing from 0%, 10%, 20% and 30%), the values for serum triglyceride concentration (Figure 2C) were decreased from 140 ± 7 mg/dL in the control group to 130 ± 6, 120 ± 5 and 110 ± 4 mg/dL in the 10%, 20% and 30% BPM groups, respectively. The 20% BPM group and the 30% BPM group both had significantly lower levels of triglycerides than the control group. ALT activity (Figure 2D) and AST activity (Figure 2E) also decreased with increase in BPM inclusion in the diet. ALT activity decreased from 45 ± 3 U/L in the control group to 42 ± 2, 40 ± 2, and 38 ± 2 U/L in the 10%, 20%, and 30% BPM groups, respectively. Similarly, AST activity decreased from 48 ± 4 U/L in the control group to 45 ± 3, 43 ± 2, and 40 ± 2 U/L in the 10%, 20%, and 30% BPM groups, respectively. There were no significant difference between the control and 10% BPM group in both ALT and AST activities and the 20% & 30% BPM group were significantly lower than that of both control and 10% BPM group in both the enzymes.

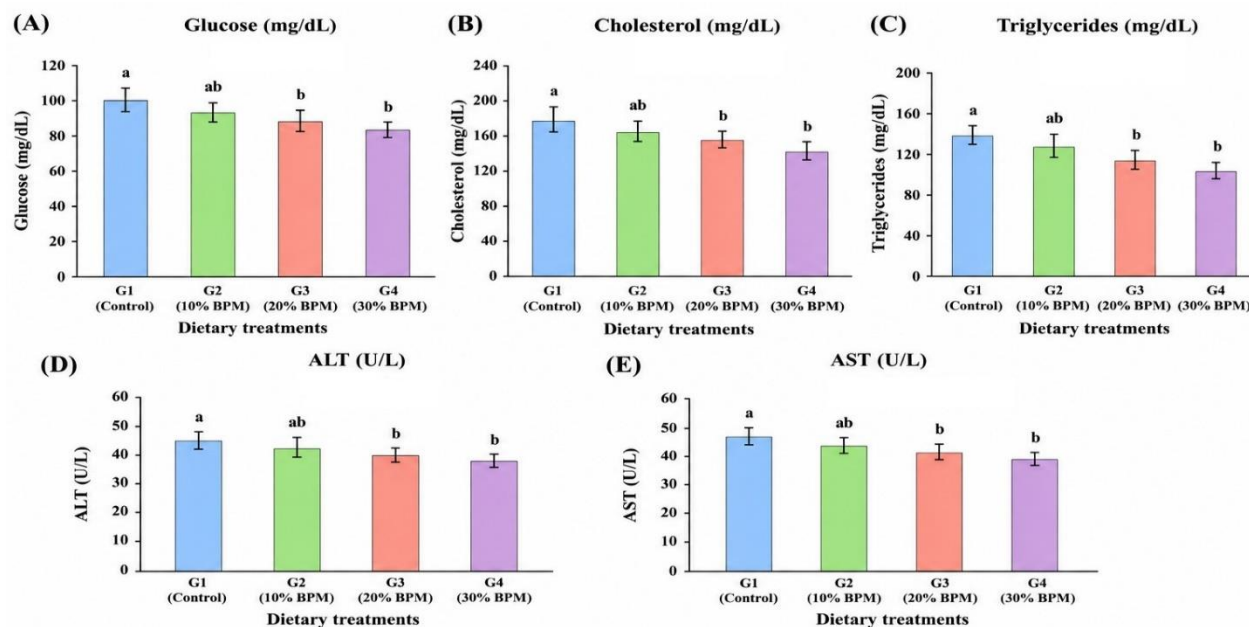


Figure 2. Blood biochemical profile of broiler chickens fed graded levels of banana peel meal (BPM). (A) Glucose, (B) cholesterol, (C) triglycerides, (D) alanine aminotransferase (ALT), and (E) aspartate aminotransferase (AST). Values are presented as mean $\pm$ SEM ($n = 6$ replicates per treatment). Different superscript letters within each panel indicate significant differences among dietary treatments ($P < 0.05$). G1 = control (0% BPM), G2 = 10% BPM, G3 = 20% BPM, and G4 = 30% BPM.

3.5. Intestinal Morphology and Luminal pH

Banana peel meal (BPM) had significant influence on the intestinal morphology and the luminal pH of broiler chicken (Table 4). Villus height, villus width, crypt depth, and intestinal pH were significantly different for the different dietary treatments ($P < 0.001$). The height of villi was also gradually increased as the dietary BPM level increased, from $200 \pm 15 \mu\text{m}$ in the control group to $250 \pm 20 \mu\text{m}$ in the 10% BPM group, $270 \pm 25 \mu\text{m}$ in the 20% BPM group and $290 \pm 30 \mu\text{m}$ in the 30% BPM group. The villus height of the 30% BPM group increased 45.0% from the control group. Dietary treatments were different and the differences were significant, indicated in the difference of the superscripts. In the same way, there was a 40.0% increase in villus width in the 30% BPM group compared with the control group, as it was found to be $100 \pm 10 \mu\text{m}$ in control group, $120 \pm 15 \mu\text{m}$ in 10% BPM, $130 \pm$

$18 \mu\text{m}$ in 20% BPM and $140 \pm 20 \mu\text{m}$ in 30% BPM group. Crypt depth increased progressively from $50 \pm 5 \mu\text{m}$ in the control group to 60 ± 7 , 70 ± 10 , and $80 \pm 12 \mu\text{m}$ in the 10%, 20%, and 30% BPM groups, respectively, corresponding to increases of 20%, 40%, and 60% relative to the control group. The pH of the intestine was 10.8% lower than the control group at the 30% BPM inclusion level. Significant differences between the dietary treatments were indicated by different superscript letters. In general, the greater the percentage of BPM that was included, the greater were the measurements of villus height, villus width, and crypt depth together with a gradual decrease in intestinal pH. Birds fed the 30% BPM had the highest numbers of changes. The results of the present study show a significant effect of BPM inclusion into the diet on intestinal morphology and luminal pH.

Table 4. Effects of dietary banana peel meal (BPM) inclusion on intestinal morphology and luminal pH in broiler chickens

Parameter	G1 Control	G2 10% BPM	G3 20% BPM	G4 30% BPM
Villus height (μm)	200 $\pm$ 15 ^a	250 $\pm$ 20 ^b	270 $\pm$ 25 ^c	290 $\pm$ 30 ^d
Villus width (μm)	100 $\pm$ 10 ^a	120 $\pm$ 15 ^b	130 $\pm$ 18 ^c	140 $\pm$ 20 ^d
Crypt depth (μm)	50 $\pm$ 5 ^a	60 $\pm$ 7 ^b	70 $\pm$ 10 ^c	80 $\pm$ 12 ^d
Intestinal pH	6.5 $\pm$ 0.2 ^a	6.2 $\pm$ 0.3 ^b	6.0 $\pm$ 0.4 ^c	5.8 $\pm$ 0.5 ^d

Values are presented as mean $\pm$ SEM. Different superscript letters within a row indicate significant differences among dietary treatments ($P < 0.05$). G1 = control (0% BPM), G2 = 10% BPM, G3 = 20% BPM, and G4 = 30% BPM. BPM = banana peel meal.

4. Discussion

The findings of the present study showed that the use of banana peel meal (BPM) in the diet did not significantly effect hematological parameters and humoral immune responses but significantly affected immune organ development, serum biochemical parameters and intestinal morphology of broiler chickens. The results indicate that BPM has potential applications as a functional feed ingredient without any negative effect on the studied hematological and immune parameters. There were no significant differences in WBC, RBC and hematocrit, indicating that the inclusion of BPM did not seem to have any negative impact on the birds' hematological status. The present findings corroborate those of Kumalo et al. (2024) who reported stable hematological profile in broilers being raised on the banana peel based diets, and Arogbodo et al. (2024) who reported stable hematological response in broilers receiving diets supplemented with banana peel. In the same way, there were no significant differences among the antibody levels against the NDV, H9 or IBV, showing that BPM had a very small impact on the humoral immune response measured by antibody levels. Phillips et al. (2023) found the same, that fruit based feed additives could help maintain the health of the birds without significantly impacting antibody responses. An important finding of the present study was the effect of BPM inclusion on the relative weights of the immune organs. The bursa of Fabricius, thymus and spleen were found to have higher relative weights in the 20% BPM birds compared to control group. They have significant functions in the development of the lymphoid organs and

the regulation of the immune system. These responses observed may relate to the antioxidant and immunomodulatory effect of polyphenols and flavonoids found in banana peel. Similar effects of phytogetic feed additives on the development of immune organs are reported by Chang et al. (2023) and Ntsongota et al. (2025). But it is too early to conclude that the increases in lymphoid organ weights represent direct evidence of improved immune competence and additional evaluations of lymphoid function must be done to confirm this. Incorporation of the dietary BPs also markedly influenced the serum biochemical parameters. Serum glucose, cholesterol, triglycerides, ALT and AST concentrations or activities decreased with increasing BPM inclusion. These alterations are suggestive of changes in carbohydrate and lipid metabolism and biochemical changes in liver. The results agree with those of Nuriyasa et al. (2022) and Huong et al. (2026) which showed that blood lipid profile in broilers fed banana peel based diets did not lead to negative changes. These responses can be attributed to the high polyphenol and fiber content of banana peel, which can have an impact on lipid metabolism and nutrient utilization (da Silva Bomfim et al., 2025). The decrease in ALT and AST activities may also suggest the metabolic changes in the liver, but biochemical enzyme changes are not sufficient enough to prove the improvement in liver integrity. These may be especially important in the current fast growing broiler production system that involves metabolic challenges (Hafez et al., 2022). The inclusion of BPM in the diet had significant impact on intestinal morphological parameters, such as villus

height, villus width and crypt depth, which were increased while intestinal pH was lowered progressively. The greater the size of the villus, the greater the absorptive surface area, but caution needs to be used in considering the biological significance of the increase in crypt depth. Similarly, positive effects of banana peel supplementation on intestinal development of broilers was reported by Huong et al. (2026). The decreased pH in the gut can promote the growth of beneficial microorganisms and perhaps inhibit the growth of pathogenic bacterial species (Wickramasuriya et al., 2022). However, this proposed mechanism has been suggested but has not been tested in the present study as gut microbiota composition was not measured. The improved intestinal architecture could have the potential to contribute to nutrient utilization and feed efficiency, but growth performance and nutrient digestibility were not assessed in the current study (Gao et al., 2025). The responses observed could be related with the presence of fibre, resistant starch, flavonoids, phenolic compounds and other bioactive ingredients in banana peel. These components can impact intestinal functions, lipid metabolism, and immune-related responses (Sullivan & Jones, 2024). Moreover, the use of banana peel as feed ingredient offers a possible solution for valorizing fruit-processing waste and can help to improve sustainable use of feeds resources. It is important to note here that the experimental diets were not isoenergetic and isonitrogenous, and as the BPM was increased, so were the levels of metabolizable energy, crude protein and crude fiber. Thus, some of the current responses could be attributed to subtle differences in overall nutrient composition of the diet as well as to the direct effect of BPM. Future research should compare isoenergetic and isonitrogenous formulations to determine the unique effects of BPM when compared with changes in dietary nutrient density. In the present study, however, we did not evaluate antioxidant status, nutrient digestibility, molecular mechanisms, gut microbiota composition or economic outcomes. The mechanisms in the observed responses and the potential applicability

of BPM in commercial poultry production should therefore be investigated in future studies. Also, long term feeding test should be conducted in the commercial condition to determine the optimum level of inclusion keeping in mind the growth performance, health, feed efficiency and economic viability.

Conclusion

The banana peel meal in feed had a significant influence on several physiological and intestinal parameters of broiler chickens. While antibody levels against NDV, H9 or IBV and the measured hematological parameters were not significantly affected by BPM, the relative weights of the bursa of Fabricius, thymus, and spleen, and serum glucose, cholesterol, triglycerides, ALT and AST were influenced by BPM. As BPM levels increased, villus height, villus width, and crypt depth increased, and there was a gradual decrease in intestinal pH. In general, results showed that BPM may be used as a functional feed ingredient for broiler chickens; however, the present study did not determine the optimum level for inclusion in the broiler feed. Growth performance and nutrient digestibility, antioxidant status, gut microbiota, molecular responses, long-term health outcomes and economic feasibility should be evaluated in further investigations under commercial production conditions.

REFERENCES:

- Alshehri, A. A., Younes, N. M., Kamel, R., & Shawir, S. M. (2024). Characterization and potential health benefits of millet flour and banana peel mixtures on rats fed with a high-fat diet. *Heliyon*, 10(20).
- Ansari, N. A. I. M., Ramly, N., Faujan, N. H., & Arifin, N. (2023). Nutritional content and bioactive compounds of banana peel and its potential utilization: a review. *Malaysian Journal of Science Health & Technology*, 9(1), 74-86.

- Arogbodo, J. O., Igbe, F. O., & Adebayo, I. A. (2024). Effects of feeding unripe plantain peel meal on haematological parameters and serum bio-chemicals of growing broilers. *Journal of Basic and Applied Pharmacology*, 4(2), 049-61.
- Chang, S. Y., Lee, J. H., Oh, H. J., An, J. W., Song, D. C., Cho, H. A., ... & Cho, J. H. (2023). Effect of different ratios of phytogetic feed additives on growth performance, nutrient digestibility, intestinal barrier integrity, and immune response in weaned pigs challenged with a pathogenic *Escherichia coli*. *Journal of Animal Science*, 101, skad148.
- da Silva Bomfim, N., de Souza Ferreira, R., Silva e Oliveira, J., & de Cássia Gonçalves Alfenas, R. (2025). Green banana biomass anti-obesogenic, anti-hyperlipidemic, antidiabetic, and intestinal function potential effects: a systematic review. *Nutrition Reviews*, 83(2), e290-e303.
- Enciso-Martínez, Y., Zuñiga-Martínez, B. S., Ayala-Zavala, J. F., Domínguez-Avila, J. A., González-Aguilar, G. A., & Viuda-Martos, M. (2024). Agro-industrial by-products of plant origin: therapeutic uses as well as antimicrobial and antioxidant activity. *Biomolecules*, 14(7), 762.
- Gao, Z., Zheng, J., & Xu, G. (2025). Molecular mechanisms and regulatory factors governing feed utilization efficiency in laying hens: Insights for sustainable poultry production and breeding optimization. *International Journal of Molecular Sciences*, 26(13), 6389.
- Getahun, A., Kechero, Y., Yemane, N., Dessie, T., & Esatu, W. (2025). Nutritional evaluation and potential of locally available alternative feed resources for sustainable poultry production: a case study of smallholder farms in central and Southern Ethiopia. *Tropical Animal Health and Production*, 57(7), 317.
- Hafez, M. H., El-Kazaz, S. E., Alharthi, B., Ghamry, H. I., Alshehri, M. A., Sayed, S., ... & El-Sayed, Y. S. (2022). The impact of curcumin on growth performance, growth-related gene expression, oxidative stress, and immunological biomarkers in broiler chickens at different stocking densities. *Animals*, 12(8), 958.
- Hikal, W. M., Said-Al Ahl, H. A., Bratovic, A., Tkachenko, K. G., Sharifi-Rad, J., Kačániová, M., ... & Atanassova, M. (2022). Banana peels: A waste treasure for human being. *Evidence-Based Complementary and Alternative Medicine*, 2022(1), 7616452.
- Huong, D. T., Phuong, T. B., Van Thong, N., Anh, D. T. N., Doanh, B. H., Giang, N. T. P., & Vinh, N. T. (2026). Effect of Banana Peel Powder as a Feed Ingredient on the Growth Performance, Intestinal Morphology, Carcass Yield, and Meat Quality of Broiler Chickens. *Vietnam Journal of Agricultural Sciences*, 9(1), 2804-2813.
- Khaskheli, S. G., Soomro, A. H., Mari, N. U. N., Khaskheli, A. A., Soomro, S., Nawaz, S., ... & Tufail, T. (2026). Banana and Its By-products: A Comprehensive Overview of Nutritional Value and Beneficial Effects. *Importance of Plant Based Byproducts: Nutritional and Functional Properties*, 25-43.
- Kumalo, I., Mlambo, V., & Mnisi, C. M. (2024). The impact of partially replacing dietary maize with graded levels of banana peels on nutrient digestibility, physiology, and meat quality traits in jumbo quail. *Poultry*, 3(4), 437-451.
- Madej, J. P., Graczyk, S., Bobrek, K., Bajzert, J., & Gaweł, A. (2024). Impact of early posthatch feeding on the immune system and selected hematological, biochemical, and hormonal parameters in broiler chickens. *Poultry Science*, 103(3), 103366.

- Mbah, J. I., Bwititi, P. T., Gyawali, P., Nwose, E. U., & Bwititi, P. (2024). Changes in haematological parameters and lipid profiles in diabetes mellitus: a literature review. *Cureus*, 16(7).
- Nassar, F. S. (2026). Strategic role of poultry production sciences in shaping the future of global food security and strengthen sustainability. *Poultry Science*, 106617.
- Ntsongota, Z., Ikusika, O., & Jaja, I. F. (2025). The role of phytogetic feed additives in growth and immune response in livestock production: a global systematic review. *Frontiers in Animal Science*, 6, 1703112.
- Nuriyasa, I. M., Puja, I. K., & Puger, A. W. (2022). Growth performance and lipids profile of meat of native chicken fed with feed substituted with fermented banana peel.
- Phillips, C. J., Hosseintabar-Ghasemabad, B., Gorlov, I. F., Slozhenkina, M. I., Mosolov, A. A., & Seidavi, A. (2023). Immunomodulatory effects of natural feed additives for meat chickens. *Life*, 13(6), 1287.
- Rajib, M. M. R., & Suborna, M. N. (2022). Management: Industrial and Environmental Perspective. *Pectins: The New-Old Polysaccharides*, 19. doi.org/10.5772/intechopen.101689
- Rawat, N., Das, S., Waheed Wani, A., & Javeed, K. (2024). Antioxidant potential and bioactive compounds in banana peel: A review. *Peer Reviewed Journal*, 7(7).
- Saini, R. K., Khan, M. I., Kumar, V., Shang, X., Lee, J. H., & Ko, E. Y. (2025). Bioactive compounds of agro-industrial by-products: current trends, recovery, and possible utilization. *Antioxidants*, 14(6), 650.
- Sorrenti, V., Burò, I., Consoli, V., & Vanella, L. (2023). Recent advances in health benefits of bioactive compounds from food wastes and by-products: Biochemical aspects. *International journal of molecular sciences*, 24(3), 2019.
- Stefanetti, V., Mancinelli, A. C., Pascucci, L., Menchetti, L., Castellini, C., Mugnai, C., ... & Proietti, P. C. (2023). Effect of rearing systems on immune status, stress parameters, intestinal morphology, and mortality in conventional and local chicken breeds. *Poultry Science*, 102(12), 103110.
- Sullivan, J. P., & Jones, M. K. (2024). The multifaceted impact of bioactive lipids on gut health and disease. *International Journal of Molecular Sciences*, 25(24), 13638.
- Teshome, E., Teka, T. A., Nandasiri, R., Rout, J. R., Harouna, D. V., Astatkie, T., & Urugo, M. M. (2023). Fruit by-products and their industrial applications for nutritional benefits and health promotion: a comprehensive review. *Sustainability*, 15(10), 7840.
- Viana, L. M., da Silva, B. P., Rodrigues, F. S. R., Paes, L. T., Mishima, M. D. V., Toledo, R. C. L., ... & Barros, F. (2025). Mixed Green Banana (*Musa* spp.) Pulp and Peel Flour Reduced Body Weight Gain and Adiposity and Improved Lipid Profile and Intestinal Morphology in Wistar Rats. *Nutrients*, 17(15), 2493.
- Wickramasuriya, S. S., Park, I., Lee, K., Lee, Y., Kim, W. H., Nam, H., & Lillehoj, H. S. (2022). Role of physiology, immunity, microbiota, and infectious diseases in the gut health of poultry. *Vaccines*, 10(2), 172.