Trop. Anim. Prod. Invest. 29 (01):1-9 (2026)
ISSN: 1115-2540
https://journals.ui.edu.ng/index.php/tapi

ORIGINAL RESEARCH ARTICLE

Influence of Poultry Manure on the Nutritional, Fibre and Mineral Characteristics Of *Brachiaria ruziziensis* Silage

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ABSTRACT

Sustainable livestock production requires innovative feeding strategies that enhance forage quality while utilizing locally available agricultural resources efficiently.This study evaluated the influence of graded inclusion levels of air-dried layer droppings on the nutritional, fibre and mineral characteristics of *Brachiariaruziziensis* silage. The experiment was arranged as a 3 × 4 factorial in a Completely Randomised Design (CRD), comprising three inclusion levels of air-dried layer droppings (0%, 5%, and 10% on a dry matter basis) and four ensiling durations (0, 21, 42, and 63 days), replicated three times. Proximate composition (dry matter, crude protein, ash, ether extract, crude fibre), fibre fractions [neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL)], in vitro organic matter digestibility (IVOMD), and mineral content (macro and micro) were determined using standard methods. Significant ($P < 0.05$) interaction effects of inclusion level and ensiling duration were observed for all proximate, fibre, and mineral parameters evaluated. The highest crude protein (7.73%) was recorded at 10% inclusion level after 42 days of ensiling, compared to 5.53% in the un-ensiled control. In vitro organic matter digestibility peaked at 51.02% at 5% inclusion after 21 days of ensiling. Neutral detergent fibre ranged from (66.65 - 70.04%), with acid detergent lignin increasing progressively with ensiling duration, peaking at 4.64% at 5% inclusion after 63 days. Mineral concentrations were significantly enhanced by inclusion of layer droppings; phosphorus peaked at 2.99 g/kg (10% inclusion, 42 days), calcium at 2.77 g/kg (5% inclusion, 21 days), and magnesium at 3.06 g/kg (5% inclusion, 21 days). Findings indicate that ensiling *B. ruziziensis* with 5–10% air-dried layer droppings for 21–42 days optimises crude protein content, digestibility, and macro-mineral enrichment, supporting its use as a high-quality supplement for ruminant feeding in tropical production systems.

Keywords: *Brachiaria ruziziensis,* Poultry manure, Mineral enrichment, silage, crude protein, ruminant nutrition

INTRODUCTION

The rising demand for sustainable livestock production in tropical regions has underscored the critical importance of improving forage quality through cost-effective and environmentally responsible approaches. *Brachiariaruziziensis* (Congo grass) is a widely cultivated tropical forage grass valued for its adaptability to diverse soil types, high biomass production, and moderate nutritional quality (Ariyo et al., 2025; Azangue et al., 2019). Its crude protein (CP) content, however, frequently falls below the minimum threshold of 70 g/kg DM required for adequate rumen microbial activity, particularly during the dry season when levels may decline to as low as 50 g/kg DM (Pamo et al., 2007). Such protein deficiency constrains microbial fermentation efficiency in the rumen, limits organic matter digestibility, and ultimately depresses animal performance, making nutritional supplementation or forage improvement strategies indispensable for supporting productive ruminant systems (Ariyo et al., 2025).

Ensiling is a principal method for preserving tropical forages, maintaining nutritional quality and ensuring a consistent feed supply during feed-scarce periods (Sánchez-Guerra et al., 2024). The fermentation process during ensiling is driven primarily by lactic acid bacteria (LAB), which produce lactic acid, thereby rapidly lowering pH and inhibiting the proliferation of undesirable spoilage microorganisms (Kazemi, 2025; Guo et al., 2023). However, the quality of silage is determined not only by the forage species and its buffering capacity but also by the availability of soluble carbohydrates and the diversity of epiphytic microbial populations. Tropical grasses such as *B. ruziziensis* often pose silage-making challenges due to their relatively low water-soluble carbohydrate content and high buffering capacity, necessitating the use of appropriate additives to optimise

fermentation dynamics (Sánchez-Guerra et al., 2024).

One promising and readily available additive in smallholder tropical farming systems is poultry manure, particularly air-dried layer droppings. Layer droppings are characterised by high nitrogen content (4.55–5.6%), substantial phosphorus (2.46–2.82%), calcium (4.52–8.15%), and magnesium (0.52–0.73%), as well as appreciable concentrations of micronutrients including copper, zinc, iron and manganese (Islam et al., 2024; Agbede&Oyewumi, 2022). The incorporation of poultry droppings as a nitrogen-rich additive in silage has been demonstrated to significantly enhance crude protein content, stimulate LAB activity, and improve the overall fermentation quality of tropical grass silages (Islam et al., 2024; Azangue et al., 2019). Beyond nutritional benefits, the valorisation of poultry waste through silage production contributes to environmental sustainability by reducing waste disposal challenges and enhancing nutrient cycling in integrated crop-livestock systems, consistent with the principles of circular bioeconomy (Kazemi, 2025; FAO, 2023).

Despite growing documentation of the effects of poultry manure on proximate composition of tropical grass silages, a comprehensive evaluation encompassing fibre fractions and mineral enrichment of *B. ruziziensis* silage remains limited. Minerals are indispensable for ruminant physiological functions, reproduction, skeletal integrity, and immune competence, and their deficiency can precipitate subclinical health disorders and reduced productivity (Emily, 2021). This study therefore evaluated the influence of graded levels of air-dried layer droppings and ensiling duration on the nutritional, fibre, and mineral characteristics of *Brachiariaruziziensis* silage, with the ultimate objective of defining optimal inclusion rates and ensiling periods for enhanced ruminant feed quality in tropical production systems.

MATERIALS AND METHODS

Experimental site and design

The experiment was conducted at the Pasture and Range Management Laboratory, Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria (latitude 7°10'N, longitude 3°26'E; altitude 76 m above sea level). Freshly harvested *Brachiariaruziziensis* was collected from the University Teaching and Research Farm at vegetative stage. Air-dried layer droppings were obtained from a commercial poultry farm and sun-dried to a moisture content of approximately 10% before use. The experiment was laid out as a 3 × 4 factorial arrangement in a Completely Randomised Design (CRD). The two factors were: (i) inclusion level of air-dried layer droppings at 0%, 5%, and 10% (dry matter basis), and (ii) ensiling duration at 0, 21, 42, and 63 days. Each treatment combination was replicated three times, yielding 36 experimental units. The forages were wilted for 4–6 hours to reduce moisture content to between 30 and 35% dry matter, a range considered optimal for ensiling (Kung et al., 2018). The appropriate quantity of air-dried layer droppings was thoroughly mixed with the wilted grass at the designated inclusion rates on a fresh-weight basis. The mixture was compacted into 5-litre airtight polyvinyl chloride (PVC) containers to simulate laboratory-scale silo conditions, each sealed to maintain strict anaerobic conditions throughout the ensiling period.

Sample collection and preparation

At each designated ensiling duration (0, 21, 42, and 63 days), silos allocated to that sampling period were opened, the silage was thoroughly mixed, and representative samples were collected. Samples were oven-dried at 65°C for 48 hours, ground to pass a 1-mm sieve, and stored in labelled airtight containers at room temperature pending laboratory analysis.

Proximate and Fibre Analysis

Proximate composition, including dry matter (DM), crude protein (CP), crude fibre (CF), ash, and ether extract (EE), was determined following the procedures of the Association of Official Analytical Chemists (AOAC, 2005). CP was estimated as total nitrogen multiplied by 6.25, with nitrogen determined by the macro-Kjeldahl method. Fibre fractions such as neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) were determined according to the detergent system of Van Soest et al. (2020), using heat-stable α-amylase and expressed on a dry matter basis. In vitro organic matter digestibility (IVOMD) was estimated using a Near-Infrared Spectroscopy (NIRS) instrument calibrated against established reference values, and metabolisable energy (ME) was calculated from IVOMD using standard equations.

Mineral Determination

After each fermentation period, silage samples were oven-dried at 65°C for 48 hours, ground to a fine powder, and analysed using a Near-Infrared Spectroscopy (NIRS) instrument to quantify macro-minerals such as calcium (Ca), phosphorus (P), potassium (K), magnesium (Mg), and sodium (Na) and micro-minerals manganese (Mn), ferric iron

(Fe^{3+}), and zinc (Zn). All mineral values are expressed in g/kg dry matter.

Statistical Analysis

Data was subjected to a two-way analysis of variance (ANOVA) using the General Linear Model (GLM) procedure appropriate for a factorial arrangement in a Completely Randomised Design. The statistical model included the main effects of inclusion level and ensiling duration, as well as their two-way interaction term. Where significant F-values ($P < 0.05$) were obtained, treatment means were separated using Duncan's Multiple Range Test (DMRT) at a 5% level of significance. All statistical analyses were performed using SAS (Statistical Analysis System) software, version 27 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Effects of inclusion levels and ensiling duration on proximate, fiber composition and post incubation parameters of *Brachiaria ruziziensis* ensiled with airdried layer droppings:

The main effects of inclusion level and ensiling duration on the proximate and fibre composition of *B. ruziziensis* silage are presented in Table 1. Regarding inclusion level, significant differences ($P < 0.05$) were confined to crude protein (CP) and in vitro organic matter digestibility (IVOMD), while dry matter (DM), ash, ether extract (EE), crude fibre (CF), NDF, ADF, ADL, and metabolisable energy (ME) were not significantly ($P > 0.05$) affected. Crude protein increased significantly from 5.90% at 0% inclusion to 6.29% at 5% inclusion and further to 7.08% at 10% inclusion ($P < 0.05$), representing a 19.9% relative improvement over the control. This progressive increase in CP with higher inclusion rates is consistent with the substantial nitrogen content of layer droppings and the activity of ammonia-utilising bacteria during fermentation. Similarly, IVOMD differed significantly among inclusion levels ($P < 0.05$), with the highest value (50.11%) recorded at 5% inclusion compared to 48.97% at 0% inclusion, suggesting that moderate supplementation with layer droppings favourably supported microbial populations responsible for cell-wall degradation, enhancing the nutritive value of the silage.

With respect to ensiling duration, significant ($P < 0.05$) differences were observed for CP, EE, NDF, ADF, and ADL, while DM, ash, CF, and ME remained unaffected ($P > 0.05$). Crude protein was highest at 42 days (6.79%), closely followed by 21 days (6.75%), and declined to 6.26% by day 63, indicating that the optimal fermentation window for protein retention lies between 21 and 42 days. The reduction in CP beyond 42 days is attributable to secondary fermentation activity and increased proteolytic degradation over prolonged ensiling, consistent with known silage fermentation dynamics (Kung et al., 2018). Acid detergent lignin increased progressively from 3.81% at day 0 to 4.27% at day 63 ($P < 0.05$), reflecting gradual lignification of cell wall structures over extended ensiling periods, which is known to reduce the proportion of potentially digestible fibre (Borreani and Tabacco, 2018). The IVOMD was highest at 21 days (50.42%) and declined to 48.63% by 63 days ($P < 0.05$), corroborating the detrimental effect of increased lignin deposition on forage digestibility.

Table 1: Effects of inclusion levels and ensiling duration on proximate, fiber composition and post incubation parameters of *Brachiariaruziziensis* ensiled with airdried layer droppings

Parameters	DM	CP	CF	ASH	EE	NDF	ADF	ADL	ME	IVOMD
Inclusion Level (%)										
0	92.62	5.90^{c}	30.80	9.14	0.45	68.70	40.24	3.87	7.20	48.97^{b}
5	92.24	6.29^{b}	30.40	9.24	0.36	68.55	39.14	4.01	7.32	50.11^{a}
10	92.34	7.08^{a}	30.78	9.58	0.42	68.77	39.45	4.05	7.30	49.96^{a}
SEM	0.54	0.42	0.66	0.32	0.41	0.67	0.61	0.98	0.95	0.68
Ensiling Duration (days)										
0	92.46	5.90^{b}	31.02	8.97	0.46^{a}	68.36^{ab}	39.55^{ab}	3.81^{b}	7.30	49.71^{ab}
21	92.21	6.75^{a}	30.30	9.41	0.27^{b}	67.55^{b}	38.59^{b}	3.80^{b}	7.30	50.42^{a}
42	92.58	6.79^{a}	30.75	9.46	0.44^{a}	69.02^{a}	39.74^{ab}	4.05^{ab}	7.26	49.73^{ab}
63	92.35	6.26^{b}	30.57	9.43	0.47^{a}	68.23^{ab}	40.55^{a}	4.27^{a}	7.25	48.63^{b}
SEM	0.40	6.41	0.66	9.31	0..41	0.32	0.61	0.98	0.28	0.62

^{abc}..... Means in the same column with different superscripts are significantly different ($P < 0.05$), SEM = Standard error of mean.DM; Dry Matter, CP; Crude Protein, CF; Crude Fibre, EE; Ether Extract, NDF; Neutral Detergent Fibre, ADF; Acid Detergent Fibre, ADL; Acid Detergent Lignin, ME; Methane Extract, IVOMD; *In vitro* Organic Matter Digestibility.

Effects of inclusion levels and ensiling duration on mineral composition (g/kg) of *Brachiaria ruziziensis* ensiled with airdried layer droppings

The main effects of inclusion level and ensiling duration on the mineral composition of *B. ruziziensis* silage are presented in Table 2. With respect to inclusion level, significant differences ($P < 0.05$) were observed for Na, Mn, and P, while K, Mg, Ca, Fe^{3+}, and Zn were not significantly ($P > 0.05$) affected. Na increased significantly from 1.59 g/kg at 0% inclusion to 1.96 g/kg and 1.95 g/kg at 5% and 10% inclusion, respectively. P increased consistently with increasing inclusion from 1.97 g/kg (0%) to 2.44 g/kg (5%) and 2.50 g/kg (10%), confirming the P-enriching effect of layer droppings, which contain 2.46–2.82% P on a dry matter basis (Agbede&Oyewumi, 2022). Mn increased significantly from 0.03 g/kg (0%) to 0.06 g/kg (10%) ($P < 0.05$), reflecting the trace mineral contributions of the incorporated droppings.

The ensiling duration, calcium and magnesium exhibited significant ($P < 0.05$) variation, while Na, K, Mn, Fe^{3+}, Zn, and P were not significantly ($P > 0.05$) affected by ensiling period. Ca was highest at 21 days (2.41 g/kg) and declined thereafter to 1.54 g/kg at 63 days ($P < 0.05$). Mg peaked at 2.81 g/kg at 21 days and decreased to 2.49–2.51 g/kg at later periods ($P < 0.05$). The observed reduction in Ca and Mg concentrations beyond 21 days is consistent with progressive microbial immobilisation of divalent cations into insoluble mineral-organic complexes during advanced fermentation stages. K concentration showed a gradual numerical increase over time, attaining 12.81 g/kg at 63 days, though this trend was not statistically significant ($P > 0.05$). Zn remained stable across all treatments (0.02 g/kg), indicating that this micromineral is largely unaffected by ensiling conditions.

Interaction effects of inclusion levels and ensiling duration on proximate composition of *Brachiaria ruziziensis* ensiled with airdried layer droppings

The interaction effects of inclusion level and ensiling duration on the proximate composition of *B. ruziziensis* silage are presented in Table 3. Significant interactions ($P < 0.05$) were observed for CP, ash, and EE, confirming that the effect of inclusion level on these parameters was modulated by ensiling duration and vice versa. The highest CP (7.73%) was recorded at 10% inclusion after 42 days of ensiling, compared to the lowest value of 5.52% at 0% inclusion at day 42, representing a relative improvement of 40.0% due to the combined effect of nitrogen supplementation and optimal fermentation duration. CP at 10% inclusion also remained elevated at 7.43% (21 days) and 6.99% (63 days), indicating that higher manure inclusion conferred a sustained protein enrichment advantage. At 5% inclusion, CP peaked at 7.11% on day 42 and declined to 5.56% at day 63, reflecting the interaction between substrate nitrogen availability and the duration-dependent proteolytic activity of ensiling microflora. The control (0% inclusion) exhibited CP values of 5.53% and 5.52% at days 0 and 42, respectively, rising to 6.24–6.30% at days 21 and 63. Ash content ranged significantly ($P < 0.05$) from 8.42% (5% inclusion, day 0) to 10.06% (5% inclusion, day 42), reflecting dynamic mineral accumulation influenced by both the mineral rich composition of layer droppings and ongoing fermentative mineral concentration processes.

Table 2: Effects of inclusion levels and ensiling duration on mineral composition (g/kg) of *Brachiariaruziziensis* ensiled with airdried layer droppings

Parameters	Na	K	Mg	Ca	Mn	Fe^{3+}	Zn	P
Inclusion Level (%)								
0	1.59^{b}	12.31	2.54	1.61a	0.03^{c}	0.62	0.02	1.97^{b}
5	1.96^{a}	12.50	2.61	1.63	0.05^{b}	0.54	0.02	2.44^{a}
10	1.95^{a}	12.53	2.41	1.44	0.06^{a}	0.59	0.02	2.50^{a}
SEM	0.04	0.32	0.09	0.22	0.00	0.03	0.00	0.07
Ensiling Duration (days)								
0	1.72	12.65	2.26^{b}	0.88^{c}	0.04	0.65	0.02	2.13^{b}
21	1.80	12.09	2.81^{a}	2.41^{a}	0.05	0.56	0.02	2.45^{a}
42	1.84	12.21	2.49^{b}	1.43^{b}	0.04	0.57	0.02	2.29^{ab}
63	1.97	12.81	2.51^{b}	1.54^{b}	0.05	0.55	0.02	2.35^{ab}
SEM	0.07	0.37	0.09	0.17	0.01	0.04	0.00	0.12

^{abc}…. means in the same column with different superscripts are significantly different ($P < 0.05$), SEM = Standard error of mean, Na = Sodium, K = Potassium, Mg = Magnesium, Ca = Calcium, Mn = Manganese, Fe^{3+} = Ferric, Zn = Zinc, P = Phosphorus.

Table 3: Interaction effects of inclusion level and ensiling duration on proximate composition of *Brachiaria ruziziensis* ensiled with airdried layer droppings

Inclusion level (%)	Ensiling duration(days)	DM	CP	CF	ASH	EE
0	0	92.52	5.53^{f}	31.24^{a}	8.72^{ce}	0.54^{a}
	21	92.60	6.30^{de}	30.73^{ab}	9.59^{ac}	0.33^{e}
	42	92.57	5.52^{f}	31.24^{a}	8.67^{e}	0.53^{ab}
	63	92.63	6.24^{de}	29.97^{ab}	9.58^{ae}	0.40^{ce}
5	0	92.71	5.99^{e}	30.66^{ab}	8.42^{e}	0.36^{de}
	21	91.66	6.53^{d}	29.41^{b}	9.23^{ae}	0.06^{f}
	42	93.36	7.11^{bc}	30.91^{ab}	10.06^{a}	0.50^{ac}
	63	92.24	5.56^{f}	30.63^{ab}	9.23^{ad}	0.51^{ac}
10	0	92.09	6.18^{de}	31.15^{a}	9.78^{ab}	0.48^{ad}
	21	90.30	7.43^{ab}	30.76^{ab}	9.64^{ab}	0.41^{be}
	42	92.82	7.73^{a}	30.09^{ab}	9.65^{ab}	0.29^{e}
	63	92.15	6.99^{c}	31.12^{a}	9.48^{ad}	0.50^{ac}
SEM		0.24	0.12	O.15	0.10	0.03

^{abc}….. Means in the same column with different superscripts are significantly different (P <0.05), SEM = Standard error of mean.DM; Dry Matter, CP; Crude Protein, CF; Crude Fibre, EE; Ether Extract.

EE was highest (0.54%) in the un-ensiled control (0%, day 0) and declined progressively with increasing ensiling duration across all inclusion levels, reaching a minimum of 0.06% at 5% inclusion at day 21 ($P < 0.05$). This pronounced reduction in EE with advancing ensiling is consistent with the oxidative and microbial utilisation of lipids as a fermentation substrate during early anaerobic fermentation. DM and CF did not show significant ($P > 0.05$) interaction effects, remaining relatively stable at 90.30–93.36% and 29.41–31.24%, respectively, across all treatment combinations.

Interaction effects of inclusion levels and ensiling duration on fiber fraction and post incubation parameters of *Brachiaria ruziziensis* ensiled with airdried layer droppings

Significant interactions ($P < 0.05$) between inclusion level and ensiling duration were observed for NDF, ADF, ADL, and IVOMD, but not for metabolisable energy (ME) (Table 4). Neutral detergent fibre ranged from 66.65% (5% inclusion, 21 days) to 70.04% (5% inclusion, 42 days). The lowest NDF at 5% inclusion and 21 days. ADL increased progressively with ensiling duration across all inclusion levels ($P < 0.05$), reaching its peak value of 4.64% at 5% inclusion after 63 days

Table 4: Interaction effects of inclusion levels and ensiling duration on fiber fraction and post incubation parameters of *Brachiariaruziziensis* ensiled with layer droppings

Inclusion level (%)	Ensiling duration (days)	NDF	ADF	ADL	ME	IVOMD
0	0	69.68^{ab}	40.43	4.08^{bd}	7.18	49.03^{bc}
	21	68.14^{be}	40.26	3.73^{de}	7.15	49.54^{ac}
	42	69.71^{ab}	39.63	4.02^{cd}	7.34	49.03^{bc}
	63	67.28^{e}	40.65	3.67^{de}	7.13	48.29^{c}
5	0	68.27^{ae}	39.28	3.90^{de}	4.44	50.53^{ab}
	21	66.65^{e}	37.15	3.88^{de}	7.40	51.02^{a}
	42	70.04^{a}	39.50	3.62^{de}	7.19	49.84^{ac}
	63	69.26^{ac}	40.68	4.64^{a}	7.25	49.09^{bc}
10	0	67.14^{e}	38.96	3.44^{e}	7.27	49.58^{ac}
	21	67.56^{ce}	38.36	3.78^{de}	7.34	50.70^{ab}
	42	67.32^{de}	40.16	4.50^{ab}	7.23	50.33^{ab}
	63	69.05^{ad}	40.33	4.47^{ac}	7.37	49.24^{ac}
SEM		0.23	0.31	0.07	0.04	0.18

^{abc}….. Means in the same column with different superscripts are significantly different (P <0.05), SEM = Standard error of mean; NDF; Neutral Detergent Fibre, ADF; Acid Detergent Fibre, ADL; Acid Detergent Lignin, ME; Methane Extract, IVOMD; *In vitro* Organic Matter Digestibility.

Table 5: Interaction effects of inclusion level and ensiling duration on mineral composition of *Brachiaria ruziziensis* ensiled with airdried layer droppings

Inclusion level (%)	Ensiling duration (days)	Na	K	Mg	Ca	Mn	Fe^{3+}	Zn	P
0	0	1.57^{a}	12.02^{de}	2.22^{ef}	1.02^{f}	0.02^{c}	0.62^{c}	0.02^{a}	1.91^{h}
	21	1.61^{e}	12.42^{c-e}	2.79^{ab}	2.24^{c}	0.03^{bc}	0.62^{c}	0.02^{a}	2.04^{f}
	42	1.57^{e}	12.36^{c-e}	2.35^{d-f}	1.02^{f}	0.02^{c}	0.62^{c}	0.02^{a}	1.91^{h}
	63	1.61^{e}	12.42^{c-e}	2.79^{ab}	2.24^{c}	0.03^{bc}	0.62^{c}	0.02^{a}	2.04^{f}
5	0	1.71^{de}	11.50^{d-f}	2.51^{b-e}	1.48^{d}	0.05^{ab}	0.53^{d}	0.02^{a}	2.54^{c}
	21	1.82^{cd}	12.63^{b-d}	3.06^{a}	2.77^{a}	0.05^{ab}	0.42^{e}	0.02^{a}	2.83^{b}
	42	2.10^{ab}	13.55^{a-c}	2.41^{c-e}	0.92^{g}	0.05^{ab}	0.71^{b}	0.02^{a}	1.97^{g}
	63	2.19^{a}	12.31^{de}	2.44^{c-e}	1.37^{e}	0.05^{ab}	0.50^{d}	0.02^{a}	2.43^{e}
10	0	1.87^{cd}	12.43^{a}	2.04^{f}	0.15^{h}	0.05^{ab}	0.81^{a}	0.02^{a}	1.95^{gh}
	21	1.97^{bc}	11.23_{ef}	2.58^{b-d}	2.22^{c}	0.06^{a}	0.63^{c}	0.02^{a}	2.48^{d}
	42	1.84^{cd}	10.74^{f}	2.72^{bc}	2.35^{b}	0.06^{a}	0.39^{e}	0.02^{a}	2.99^{a}
	63	2.12^{ab}	13.71^{ab}	2.29^{d-f}	1.02^{f}	0.07^{a}	0.52^{d}	0.02^{a}	2.57^{c}
SEM		0.08	0.50	0.06	0.23	0.01	0.15	0.00	0.18

^{abc}…. means in the same column with different superscripts are significantly different (P <0.05), SEM = Standard error of mean, Na = Sodium, K = Potassium, Mg = Magnesium, Ca = Calcium, Mn = Manganese, Fe^{3+} = Ferric, Zn = Zinc, P = Phosphorus.

and its minimum of 3.44% at 10% inclusion before ensiling. IVOMD was highest at 51.02% when *B. ruziziensis* was ensiled with 5% layer droppings for 21 days, and declined to 49.09% and 48.29% under longer ensiling durations at 5% inclusion (63 days) and 0% inclusion (63 days), respectively. At 10% inclusion, IVOMD values were similarly elevated at 21 days (50.70%) and 42 days (50.33%), indicating that higher manure levels sustain digestibility across a broader ensiling window. Metabolisable energy did not differ significantly (P > 0.05) among interaction treatments.

Interaction effects of inclusion level and ensiling duration on mineral composition of *Brachiaria ruziziensis* ensiled with airdried layer droppings

Highly significant difference (P < 0.05) interaction effects of inclusion level and ensiling duration were observed for all evaluated mineral parameters, Na, K, Mg, Ca, Mn, Fe^{3+}, and P with the exception of zinc (Zn), which did not vary significantly (P > 0.05) across treatment combinations (Table 5). Ca content was highest (2.77 g/kg) at 5% inclusion after 21 days of ensiling and lowest (0.15 g/kg) at 10% inclusion before ensiling (day 0) (P < 0.05). By day 21, Ca concentrations increased substantially across all inclusion levels. Similarly, Mg was highest at 3.06 g/kg (5% inclusion, 21 days) and declined progressively with extended ensiling to 2.44 g/kg at the same inclusion level by day 63 (P < 0.05). P was highest at 2.99 g/kg at 10% inclusion after 42 days (P < 0.05) and lowest at 1.91 g/kg in the control (0% inclusion) at days 0 and 42, representing a 56.5% increase attributable to the progressive solubilisation of phytate-bound and organically complexed phosphorus from the droppings during fermentation. K was highest at 13.71 g/kg (10% inclusion, 63 days) and lowest at 10.74 g/kg (10% inclusion, 42 days). Na increased consistently with both inclusion level and ensiling duration, reaching its maximum at 2.19 g/kg (5% inclusion, 63 days). Mn was highest at 0.07 g/kg (10% inclusion, 63 days) and ferric iron peaked at 0.81 g/kg (10% inclusion, day 0) before declining with increasing ensiling duration, possibly reflecting reduction of Fe^{3+} to Fe^{2+} under progressively anaerobic conditions. Zinc remained constant at 0.02 g/kg across all treatments (P > 0.05), confirming its stability in this ensiling system.

DISCUSSION

The progressive and significant improvement in crude protein content of *B. ruziziensis* silage with increasing inclusion of air-dried layer droppings validates the long-established premise that poultry manure serves as a concentrated organic nitrogen source capable of enriching the fermentation substrate (Azangue et al., 2019; Islam et al., 2024). The highest CP of 7.73% recorded at 10% inclusion after 42 days surpassed the critical threshold of 7% CP below which rumen microbial activity and fibre digestion are significantly constrained (Ariyo et al., 2025). The nitrogen enrichment mechanism operates through two complementary pathways: first, the direct incorporation of ammonia-nitrogen and non-protein nitrogen compounds from the droppings into the fermentation mass, which are subsequently utilised by ammonia-assimilating bacteria within the silo; and second, the stimulation

of lactic acid bacterial growth by the elevated nitrogen pool, which enhances overall fermentation efficiency and protein retention (Islam et al., 2024; Kung et al., 2018). The decline in CP observed beyond 42 days is attributable to intensified proteolysis by Clostridium species and other secondary fermenters under prolonged anaerobic conditions, with the resulting amino acid catabolism and ammonia volatilisation reducing net protein retention (Kung et al., 2018; Borreani and Tabacco, 2018). These findings emphasise the importance of harvesting silage within the 21–42-day window to maximise protein conservation.

The significant improvement in *in vitro* organic matter digestibility (IVOMD), peaking at 51.02% at 5% inclusion after 21 days, reflects the synergistic effect of moderate nitrogen supplementation and early active fermentation in enhancing the digestible fraction of the silage. The nitrogen supplied by layer droppings likely supported cellulolytic bacterial populations within the silo, facilitating partial hydrolysis of cell-wall carbohydrates and thereby increasing the proportion of potentially fermentable organic matter (Ma et al., 2023; Kazemi, 2025). Beyond 42 days, the decline in IVOMD across most treatment combinations is mechanistically linked to the progressive accumulation of ADL observed in this study. Lignin is extensively cross-linked with cellulose and hemicellulose through ester and ether bonds, forming a physical barrier that impedes microbial and enzymatic access to potentially digestible cell-wall polysaccharides (Borreani and Tabacco, 2018; Ariyo et al., 2025). The correlation between increasing ADL and declining IVOMD across ensiling durations therefore reflects a biologically coherent fibre-digestibility relationship that has important practical implications for the timing of silage feeding in ruminant systems.

The fibre fractions, NDF, ADF, and ADL showed significant interaction effects but remained within ranges considered acceptable for ruminant nutrition (NDF 66–70%; ADF 37–41%), indicating that the incorporation of layer droppings did not structurally compromise the cell-wall integrity of the silage. The pattern of NDF reduction at 5% inclusion at 21 days followed by an increase at 42 days is consistent with a biphasic fermentation model in which initial microbial hydrolysis of hemicellulose reduces total cell-wall content, but subsequent re-condensation of fermentation by-products and selective preservation of more recalcitrant fractions restores the NDF towards baseline values (Guo et al., 2023). The gradual elevation of ADL across all treatments with increasing ensiling duration is a well-documented phenomenon in tropical grass silages and underscores the risk of prolonged storage in systems relying primarily on forage quality for animal performance (Sánchez-Guerra et al., 2024; Ma et al., 2023).

The significant enrichment of macro-minerals, particularly phosphorus, calcium, magnesium, and sodium in the silage as a function of layer droppings inclusion represents one of the most agronomically important findings of this study. Layer droppings are among the richest organic sources of phosphorus (2.46–2.82%), calcium (4.52–8.15%), and magnesium (0.52–0.73%) in smallholder farming systems (Agbede and Oyewumi, 2022). The highest phosphorus (2.99 g/kg) recorded at 10% inclusion after 42 days likely reflects both the direct phosphorus load from the incorporated droppings and the enzymatic liberation of phytate-bound phosphorus by microbial phytases under anaerobic fermentation conditions. Adequate dietary phosphorus is indispensable for skeletal development, energy metabolism (as a component of ATP and phospholipids), and reproduction in ruminants (Emily, 2021). The peak concentrations of calcium and magnesium at 21 days of ensiling (2.77 g/kg and 3.06 g/kg), respectively, at 5% inclusion suggest that this early fermentation period maximises mineral solubilisation from the droppings before progressive mineral complexation with organic acids and cell-wall components reduces their extractable concentrations at later timepoints (Oladosu et al., 2021). The subsequent decline in Ca and Mg beyond 21 days is consistent with mineral immobilisation within microbial biomass and precipitation as insoluble organo-mineral complexes during advanced fermentation (Kazemi, 2025).

The relative stability of trace mineral concentrations, particularly zinc, which remained constant at 0.02 g/kg across all treatments indicates that the ensiling process, while profoundly affecting macro-mineral dynamics, exerted limited influence on micro-mineral equilibrium. The increase in manganese with higher inclusion levels (0.03 to 0.07 g/kg) is consistent with the trace mineral composition of poultry droppings, which contain appreciable quantities of manganese from feed additives and gastrointestinal secretions (Agbede and Oyewumi, 2022). The initial high ferric iron content (0.81 g/kg) at 10% inclusion before ensiling, declining with prolonged anaerobic fermentation, likely reflects the well-established reduction of Fe^{3+} to Fe^{2+} under the reducing conditions of anaerobic silage environments, a geochemical process facilitated by ferric-iron-reducing bacteria (Islam et al., 2024).

Collectively, the results affirm that ensiling *B. ruziziensis* with 5–10% air-dried layer droppings for 21–42 days represents a biologically sound and practically feasible strategy for improving the nutritive value of this tropical forage without compromising its structural integrity. This approach aligns with the principles of circular bioeconomy, which advocates the valorisation of organic waste streams such as poultry manure to enhance agricultural productivity while simultaneously reducing environmental pollution associated with open disposal of poultry excreta (Kazemi, 2025; FAO, 2023). The dual benefit of nutritional enrichment and waste utilisation positions this strategy as a compelling option for smallholder livestock producers in sub-Saharan Africa, where both feed quality deficits and poultry waste management challenges are prevalent.

CONCLUSION

This study demonstrates that the incorporation of air-dried layer droppings significantly improved the nutritional, fibre, and mineral characteristics of *Brachiariaruziziensis* silage in a dose- and duration-dependent manner, with significant interaction effects confirming that the nutritional outcome of this practice cannot be predicted from main effects alone. The highest crude protein (7.73%), peak in vitro organic matter digestibility (51.02%), and maximum concentrations of phosphorus (2.99 g/kg), calcium (2.77 g/kg), and magnesium (3.06 g/kg) were achieved at 5–10% inclusion of layer droppings ensiled for 21–42 days. Beyond this window, increasing acid detergent lignin accumulation reduced digestibility, indicating that prolonged ensiling beyond 63 days is sub-optimal for nutritional quality. Future studies should investigate the effect of different poultry manure sources, anaerobic fermentation kinetics, microbial community dynamics, and in vivo animal performance responses to further optimise inclusion rates and guide large-scale practical adoption.

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