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The Impact of Partially Replacing Dietary Maize with Graded Levels of Banana Peels on Nutrient Digestibility, Physiology, and Meat Quality Traits in Jumbo Quail

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Abstract: We evaluated the effect of replacing maize with graded levels of banana (*Musa acuminata*) peels (BPs) on feed utilisation, physiological performance, and meat quality traits in Jumbo quail. In a completely randomised design, 341 one-week-old, unsexed quail chicks were randomly allocated to 30 cages and reared on five experimental diets containing 0 (BP0), 25 (BP25), 50 (BP50), 75 (BP75), and 100 g/kg BP (BP100) in a conventional grower diet. Dry matter, organic matter, and gross energy digestibility values linearly declined ($p < 0.05$) with BP levels. Feed intake in the 5th week linearly declined ($p < 0.05$) as BP levels increased. The BP0 diet promoted greater overall body weight gain than BP100. Similarly, birds on BP0 had a higher ($p < 0.05$) overall gain-to-feed ratio than birds on BP75 and BP100. Significant linear increases were observed for relative gizzard, and small and large intestine weights. There were negative quadratic effects ($p < 0.05$) for relative proventriculus weight, breast lightness, and thigh chroma as BP levels increased. Furthermore, thigh yellowness linearly decreased, while hue angle linearly increased with BP levels. The partial substitution of maize with BP in Jumbo quail diet compromised feed digestibility and performance parameters, stimulated visceral organ development, and altered some meat colour attributes.

Keywords: agro-waste by-products; blood parameters; *Coturnix* species; performance; poultry feed; product quality

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1. Introduction

The poultry subsector is a major source of animal protein and thus, plays a crucial role in ensuring food and nutrition security globally [1]. To meet the rising demand of animal protein in response to a rapidly growing population, increasing income sources, and high levels of urbanisation [2], there is a need to expand poultry production. One strategy involves diversifying the poultry industry with non-chicken poultry species like the Jumbo quail (*Coturnix* sp.), which is gaining popularity for its high-quality meat and eggs [3,4]. These birds have faster growth rates, high feed utilisation efficiency, shorter generation intervals, high prolificacy, and high avian disease resistance [5,6]. However, the upscaling of Jumbo quail production is limited by high feed costs, which are due to the use of cost-intensive feed ingredients, namely maize and soybeans [7,8]. In many countries, these ingredients are also used as direct nutrient sources for humans, further increasing their demand to the detriment of global food and nutrition security. To address this issue, agro-fruit waste by-products such as banana peels (BPs) could be incorporated in quail feeds instead of being disposed through landfilling or incineration.

Globally, bananas are one of the major tropical fruit crops, with a total gross domestic product value of USD 25 billion [9]. Their peels, which are traditionally discarded as waste, contain valuable nutrients [10] and phytochemicals that can enhance feed quality and improve animal performance. Their incorporation in Jumbo quail feeds could potentially alleviate high feeding cost and ensure sustainable intensification of the birds. About 36 million tons of BPs are generated annually from households, restaurants, and food processing agro-industries, with most ending up in landfills or being incinerated [11]. These disposal methods cause environmental pollution through the release of pollutants such as carbon dioxide, methane, and hydrogen sulphide [12]. Thus, integrating BPs into quail diets as a nutraceutical source could mitigate these environmental challenges while promoting the sustainable intensification of quail by reducing feed costs.

Banana peels contain protein (1.95 ± 0.14%), carbohydrates (11.82 ± 2.17%), lipids (5.93 ± 0.13%), vitamins A and C (32.3 mg/100 g) [13], and minerals, including 4.39 mg/100 g potassium, 44.5 mg/100 g magnesium, 47.0 mg/100 g iron, and 59.1 mg/100 g calcium [11,13]. Additionally, BP contains polyunsaturated fatty acids such as α-linolenic (2.1%) and linoleic acids (2%) [14], which could enhance physiological, reproductive and metabolic activities in quail. Furthermore, it is abundantly composed of bioactive compounds, including anthocyanins, flavonoids, alkaloids, terpenoids, and glycosides, which exhibit various pharmacological properties, including anti-diabetic, antioxidant, anti-inflammatory, antimicrobial, and anti-hypertensive effects [11]. These attributes make BP a potentially valuable supplement in quail diets. However, BP contains tannins (4.69%) and structural components such as cellulose (7.6–9.6%), hemicellulose (6.4–9.4%), and lignin (6–12%) [15], which may adversely affect nutrient digestibility in Jumbo quail. This warrants scientific exploration to optimise dietary BP inclusion and enhance the sustainability and efficiency of quail production systems. Moreover, this approach could reduce reliance on conventional feed sources while repurposing waste that would otherwise be landfilled or incinerated into valuable quail feed. Several authors have investigated the inclusion of BP in chicken diets [16–18], but no such reports exist for the Jumbo quail. Thus, this study evaluated the effect of varying levels of BP inclusion in Jumbo quail diets on nutrient digestibility, and physiological and meat quality traits.

2. Materials and Methods

2.1. Ingredient Acquisition and Analysis

Fresh, ripe bananas were bought from a local retailer (People's Market, Mahikeng, North West, South Africa). The bananas were hand-peeled, and the peels were sun-dried for four days with regular turning to prevent mould formation. The dried peels were then ground (1 mm sieve; Polymix PX-MFC 90 D, Switzerland) into a powder and analysed for dry matter (DM; AOAC, 2005: method no. 930.15), organic matter (OM; AOAC, 2005: method no. 942.05), ether extract (EE; AOAC, 2005: method no. 945.16), and crude protein (CP; AOAC, 2005: method no. 984.13). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents were determined using an ANKOM^{DELTA} Fibre Analyzer (ANKOM Technology, Macedon, NY, USA), according to the guidelines by van Soest et al. [19]. For the NDF analysis, heat-stable α-amylase was used and expressed inclusive of residual ash. The ADF residue was treated with 72% sulphuric acid to determine acid detergent lignin (ADL) content after drying for 4 h in an oven set at 105 °C. Gross energy was analysed at Nutrilab at the University of Pretoria (Pretoria, Gauteng, South Africa). Metabolisable energy (ME) was calculated using the following formula by Carpenter & Clegg [20]: [ME (kcal/kg) = (35.3 × %CP) + (79.5 × %EE) + (40.6 × %Nitrogen-free extract) + 199.0]. Amino acids were determined using a Waters-acquity Ultra Performance Liquid Chromatograph (AccQ-Tag Ultra; Waters Corporation, Milford, CT, USA) at Stellenbosch University (Western Cape, South Africa).

2.2. Diet Formulation

Isocaloric and isonitrogenous mash diets were formulated [21] to meet the daily requirements of Jumbo quail. As shown in Table 1, experimental diets were formulated by replacing maize with BP in a standard grower *Coturnix* quail diet at 0 (BP0), 25 (BP25), 50 (BP50), 75 (BP75) and 100 (BP100) g/kg (*w*/*w*). Titanium dioxide was added (3 g/kg) to the diet as an external indicator for the determination of nutrient digestibility. The composition of the diets was determined as described for the BP above.

Table 1. Gross ingredient composition (g/kg as fresh weight basis) of the experimental diets.

	[1] Diet				
Ingredient	**BP0**	**BP25**	**BP50**	**BP75**	**BP100**
[¥] Banana peel	0	25	50	75	100
Yellow maize (8%)	486.0	459.5	433.0	406.7	380.6
Soybean meal (44%)	317.7	316.9	316.1	316.2	316.3
[#] Corn gluten 60	95.9	98.0	100	100	100
Monodicalcium phosphate	14.2	14.2	14.3	14.3	14.4
Limestone powder	13.8	13.8	13.7	13.7	13.6
Salt (fine)	4.0	4.0	4.0	4.0	4.0
L-Lysine HCl	3.9	3.9	3.9	4.0	4.0
Soy oil	53.4	53.6	53.8	53.8	53.8
DL-methionine	2.4	2.4	2.4	2.5	2.5
Threonine	2.7	2.7	2.8	2.8	2.8
L-tryptophan	0.0	0.0	0.0	1.0	2.0
[β] Premix	2.5	2.5	2.5	2.5	2.5
[$] Titanium dioxide	3.0	3.0	3.0	3.0	3.0
Salinomycin	0.5	0.5	0.5	0.5	0.5
Total volume	1000	1000	1000	1000	1000
	Calculated composition (g/kg as is basis)				
Crude protein	240	240	240	240	240
Crude fat	78.4	77.9	77.4	76.8	76.2
Crude fibre	33.7	33.9	34.1	34.3	34.5
Calcium	8.5	8.5	8.5	8.5	8.5
Available phosphorus	3.0	3.0	3.0	3.0	3.0
Metabolisable energy (MJ/kg)	12.9	12.9	12.9	12.9	12.9
* SID methionine	6.1	6.1	6.1	6.1	6.1
* SID lysine	12.5	12.5	12.5	12.5	12.5
* SID threonine	9.4	9.4	9.4	9.4	9.4
Sodium	1.6	1.6	1.6	1.6	1.6
Chloride	3.2	3.2	3.2	3.2	3.2

[1] Diets: BP0 = a standard grower diet without the inclusion of banana peel; BP25 = a standard grower diet with 25 g/kg inclusion of banana peel; BP50 = a standard grower diet with 50 g/kg inclusion of banana peel; BP75 = a standard grower diet with 75 g/kg inclusion of banana peel; BP100 = a standard grower diet with 100 g/kg inclusion of banana peel. * SID: standard ileal digestibility. [β] Premix: 8.0 mg copper sulphate; 79 mg zinc sulphate; 80 mg ferrous sulphate; 30 mg niacin; 100 mg magnesium sulphate; 11 000 IU vitamin A; 10 mg pantothenic acid; 0.34 mg potassium iodine; 0.7 mg folic acid; 0.12 g biotin; 25 IU vitamin E; 2.5 mg vitamin B1; 2500 IU vitamin D3; 4.5 mg vitamin B2; 5.1 mg vitamin B6; 2.0 mg vitamin K3; and 0.25 mg sodium selenite. Ingredient source: [¥] Mahikeng People's Market (Mahikeng, South Africa); [#] Intofeed (Modderfontein, South Africa); [$] Promark Chemicals (Robertsham, South Africa); All other ingredients were purchased from Simplegrow Agric Services and Nutroteq (Centurion, South Africa).

2.3. Experimental Design and House Management

A total of 341 three-day-old unsexed Jumbo quail chicks were bought from Jumbo Quail & Fertile Eggs (Pretoria, Gauteng, South Africa) and transported to North-West University's Molelwane farm (25°57′00″ S; 25°39′21″ E; North West, South Africa). In a completely randomised design, the chicks were weighed (27.56 ± 1.25 g live-weights) and randomly placed into 30 cages (experimental units carrying 11 or 12 birds each), where they were allowed to adapt for 4 days before the feeding experiment commenced at 7 days of age. The floor surface of the cages (100 cm long × 60 cm wide, each) was layered with polyester plastic sheets as bedding. The cages were placed in a house with an entrant door and windows. The initial temperature during the first week of age was 35 °C, which was maintained using infrared lights, and then gradually decreased by switching off some lights until it reached 27 °C in week 5, with an average humidity of 60%. Furthermore, the house was cleaned regularly and well-ventilated by opening the entrant door and windows. Throughout the feeding trial, the birds were offered fresh, clean water daily and had unlimited access to diets. Mortalities were recorded and the carcasses were weighed to correct the gain-to-feed ratio.

2.4. Determination of Feed Components and Amino Acid Digestibility

Titanium dioxide (TiO_2) was added to the diet for use as an external indicator to determine diet digestibility by measuring and comparing its concentration in diet and excreta. A stock solution was made by dissolving 250 mg of TiO_2 in 100 mL of concentrated sulphuric acid (H_2SO_4). After cooling, it was mixed with 200 mL of deionized water in a volumetric flask (500 mL). Standards were created by pipetting incremental volumes of this solution into 50 mL flasks, adding concentrated H_2SO_4 and 10 mL of 30% hydrogen peroxide (H_2O_2), and measuring absorbance at 410 nm. For sample analysis, ash was burned at 550 °C for 6 h, and 0.1 g of feed ash and 0.03 g of faecal ash were weighed and digested in acid. After settling overnight, the colour response was measured at 408 nm using a spectrophotometer (V-730, Japan Spectroscopic Company (JASCO), Tokyo, Japan). The TiO_2 concentration on the samples was prepared and calculated using a site-derived standard curve following the protocols by Fowler et al. [22].

2.5. Growth Performance Measurements

All the birds were offered feed *ad libitum* and feed refusals were weighed (Richter scale model 330 weighing, South Africa) daily to calculate feed intake (FI = feed offered − feed refused). The birds were group-weighed using the same scale weekly until 35 days of age to determine the average weekly body weight gain (BWG). Average weekly BWG and FI were used to calculate the weekly gain-to-feed ratio (G:F).

2.6. Slaughter and Blood Analyses

At day 35 of age, all birds per cage were group-weighed to record the final body weights, and then placed in crates and transported to Rooigrond farm abattoir (Rooigrond, North West, South Africa) for slaughter. The birds were rested for 2 h on arrival and electrocuted before being sacrificed by slicing the jugular vein with a sharp knife. While bleeding, blood from two randomly selected birds from each experimental unit was allowed to drip in clean containers, from which 4 mL of blood was immediately collected using 5 mL syringes and deposited into two sets of sterilised tubes using 23-gauge needles. The tubes for haematological analysis contained ethylene diamine tetra acetic acid. Haematological parameters (haematocrit, neutrophils, red blood cells (RBC), basophils, mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), reticulocytes, lymphocytes, monocytes, eosinophils, mean platelet volume (MPV), platelet distribution width (PDW), and plateletcrit (PCT) were determined within 48 h in Molelwane farm using an automated LaserCyte Haematology Analyser (IDEXX Laboratories S.A. (Pty) Ltd. Johannesburg, Gauteng, South Africa). Serum was generated according to guidelines by Washington & van Hoosier [23] where the clotted blood without the anti-coagulant was centrifuged for 15 min at 1000 centrifugal force. The serum was then transferred into air-tight vials and stored in a freezer below −5 °C [23]. Serum biochemical parameters (total protein, urea, creatinine, albumin, globulin, amylase, phosphorus, calcium, bilirubin, lipase, cholesterol and alkaline phosphatase (ALKP)) were analysed using an automated the Vet Test Chemistry Analyser at Ampath Laboratories (Mafikeng, North West, South Africa).

2.7. Carcass and Visceral Organs Measurements

After slaughter, all the carcasses from each experimental unit were defeathered, eviscerated, and packaged in labelled plastic bags. The warm carcass mass (WCM) was weighed immediately after slaughter. The warm carcasses were then chilled in a cold room (4 °C) for 24 h and re-weighed to determine chilled carcass mass (CCM). The ratio of CCM and slaughter weight at day 35 of age were used to calculate the dressing (%). After weighing the CCM, the breast, thighs, wings, and drumsticks were separated to determine their weights, which were expressed as a proportion of the CCM. The relative weights of proventriculus, gizzard, spleen, liver, and small and large intestines were also determined. All carcass cuts and visceral organ weights were expressed relative to the CCM.

2.8. Breast and Thigh Meat Quality Measurements

At 24 hours post-slaughter, raw breast and thigh muscle samples were measured for meat colour (L^* = lightness, a^* = redness, and b^* = yellowness) using spectrophotometer (BYK-Gardener GmbH, Geretsried, Germany) on a 20 mm diameter measuring area with illuminant D65-day light, and 10-degree observation angle. The colour meter was calibrated before measurements were taken. Hue angle and chroma were calculated as guided by Priolo et al. [24]. Then, meat pH and temperature measurements were also taken using a Corning Model 4 pH-temperature meter (Corning Glass Works, Medfield, MA, USA) that comes equipped with an Ingold spear-type electrode. The pH meter was calibrated with standard solutions having a pH of 4, 7, and 14. Meat tenderness was measured in a breast sample using a Meullenet-Owens Razor Shear Blade (A/MORS) set up on a Texture Analyser (TA-XT plus, Stable Micro Systems, Surrey, UK). The reported value in Newtons represented the average shear force measurements of each sample. Cooking loss was determined as the weight difference between raw and oven-cooked (75 °C) meat samples in proportion to the weight of raw meat following the method by Honikel [25].

Breast meat water holding capacity (WHC) was determined according to Grau & Hamm [26] where breast meat samples (28–36 g) were placed between two filter papers and subjected to 60 kg of pressure for 5 min. For drip loss, 2–3 g breast meat samples were suspended using wire steel in a plastic bottle at 4 °C for 48 h [25]. The difference between initial and final sample weight in proportion of the initial weight was expressed as drip loss.

2.9. Statistical Analysis

All data were tested for normality and homogeneity using the normal option in the PROC Univariate statement SAS® 9.4 [27]. Data for growth performance, nutrient digestibility, and physiological and meat quality parameters were analysed using a general linear model procedure of SAS version 9.4 with dietary treatment as the only factor. Differences between significant means ($p < 0.05$) were compared using Tukey's honest significant difference (HSD) test. The data were further examined using response surface regression analysis procedure (PROC RSREG) in SAS to determine linear and quadratic coefficients, which were declared significant at $p < 0.05$. The values that minimised or maximised the response variables were determined using the second differentiation of the quadratic equation:

$$y = ax^2 + bx + c$$

where y = dependent variable, x = independent variable, a and b are the coefficients of the quadratic equation, and c is dietary BP levels.

3. Results

3.1. Analysed Composition of Banana Peel and Formulated Diets

Table 2 shows that BP is high in gross energy (GE), organic matter and fibre, but low in protein. Diet BP75 had a high GE value compared to all the other treatments. Meanwhile, diet BP25 tended to have the lowest GE value. Diet BP0 tended to have a higher DM, OM, and NDF contents than the BP-containing treatments. The BP100 diet tended to have higher ADF, ADL, ash, and EE values than the other diets. Furthermore, the inclusion of dietary BP tended to reduce histidine but increased all other measured AA levels.

Table 2. Analysed chemical composition and gross energy of banana peels and diets containing graded levels of banana peels.

[3] Component	[2] BP	[1] Diet				
		BP0	BP25	BP50	BP75	BP100
Gross energy (MJ/Kg)	15.79	18.54	18.00	18.60	18.67	18.65
Dry matter (g/kg)	919.2	932.3	931.8	932.0	928.4	931.8
Ash (g/kg DM)	142.8	65.83	69.43	68.02	68.66	71.96
Organic matter (g/kg DM)	776.4	866.4	862.4	864.0	859.7	859.8
NDF (g/kg DM)	276.7	101.3	108.1	102.3	105.9	107.9
ADF (g/kg DM)	174.2	40.55	42.49	41.98	43.55	46.86
ADL (g/kg DM)	54.42	6.991	8.540	8.744	8.912	9.703
Ether extract (g/kg DM)	54.85	84.41	81.46	83.16	83.19	85.71
Histidine (g/100 g DM)	0.076	0.645	0.465	0.513	0.538	0.618
Arginine (g/100 g DM)	0.207	1.507	1.40	1.507	1.563	1.618
Serine (g/100 g DM)	0.234	1.399	1.323	1.410	1.332	1.394
Glycine (g/100 g DM)	0.227	1.083	1.00	1.090	1.037	1.108
Aspartic acid (g/100 g DM)	0.425	2.315	2.348	2.455	2.361	2.475
Glutamic acid (g/100 g DM)	0.468	5.212	5.006	5.184	5.00	5.359
Threonine (g/100 g DM)	0.189	1.387	1.286	1.303	1.20	1.341
Valine (g/100 g DM)	0.241	1.042	1.059	1.132	1.133	1.270
Leucine (g/100 g DM)	0.313	2.797	2.738	3.097	2.892	3.129
Phenylalanine (g/100 g DM)	0.192	1.649	1.20	1.447	1.439	1.603

[1] Diets: BP0 = a standard grower diet without the inclusion of banana peels; BP25 = a standard grower diet with 25 g/kg inclusion of banana peels; BP50 = a standard grower diet with 50 g/kg inclusion of banana peels; BP75 = a standard grower diet with 75 g/kg inclusion of banana peels; BP100 = a standard grower diet with 100 g/kg inclusion of banana peels. [2] BP: banana peels. [3] Components: NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin.

3.2. Feed Components and Amino Acid Digestibility

Table 3 shows that there were neither linear nor quadratic effects on the digestibility of amino acids. However, a linear decline was observed on DM digestibility [y = 84.86 (±0.380) − 0.009 (±0.018) x; R^2 = 0.324; p = 0.011], OM digestibility (OMD) [y = 83.44 (±0.386) − 0.017 (±0.018) x; R^2 = 0.440; p = 0.002], and GE digestibility [y = 81.07 (±0.417) − 0.028 (±0.020) x; R^2 = 0.506; p = 0.001] with incremental BP levels. The OM digestibility and GE digestibility values were higher in birds fed diet BP100 than those fed diet BP0, but were both similar to birds fed diets BP25, BP50, and BP75. Moreover, arginine digestibility was found to be higher in birds fed diet BP25 compared to birds fed diet BP50. Jumbo quail fed diet BP100 had higher tyrosine digestibility compared to quail birds on diet BP0 and BP25. Valine digestibility was found to be higher in birds fed diet BP100 than birds fed diet BP0. However, both groups were not different from birds on diets BP25, BP50, and BP75 in terms of valine digestibility.

3.3. Growth Performance

Table 4 shows that feed intake [y = 0.576 (±0.289) x − 215.2 (±5.869); R^2 = 0.195, p = 0.022] decreased linearly in five-week-old quail with increasing levels of BP. A linear decrease was observed for BWG in four-week-old [y = 0.203 (±0.158) x − 65.34 (±3.197); R^2 = 0.205, p = 0.004] and five-week-old Jumbo quail birds [y = 0.275 (±0.197) x − 47.23 (±4.008); R^2 = 0.231, p = 0.014], as well as overall [y = 0.474 (±0.278) x − 223.5 (±5.645); R^2 = 0.392, p = 0.001], as BP levels increased. Furthermore, FBW [y = 250.3 (±6.291) − 0.155 (±0.301) x; R^2 = 0.196, p = 0.026] showed a decreasing linear effect in response to increasing BP levels. A linear negative effect for an overall gain-to-feed ratio [y = 0.001 (±0.0003) x − 0.389 (±0.006); R^2 = 0.501, p = <0.0001] in response to increasing BP levels. The GLM results showed that four-week-old quail fed diets BP0 and BP25 had a higher (p < 0.05) BWG than birds on BP100, but both did not differ (p > 0.05) from birds on BP50 and BP75 diets. Furthermore, birds on diet BP0 had a higher ($p < 0.05$) overall BWG than birds on diet BP100, but both groups were similar ($p > 0.05$) to BP25, BP50, and BP75 groups.

Table 3. Nutrient digestibility (g/kg) of conventional diet and banana containing Jumbo quail diets.

	[1] Diet						Significance		
[2] Parameter	BP0	BP25	BP50	BP75	BP100	[3] SEM	p-Overall	p-Linear	p-Quadratic
DMD	85.07	84.19	84.24	84.32	83.18	0.392	0.055	0.011	0.747
OMD	83.64 [a]	82.64 [ab]	82.46 [ab]	82.56 [ab]	81.31 [b]	0.398	0.016	0.002	0.899
GED	81.04 [a]	80.48 [ab]	79.71 [ab]	79.22 [ab]	78.74 [b]	0.471	0.023	0.001	0.793
HisD	72.98	76.43	74.35	73.91	68.50	4.344	0.767	0.715	0.849
ArgD	61.50 [ab]	64.10 [a]	50.82 [b]	54.95 [ab]	52.90 [ab]	2.112	0.026	0.295	0.863
SerD	71.74	71.62	65.61	67.40	67.65	2.210	0.320	0.272	0.856
GlyD	80.81	82.77	82.11	83.35	79.21	1.302	0.301	0.489	0.087
AspD	72.51	68.56	59.73	61.47	64.74	5.176	0.480	0.144	0.761
GluD	57.60	54.97	47.93	44.83	49.41	6.296	0.630	0.325	0.985
ThrD	71.85	73.10	69.58	70.58	69.59	2.560	0.831	0.608	0.150
AlaD	58.25	51.64	43.61	43.94	45.63	5.250	0.347	0.172	0.424
ProD	60.87	57.18	49.39	59.27	52.77	2.820	0.143	0.544	0.565
TyrD	75.63 [a]	81.91 [a]	72.92 [ab]	63.84 [bc]	62.94 [c]	1.726	0.002	0.068	0.601
ValD	72.33 [a]	69.78 [ab]	66.99 [ab]	67.61 [ab]	61.96 [b]	1.515	0.033	0.068	0.601
ILeD	68.18	66.44	61.84	61.43	57.61	1.935	0.059	0.055	0.782
LeuD	51.81	49.67	36.92	43.68	37.69	4.756	0.229	0.330	0.673
PheD	58.88	73.08	64.28	67.00	56.46	5.265	0.312	0.967	0.701

[a,b,c] Common superscripts in a row denote the means that do not significantly differ ($p > 0.05$). [1] Diets: BP0 = a standard grower diet without the inclusion of banana peels; BP25 = a standard grower diet with 25 g/kg inclusion of banana peels; BP50 = a standard grower diet with 50 g/kg inclusion of banana peels; BP75 = a standard grower diet with 75 g/kg inclusion of banana peels; BP100 = a standard grower diet with 100 g/kg inclusion of banana peels. [2] Parameters: DMD = dry matter digestibility; OMD = organic matter digestibility; GED = gross energy digestibility; HisD = histidine digestibility; ArgD = arginine digestibility; SerD = serine digestibility; GlyD = glycine digestibility; AspD = aspartic acid digestibility; GluD = glutamic acid digestibility; ThrD = threonine digestibility; AlaD = alanine digestibility; ProD = proline digestibility; TyrD = tyrosine digestibility; ValD = valine digestibility; IleD = isoleucine digestibility; LeuD = leucine digestibility; PheD = phenylalanine digestibility. [3] SEM: standard error of means.

Table 4. Impact of banana peel inclusion in Jumbo quail diet on growth performance parameters.

	[1] Diet						Significance		
[2] Metric	BP0	BP25	BP50	BP75	BP100	[3] SEM	p-Overall	p-Linear	p-Quadratic
Initial BW (g/bird)	27.85	28.43	27.06	27.20	27.24	0.511	0.312	0.201	0.634
Final BW (g/bird at 5 weeks)	249.7	252.5	239.5	236.4	229.7	6.931	0.146	0.026	0.856
			Feed intake (g/bird)						
Week 2	76.82	79.97	76.78	76.89	76.40	1.701	0.572	0.898	0.947
Week 3	118.1	120.3	120.2	116.8	118.6	2.742	0.878	0.704	0.981
Week 4	163.2	162.8	162.1	163.0	159.4	3.257	0.915	0.880	0.875
Week 5	215.3	207.1	193.4	199.0	194.5	6.685	0.139	0.022	0.191
			Body weight gain (g/bird)						
Week 2	49.18	50.91	48.39	47.22	46.14	1.348	0.151	0.102	0.705
Week 3	61.23	62.35	61.78	59.39	59.23	1.468	0.464	0.367	0.661
Week 4	64.0 [b]	60.80 [b]	58.67 [ab]	60.50 [ab]	52.0 [a]	2.139	0.028	0.004	0.544
Week 5	46.31	44.34	35.50	32.25	36.56	4.431	0.149	0.014	0.514
Overall G:F (g:g)	0.391 [a]	0.376 [ab]	0.370 [ab]	0.358 [b]	0.354 [b]	0.007	0.009	<0.0001	0.854
Overall survival (%)	99.27	99.24	99.62	98.96	100.0	0.400	0.425	0.417	0.658

[a,b] Common superscripts in a row denote the means that do not significantly differ ($p > 0.05$). [1] Diets: BP0 = a standard grower diet without the inclusion of banana peels; BP25 = a standard grower diet with 25 g/kg inclusion of banana peels; BP50 = a standard grower diet with 50 g/kg inclusion of banana peels; BP75 = a standard grower diet with 75 g/kg inclusion of banana peels; BP100 = a standard grower diet with 100 g/kg inclusion of banana peels. [2] Metrics: initial BW = initial body weight; Final BW = Final body weight. [3] SEM: standard error of means.

3.4. Blood Indicators

Table 5 shows that no linear or quadratic effects ($p > 0.05$) were observed on serum biochemical and haematological parameters, apart from total protein, which linearly declined [$y = 32.65\ (\pm 0.729) - 0.05(\pm 0.033)\ x$; $R^2 = 0.227$; $p = 0.036$] with the incremental levels of BP. The GLM results showed that birds on diet BP25 had higher ($p < 0.05$) albumin levels (16.50 mmol/L) than birds on diets BP50, BP75, and BP100, but were all similar to the control ($p > 0.05$).

Table 5. Impact of a diet containing graded levels of banana peel on serum biochemistry and haematological parameters in Jumbo quail.

[2] Parameter	[1] Diet					[3] SEM	Significance		
	BP0	BP25	BP50	BP75	BP100		p-Overall	p-linear	p-quadratic
RBC (cells/µL)	2.35	2.59	1.99	2.23	2.20	0.388	0.843	0.210	0.410
Haematocrits (%)	14.70	15.11	13.78	14.10	16.06	2.95	0.978	0.628	0.352
MCV (fL)	63.91	55.28	63.90	62.62	71.05	7.21	0.626	0.434	0.388
MCH (pg/cell)	52.03	66.37	67.90	67.23	62.55	10.71	0.778	0.566	0.193
Reticulocytes (%)	34.46	24.31	28.33	33.33	28.64	2.25	0.022	0.688	0.849
Neutrophils (%)	30.07	34.21	43.47	40.23	28.26	8.326	0.579	0.923	0.193
Lymphocytes (%)	7.63	10.38	11.09	5.00	6.05	2.66	0.356	0.341	0.282
Monocytes (%)	65.27	53.23	63.38	62.92	63.59	7.19	0.761	0.903	0.479
Basophils (%)	6.41	8.89	5.03	5.60	8.04	2.16	0.652	0.992	0.551
MPV (fL)	2262	2500	2378	2500	2269	136.1	0.531	0.838	0.117
PDW (%)	10.44	10.71	10.73	10.73	10.54	0.298	0.932	0.996	0.666
PCT (%)	15.03	15.24	15.14	15.17	14.98	0.146	0.689	0.632	0.297
Eosophils (%)	20.41	19.76	25.01	27.32	22.24	4.90	0.747	0.287	0.281
Creatinine (mmol/L)	5.40	5.00	5.40	5.00	5.00	0.309	0.567	0.199	0.974
Urea (µmol/L)	0.860	0.867	0.850	0.858	0.883	0.049	0.988	0.768	0.368
Phosphorus (mmol/L)	2.88	2.58	2.38	2.84	2.72	0.462	0.854	0.552	0.310
Calcium (mmol/L)	2.82	13.39	2.22	2.58	2.27	3.45	0.905	0.349	0.831
Total protein (g/L)	32.20	25.83	30.80	30.67	30.33	2.08	0.236	0.036	0.400
Albumin (mmol/L)	15.30 [ab]	16.50 [b]	15.00 [a]	15.00 [a]	15.00 [a]	0.351	0.023	0.090	0.745
ALKP (U/L)	1271	1170	1241	1411	1290	237.4	0.927	0.857	0.895
Bilirubin (µmmol/L)	5.10	5.83	4.50	4.42	3.67	1.15	0.709	0.366	0.679
Amylase (U/L)	180.1	386.8	246.4	196.3	149.8	72.37	0.176	0.375	0.251
Lipase (U/L)	32.30	32.50	35.30	53.92	42.00	8.89	0.167	0.179	0.995
Globulin (g/L)	16.90	15.50	15.80	15.67	15.33	1.031	0.554	0.066	0.403
Cholesterol (mmol/L)	5.65	4.35	4.35	4.81	4.98	0.581	0.375	0.538	0.082

[a,b] Common superscripts in a row denote the means that do not significantly differ ($p > 0.05$). [1] Diets: BP0 = a standard grower diet without the inclusion of banana peels; BP25 = a standard grower diet with 25 g/kg inclusion of banana peels; BP50 = a standard grower diet with 50 g/kg inclusion of banana peels; BP75 = a standard grower diet with 75 g/kg inclusion of banana peels; BP100 = a standard grower diet with 100 g/kg inclusion of banana peels. [2] Parameters: RBC = red blood cells; MCV = mean corpuscular volume; MCH = mean corpuscular haemoglobin; MPV = mean platelet volume; PDW = platelet distribution width; PCT = plateletcrit; ALKP = alkaline phosphatase. [3] SEM: standard error of means.

3.5. Carcass and Visceral Organs

Table 6 shows that there were positive linear effects for a relative gizzard weight [y = 0.002 (±0.002) x + 2.215 (±0.039); R^2 = 0.558, p = <0.0001], and small [y = 0.027 (±0.126) x + 57.62 (±2.553); R^2 = 0.173, p = 0.006] and large intestine lengths [y = 0.013 (±0.016) x + 9.159 (±0.322); R^2 = 0.265, p = 0.009] with incremental levels of BP. A quadratic trend was observed for the relative proventriculus weight [y = 0.00003 (±0.00001) x^2 − 0.003 (±0.001) x + 0.516 (±0.023); R^2 = 0.169, p = 0.031] as the BP levels increased. Experimental diets had a significant influence ($p < 0.05$) on the relative weights of gizzard, small intestines, and large intestines. Quail fed diet BP100 had larger ($p < 0.05$) relative gizzard weight than BP0 and BP25 birds, but were all similar ($p > 0.05$) to BP50 and BP75 birds. Diet BP100 resulted in heavier ($p < 0.05$) relative large intestine weight than diet BP75, which did not differ ($p > 0.05$) with BP0, BP25, and BP50 diets.

3.6. Breast and Thigh Meat Quality

Table 7 shows that positive and negative quadratic effects were observed for breast lightness (L^*) [y = 0.001 (±0.0005) x^2 − 0.123 (±0.047) x + 38.23 (±0.945); R^2 = 0.159, p = 0.036] and thigh Chroma [y = 8.642 (±0.475) 0.096 (±0.023) x − 0.0006 (±0.0002) x^2; R^2 = 0.655, p = 0.022] with increasing levels of BP, respectively. Furthermore, thigh yellowness (b^*) [y = 6.193 (±0.3601- 0.011 (±0.018) x +); R^2 = 0.343, p = 0.002] decreased linearly while thigh hue angle [y = 0.0004 (±0.002) x + 0.722 (±0.037); R^2 = 0.323, p = 0.002] linearly increased as the BP levels increased. Birds on diets BP0 and BP25 had higher ($p < 0.05$) thigh yellowness than birds on diet BP100, which were similar to birds on BP50 and BP75. Birds fed diet BP0 had a greater ($p < 0.05$) thigh chroma than birds fed BP25, BP50, BP75, and BP100.

Table 6. Visceral organ and carcass traits (g/100 g CCM) of Jumbo quail fed a diet containing graded levels of banana peel.

Parameter	[1] Diet					[2] SEM	Significance		
	BP0	BP25	BP50	BP75	BP100		p-overall	p-Linear	p-Quadratic
Breast	19.23	18.92	19.86	18.81	19.73	0.414	0.293	0.466	0.684
Drumstick	4.441	4.345	4.545	4.441	4.467	0.066	0.348	0.521	0.647
Thigh	6.736	6.920	7.037	6.806	7.020	0.127	0.388	0.293	0.455
Wing	4.411	4.404	4.618	4.455	4.602	0.090	0.284	0.089	0.946
Hot carcass (g)	174.6	175.4	165.8	165.2	169.3	4.151	0.288	0.155	0.201
Cold carcass (g)	172.4	173.6	164.5	164.8	167.6	4.000	0.369	0.217	0.289
Dressing (%)	69.48	68.95	68.66	69.74	73.17	1.879	0.458	0.248	0.196
Liver	2.728	3.049	2.673	2.729	2.809	0.166	0.5352	0.9728	0.8200
Gizzard	2.212 ^{b}	2.254 ^{b}	2.374 ^{ab}	2.423 ^{ab}	2.470 ^{a}	0.051	0.006	<0.0001	0.629
Spleen	0.094	0.101	0.103	0.110	0.096	0.008	0.647	0.446	0.214
Proventriculus	0.520	0.572	0.611	0.579	0.579	0.026	0.204	0.098	0.031
Small intestine	3.234	3.501	3.543	3.714	4.156	0.215	0.066	0.006	0.387
Large intestine	0.801 ^{ab}	0.892 ^{ab}	1.070 ^{ab}	0.788 ^{b}	1.128 ^{a}	0.080	0.015	0.107	0.962

[a,b] Common superscripts in a row denote the means that do not significantly differ ($p > 0.05$). [1] Diets: BP0 = a standard grower diet without the inclusion of banana peels; BP25 = a standard grower diet with 25 g/kg inclusion of banana peels; BP50 = a standard grower diet with 50 g/kg inclusion of banana peels; BP75 = a standard grower diet with 75 g/kg inclusion of banana peels; BP100 = a standard grower diet with 100 g/kg inclusion of banana peels. [2] SEM: standard error of means.

Table 7. Breast and thigh meat quality traits of Jumbo quail fed a diet containing banana peels.

[2] Parameter	[1] Diet					[3] SEM	Significance		
	BP0	BP25	BP50	BP75	BP100		p-Overall	p-Linear	p-Quadratic
Breast measurements									
Temperature (°C)	15.30	15.66	15.48	14.15	14.94	0.653	0.511	0.309	0.917
a^*	7.31	6.80	6.93	6.94	7.09	0.312	0.815	0.863	0.147
b^*	3.74	4.53	3.75	4.05	4.47	0.454	0.598	0.819	0.341
L^*	37.91	41.76	40.58	41.31	40.63	1.15	0.125	0.089	0.036
Hue angle	0.475	0.588	0.498	0.529	0.549	0.054	0.631	0.918	0.205
Chroma	8.24	8.22	7.94	8.06	8.53	0.299	0.692	0.699	0.338
pH	6.17	6.11	6.15	6.14	6.11	0.022	0.234	0.219	0.578
Thigh measurements									
Temperature (°C)	15.64	16.11	15.59	14.21	15.27	0.691	0.398	0.276	0.867
a^*	7.06	6.57	19.19	6.64	6.99	0.255	0.419	0.995	0.248
b^*	6.21 ^{b}	5.88 ^{b}	4.66 ^{ab}	5.74 ^{ab}	4.25 ^{a}	0.407	0.013	0.002	0.688
L^*	40.08	40.15	39.62	40.81	39.62	0.589	0.609	0.395	0.365
Hue angle	0.723	0.729	0.529	0.709	0.679	0.091	0.509	0.002	0.229
Chroma	8.92 ^{b}	5.88 ^{a}	4.66 ^{a}	5.74 ^{a}	4.25 ^{a}	0.530	<0.0001	<0.0001	0.022
pH	6.47	6.42	6.41	6.47	6.42	0.033	0.493	0.474	0.608
Water holding capacity (%)	84.15	85.29	89.67	89.82	83.84	2.744	0.349	0.599	0.154
Shear force (N)	5.80	6.49	4.97	5.99	5.69	0.751	0.712	0.532	0.708
Drip loss (%)	4.14	3.50	3.98	3.77	3.69	0.290	0.567	0.448	0.434
Cooking loss (%)	28.08	26.06	26.91	26.42	31.17	1.84	0.309	0.471	0.096

[a,b] Common superscripts in a row denote the means that do not significantly differ ($p > 0.05$). [1] Diets: BP0 = a standard grower diet without the inclusion of banana peels; BP25 = a standard grower diet with 25 g/kg inclusion of banana peels; BP50 = a standard grower diet with 50 g/kg inclusion of banana peels; BP75 = a standard grower diet with 75 g/kg inclusion of banana peels; BP100 = a standard grower diet with 100 g/kg inclusion of banana peels. [2] Parameters: a^* = redness, b^* = yellowness, L^* = lightness. [3] SEM: standard error of means.

4. Discussion

4.1. Analysed Composition of Banana Peel and Formulated Diets

Banana peels can be upcycled for use as an affordable feed ingredient for Jumbo quail, providing nutrients such as carbohydrates and lipids [11], and pharmacological compounds such as flavonoids, alkaloids, saponins, and tannins [14]. This approach could reduce BP waste that is discarded into landfills or through incineration, and thus reduce environmental pollution [28]. However, the feed value of BP has not been investigated, particularly for Jumbo quail. In this study, partial replacement of maize with incremental levels of BP increased ash, ADF and ADL contents of the diets. This was anticipated given that BP has high dietary fibre values of 276.0, 195.8, and 54.42 g/kg DM for NDF, ADF, and ADL, respectively, as well as a high mineral concentration. The low CP value indicates that BP containing diets may require supplementation with high CP or nitrogen sources given that poultry birds including quail have precise requirements for AA.

Amino acids have an important metabolic function since, following absorption, they are metabolised to synthesise protein, which is a key growth component in poultry [29]. Thus, AA deficiency due to BP inclusion may pose a deleterious impact on quail health and performance [30]. On the contrary, leucine content increased with BP inclusion, which is imperative since it is known to promote growth and development through a variety of pathways, including protein synthesis, energy metabolism, and immunological function in poultry [31]. Thus, the increase in leucine, an essential AA, means that the birds will be able to optimally perform the aforementioned bodily activities.

4.2. Feed Components and Amino Acid Digestibility

Nutrient digestibility is a measure of the level at which dietary nutrients or feed components are absorbed and utilised by the bird as the digesta moves through the digestive system [32]. Sugiharto [33] reported that fruit peels have a high fibre content that can reduce nutrient digestibility in poultry. In this study, the partial replacement of maize at 100 g BP/kg diet reduced the digestibility of DM, OM, GE, arginine, tyrosine, and valine. These results indicate that BP inclusion may reduce nutrient availability and absorption. Similarly, Abel et al. [34] reported a decline in DM digestibility in broiler chickens fed diets containing dried BP. Similarly, Abdel-Daim [35] reported a decline in OM digestibility in broilers fed diets with potato peels and sugar-beet pulp. These reductions in digestibility could be due to high fibre levels in these fruit waste by-products that have also been reported to reduce nitrogen retention, metabolisable energy, starch digestibility, and the utilisation of other nutrients, resulting in poor performance [36]. Numerically, the digestibility values decreased with increasing BP levels; this shows that higher levels of BP could have compromised nutrient utilisation by the birds.

4.3. Growth Performance

Feeding Jumbo quail with diets containing BP decreased FI in 5-week-old birds. Nuriyasa et al. [37] reported similar results of low feed intake in native chicken fed a fermented banana peel-containing diet, which was due to higher dietary fibre that can reduce palatability, and thus the intake of feed. Moreover, Niknafs et al. [38] reported that poultry have an acute sense of taste, which allows them to distinguish at least five of the six major tastes. Therefore, the lower feed intake in week 5 could be that the maturing birds' developed sense of taste, which might have resulted in reduced preference and acceptance of the BP-containing diets. The decline in FI resulted in a lower BWG and overall gain-to-feed ratio in 4- and 5-week-old birds. Similarly, BP inclusion up to 100 g/kg resulted in poor final body weights for Jumbo quail. However, the BP25 treatment showed numerically higher final body weights than all the other treatments, which could indicate that lower levels may be desirable. Overall, BP inclusion up to 100 g/kg caused adverse effects on growth performance metrics in Jumbo quail.

4.4. Blood Indicators

Incorporating new ingredients in a diet requires blood profiling to assess its impact on bird health and welfare [39]. Blood tests reveal important information such as the neuroendocrine and immune system activation state, acute and chronic effects of poor husbandry, possible illnesses, and genetic susceptibility [40]. In this study, the partial replacement of maize with BP did not affect the overall health of the birds as indicated by the analysed haematological parameters. These results were comparable to those reported by Ojediran et al. [41], who replaced maize with cassava root meal in Japanese quail diets.

Red blood cells (RBCs) transport oxygen and carbon dioxide throughout the body. Thus, a lower RBC count could point to an insufficient circulation of oxygen that is transported to the tissues and the level of carbon dioxide returned to the lungs [42]. Haematocrit indicates the volume of RBCs in the plasma, which is a positive indicator of optimal oxygen transportation and health [43]. The results suggest that the incorporation of BPs in the diet did not compromise the circulatory system. Mean corpuscular haemoglobin (MCH) is one of the crucial indices for assessing circulatory erythrocytes, and it is important in the diagnosis of anaemia [44], with low levels indicating anaemia [43]. The results suggest that BP inclusion in the diet did not interfere with the circulation of the electrolytes.

Serum biochemical indicators reflect the metabolism of nutrients in the body and identify potential alterations caused by internal and external influences [45]. The liver plays a critical role in the metabolism, detoxification, and removal of endogenous and foreign substances [46]. The activity levels of alkaline phosphatase (ALKP) are considered one of the diagnostic tools that may be used to evaluate hepatotoxicity [47]. Any toxic substance elevates ALKP, aspartate aminotransferase and alanine transaminase activity levels, indicating liver damage or impairment [48]. Thus, the absence of diet-induced changes on these parameters suggest that BP inclusion did not cause any toxicity to the birds; hence, the liver was not affected.

Serum proteins are largely produced in the liver, and their quantities reflect the functional state of hepatocytes. Any decrease in total protein and albumin could indicate malnutrition, active inflammation, and hepatic insufficiency, which may be caused by repeated infections and immunological deficiencies [49]. Moreover, high protein and albumin levels in blood serum indicate a greater chance of protein deposition in meat [50,51]. In this study, total protein reduced with BP inclusion, suggesting lower protein deposition. Moreover, the albumin levels were the highest in the 25 g BP/kg diet and the lowest in the 50, 75, and 100 g BP/kg diets, further indicating that BP is a poor source of protein. Overall, the lack of dietary effects on the health indicators of the birds signifies that BP inclusion is a safe alternative to maize in Jumbo quail diets. However, valorisation strategies can be applied to reduce the antinutritional activities of fibre to achieve optimal performance and health.

4.5. Carcass and Visceral Organs

Higher carcass yields imply that birds are more efficient and capable of producing meat, and has a significant impact on quail prices [6]. In this study, BP inclusion in the place of maize in Jumbo quail diet did not influence all measured carcass traits such as carcass, thigh, drumstick, and breast weights. This suggests that BP does not compromise economic traits and carcass performance. Visceral organs are important in ensuring the efficient digestion of feedthrough the gizzard that mechanically digests, and the proventriculus that performs chemical digestion. The relative weights of organs serve as indicators of bird responses to harmful or nutritionally challenging substances, which may lead to their anatomical alterations [48]. In this study, the relative weights of gizzards and large intestines were greater in birds fed the 100 g BP/kg diet in place of maize than the control birds, which could be attributed to physio-anatomical adaptation towards increasing the ability to mechanically digest the fibrous diet. Indeed, Marareni et al. [52] reported heavier gizzard, small, and large intestines in response to a high fibrous diet fed to Jumbo quail. Similarly, the increase in large intestines could have been an adaptive strategy to optimise nutrient absorption from the digested fibrous feed [53]. The observed results were in accordance with Moyle et al. [53], who reported increased gizzard and intestine sizes when broilers were fed a fibrous diet. The increase in visceral organ weights correlates with reports that fibrous diets result in an enlargement of internal organs, especially the intestines [54,55].

There were no dietary effects observed on relative spleen and liver weights. The spleen is involved in the production and filtering of blood, while the liver, as previously discussed, detoxifies any toxic substances. Thus, the lack of dietary influences on these organs suggest that BP inclusion did not interfere with their normal functions. The proventriculus showed a negative quadratic effect with increasing BP levels. The proventriculus is the glandular stomach where digestion starts [56]; thus, the negative quadratic response indicates that lower levels of BP increased the proventriculus weight but declined with increasing levels. It is not clear why the proventriculus weight was heaviest at 50 g BP/kg but lowest at 75 and 100 g BP/kg.

4.6. Breast and Thigh Meat Quality

Consumer preference for safe and quality meat drives the market for poultry meat. Meat quality consists of a variety of traits linked to the appearance and palatability of both fresh and processed meat, such as pH, colour, flavour, water-holding capacity, textural structure, and tenderness [57]. In the current study, increasing BP levels in place of maize caused a negative quadratic effect in breast lightness. Similarly, it caused a reduction in thigh chroma and yellowness than the control group, which had the highest thigh chroma and yellowness. This outcome was expected given that the diets were formulated using yellow maize which contains β-carotene that has yellow pigmentation effects [58]. Meat pH is determined by the level of glycogen and the rate at which adenosine triphosphate is broken down within the muscles of the bird post-slaughter [59]. Meat pH plays a crucial role in determining the quality of the meat and has influence on other parameters like tenderness (measured by shear force), WHC, and drip and cook losses that points to the muscle protein ability to maintain internal moisture and loss of nutrients [59]. In this study, these parameters were not affected, which signifies that the partial replacement of maize with BP up to 100 g BP/kg has no adverse effect on meat quality. A similar study by Azman and Ahman [60] also reported no dietary effect on meat tenderness and drip loss in Japanese quail fed pumpkin peels.

5. Conclusions

The partial replacement of maize with banana peels resulted in a low amino acid content in the diets, resulting in poor feed utilisation. Moreover, the decrease in the digestibility of feed components and amino acids led to poor productive and physiological performance in the birds. It was concluded that BP inclusion up to 100 g/kg in place maize in Jumbo quail diets did not improve growth performance, and physiological and meat quality attributes. Future studies should explore nutritional strategies to ameliorate the antinutritional activities of fibre and tannins in BP to improve its utilisation efficiency in poultry feeds.

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