



Evaluation of Mineral and Anti-Nutritional Characteristics of Maize (*Zea mays*) and Copaiba Balsam Tree (*Daniellia oliveri*) Silage Affected by Ensiling Duration

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ABSTRACT

Ensiling is an important forage preservation method that can improve feed quality, nutrient availability, and dry-season feeding of ruminants. This study evaluated the effects of ensiling duration and *Daniellia oliveri* inclusion on the mineral profile, mineral ratios, and anti-nutritional contents of maize silage. Maize and *D. oliveri* leaves were combined at five forage proportions (100M:0D, 75M:25D, 50M:50D, 25M:75D, and 0M:100D) and ensiled for 0, 2, 4, 8, and 12 weeks in laboratory silos. The experiment was arranged in a 5 × 5 factorial Completely Randomized Design with six replicates. Results showed that Calcium concentration increased with higher *D. oliveri* inclusion, ranging from 2.34 to 9.06 g/kg DM, while potassium decreased from 14.15 to 6.01 g/kg DM as ensiling progressed, which indicates lower tetany risk in ruminants. Iron and manganese concentrations improved with increasing browse inclusion, reaching peak values of 230.45 and 77.24 mg/kg DM, respectively, after 8 weeks of ensiling. Mineral ratios such as Ca:P and Fe:Cu were also significantly enhanced in mixtures containing higher proportions of *D. oliveri*. Anti-nutritional compounds declined with prolonged ensiling, with tannin, phytate, and saponin contents reducing to 0.24, 0.20, and 0.26%, respectively, after 12 weeks. The study indicated that inclusion of *D. oliveri* improved mineral composition of maize silage, while extended ensiling reduced anti-nutritional factors and enhanced overall feed quality for ruminant production. It is recommended that maize–*D. oliveri* be ensiled for 8–12 weeks to optimize mineral balance and reduce anti-nutritional contents in ruminant diets.

Keywords: Browse plant, fermentation, nutrient, preservation, tropical livestock, dry-season feeding.

INTRODUCTION

Tropical ruminant production is constrained by seasonal feed shortages, poor pasture quality, and inadequate nutrient supply, particularly during the dry season, resulting in reduced productivity and increased production costs (Lamidi and Ologbose, 2014; Kgosikoma *et al.*, 2012; Kraai *et al.*, 2022; Cooke *et al.*, 2024). Natural pastures and crop residues, the major feed resources in tropical regions, are often characterized by

low crude protein, poor digestibility, mineral deficiencies, and high fiber content during feed-scarce periods (Mtengeti *et al.*, 2008). Consequently, interest has increased in alternative feed preservation techniques and underutilized browse resources capable of improving ruminant nutrition year-round. Maize (*Zea mays* L.) is the third most important cereal crop globally after wheat and rice (Bilal *et al.*, 2005). It is the most widely

conserved cereal as silage due to its high dry matter yield, low buffering capacity, and abundant water-soluble carbohydrates that enhance lactic acid fermentation. In Nigeria, maize is the leading silage crop (Amodu et al., 2014). *Daniellia oliveri* (Rolfe) Hutch. & Dalziel is a multipurpose deciduous tree of the family Fabaceae, widely distributed in West and Central African savannas and woodland transition zones (Balogun et al., 2023). The species is a valuable fodder tree for ruminants, supporting rumen fermentation and nutrient digestibility despite its tannin content (Osakwe et al., 2004; Badejo et al., 2026).

Ensiling is an effective forage conservation method that preserves nutrients and ensures feed availability during periods of scarcity (Manganyi et al., 2024). The process involves anaerobic fermentation by lactic acid bacteria, which produce organic acids that lowers pH and inhibit spoilage microorganisms (Kung et al., 2018). Properly fermented silage improves feed intake, nutrient utilization, and animal performance while reducing nutrient losses. Maize (*Zea mays* L.) is widely used for silage because of its high soluble carbohydrate content, favorable fermentation characteristics, high dry matter yield, and palatability, although it is relatively deficient in protein and some essential minerals (Zafar et al., 2020).

To improve maize silage quality, protein-rich browse plants are increasingly incorporated into silage mixtures (Ojo et al., 2016). Browse species remain valuable during the dry season and often contain higher concentrations of protein, minerals, and bioactive compounds than grasses and cereal forages (Njidda, 2020; Amad and Zentek, 2023). Among these, *D. oliveri* has attracted attention due to its adaptability and nutritional potential in ruminant feeding systems (Badejo et al., 2026). Its leaves reportedly contain appreciable levels of minerals, digestible nutrients, and secondary metabolites that support rumen function and animal productivity (Osakwe et al., 2004; Balogun et al., 2023).

Minerals are essential for skeletal development, enzyme activity, immunity, reproduction, and nutrient utilization, while mineral imbalances may impair animal health and productivity (Suttle, 2022). However, browse plants may also contain anti-nutritional compounds such as tannins, phytates, and saponins that reduce nutrient digestibility and mineral bioavailability, although saponins may exert beneficial antiprotozoal effects in the rumen (Meka, 2021; Niderkorn and Jayanegara, 2021; Kholif, 2023). Ensiling may reduce these compounds through microbial and enzymatic activities, depending on forage composition and fermentation duration (Martens et al., 2014; Tuovinen et al., 2025). Therefore, this study evaluated the effects of *D. oliveri* inclusion levels and ensiling duration on the mineral profile, mineral ratios, and anti-nutritional characteristics of maize silage mixtures.

MATERIALS AND METHODS

Study Area

The experiment was conducted at the Department of Pasture and Range Management, College of Animal Science and Livestock Production, Federal University of Agriculture, Abeokuta, Nigeria, where both the ensiling procedure and laboratory analyses were carried out. The experimental location lies within the rainforest agro-ecological zone of Southwestern Nigeria and is geographically located at latitude 7°13'56.32" N and longitude 3°26'12.16" E, with elevation of 492 feet (Google earth, 2026). The region is characterized by a humid tropical climate with distinct wet (April - October) and dry (November – March) seasons. The area receives an average annual rainfall of approximately 1037 mm, and with a mean annual temperature of about 34.7°C, while the relative humidity averages 82% (Source: Agrometeorology Department, FUNAAB).

Sample Collection and Ensiling Procedure

Fresh leaves of *D. oliveri* were harvested from the Directorate of University Farms of the Federal University of Agriculture, Abeokuta, while maize (*Zea mays* L., Suwan-

1 variety) was harvested at the milky growth stage in the same Directorate of University Farms. Immediately after harvesting, both forage materials were wilted overnight under ambient environmental conditions to reduce excess moisture and minimize seepage losses during ensiling.

Following wilting, the forage materials were chopped manually into particle sizes not exceeding 2 cm. The chopped maize and *D. oliveri* leaves were subsequently weighed and thoroughly mixed according to the predetermined treatment proportions.

Five experimental forage mixtures were formulated as follows: 100% Maize + 0% *D. oliveri*, 75% Maize + 25% *D. oliveri*, 50% Maize + 50% *D. oliveri*, 25% Maize + 75% *D. oliveri*, 0% Maize + 100% *D. oliveri*

The mixed forage samples were tightly compacted into airtight laboratory silos (glass jar) with a capacity of 960 ml. Each silo was carefully sealed immediately after filling to prevent air infiltration and moisture loss during fermentation. The silos were thereafter stored at room temperature under laboratory conditions for designated ensiling periods of 0, 2, 4, 8, and 12 weeks.

At the end of each ensiling duration, the corresponding silos were opened, and representative samples were collected from each treatment and replicate for laboratory analyses. The collected silage samples were sub-sampled and oven-dried at 65°C until a constant weight was achieved. The dried samples were then milled using a laboratory hammer mill to pass through a fine sieve and stored in airtight sample bottles pending chemical analyses.

Experimental Design

The experiment was arranged as a 5 × 5 factorial combination in a Completely Randomized Design (CRD) with six (6) replicates. The two experimental factors consisted of five forage proportions of maize and *D. oliveri* mixtures and five ensiling durations. The forage mixture treatments included 100M:0D, 75M:25D, 50M:50D, 25M:75D, and 0M:100D, while the ensiling durations consisted of 0, 2, 4, 8, and 12

weeks, which amounts to a total of twenty-five (25) treatment combinations.

Laboratory Analysis

The dried and milled silage samples were subjected to mineral and anti-nutritional analyses using standard laboratory procedures. Samples were oven-dried at 65°C to constant weight prior to analysis. Mineral analyses were conducted at the laboratory of the Department of Pasture and Range Management, Federal University of Agriculture, Abeokuta. The mineral composition of the silage samples was determined using the wet digestion method. 0.5 g of the milled samples were digested using a mixture of nitric acid (HNO₃) and hydrochloric acid (HCl) in a ratio of 3:1. After digestion, the solution volume was adjusted to 100 ml using distilled water for subsequent mineral determination (Abbruzzini et al., 2014). Macro minerals including calcium (Ca), phosphorus (P), potassium (K), magnesium (Mg), and sodium (Na), as well as micro minerals such as manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn), were determined following the procedures described by AOAC (2005). Macro mineral concentrations were expressed as g/kg dry matter (DM), whereas micro mineral concentrations were expressed as mg/kg DM. To determine the correlations between the minerals, ratio values were generated.

Determination of Anti-Nutritional Factors (ANF)

Tannin determination

Samples were weighed (1g) into a labeled crucible and agitated in 10ml of distilled water, leaving the residue for 30 minutes at room temperature. These were then centrifuged, and 2.5ml of the supernatant was dispersed into a 50ml vaporizing flask. Also, into another separate 50ml flask, 2.5ml of standard tannic acid was dispersed, followed with an addition of 1.0ml of folin-dennis reagent and then 2.5ml of saturated sodium bicarbonate (Na₂CO₃) solution into each flask. Absorbance was subsequently measured at 725 nm using a UV-visible spectrophotometer. Tannin concentration was

quantified by comparison with a calibration curve prepared from a standard tannin solution, and results were expressed on a dry-matter basis (Makkar, 2003; AOAC, 2005).

Saponin determination

Saponin content of the samples was determined using standard analytical procedures. A known weight 10g of finely milled sample was extracted using 100 ml of ethanol to obtain a crude saponin fraction. The combined extracts were concentrated and subjected to purification steps to eliminate interfering substances. The purified extract was then reacted with an appropriate colour-developing reagent, and colour intensity was measured spectrophotometrically at 544 nm using a UV-visible spectrophotometer. Saponin concentration was quantified based on a standard calibration curve or appropriate standard reference, and results were expressed on a dry matter basis (Obadoni and Ochuko, 2001).

Phytate determination

Phytate content was determined using the method of Wheeler and Ferrel (1971) with 2.0 g of dried sample. A standard curve was prepared and results expressed as $\text{Fe}(\text{NO}_3)_3$ equivalents. Phytate phosphorus was calculated from the standard curve, assuming a 4:6 iron-to-phosphorus molar ratio as described by Babiker et al. (2018).

Statistical Analysis

All data generated from the experiment were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) software package version 9.1. Significant means were separated using Duncan's Multiple Range Test (DMRT). Statistical significance was declared at the 5% probability level ($P < 0.05$).

RESULTS AND DISCUSSION

Macro Mineral Contents of Silage

There was a significant difference ($p < 0.05$) in the Ca, Mg, K, and P contents of silage at different proportions as influenced by ensiling duration. Pure ensiled *D. oliveri* recorded the highest Ca contents (90.56 g/kg DM) for silage stored for eight weeks. Calcium (Ca) concentration increased with higher inclusion

of *D. oliveri*, indicating that the browse species is richer in Ca than maize. This supports reports that tropical browse plants generally contain higher mineral concentrations than cereal forages because of their deeper rooting systems and greater mineral uptake capacity (Castro-Montoya and Dickhoefer, 2020). The Ca concentration of sole maize fresh and ensiled fodder was lower than the mean reported for grasses by Castro-Montoya and Dickhoefer (2020), whereas mixtures and sole *D. oliveri* silage contained higher Ca levels. However, Ca values in maize silage remained below the recommended range for lactating dairy cattle (4.3–7.7 g/kg DM) (National Research Council (NRC), 2001; Erickson and Kalscheur, 2020). The contents of Mg decreased in pure maize silage with increasing duration of storage, and recorded the highest significant ($p < 0.05$) Mg content (6.51 g/kg DM) in fresh un-ensiled pure *D. oliveri*. The Mg concentration of pure maize silage met the recommended requirement of 2 g/kg DM for ruminants (NRC, 2001).

Potassium content ranged from 6.01 of pure ensiled *D. oliveri* stored for 12 weeks to 14.15 g/kg DM of fresh un-ensiled maize. The 50% un-ensiled maize recorded the highest significant ($p < 0.05$) phosphorus content (2.70 g/kg DM) (Table 1). The potassium concentrations obtained in the present study were comparable with values reported for well-preserved tropical forage silages and exceeded the minimum dietary requirements for ruminants, suggesting adequate potassium nutrition (NRC, 2001; Kung et al., 2018). Phosphorus (P) concentrations exceeded the critical level of 2.5 g/kg DM for ruminants and the mean value reported by Muhammad et al. (2004). The P values were also higher than the normal requirements for growing cattle, pregnant heifers, and lactating cows (Eastridge et al., 2006), as well as the range reported by NRC (2001) for lactating animals. The P concentration of sole maize silage was comparable to that reported by Amole et al. (2011).

Table 1: Effects of Ensiling Duration and Forage Proportion on the Macro Mineral Contents (g/kg DM) of Silage Produced from Maize-*D. oliveri* Mixtures

Duration (weeks)	Forage Proportion (%)	Ca	Mg	K	P
0	100M:0D	2.61 ^x	2.06 ^s	14.15 ^a	2.20 ^b
	75M:25D	2.34 ^y	2.78 ^o	9.53 ^h	1.25 ^{gh}
	50M:50D	3.32 ^t	4.31 ^b	8.98 ^k	2.70 ^a
	25M:75D	6.10 ^m	3.33 ^c	6.89 ^s	1.75 ^c
	0M:100D	6.96 ^h	6.51 ^a	7.82 ^o	1.65 ^{cd}
2	100M:0D	2.86 ^v	2.18 ^q	13.25 ^c	1.10 ^{ijk}
	75M:25D	3.48 ^s	2.79 ^o	12.26 ^f	1.05 ^{jk}
	50M:50D	6.11 ⁱ	2.95 ^k	8.10 ^m	1.10 ^{ijk}
	25M:75D	6.50 ^j	3.02 ⁱ	10.06 ^g	0.90 ^{lm}
	0M:100D	8.57 ^b	3.27 ^d	6.20 ^w	0.75 ⁿ
4	100M:0D	3.53 ^r	2.13 ^r	12.60 ^e	1.15 ^{hij}
	75M:25D	4.26 ^p	2.81 ⁿ	9.41 ⁱ	1.20 ^{hi}
	50M:50D	6.03 ⁿ	2.98 ^j	9.41 ⁱ	1.65 ^{cd}
	25M:75D	8.22 ^c	3.13 ^g	6.65 ^t	0.80 ^{mn}
	0M:100D	8.10 ^f	3.09 ^h	6.24 ^v	0.85 ^{mn}
8	100M:0D	4.01 ^q	2.05 ^t	12.66 ^d	1.10 ^{ijk}
	75M:25D	4.39 ^o	2.83 ^m	12.61 ^e	1.15 ^{hij}
	50M:50D	6.47 ^k	2.97 ^j	8.67 ^l	1.45 ^{ef}
	25M:75D	8.27 ^d	3.15 ^f	7.24 ^r	1.55 ^{de}
	0M:100D	9.06 ^a	3.21 ^e	6.25 ^u	2.15 ^b
12	100M:0D	2.76 ^w	2.04 ^l	14.00 ^b	1.35 ^{fg}
	75M:25D	2.96 ^u	2.45 ^p	7.85 ⁿ	1.25 ^{gh}
	50M:50D	6.98 ^g	3.10 ^h	7.63 ^p	1.10 ^{ijk}
	25M:75D	6.56 ⁱ	2.91 ^l	7.36 ^q	1.00 ^{kl}
	0M:100D	8.47 ^c	3.16 ^f	6.01 ^x	1.15 ^{hij}
SEM		0.00	0.10	0.03	0.05
P-value					
Duration (D)		0.0008	<0.0001	<0.0001	0.0048
Forage proportion (F)		<0.0001	<0.0001	<0.0001	<0.0001
D x F		0.0003	<0.0001	0.0004	0.0031

Key: ^{abc...y} means on the same column with different superscripts are significantly (p<0.05) different, M = Maize, D = *Daniellia* and SEM = Standard Error of Mean.

Micro mineral contents of silage

Table 2 shows that ensiling duration and forage proportion significantly influenced the micro mineral composition of maize – *D. Oliveri* silage mixtures. Iron (Fe) concentration generally increased with increasing inclusion level of *D. oliveri* in the mixture across all ensiling periods. The lowest Fe value (120.42 mg/kg DM) was observed in the sole un-ensiled maize, while the highest value (230.45 mg/kg DM) was recorded for sole *D. oliveri* ensiled for 8 weeks. Iron (Fe) concentration increased with higher *D. oliveri* inclusion and longer ensiling duration, confirming that *D. oliveri* is inherently richer in Fe than maize. The increase in Fe during ensiling may result from improved Fe solubility under acidic fermentation conditions and microbial degradation of fibrous tissues, which enhances mineral release and bioavailability (Hansen and Spears, 2009; Bueno *et al.*,

2020; Adebisi *et al.*, 2017; Adebo *et al.*, 2022).

A similar trend as in Fe was observed for manganese (Mn), with values ranging from 48.63 mg/kg DM in sole un-ensiled maize to 77.24 mg/kg DM in the sole *D. oliveri* silage ensiled for 8 weeks. Manganese (Mn) concentration increased with higher *D. oliveri* inclusion and prolonged ensiling, probably due to mineral liberation during fermentation and concentration effects associated with carbohydrate losses. Similar increases in Mn following ensiling were reported by Bueno *et al.* (2020). All Mn values exceeded the recommended range of 20–40 mg/kg for ruminants.

In contrast, zinc (Zn) and copper (Cu) concentrations decreased as the proportion of *D. oliveri* increased. Zinc values for Sole maize were the highest throughout the ensiling periods, with the highest value (35.03 mg/kg DM) recorded for 8 weeks, while the lowest Zn concentration (28.52 mg/kg DM)

was observed for the sole *D. oliveri* silage at 4 weeks. In contrast, zinc (Zn) concentration declined with increasing *D. Oliveri* inclusion, suggesting that maize contributed more Zn than *D. Oliveri*. Nevertheless, most silages exceeded the 30 mg/kg Zn requirement for ruminants and remained below the tolerable limit of 500 mg/kg (NRC, 2016; National Academies of Sciences, Engineering, and Medicine (NASEM), 2021). The relative stability of Zn during fermentation agrees with Grujcic *et al.* (2018). Copper (Cu)

concentration increased slightly up to 8 weeks of ensiling, likely due to dry matter losses and improved mineral solubility under acidic conditions (Genther and Hansen, 2015; Vigh *et al.*, 2023). However, prolonged ensiling reduced Cu concentration, possibly because of oxidation, effluent losses, and formation of insoluble complexes (Food and Agriculture Organization (FAO), 2001). Although, Cu levels were below cattle requirements, they remained within the recommended range for small ruminants (NRC, 2007; 2016).

Table 2: Effects of Ensiling Duration and Forage Proportion on the Micro Mineral (mg/kg DM) Contents of Silage Produced from Maize-*D. oliveri* Mixtures

Duration (weeks)	Plant Proportion (%)	Fe	Zn	Cu	Mn
0	100M:0D	120.42 ^y	34.23 ^a	8.50 ^b	48.63 ^v
	75M:25D	145.83 ^u	32.54 ^c	8.13 ^d	55.22 ^q
	50M:50D	168.34 ^q	30.85 ^e	7.74 ^f	60.73 ^m
	25M:75D	192.62 ^l	29.64 ^g	7.25 ^h	66.92 ⁱ
	0M:100D	210.84 ^f	28.95 ^h	6.95 ⁱ	72.54 ^e
2	100M:0D	125.73 ^x	34.55 ^a	8.53 ^a	49.82 ^u
	75M:25D	152.44 ^t	32.93 ^b	8.22 ^c	56.83 ^p
	50M:50D	175.92 ^p	31.24 ^d	7.80 ^e	62.45 ^l
	25M:75D	198.23 ^j	29.85 ^f	7.34 ^g	68.12 ^h
	0M:100D	218.54 ^d	28.72 ^h	7.02 ⁱ	74.34 ^d
4	100M:0D	130.12 ^w	34.82 ^a	8.70 ^a	50.52 ^t
	75M:25D	158.63 ^s	33.02 ^b	8.33 ^c	57.53 ^o
	50M:50D	180.24 ⁿ	31.53 ^d	7.92 ^e	63.14 ^k
	25M:75D	205.42 ^h	30.03 ^f	7.43 ^g	69.52 ^g
	0M:100D	222.73 ^c	28.52 ⁱ	7.05 ⁱ	75.63 ^c
8	100M:0D	135.60 ^v	35.03 ^a	8.75 ^a	52.00 ^s
	75M:25D	162.92 ^r	33.24 ^b	8.35 ^c	58.94 ⁿ
	50M:50D	185.73 ^m	31.83 ^d	7.95 ^e	64.83 ^j
	25M:75D	210.62 ^g	30.24 ^f	7.45 ^g	70.82 ^f
	0M:100D	230.45 ^a	28.83 ^h	7.10 ^h	77.24 ^a
12	100M:0D	128.32 ^{wx}	34.34 ^a	8.55 ^b	50.03 ^t
	75M:25D	150.23 ^{tu}	32.72 ^{bc}	8.15 ^d	56.02 ^q
	50M:50D	178.64 ^o	31.02 ^{de}	7.75 ^f	62.03 ^l
	25M:75D	202.33 ⁱ	29.73 ^{fg}	7.35 ^g	68.74 ^{gh}
	0M:100D	225.94 ^b	28.64 ^{hi}	7.03 ⁱ	76.52 ^b
SEM		3.32	0.51	0.01	0.71
P-Value					
Duration (D)		<0.0001	<0.0001	<0.0001	<0.0001
Forage Proportion (F)		0.0074	<0.0001	0.0096	<0.0001
D × F		0.0048	<0.0001	<0.0001	<0.0001

Key: ^{abc...y} means on the same column with different superscripts are significantly (p<0.05) different, M = Maize, D = *Daniellia* and SEM = Standard Error of Mean.

Macro Mineral Ratios of Silage

The effects of ensiling duration and forage proportion on the macro mineral ratios of silage produced from maize-*D. oliveri* mixtures are presented in Table 3. Mineral ratios are nutritionally important because they influence mineral utilization efficiency, metabolic stability, skeletal development, osmotic regulation, and rumen microbial

activity in ruminants (Soetan *et al.*, 2010). Even when mineral concentrations are adequate, imbalanced ratios may impair nutrient absorption and animal performance (Dele *et al.*, 2025). The Ca:P ratio increased markedly with increasing inclusion of *D. oliveri* across all ensiling periods. The lowest Ca:P ratio (1.19) was observed in the sole un-ensiled maize fodder, while the highest value

(11.43) occurred in the sole *D. oliveri* ensiled for 2 weeks. The calcium-to-phosphorus (Ca:P) ratio increased with higher inclusion of *D. oliveri* and prolonged ensiling, indicating that *D. oliveri* contains substantially higher calcium relative to phosphorus than maize forage. Browse plants and tree foliage are generally rich in calcium because Ca is a major structural component of mature plant tissues and cell walls (Broadley and White, 2003). During ensiling, organic acid production and cell wall degradation may have enhanced Ca release from structural complexes (Adesogan et al., 2019), while microbial utilization of phosphorus for ATP synthesis and metabolism likely reduced relative P concentration, thereby widening the Ca:P ratio. Although optimal Ca:P ratios for ruminants range from 1:1 to 2:1, excessively wide ratios in *D. oliveri*-dominant silages may impair phosphorus absorption and predispose animals to urinary calculi and poor growth performance.

The Ca:Mg ratio followed a similar trend, with values increasing as *D. oliveri* inclusion increased. The sole silage (100M:0D) consistently recorded the lowest Ca:Mg ratios, ranging from 1.27 to 1.96, whereas the sole *D. oliveri* silage recorded the highest values (2.82) at 8 weeks. The increase in the Ca:Mg ratio similarly reflects the greater calcium contribution of *D. oliveri* relative to magnesium. Fermentation acids may have released Ca more readily than Mg from plant tissues, while Mg, being more soluble and mobile, may have been partially lost or utilized during fermentation. Comparable mineral redistribution during ensiling has been reported in fermented forage systems (Ewetola et al., 2023).

The K:P ratio exhibited a less consistent pattern. In most cases, higher values were recorded at lower levels of *D. oliveri* inclusion. The highest K:P ratio (12.05) was observed for sole maize ensiled for 2 weeks, while the least value (2.91) was observed in 0M:100D ensiled for 8 weeks. Ratios fluctuated across ensiling periods, with several treatments showing reductions as

ensiling progressed. Maize-dominant silages exhibited higher K:P ratios, indicating greater potassium relative to phosphorus than *D. oliveri*-based silages. Potassium remains relatively stable during fermentation because it exists mainly in soluble ionic form within plant cells and is not structurally bound to cell wall components. Consequently, ensiling has little direct effect on potassium concentration compared with nutrients that undergo extensive microbial or biochemical transformation during fermentation. (Kung et al., 2018; Shi et al., 2023). The initial increase in K:P ratio may therefore reflect rapid microbial utilization of phosphorus, whereas the decline observed in *D. oliveri*-rich silages may result from enhanced phosphorus release under acidic conditions.

Mineral Ratios of Silage

Table 4 shows the effects of ensiling duration and forage proportion on the micro mineral ratios of maize– *D. oliveri* silage mixtures. The micro mineral ratios were all significantly ($P<0.05$) influenced by ensiling duration and forage proportion. The Fe:Cu ratio increased with increasing inclusion level of *D. oliveri* across all ensiling periods. The lowest Fe:Cu ratio (14.17) was observed in the sole un-ensiled maize fodder, while the highest value (32.46) was recorded in the 0M:100D ensiled for 8 weeks. The Fe:Cu ratio increased progressively with increasing *D. oliveri* inclusion and ensiling duration because Fe concentration increased substantially while Cu concentration declined. Browse plants and tree foliage are known to accumulate high Fe concentrations due to deeper rooting systems and greater mineral extraction capacity (Buchbauerová et al., 2026). Acidic fermentation likely enhanced Fe solubility, whereas Cu became relatively stable or bound in insoluble complexes. Elevated Fe:Cu ratios are nutritionally important because excess dietary Fe can impair Cu absorption and induce secondary Cu deficiency through Fe–Cu antagonism (Dele et al., 2025).

Table 3: Effects of Ensiling Duration and Forage Proportion on the Macro Mineral Ratio of Silage Produced from Maize-*D. oliveri* Mixtures

Duration	Proportion	Ca:P	Ca:Mg	K:P	K:Mg
0	100M:0D	1.19 ^w	1.27 ^{kl}	6.43 ^m	6.87 ^a
	75M:25D	1.87 ^u	0.84 ⁿ	7.62 ^j	3.43 ^e
	50M:50D	1.23 ^{vw}	0.77 ^o	3.33 ^t	2.08 ^l
	25M:75D	3.49 ^o	1.83 ^h	3.94 ^s	2.07 ^l
	0M:100D	4.22 ^k	1.07 ^m	4.74 ^r	1.20 ⁿ
2	100M:0D	2.60 ^r	1.31 ^k	12.05 ^a	6.08 ^b
	75M:25D	3.31 ^p	1.25 ^{kl}	11.68 ^b	4.39 ^d
	50M:50D	5.55 ^h	2.07 ^e	7.36 ^k	2.75 ⁱ
	25M:75D	7.22 ^d	2.15 ^d	11.18 ^d	3.33 ^f
	0M:100D	11.43 ^a	2.62 ^b	8.27 ^h	1.90 ^{mn}
4	100M:0D	3.07 ^q	1.66 ⁱ	10.96 ^e	5.92 ^c
	75M:25D	3.55 ⁿ	1.52 ^j	7.84 ⁱ	3.35 ^f
	50M:50D	3.65 ^m	2.02 ^f	5.70 ^p	3.16 ^g
	25M:75D	10.28 ^b	2.63 ^b	8.31 ^g	2.12 ^l
	0M:100D	9.53 ^c	2.62 ^b	7.34 ^k	2.02 ^m
8	100M:0D	3.65 ^m	1.96 ^g	11.51 ^c	6.17 ^b
	75M:25D	3.82 ^l	1.55 ^j	10.97 ^e	4.46 ^d
	50M:50D	4.46 ^j	2.18 ^d	5.98 ^o	2.92 ^h
	25M:75D	5.34 ⁱ	2.63 ^b	4.67 ^r	2.30 ^k
	0M:100D	4.21 ^k	2.82 ^a	2.91 ^u	1.95 ^m
12	100M:0D	2.04 ^t	1.35 ^k	10.37 ^f	6.86 ^a
	75M:25D	2.37 ^s	1.21 ^l	6.28 ⁿ	3.20 ^g
	50M:50D	6.35 ^f	2.25 ^c	6.94 ^l	2.46 ^{jk}
	25M:75D	6.56 ^e	2.25 ^c	7.36 ^k	2.53 ^j
	0M:100D	7.37 ^d	2.68 ^b	5.23 ^q	1.90 ^{mn}
SEM		0.07	0.01	0.06	0.03
P-value					
Duration (D)		<0.0001	<0.0001	<0.0001	<0.0001
Forage proportion (F)		<0.0001	<0.0001	0.0003	<0.0001
D x F		<0.0001	<0.0001	<0.0001	0.0259

Key: ^{abc....w} means on the same column with different superscripts are significantly (p<0.05) different,

M = Maize, D = *Daniellia* and SEM = Standard Error of Mean.

The Fe:Mn ratio significantly (P<0.05) increased with increasing *D. oliveri* inclusion. The ratio generally showed a gradual increase across forage proportions and ensiling periods, with higher values consistently associated with greater inclusion of *D. oliveri*. The Fe:Mn ratio increased from 2.48 in sole maize silage to 2.98 in sole *D. oliveri* silage, indicating a greater increase in iron relative to manganese as the proportion of *D. oliveri* increased. Although both minerals are essential, excessive dietary iron may negatively affect the metabolism and utilization of other trace minerals. High iron concentrations have been reported to interfere with the absorption and bioavailability of copper and, to a lesser extent, manganese through competitive interactions within the gastrointestinal tract (Arthington and Ranches, 2021). The values were within the

range of values (1.29 – 4.39) reported by Dele et al. (2025) for two Megathyrus varieties.

A significant increase (P<0.05) in Fe:Zn ratio was observed with increasing *D. oliveri* inclusion and ensiling duration, ranging from 3.52 to 7.99. The highest value was recorded in sole *D. oliveri* silage after 8 weeks. Similarly, the Fe:Zn ratio widened with increasing *D. oliveri* inclusion and prolonged ensiling because Fe concentration increased while Zn concentration declined, indicating that *D. oliveri* supplied more Fe whereas maize contributed more Zn. Acidic fermentation likely enhanced Fe solubility more than Zn, consistent with findings of Dele et al. (2025).

The Zn:Cu ratio recorded relatively narrow variation across treatments and ensiling periods. The highest Zn:Cu ratio (4.17) was observed in the sole un-ensiled *D. oliveri*, while the lowest value (3.96) was recorded in

the 75M:25D ensiled for 4 weeks. The Zn:Cu ratio is a critical indicator of ruminant mineral balance because Zn and Cu share absorption pathways and interact antagonistically, with Zn supporting immunity, epithelial integrity, and enzyme activity, while Cu is essential for iron metabolism, antioxidant defense, reproduction, pigmentation, and immune function (Hill and Shannon, 2019). The Zn:Cu ratios recorded in this study are

considerably lower than values typically associated with zinc-induced copper (10:1) antagonism and suggest that the mineral balance remained favorable throughout fermentation (NASEM, 2021). Therefore, the maize-*D. oliveri* silages can be considered nutritionally balanced with respect to zinc and copper interactions, minimizing the risk of antagonistic effects on trace mineral metabolism.

Table 4: Effects of Ensiling Duration and Forage Proportion on the Micro Mineral Ratio of Silage Produced from Maize-*D. oliveri* Mixtures

Duration (weeks)	Proportion (%)	Fe:Cu	Fe:Mn	Fe:Zn	Zn:Cu
0	100M:0D	14.17 ^p	2.48 ^m	3.52 ^q	4.03 ^d
	75M:25D	17.94 ^m	2.64 ⁱ	4.48 ⁿ	4.00 ^f
	50M:50D	21.75 ^j	2.77 ^g	5.46 ^k	3.99 ^f
	25M:75D	26.57 ^g	2.88 ^d	6.50 ^g	4.09 ^b
	0M:100D	30.34 ^c	2.91 ^c	7.28 ^d	4.17 ^a
2	100M:0D	14.74 ^o	2.52 ^l	3.64 ^p	4.05 ^e
	75M:25D	18.55 ^l	2.68 ^h	4.63 ^m	4.01 ^e
	50M:50D	22.55 ⁱ	2.82 ^f	5.63 ^j	4.01 ^e
	25M:75D	27.01 ^g	2.91 ^c	6.64 ^f	4.07 ^b
	0M:100D	31.13 ^d	2.94 ^b	7.61 ^c	4.09 ^b
4	100M:0D	14.96 ^o	2.58 ^k	3.74 ^o	4.00 ^f
	75M:25D	19.04 ^k	2.76 ^g	4.80 ^l	3.96 ^b
	50M:50D	22.76 ⁱ	2.85 ^e	5.72 ⁱ	3.98 ^g
	25M:75D	27.65 ^{fg}	2.95 ^b	6.84 ^e	4.04 ^c
	0M:100D	31.59 ^c	2.94 ^b	7.81 ^b	4.05 ^c
8	100M:0D	15.50 ⁿ	2.61 ^j	3.87 ^o	4.00 ^f
	75M:25D	19.51 ^k	2.76 ^g	4.90 ^l	3.98 ^g
	50M:50D	23.36 ^h	2.86 ^{de}	5.84 ^h	4.00 ^f
	25M:75D	28.27 ^f	2.97 ^a	6.96 ^e	4.06 ^b
	0M:100D	32.46 ^a	2.98 ^a	7.99 ^a	4.06 ^b
12	100M:0D	15.01 ⁿ	2.56 ^k	3.74 ^o	4.02 ^d
	75M:25D	18.43 ^l	2.68 ^h	4.59 ^m	4.01 ^e
	50M:50D	23.05 ^h	2.88 ^d	5.76 ^{hi}	4.00 ^f
	25M:75D	27.53 ^{fg}	2.94 ^b	6.81 ^{ef}	4.04 ^c
	0M:100D	32.14 ^b	2.95 ^b	7.89 ^b	4.07 ^b
SEM		1.23	0.06	0.29	0.03
P-value					
Duration (D)		<0.0001	<0.0001	<0.0001	<0.0001
Forage proportion (F)		<0.0001	0.0031	0.0004	0.0002
D x F		0.0103	<0.0001	<0.0001	<0.0001

Key: ^{abc....y} means on the same column with different superscripts are significantly ($p < 0.05$) different, M = Maize, D = *Daniellia* and SEM = Standard Error of Mean

Anti-nutritional contents of silage

Ensiling duration and plant proportion influenced the anti-nutritional composition of the maize - *D. oliveri* silage mixtures (Table 5). There was a significant difference ($p < 0.05$) in the tannin, phytate, and saponin content of Maize- *D. oliveri* mixtures at different proportions as influenced by ensiling duration. Tannin content ranged from 0.24 to 0.85%, with the highest value recorded in the un-ensiled 50M:50D, while the lowest value

was recorded in the 100M:0D ensiled for 12 weeks. Higher tannin concentrations in *D. oliveri* -based silages are attributable to the naturally high phenolic and condensed tannin contents of browse plants (Hattas et al., 2011). Tannin concentration declined with prolonged ensiling due to microbial degradation, enzymatic hydrolysis, and acidic fermentation conditions (Chen et al., 2014; Peng et al., 2018). The lower tannin concentration in sole maize silage agrees with

Okonwu and Ugiomoh (2015), while all tannin values remained below the 5% DM threshold above which intake and digestibility may be impaired in small ruminants (Aliyu et al., 2016; Besharati et al., 2022).

Phytate values ranged from 0.11 to 0.97%, with the highest concentration observed in the un-ensiled 25M:75D. Lower phytate contents were mostly associated with longer ensiling periods and greater maize inclusion. The reduction in phytate concentration during ensiling may be associated with endogenous and microbial phytase activity under acidic conditions, leading to hydrolysis of phytate into lower inositol phosphates and inorganic phosphorus (Haros et al., 2008; Joudaki et al.,

2023). The un-ensiled 50M:50D had the highest saponin value (0.88 %) while the lowest value (0.26 %) was observed for the sole 100M:0D ensiled for 12 weeks. Higher saponin concentrations in *D. oliveri* -based silages confirm the contribution of the browse component to total saponin content. However, saponin concentration progressively declined during ensiling due to microbial hydrolysis of glycosidic bonds (Kalač et al., 1996; Susanto et al., 2025). Saponin levels remained below the 4% DM threshold associated with reduced intake and palatability in ruminants (Yanza et al., 2024), although higher concentrations may reduce protein digestibility and impair rumen microbial activity (Kholif, 2023).

Table 5: Effects of Ensiling Duration and Plant Proportion on some Anti-Nutritional factors (%) of Silage Produced from Maize-*D. oliveri* Mixtures

Duration (weeks)	Plant Proportion (%)	Tannin	Phytate	Saponin
0	100M:0D	0.32 ^h	0.30 ^f	0.42 ^g
	75M:25D	0.38 ^g	0.26 ^g	0.51 ^e
	50M:50D	0.85 ^a	0.26 ^g	0.88 ^a
	25M:75D	0.79 ^a	0.97 ^a	0.81 ^{ab}
	0M:100D	0.68 ^{bc}	0.51 ^c	0.73 ^b
2	100M:0D	0.28 ^{hi}	0.11 ^j	0.35 ^h
	75M:25D	0.46 ^f	0.25 ^g	0.56 ^{de}
	50M:50D	0.75 ^{ab}	0.64 ^b	0.79 ^{ab}
	25M:75D	0.65 ^{bc}	0.36 ^d	0.69 ^b
	0M:100D	0.58 ^{cd}	0.35 ^d	0.62 ^c
4	100M:0D	0.28 ⁱ	0.18 ⁱ	0.31 ⁱ
	75M:25D	0.53 ^{de}	0.23 ^h	0.49 ^f
	50M:50D	0.44 ^f	0.34 ^e	0.58 ^d
	25M:75D	0.67 ^{bc}	0.35 ^d	0.64 ^c
	0M:100D	0.35 ^g	0.32 ^e	0.51 ^e
8	100M:0D	0.25 ^j	0.50 ^c	0.28 ^j
	75M:25D	0.35 ^g	0.21 ^h	0.41 ^g
	50M:50D	0.35 ^g	0.31 ^f	0.46 ^{fg}
	25M:75D	0.50 ^e	0.31 ^f	0.55 ^{de}
	0M:100D	0.34 ^{gh}	0.38 ^d	0.48 ^f
12	100M:0D	0.24 ^j	0.50 ^c	0.26 ^j
	75M:25D	0.34 ^{gh}	0.20 ^h	0.38 ^h
	50M:50D	0.30 ^h	0.32 ^e	0.40 ^g
	25M:75D	0.52 ^{de}	0.29 ^f	0.52 ^e
	0M:100D	0.35 ^g	0.33 ^e	0.45 ^{fg}
SEM		0.02	0.02	0.02
P-Value				
Duration (D)		<0.0001	<0.0001	<0.0001
Forage Proportion (F)		0.0048	<0.0001	<0.0001
D x F		<0.0001	0.0007	<0.0001

Key: ^{abcde fghij} means on the same column with different superscripts are significantly (P<0.05) different, M = Maize, D = *Daniellia* and SEM = Standard Error of Mean

CONCLUSION

The study showed that the inclusion of *D. oliveri* and ensiling duration significantly affected the mineral profile and anti-nutritional characteristics of maize silage. Increasing *D. oliveri* inclusion enhanced Ca (2.34–9.06 g/kg DM), Fe (120.42–230.45 mg/kg DM), and manganese (48.63–77.24 mg/kg DM) concentrations, while prolonged ensiling reduced tannin (0.85–0.24%), phytate (0.97–0.20%), and saponin (0.88–0.26%) contents, indicating improved nutrient availability. Despite variations in mineral ratios, particularly Ca:P (1.19–11.43) and Fe:Cu (14.17–32.46), the Zn:Cu ratio remained relatively stable (3.96–4.17), suggesting an acceptable mineral balance for ruminants. Silages containing higher (50–75%) proportions of *D. oliveri* and ensiled for 8–12 weeks exhibited superior nutritional quality and potential as sustainable dry-season feed resources for tropical ruminant production.

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