Effect of Partial Replacement of Banana Peel Powder on the Physiological and Hematological Responses of Broiler Chickens Exposed to Aflatoxin B1

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Abstract

This study aimed to evaluate the effect of partial replacement of yellow corn with banana peel powder in the diets of broiler chickens exposed to aflatoxin B1 at a concentration of 3 mg/kg feed, through the assessment of selected biochemical parameters, hematological indices, and the relative weights of certain internal organs. The experiment included eight dietary treatments: a control diet (T1), an aflatoxin-contaminated diet (T2), diets containing 5%, 10%, and 15% banana peel powder without contamination (T3–T5), and the same replacement levels under aflatoxin contamination (T6–T8). Aflatoxin contamination (T2) caused significant physiological disturbances compared with the control group, including increased cholesterol, triglycerides, LDL, VLDL, and uric acid, accompanied by reduced HDL and decreased serum protein fractions. Hematological indices (RBC, WBC, Hb, and PCV) were significantly reduced, while the H/L ratio increased. In addition, the relative weights of the liver, spleen, and heart increased, whereas the bursa of Fabricius weight decreased. In contrast, dietary replacement with banana peel powder improved several physiological indicators. The 10% replacement level (T4) showed the most favorable results under non-contaminated conditions. Under aflatoxin contamination, the 10–15% replacement levels (T7 and T8) alleviated many adverse effects compared with T2, including improvements in lipid-related indicators, serum protein fractions, hematological parameters, and immune organ weight. These findings indicate that partial replacement of yellow corn with banana peel powder, particularly at the 10% level, may contribute to physiological stability and mitigate some toxic effects of aflatoxin B1 in broiler chickens.

Keywords

Aflatoxin B1, Banana peel powder, Broiler, Hematological indicators, Internal organs.

Introduction

The efficiency of broiler production systems depends on maintaining physiological homeostasis under intensive feeding conditions, as any disruption in metabolic stability is directly reflected in performance and overall health. Among the factors that compromise this balance, mycotoxins are recognized as silent contaminants that can induce progressive disturbances in vital functions without obvious clinical manifestations in the early stages [1,2]. Aflatoxin B1 is considered one of the most potent of these toxins due to its biotransformation in the liver into reactive

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metabolites that bind to cellular macromolecules and interfere with protein synthesis as well as lipid and carbohydrate metabolism [3]. Consequently, alterations occur in serum protein fractions, lipid profile parameters, and indicators of nitrogen metabolism. The oxidative stress associated with its toxicity further activates compensatory immune responses, As evidenced by hematological alterations and an elevated heterophil-to-lymphocyte (H/L) ratio as a physiological stress indicator. These effects extend to changes in the relative weights of organs involved in detoxification and immune function, highlighting the systemic nature of aflatoxicosis [4,5]. In light of the growing trend toward reducing reliance on synthetic chemical compounds, increasing attention has been directed toward bioactive plant-derived ingredients, particularly those rich in phenolic compounds with the capacity to neutralize free radicals and support the endogenous antioxidant defense system [6]. Banana peels represent a plant source containing a diverse spectrum of such bioactive constituents, conferring a theoretical potential to enhance oxidative balance under toxic stress conditions. However, data evaluating their inclusion in broiler diets exposed to aflatoxin remain limited, especially with regard to integrated hematological and physiological responses [7,8].

Accordingly, the present study aimed to evaluate the effect of partial replacement of banana peel powder in the diets of broiler chickens exposed to aflatoxin B1 by assessing selected hematological, biochemical, and physiological indicators, in order to determine its potential contribution to maintaining biological stability under toxic stress conditions.

Materials and Methods

Experimental Location and Conditions

The experiment was conducted at the poultry experimental field, Department of Animal Production, College of Agriculture, Tikrit University, from 17 February 2025 to 25 March 2025, for a total period of five weeks (35 days). The study was carried out according to the Ross 308 broiler management guidelines (2025). Standard intensive rearing conditions were maintained, including controlled temperature, relative humidity, ventilation, lighting program, and preventive health management, to minimize the influence of non-experimental environmental variables on the study outcomes.

Birds and Experimental Design

A total of 120 one-day-old Ross 308 broiler chicks were used. Birds were randomly assigned to eight dietary treatments according to a Completely Randomized Design (CRD), with three replicates per treatment and five birds per replicate (15 birds per treatment).

Birds were reared in a battery cage system (multi-tier vertical cages), and all cages were identical in dimensions and equipment to ensure environmental uniformity among treatments. Feed and water were provided ad libitum throughout the experimental period (35 days). Broiler were reared under controlled environmental conditions. The house temperature was maintained according to the age of the birds, starting at approximately 33–34 °C during the first week and gradually reduced to about 22–24 °C by the end of the rearing period. Relative humidity was maintained at approximately 60–70%. A lighting program of 23 h light and 1 h dark was applied throughout the

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experimental period. Birds were housed in battery cages measuring approximately 70 × 50 cm, with five birds per cage, and routine preventive health management practices were applied during the experimental period.

Dietary Treatments

The experiment included eight dietary treatments as follows:

T1: Standard control diet free of aflatoxin B1 and without banana peel powder replacement.
T2: Control diet contaminated with aflatoxin B1 at 3 mg/kg feed without replacement.
T3: Aflatoxin-free standard diet with 5% banana peel powder replacing yellow corn.
T4: Aflatoxin-free standard diet with 10% replacement.
T5: Aflatoxin-free standard diet with 15% replacement.
T6: Diet contaminated with aflatoxin B1 at 3 mg/kg feed with 5% banana peel powder replacement.
T7: Diet contaminated with aflatoxin B1 at 3 mg/kg feed with 10% replacement.
T8: Diet contaminated with aflatoxin B1 at 3 mg/kg feed with 15% replacement.

Preparation of Banana Peel Powder

Banana peels were collected from local sources in Karbala city. The peels were washed thoroughly under running water to remove impurities and cut into small pieces. The pieces were treated with 0.5% citric acid solution for 10 minutes to reduce enzymatic browning, then sun-dried under direct sunlight at 40–45°C for 5–7 days with daily turning to ensure uniform drying. After complete drying, the peels were ground into a fine powder and stored in airtight, opaque containers in a cool and dry place until use. The preparation procedure was based on the method described by [9], with minor modifications to suit the present study. Proximate chemical analysis of banana peel powder was conducted according to standard analytical procedures. The results showed that it contained 5.70% crude protein, 9.33% crude fat, 17.77% crude fiber, and 9.66% crude ash, while the metabolizable energy was approximately 2500 kcal/kg.

Diet Formulation and Aflatoxin Contamination

Experimental diets were formulated to be isoenergetic and isonitrogenous, meeting the nutritional requirements of Ross 308 broilers according to the 2025 guidelines. Banana peel powder was partially substituted for yellow corn at the specified levels for each treatment while maintaining overall nutrient balance. Tables (1) and (2) present the ingredient composition and calculated chemical composition of the experimental diets.

Table 1. Ingredient percentages of starter, grower, and finisher diets, along with the calculated chemical composition of the three standard diets.

Feed	Starter (1-10	Grower (11-24 d)	Finisher (25-35
Corn	46.18	50.08	53.80
SBM (48%)	36.9	32.60	27.05
Wheat	9.92	10.22	12.5
Premix	2.5	2.5	2.5
D. Phosphate	1	0.9	0.6
Limestone	0.3	0.3	0.1

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Methionine	0.1	0.25	0.2
Lysine	0.3	0.2	0.2
Fat	2.8	2.7	2.8
Salt	0	0.25	0.25
Total	100	100	100
Calculated Chemical Composition**			
C.P%	23.27	21.58	19.55
ME	3028.05	3054.15	3123.47
Ca (%)	0.97	0.94	0.78
P (%)	0.46	0.44	0.38
Lys (%)	1.44	1.24	1.11
Me (%)	0.57	0.71	0.64
Me+Sys(%)	0.92	1.03	0.93

Table 2. Partial replacement levels of banana peel powder substituted for yellow corn in the starter, grower, and finisher diets.

Feed Ingredients	**Starter**			**Grower**			**Finisher**		
	5%	**10%**	**15%**	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**
Corn	43.88	41.58	39.28	47.58	45.08	42.58	51.11	48.42	45.7
BPP	2.30	4.60	6.9	2.5	5	7.5	2.69	5.38	8.07
SBM (48%)	36.9	36.9	36.9	32.6	32.76	33.22	27.1	27.4	27.85
Wheat	9.92	9.92	9.92	10.22	10.1	9	12.5	12	11
Premix*	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
D Phosphate	1	1	1	0.9	0.78	0.88	0.55	0.5	0.51
Limestone	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1
Methionine	0.1	0.1	0.1	0.25	0.15	0.2	0.2	0.14	0.14
Lysine	0.3	0.3	0.3	0.2	0.15	0.15	0.2	0.18	0.18
Fat	2.8	2.8	2.8	2.8	3.13	3.62	2.8	3.13	3.7
Salt	0	0	0	0.25	0.25	0.25	0.25	0.25	0.25
Total	100	100	100	100	100	100	100	100	100
Calculated Chemical Composition **									
C.P%	23.20	23.14	23.07	21.51	21.50	21.50	19.50	19.50	19.50
ME	3008.5	2988.95	2969.4	3050.89	3050.5	3050.25	3101.83	3100.83	3107.59
Ca (%)	0.97	0.97	0.83	0.78	0.84	0.86	0.77	0.76	0.76
P(%)	0.46	0.46	0.46	0.44	0.41	0.43	0.37	0.36	0.36
Lys (%)	1.43	1.42	1.42	1.23	1.18	1.18	1.11	1.09	1.09
Me (%)	0.57	0.56	0.56	0.70	0.6	0.64	0.63	0.57	0.56
Me+Sys(%)	0.92	0.90	0.90	1.02	0.92	0.96	0.92	0.86	0.85

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For the contaminated diets (T2, T6, T7, and T8), the required concentration of aflatoxin B1 (3 mg/kg feed) was achieved by incorporating yellow corn previously contaminated with aflatoxin. The contaminated corn was added in powdered form and thoroughly mixed with the basal diet in a stepwise manner to ensure complete homogeneity and uniform distribution of the toxin throughout the feed.

Blood Sample Collection

At the end of the experimental period (day 35), three birds were randomly selected from each treatment, with one bird chosen from each replicate to ensure proper experimental representation. Blood samples were collected from the wing vein using sterile syringes.

Each sample was divided into two portions:

- The first portion was transferred into tubes containing an anticoagulant (EDTA) for hematological analysis.
- The second portion was placed into anticoagulant-free tubes to obtain serum. The samples were allowed to clot and then centrifuged at 3000 rpm for 15 minutes. The separated serum was collected and stored at a low temperature until biochemical analyses were performed.

Biochemical Analyses

Biochemical analyses were conducted at the Central Laboratory, Tikrit University, using commercially available diagnostic kits according to the manufacturers' instructions. The evaluated parameters included total cholesterol, triglycerides, high-density lipoprotein (HDL), low-density lipoprotein (LDL), very low-density lipoprotein (VLDL), glucose, uric acid, total protein, and albumin. Globulin concentration was calculated by subtracting albumin from total protein.

Hematological Examination

Hematological analyses were performed at the Physiology Laboratory, College of Agriculture, Tikrit University. The evaluated parameters included red blood cell count (RBC), white blood cell count (WBC), hemoglobin concentration (Hb), packed cell volume (PCV), and the heterophil-to-lymphocyte ratio (H/L), following standard procedures used for hematological assessment in poultry.

Relative Weights of Internal Organs

After slaughter, the following organs were excised and weighed: heart, liver, abdominal fat, spleen, and bursa of Fabricius. The relative weight of each organ was calculated as a percentage of live body weight according to the standard equation commonly used in poultry research [10].

$$\text{Relative organ weight (\%)} = \frac{\text{Mean organ weight (g)}}{\text{Mean live body weight (g)}} \times 100$$

Statistical Analysis

Data were statistically analyzed using a Completely Randomized Design (CRD) to evaluate the effect of dietary treatments on the studied traits. Duncan's Multiple Range Test (Duncan, 1955) was used to compare means at a significance level of ($P \leq 0.05$).

All statistical analyses were performed using SAS software (2003) according to the following mathematical model:

$$Y_{ij} = \mu + T_i + e_{ij}$$

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Where:
Y_{ij}= observed value,
μ= overall mean,
T_i= effect of treatment,
e_{ij}= experimental error.

Results and Discussion

Serum Lipid Profile

The results presented in Table (3) indicate that exposure to aflatoxin B1 caused a significant disturbance in lipid metabolism, as evidenced by increased concentrations of cholesterol, triglycerides, and low-density lipoproteins (LDL and VLDL), along with a decrease in high-density lipoprotein (HDL) in treatment T2 compared with the control treatment ($P \leq 0.05$). This pattern reflects impaired hepatic function, given the central role of the liver in regulating lipid synthesis and oxidation. Aflatoxin is known to promote lipid accumulation within hepatocytes through inhibition of β-oxidation enzymes and enhancement of oxidative stress [11,12].

Table (3): Effect of dietary aflatoxin B1 contamination and partial replacement of banana peel powder on the serum lipid profile of broiler chickens.

Tretment	Cholesterol (mg/dL)	Triglycerides (mg/dL)	HDL (mg/dL)	LDL (mg/dL)	VLDL (mg/dL)
T1	144.68 ^{bcd}± 8.74	58.17 ^{bc}± 5.49	79.98 ^{bc}± 1.13	53.07 ^{cd}± 8.66	11.63 ^{bc}± 1.10
T2	174.41 ^{a} ± 5.15	75.57 ^{a}± 3.32	56.00 ^{e}± 3.42	103.29 ^{a}± 4.88	15.11 ^{a}± 0.66
T3	130.87 ^{de}± 4.93	51.61 ^{cd}± 3.33	88.59 ^{ab}± 2.92	31.96 ^{e}± 7.57	10.32 ^{cd}± 0.67
T4	118.25 ^{e}± 3.84	43.19 ^{d}± 3.79	96.52 ^{a}± 4.89	13.09 ^{f}± 4.47	8.64 ^{d}± 0.76
T5	140.45 ^{cd}± 2.14	57.22 ^{bc}± 3.42	81.01 ^{bc}± 4.06	48.00 ^{de}± 1.53	11.44 ^{bc}± 0.68
T6	159.05 ^{ab}± 8.12	68.63 ^{ab}± 5.23	68.19 ^{d}± 1.28	77.14 ^{b}± 8.93	13.73 ^{ab}± 1.05
T7	152.13 ^{bc}± 4.58	59.68 ^{bc}± 4.35	73.34 ^{cd}± 2.67	66.85 ^{bc}± 1.48	11.94 ^{bc}± 0.87
T8	145.69 ^{bcd}± 4.45	58.96 ^{bc}± 3.52	75.44 ^{cd}± 4.17	58.46 ^{cd}± 2.39	11.79 ^{bc}± 0.70

Values are expressed as mean ± standard error (Mean ± SE). Different superscript letters within the same column indicate significant differences at the probability level of ($P \leq 0.05$).

In contrast, partial replacement of banana peel powder, particularly at the 10% level (T4), resulted in a significant improvement in the lipid profile, as evidenced by increased HDL and reduced LDL and total cholesterol concentrations. This finding suggests a potential protective effect of the phenolic compounds and dietary fiber present in banana peels. Under contaminated conditions, the replacement treatments (T7 and T8) demonstrated a clear compensatory improvement compared with T2, indicating the capacity of banana peel powder to mitigate the severity of aflatoxin-induced dyslipidemia. This effect may be attributed to the role of antioxidant compounds in reducing lipid peroxidation and enhancing cholesterol clearance from the bloodstream. Additionally, dietary fiber can bind bile acids and increase their excretion, thereby reducing cholesterol reabsorption. These results are consistent with those reported in [13], which highlighted the role of natural antioxidants in supporting oxidative stability in poultry subjected to stress conditions.

Serum Biochemical Parameters

The results presented in Table (4) showed that exposure to aflatoxin B1 in treatment T2 caused significant alterations in certain biochemical parameters. Uric acid

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concentration increased markedly, whereas total protein, albumin, and globulin levels decreased compared with the control treatment ($P \leq 0.05$). In contrast, glucose concentrations were not significantly affected among the treatments.

Table (4): Effect of dietary aflatoxin B1 contamination and partial replacement of banana peel powder on selected serum biochemical parameters of broiler chickens.

Tretment	Blood glucose (mg/dL)	Uric acid (mg/dL)	Total protein (g/dL)	Albumin (g/dL)	Globulin (g/dL)
T1	221.67 ^{a} ± 13.30	5.00 ^{b}± 0.65	5.28 ^{bc}± 0.17	1.84 ^{a}± 0.05	3.44 ^{bc}± 0.12
T2	227.00 ^{a} ± 10.15	8.27 ^{a}± 0.48	3.49 ^{e}± 0.10	1.14 ^{c}± 0.05	2.35 ^{d}± 0.14
T3	234.67 ^{a}± 11.46	5.17 ^{b}± 0.67	5.70 ^{ab}± 0.15	1.88 ^{a}± 0.05	3.82 ^{ab}± 0.10
T4	241.00 ^{a} ± 7.37	5.00 ^{b}± 0.31	5.92 ^{a}± 0.18	1.93 ^{a}± 0.04	3.98 ^{a}± 0.14
T5	230.67 ^{a}± 15.60	5.13 ^{b}± 1.00	5.08 ^{cd}± 0.19	1.62 ^{b}± 0.09	3.46 ^{bc}± 0.16
T6	244.00 ^{a}± 7.94	6.87 ^{ab}± 0.67	4.56 ^{d}± 0.10	1.50 ^{b}± 0.06	3.06 ^{c}± 0.09
T7	233.67 ^{a}± 7.62	6.00 ^{b}± 0.23	4.84 ^{cd}± 0.22	1.49 ^{b}± 0.09	3.35 ^{c}± 0.14
T8	244.00 ^{a}± 4.04	5.30 ^{b}± 0.75	4.83 ^{cd}± 0.25	1.44 ^{b}± 0.10	3.39 ^{bc}± 0.16

Values are expressed as mean ± standard error (Mean ± SE). Different superscript letters within the same column indicate significant differences at the probability level of ($P \leq 0.05$).

The increase in uric acid reflects enhanced protein catabolism and disruption of nitrogen metabolism, which is associated with the hepatotoxic effect of aflatoxin, given that the liver is the primary organ responsible for serum protein synthesis and regulation of amino acid balance. The reduction in total protein and albumin further indicates inhibition of hepatic protein synthesis as a consequence of oxidative stress and hepatocellular damage. Moreover, the decrease in globulin concentration suggests impaired immune competence, considering its essential role in antibody production [14,15]. In contrast, partial replacement of banana peel powder, particularly at the 10% level (T4), resulted in a significant improvement in total protein, albumin, and globulin concentrations compared with the contaminated treatment, indicating supportive effects on hepatic function. Under contaminated conditions, the replacement treatments (T7 and T8) reduced the severity of the biochemical disturbance relative to T2, suggesting a partial compensatory effect. This improvement may be attributed to the antioxidant properties of phenolic compounds and flavonoids present in banana peels, which contribute to the attenuation of oxidative stress and protection of cellular membranes. Additionally, dietary fiber may play a role in reducing toxin absorption or binding aflatoxin within the gastrointestinal tract. These findings are consistent with recent studies indicating that plant-based additives rich in antioxidants can support hepatic stability under mycotoxin contamination [16].

Hematological Parameters

The results presented in Table (5) indicate that exposure to aflatoxin B1 in treatment T2 resulted in a significant deterioration in most hematological parameters compared with the control treatment ($P \leq 0.05$). Red blood cell count (RBC), white blood cell count (WBC), hemoglobin concentration (Hb), and packed cell volume (PCV) were significantly reduced. In contrast, heterophil

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percentage (H) increased while lymphocyte percentage (L) decreased, leading to a significant elevation in the H/L ratio, which is considered a physiological indicator of stress [17].

Table (5): Effect of dietary aflatoxin B1 contamination and partial replacement of banana peel powder on selected hematological parameters of broiler chickens.

Tretment	RBC ($\times 10^6$ /µL)	WBC ($\times 10^3$/µL)	Hb (g/dL)	PCV (%)	H (%)	L (%)	H/L
T1	2.58^{ab} ±	25.11^{ab} ±	9.56 ^{ab} ±	28.67 ^{ab} ±	27.08^{ed} ±	61.39 ^{ab} ±	0.44 ^{cd} ±
T2	1.40^{d} ± 0.20	17.80 ^{d} ±	6.89^{e} ± 0.22	20.67 ^{e} ±	44.14 ^{a} ±	34.91 ^{d} ±	1.29^{a} ±
T3	2.68 ^{ab} ±	25.38 ^{a} ±	9.78 ^{ab} ±	29.33 ^{ab} ±	25.21 ^{e} ±	62.02 ^{ab} ±	0.41^{cd} ±
T4	2.93 ^{ab} ±	25.62 ^{a} ±	10.00^{ab} ±	30.00 ^{ab} ±	21.57^{f} ±	64.53 ^{a} ±	0.34^{d} ±
T5	3.05^{a} ± 0.09	25.94 ^{a} ±	10.11^{a} ±	30.33 ^{a} ±	21.91^{f} ±	66.82 ^{a} ±	0.33^{d} ±
T6	1.85 ^{cd} ±	20.80^{c} ±	7.22^{de} ±	21.67 ^{de} ±	36.49 ^{b} ±	48.49^{c} ±	0.75^{b} ±
T7	2.29 ^{bc} ±	22.98^{b} ±	8.33^{cd} ±	25.00 ^{cd} ±	30.55 ^{c} ±	55.47^{b} ±	0.55^{c} ±
T8	2.32 ^{bc} ±	23.10^{b} ±	8.78^{bc} ±	26.33 ^{bc} ±	29.26^{cd} ±	56.77^{b} ±	0.52^{c} ±

Values are expressed as mean ± standard error (Mean ± SE). Different superscript letters within the same column indicate significant differences at the probability level of ($P \leq 0.05$).

The reduction in RBC, Hb, and PCV may indicate suppression of bone marrow activity or increased erythrocyte destruction as a consequence of oxidative stress, which is associated with aflatoxin toxicity and its direct impact on rapidly dividing cells. The decrease in WBC and lymphocyte percentage further reflects an immunosuppressive effect, whereas the elevation in heterophil percentage and the H/L ratio suggests activation of an acute stress response. In contrast, treatments supplemented with banana peel powder, particularly at the 10% and 15% levels (T4 and T5), demonstrated significant improvement in hematological parameters compared with the contaminated treatment. RBC, Hb, and PCV values increased, while the H/L ratio declined markedly. Under contaminated conditions, the replacement treatments (T7 and T8) also mitigated the severity of the adverse effects relative to T2, indicating the potential of banana peel powder to alleviate hematological and immunological stress induced by aflatoxin. This improvement may be attributed to the antioxidant compounds present in banana peels, which reduce membrane lipid peroxidation and protect blood cells from oxidative damage. Additionally, these bioactive constituents may support immune function and attenuate stress responses. These findings are consistent with recent literature demonstrating that phenolic-rich plant additives can enhance hematological and immune stability in poultry under stress conditions [18].

Relative Weights of Internal Organs

The results presented in Table (6) revealed a significant effect ($P \leq 0.05$) of the dietary treatments on the relative weights of certain internal organs. The aflatoxin-contaminated treatment (T2) showed a significant increase in the relative weights of the liver, spleen, and heart compared with the control treatment. In contrast, the relative weights of abdominal fat and the bursa of Fabricius were significantly reduced.

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Table (6): Effect of dietary aflatoxin B1 contamination and partial replacement of banana peel powder on the relative weights of selected internal organs of broiler chickens.

Tretment	Heart (%)	Liver (%)	Abdominal fat (%)	Spleen (%)	Bursa of Fabricius (%)
T1	0.57 ± 0.02^{bc}	1.83 ± 0.09^{c}	1.49 ± 0.06^{a}	0.11 ± 0.02^{a}	0.19 ± 0.01^{ab}
T2	0.72 ± 0.02^{a}	3.04 ± 0.03^{a}	0.68 ± 0.10^{d}	0.21 ± 0.03^{a}	0.10 ± 0.01^{c}
T3	0.56 ± 0.02^{bc}	1.85 ± 0.14^{c}	1.47 ± 0.09^{a}	0.13 ± 0.03^{a}	0.19 ± 0.03^{a}
T4	0.53 ± 0.01^{c}	1.93 ± 0.20^{c}	1.44 ± 0.08^{a}	0.12 ± 0.04^{a}	0.20 ± 0.01^{a}
T5	0.53 ± 0.04^{c}	1.98 ± 0.31^{c}	1.36 ± 0.10^{ab}	0.12 ± 0.03^{a}	0.17 ± 0.02^{ab}
T6	0.66 ± 0.04^{ab}	2.62 ± 0.17^{b}	0.92 ± 0.04^{cd}	0.17 ± 0.02^{a}	0.13 ± 0.01^{bc}
T7	0.58 ± 0.05^{bc}	2.27 ± 0.16^{bc}	1.08 ± 0.06^{c}	0.14 ± 0.03^{a}	0.17 ± 0.03^{b}
T8	0.59 ± 0.05^{bc}	2.14 ± 0.14^{c}	1.13 ± 0.17^{bc}	0.13 ± 0.04^{a}	0.18 ± 0.02^{ab}

Values are expressed as mean ± standard error (Mean ± SE). Different superscript letters within the same column indicate significant differences at the probability level of ($P \leq 0.05$).

The increase in relative liver weight reflects hepatomegaly resulting from lipid accumulation and histopathological alterations associated with aflatoxin toxicity, which is consistent with the disruption observed in serum lipid parameters. The elevated relative weight of the spleen may be attributed to activation of inflammatory or immune responses under oxidative stress, whereas the reduction in bursa of Fabricius weight suggests potential immunosuppression [15,19,20]. In contrast, dietary treatments supplemented with banana peel powder, particularly at the 10% level (T4), demonstrated a marked improvement, evidenced by a reduction in relative liver weight compared with the contaminated treatment and restoration of bursa of Fabricius weight to levels close to those of the control group. These findings indicate an improvement in hepatic and immune functional status. Additionally, the relative weight of abdominal fat improved in the non-contaminated replacement treatments, which is consistent with enhanced metabolic stability [21]. This potential protective effect may be explained by the ability of phenolic compounds and other antioxidant constituents in banana peels to attenuate oxidative stress and limit cellular damage in vital tissues. Moreover, dietary fiber may contribute to reducing the toxic burden within the body.

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Discussion

The findings demonstrated that exposure to aflatoxin B1 induced marked physiological disturbances, reflected in impaired lipid metabolism, reduced serum protein concentrations, deterioration of hematological parameters, and increased relative weights of the liver and spleen, thereby confirming the hepatotoxic and immunomodulatory effects of the toxin [22]. The concurrent elevation in cholesterol and triglycerides with liver enlargement may be attributed to disrupted hepatic lipid metabolism, whereas the decline in total protein and albumin indicates inhibition of protein synthesis. Moreover, the increased H/L ratio reflects a stress response associated with aflatoxicosis [23]. In contrast, partial replacement of banana peel powder, particularly at the 10% level, improved most of the evaluated parameters compared with the contaminated treatment, suggesting a supportive role in maintaining physiological stability. This effect may be explained by the presence of bioactive compounds with antioxidant properties in banana peels, which may attenuate oxidative stress and enhance hepatic and immune function. Although the protective effect was not fully restorative across all variables, it substantially mitigated the severity of aflatoxin-induced disturbances.

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