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Forage value of vegetative leaf and stem biomass fractions of selected grasses indigenous to African rangelands

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Abstract

Context. Rangeland grasses native to Africa constitute the main diet for free-ranging livestock and wild herbivores. Leaf:stem ratio is a key characteristic used for assessing quality of forages. However, studies to determine the allocation of biomass to leaves and stems as well as chemical components and nutritive value, especially of grasses in African rangelands, are rare.

Aim. This study was conducted to establish biomass allocation and chemical and mineral components in leaf and stem fractions of three grasses, *Eragrostis superba*, *Enteropogon macrostachyus* and *Cenchrus ciliaris*, all indigenous to African rangelands.

Methods. Plant height, plant densities, plant tiller densities and biomass yields were estimated at the elongation stage, before inflorescence. Chemical and mineral components were determined from biomass harvested at the vegetative phase for all three grass species. Dry matter, ash content, organic matter, crude protein, neutral detergent fibre, acid detergent fibre, acid detergent lignin, and calcium, phosphorus and potassium contents were determined.

Key results. *Enteropogon macrostachyus* displayed significantly greater plant and tiller densities and plant height than the other two species. Leaf and stem biomass fractions varied significantly ($P < 0.05$) among grasses. Leaf:stem ratio of *E. superba* was double that of *E. macrostachyus* and *C. ciliaris*. Crude protein and organic matter yields and net energy for lactation were highest ($P < 0.05$) in *E. superba* leaf biomass, as was Ca content.

Conclusions. *Eragrostis superba* demonstrated greater potential as a forage species for ruminant animal production than *E. macrostachyus* and *C. ciliaris*.

Implications. *Eragrostis superba* is a key forage species that warrants promotion in pasture establishment programs in its native environments.

Keywords: semiarid, dryland, reseeding, ruminants, nutrition, pastoralists, African foxtail grass, buffel grass, Maasai love grass, bush rye grass.

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Introduction

In Africa, arid and semi-arid rangelands cover ~41% of the total land mass (Vohland and Barry 2009). These rangeland environments provide a rich source of forage to support different livestock production systems. Nomadic and transhumant systems characterised by mobility and flexibility for best utilisation of the patchy forage resources and unpredictable climatic conditions are important livelihood strategies in African rangelands. In Africa, pastoral communities inhabiting rangelands derive most of their livelihoods from grazing livestock in natural pastures. Indigenous grasses such as *Cenchrus ciliaris* L. (African foxtail grass or buffel grass), *Eragrostis superba* Peyr (Maasai love grass), *Enteropogon macrostachyus* (Hochst. ex A.Rich.) Munro ex Benth (bush rye grass) (Mganga *et al*. 2015), *Chloris roxburghiana* Schult. (horsetail grass) (Mnene *et al*. 2005) and *Themeda triandra* Forssk. (red oat grass) (Snyman *et al*. 2013) constitute important and reliable sources of forage for free foraging livestock herds. These grasses are adaptable to harsh climatic conditions.

Cenchrus ciliaris has capacity to withstand heavy grazing and a deep, stabilising root system, and it responds quickly to rainfall events (Marshall *et al*. 2012). Herbage produced by *E. superba*, *E. macrostachyus* and *C. roxburghiana* is of good grazing value and palatable to cattle, sheep and goats (Mnene *et al*. 2005). *Themeda triandra* is often described as keystone grass forage

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species in Africa, playing a critical role in supporting grazing herbivores and thus vital to livestock production (Snyman *et al*. 2013). Despite their significant contribution to pastoral livelihoods, there is a dearth of information related to how these indigenous African grasses compare with respect to allocation of biomass to the leaf and stem fractions and the forage value of these individual biomass portions to ruminants.

Studies over the last three decades that have determined the chemical components have aggregated leaf and stem biomass fractions (Abate *et al*. 1981; Kabuga and Darko 1993; Koech *et al*. 2016). This approach conceals significant information related to the contribution of the separate biomass portions (Poorter *et al*. 2012) because: (*i*) biomass allocation to the leaf and stem fractions of terrestrial plants is not fixed and may vary over time, across environments and among species; and (*ii*) leaf:stem ratio plays a significant role in ruminant diet selection and forage value determination. Stritzler *et al*. (1996) attempted to establish the chemical components of leaf and stem biomass fractions for semi-arid warm-season forage grass species in Argentina; however, the forage value of leaf and stem fractions was not compared statistically. Furthermore, Terry and Tilley (1964), using leaf and stem fractions of temperate grasses, determined only the dry matter digestibility and not the chemical components. Koech *et al*. (2016) established the quality of hay from six tropical rangeland grasses (i.e. *C. roxburghiana*, *E. superba*, *E. macrostachyus*, *C. ciliaris*, *Chloris gayana* Kunth and *Sorghum sudanense* (Piper) Stapf), but like many previous studies, forage analysis was an aggregation of leaf and stem biomass. Studies determining and comparing allocation of biomass to leaf and stem portions and nutritive value of these separate biomass fractions in grasses forages, especially those adapted to African rangeland environments, are limited. Lack of such critical knowledge and information has partly contributed to low livestock productivity in sub-Saharan Africa (SSA). This partly explains why livestock performances in SSA have decreased in the last three decades, corresponding to regional per capita meat and milk production, relative to developed countries indicators, of ~13% and 8%, respectively (Cardoso 2012). Therefore, considerable effort is needed to enhance livestock productivity in this region, including various components such as livestock nutrition and feed resource.

In the present study, leaf and stem fractions of *E. superba*, *E. macrostachyus* and *C. ciliaris* were used to quantify biomass allocation, chemical and mineral components. These grasses were selected based on their contribution to livestock production in African rangelands, evolved adaptive mechanisms for survival, and multipurpose uses to pastoral communities, notably as a source of income through the sale of seed and baled hay, thatching material for houses and granaries, and soil conservation (Mganga *et al*. 2015). The objectives of the study were to determine and compare aboveground biomass allocation and chemical and mineral components in the leaf and stem biomass fractions of the selected forage grasses. We hypothesised that (*i*) allocation of biomass in the leaf and stem fractions would be comparable in the three forage grass species, and (*ii*) chemical rather than mineral components in the leaf and stem fractions would be significantly different in the three grasses in their vegetative phase.

Materials and methods

Morpho-ecological characteristics and forage biomass fractionation

Pure stands of *E. superba*, *E. macrostachyus* and *C. ciliaris* were established from seed (seeding rate 5 kg/ha) in early November 2017 at the South Eastern Kenya University (SEKU) research farm (1.31701, 1°19′1.02317″S; 37.7543, 37°45′26.75293″E (own GPS data)), located in a typical semi-arid rangeland in Kenya. The rainfall pattern in the area is bimodal, with the long rains in March–May and short rains in October–December. Total annual rainfall ranges between 300 and 800 mm and monthly temperatures ranges between 14°C and 34°C, with a mean of 24°C (Schmitt *et al*. 2019). Rainfall and temperature during the study fell within these ranges (Fig. 1). Basic site characteristics

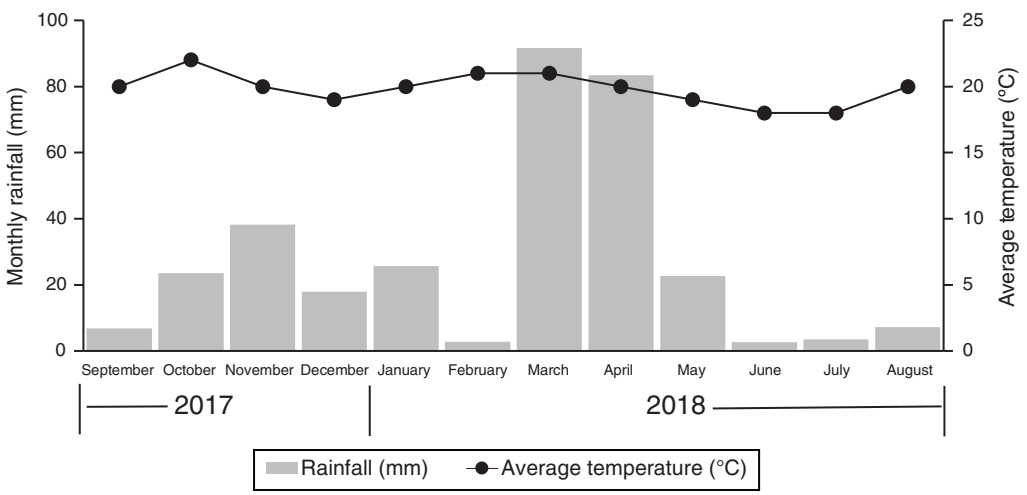


Fig. 1. Monthly rainfall and average monthly temperatures of the study area. Sources: South Eastern Kenya University (SEKU) Meteorological Station and Kitui Meteorological Department.

include: soil texture 6% sand, 31% silt, 22% clay; nitrogen (N) 0.08%; carbon 0.8%; phosphorus (P) 165 mg/kg.

The experimental layout consisted of five blocks, with an area of 150 m^2 (15 m by 10 m), each divided into three subplots of 50 m^2 (5 m by 10 m). Each grass species was established without fertilisation in one subplot per block. Grass seeds were sown by hand along ox-ploughed micro-catchments and covered with a thin layer of soil.

Morpho-ecological characteristics and biomass yield measurements were estimated at the recommended harvesting stage corresponding to the phenological stage of development of the selected grasses (i.e. elongation stage, before inflorescence). Plant densities (no. of plants/m^2) and average tiller densities per plant species were estimated by using six quadrats, each 0.25 m^2 (0.5 m by 0.5 m) within each plot (Cox 1990). Plant height was determined manually by using a ruler (2 m length). The ruler was placed vertically on the ground and the height of the top leaf was estimated to the nearest centimetre.

Forage yields (dry matter (DM) basis) were determined from fresh aboveground biomass. The quadrat sampling technique (Crocker and Tiver 1948) was used to estimate biomass yields. Briefly, fresh biomass of the grass species was clipped during the vegetative phase at a stubble height of 2 cm within a quadrat (0.25 m^2). Biomass used for each grass species was obtained from 15 quadrats (i.e. three quadrats per subplot for each species; $n = 15$). Freshly harvested biomass was placed in labelled brown paper bags and oven-dried at 60°C for 48 h to estimate DM yields. Fresh weight was not taken before drying. Stem and leaf (i.e. leaf blade and leaf sheath) biomass fractions were then manually separated to determine the leaf:stem ratios. Thereafter, dried leaf and stem biomass for each quadrat were ground separately using a mixer mill (MM 200; Retsch, Haan, Germany) and stored before chemical and mineral component analyses.

Forage laboratory analyses

Standard laboratory protocols were followed to establish the chemical components of the harvested forage. Dry matter was estimated after oven-drying at 60°C for 24 h. Ash content was determined after manual combustion in a muffle furnace at 650°C for 24 h (Henken *et al.* 1986). Organic matter (OM) content was calculated as the difference between DM and ash (i.e. OM = DM – ash content). Nitrogen content (crude protein (CP) = N × 6.25) was determined by the conventional Kjeldahl method. Additionally, in order to determine which of the established grass species presented the most protein, we calculated the CP yield (i.e. kg CP/ha) derived from the already established CP content and DM yields (kg DM/ha). This was done because it is possible for a grass forage species with high CP content to have a low net CP yield due to low DM yield. Similarly, another species may have low CP content but compensate for net CP yield through greater DM yields.

Neutral detergent fibre (NDF) was assayed without heat-stable amylase and expressed inclusive of residual ash (Mertens 2002). Acid detergent fibre (ADF) was expressed inclusive of residual ash (Latimer 2016). We used the NDF and ADF values obtained to calculate the relative feed value (RFV) as displayed in the equations below adapted from Kuehn *et al.* (1999):

$$\text{DM digestibility (DMD)} = 88.9 - (0.779 \times \%\ \text{ADF})$$

$$\text{DM intake (DMI)} = \frac{120}{\%\ \text{NDF}}$$

$$\text{RFV} = \frac{\text{DMD} \times \text{DMI}}{1.29}$$

Other studies (e.g. Mwendia *et al.* 2017; Savadogo *et al.* 2009) have also computed RFV to assess forage quality of grasses native to Africa. Acid detergent lignin (ADL) was determined by solubilisation of cellulose with sulfuric acid (Robertson and van Soest 1981). The obtained ADF values were used to calculate net energy for lactation (NEl) content as described by Coppock *et al.* (1981).

The wet ash method was used to prepare samples to determine contents of calcium (Ca; by atomic absorption spectrometry), P (by UV–visible spectroscopy), and K (by flame emission spectroscopy) (Pflaum and Howick 1956). According to Khaled *et al.* (2006), the main chemical criteria that determine the forage value for ruminants are the concentrations of NDF, ADL, CP, plant-digestible OM and minerals. Calcium, P and K were selected because they are the three most abundant mineral elements in livestock.

Statistical and data analyses

Statistical analyses were performed by using the software STATISTICA 10.0 (StatSoft, Tulsa, OK, USA). One-way ANOVA was used to test for significant differences among the forage grasses. Tukey's honestly significant difference post hoc test was used to separate significant differences between treatments at $P = 0.05$ significance level. All displayed results represent arithmetic means (± standard error) of replicates per species. Each replicate was derived from plant biomass in each sampled quadrat.

Results

Enteropogon macrostachyus exhibited significantly higher ($P < 0.05$) plant density (18 plants/m^2) and tiller density (38 tillers/plant) than *E. superba* (10 plants/m^2, 19 tillers/plant) and *C. ciliaris* (12 plants/m^2, 17 tillers/plant) (Table 1). Similarly, at

Table 1. Morpho-ecological characteristics of three grasses indigenous to African rangelands

Within a column, means followed by the same letter are not significantly different at $P = 0.05$ as determined using Tukey's honestly significant difference mean comparison test. ES, *Eragrostis superba*; EM, *Enteropogon macrostachyus*; CC, *Cenchrus ciliaris*

Species	Plant density (no. per m^2)	Tiller density (no. per plant)	Plant height (cm)	Biomass (kg DM/ha)			Leaf:stem ratio	%Leaf	%Stem
				Total	Leaf	Stem			
ES	10 ± 2a	19 ± 2a	76 ± 2a	3600 ± 687a	2200 ± 489a	1400 ± 228a	1.57a	61 ± 4a	39 ± 4a
EM	18 ± 5b	38 ± 4b	110 ± 4b	2633 ± 292a	1133 ± 266b	1500 ± 152a	0.76b	43 ± 5b	57 ± 5b
CC	12 ± 1a	17 ± 1a	46 ± 3c	2533 ± 476a	1167 ± 264b	1367 ± 248a	0.85b	46 ± 4b	54 ± 4b

Table 2. Chemical component composition (g/kg DM) in leaf and stem biomass fractions of selected forage grasses indigenous to African rangelands

Within columns, means followed by the same letter are not significantly different at $P = 0.05$ as determined using Tukey's honestly significant difference comparison test. ES, *Eragrostis superba*; EM, *Enteropogon macrostachyus*; CC, *Cenchrus ciliaris*; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin

Species	Biomass fraction	Dry matter	Ash	Organic matter	Crude protein	NDF	ADF	ADL	Calcium	Phosphorus	Potassium
ES	Leaf	950 ± 2a	95 ± 3a	905 ± 6a	85 ± 2a	751 ± 4a	389 ± 4a	67 ± 5a	2.1 ± 0.5c	5.1 ± 0.7a	5.2 ± 0.8a
	Stem	958 ± 1a	55 ± 1b	945 ± 2b	41 ± 7b	811 ± 8b	524 ± 7b	107 ± 7b	0.7 ± 0.2b	4.9 ± 0.8a	5.8 ± 0.8a
EM	Leaf	953 ± 3a	86 ± 7a	914 ± 15a	84 ± 6a	765 ± 14a	391 ± 6a	72 ± 11a	1.4 ± 0.2a	5.0 ± 0.6a	4.6 ± 0.4a
	Stem	951 ± 6a	62 ± 3b	938 ± 7b	59 ± 8b	805 ± 3b	531 ± 13b	117 ± 9b	1.0 ± 0.3b	8.8 ± 1.5b	8.1 ± 0.6b
CC	Leaf	948 ± 3a	95 ± 4a	905 ± 9a	75 ± 12a	702 ± 30a	365 ± 23a	45 ± 3a	0.9 ± 0.04b	7.0 ± 1.2ab	6.2 ± 0.5ab
	Stem	952 ± 4a	52 ± 1b	948 ± 3b	47 ± 11b	793 ± 27b	491 ± 12b	142 ± 6b	1.0 ± 0.3b	5.8 ± 0.7a	4.3 ± 0.5a

Table 3. Yields of crude protein (CP) and organic matter (OM), net energy for lactation (NE_L), digestible dry matter (DDM), dry matter intake (DMI) and relative feed values (RFV) of selected forage grasses indigenous to African rangelands

Within columns, means followed by the same letter are not significantly different at $P = 0.05$ as determined using Tukey's honestly significant difference comparison test. ES, *Eragrostis superba*; EM, *Enteropogon macrostachyus*; CC, *Cenchrus ciliaris*

Species	Biomass fraction	CP yield	OM yield (kg/ha)	NE_L (MJ/ha)	DDM (%)	DMI (% of bodyweight)	RFV
ES	Leaf	186 ± 43a	2352 ± 46a	4971 ± 109a	59 ± 0.3a	1.6 ± 0.01a	73 ± 0.7a
	Stem	58 ± 22b	1321 ± 28bc	623 ± 226b	48 ± 0.5b	1.5 ± 0.01a	55 ± 0.8b
EM	Leaf	94 ± 20c	1215 ± 38c	2477 ± 59d	58 ± 0.4a	1.6 ± 0.03a	71 ± 1.6a
	Stem	88 ± 9c	1438 ± 19b	766 ± 105b	48 ± 1.0b	1.5 ± 0.01a	55 ± 1.2b
CC	Leaf	87 ± 18c	1268 ± 84c	2971 ± 259d	61 ± 1.8a	1.7 ± 0.08a	81 ± 6.0a
	Stem	62 ± 10b	1580 ± 27b	1364c ± 381	51 ± 0.9b	1.5 ± 0.05a	60 ± 3.0b

the vegetative stage, *E. macrostachyus* plants were significantly taller (1.1 m) than *E. superba* (76 cm), which was taller than *C. ciliaris* (46 cm) (Table 1).

Leaf (i.e. leaf blade and leaf sheath) and stem biomass fractions of total DM varied among the grasses. Significant differences were mainly observed in leaves. *Eragrostis superba* (2200 ± 489 kg DM/ha) had significantly higher ($P < 0.05$) leaf biomass than *C. ciliaris* (1167 ± 263 kg DM/ha) and *E. macrostachyus* (1133 ± 265 kg DM/ha). However, stem biomass was not significantly different ($P > 0.05$) among species: range 1500 DM/ha (*E. macrostachyus*) to 1367 DM/ha (*C. ciliaris*) (Table 1). Leaf biomass fraction of aboveground biomass for *E. superba* (0.61) was significantly higher ($P < 0.05$) than of *C. ciliaris* (0.46) and *E. macrostachyus* (0.43); consequently, the leaf:stem ratio of *E. superba* (1.57) was significantly different ($P < 0.05$) from, and two times higher than, that of *C. ciliaris* (0.85) and *E. macrostachyus* (0.76) (Table 1).

Dry matter content in biomass was not significantly different among the grasses or between leaf and stem components (Table 2). However, ash, OM, CP, NDF, ADF and ADL contents differed significantly ($P < 0.05$) between the leaf and stem biomass fractions of the grasses, but not among the grasses (Table 2). Net energy for lactation was significantly higher ($P < 0.05$) in leaf than stem biomass in all grass species, and highest in *E. superba* leaf; CP yield was higher in leaf than stem biomass of *E. superba* and *C. ciliaris* and was also highest ($P < 0.05$) in *E. superba* (Table 3). RFV was also significantly higher ($P < 0.05$) in leaf than stem biomass fractions, and was comparable in all of the grass species (Table 3). OM yield was higher in leaf than stem biomass of *E. superba*, whereas the reverse occurred in the other two species; OM yield was highest in *E. superba* leaf.

Mineral (Ca, P and K) contents did not differ significantly ($P > 0.05$) between leaf and stem biomass fractions in *C. ciliaris* (Tables 2). Leaf and stem biomass fractions in *E. superba* also displayed comparable P and K contents. Calcium content was significantly ($P < 0.05$) different between the leaf and stem biomass in *E. superba* and, to a lesser extent, *E. macrostachyus*, and was highest in *E. superba* leaves (2.1 g/kg DM). Phosphorus and K contents were significantly higher ($P < 0.05$) in stem than in leaf biomass in *E. macrostachyus* (Table 2).

Discussion

Greater plant height (of up to 1.1 m) and plant and tiller densities of *E. macrostachyus* than of *E. superba* and *C. ciliaris* is mainly attributed to its faster seed germination and establishment. This species is known to establish easily, grow very quickly and mature early (Mganga *et al*. 2015). These morpho-ecological characteristics of *E. macrostachyus* show its competitive advantage and strength particularly for light interception. During the same growing season, *C. ciliaris* and *E. superba* exhibited much shorter culms, and lower plant and tiller densities. Shorter culms of *C. ciliaris* (0.5 m) are attributed to its slow-growing nature, which is also a coping mechanism

against drought, similar to other tropical forages such as *E. superba*. The measured height is within the average range (0.2–1.5 cm tall) for *C. ciliaris* culms as reviewed by Marshall *et al*. (2012). Tinoco-Ojanguren *et al*. (2016) showed that *C. ciliaris* exhibits seed dormancy that often hinders successful germination and subsequent establishment. The dormancy mechanism of *C. ciliaris* lies both within the caryopsis and in the associated structures of the fascicle (Mganga *et al*. 2015). Similarly, low germination rates of *E. superba*, which contributed to significantly lower plant densities, have been attributed to involvement of some physiological inhibition mechanism (Krichen *et al*. 2014) whose effects are partially nullified by the presence of florets. These mechanisms in *C. ciliaris* and *E. superba* probably indicate drought-avoidance dormancy syndrome.

Leaf biomass fraction and leaf:stem ratio were higher in *E. superba* than in *E. macrostachyus* and *C. ciliaris*. These results confirm that biomass allocation to different morphological components of terrestrial plants is not fixed and may vary among herbaceous species including grasses (Poorter *et al*. 2012). A meta-analysis to investigate the effect of nutrient availability on biomass allocation patterns in 27 species of herbaceous plants including grasses (*Poa pratensis*, *Lolium perenne*, *Bromus inermis*) also demonstrated variability in leaf and stem biomass allocation (Müller *et al*. 2000). Ratio of leaf to stem biomass fractions in tropical forage grasses is of greater significance considering its contribution to diet selection, forage quality and intake by ruminants. Higher mean voluntary intake of leaf than of stem biomass has been demonstrated in tropical grass forages *C. ciliaris* cv. Biloela, *C. ciliaris* cv. Gayndah, *Panicum coloratum* cv. Bambatsi and *C. gayana*, associated with a shorter retention time of dry matter in the reticulorumen (Mero and Udén 1998). Relative proportions of the different morphological components (leaf blades and stems) have an essential role in controlling the chemical composition of tropical forage grasses. Considering the proportions of the leaf and stem fractions of the three grasses, it is envisaged that *E. superba* will demonstrate higher voluntary intake indices than *E. macrostachyus* and *C. ciliaris*.

Biomass allocation between the leaves and stems also has a significant influence on plant growth and development (Poorter and Nagel 2000). Leafy biomass is a strong driver of the capacity of plants to take up light and CO_2. Greater leaf biomass fraction and higher leaf:stem ratio in *E. superba* strongly suggest its competitive advantage over *E. macrostachyus* and *C. ciliaris* in intercepting light for photosynthesis, and its greater leaf fraction strongly indicates its potential for carbon sequestration by capturing and reducing CO_2 levels in the atmosphere. Furthermore, higher leaf:stem ratio in *E. superba* demonstrates its adaptation to nutrient-poor soils in rangeland environments. According to Yan *et al*. (2016), plants adapted to nutrient limitation allocate less biomass to stems in arid–hot grasslands. Interestingly, the stem biomass fraction did not show significant differences among the three grasses. This suggests that under the prevailing environmental conditions, the grasses allocated a comparable amount of biomass to the stems to provide mechanical support and a hydraulic pathway. Understanding such patterns in biomass allocation is of fundamental importance to agricultural practice and implementation (Poorter *et al*. 2012).

Differences in the chemical components and RFV in the stem and leaf biomass fractions were not significant between the grass species. These findings conform with previous studies that showed no significant differences in the chemical components (e.g. CP, Ash, ADL, ADF and NDF) of the aggregated aboveground biomass of the same pasture species (Kabuga and Darko 1993; Koech *et al*. 2016). Aggregate CP of 50 g/kg DM in all three grasses analysed in this study demonstrates that they have the required content for maintenance levels of CP for ruminants (50 g/kg DM) (Boutton *et al*. 1988) and therefore provide good source of forage for free-grazing herbivores in rangeland environments in Africa. Our findings compare well with those of Ramírez *et al*. (2004), who reported a CP content of 90 g/kg DM in *C. ciliaris* and introduced species in arid and semi-arid environments in Mexico. However, these values are lower than the reported CP content of other tropical grass forages, notably *C. gayana* (121 g/kg DM) and *Pennisetum clandestinum* (146 g/kg DM) (Tran *et al*. 2009). On the other hand, *E. superba*, *E. macrostachyus* and *C. ciliaris* had significantly higher DM content (>900 g/kg DM) than *C. gayana* (390 g/kg DM) (Abate *et al*. 1981). Low DM content in *C. gayana* is a characteristic of both mature and immature forages adapted to a humid climate compared with the three grasses adapted to arid and semi-arid climatic conditions in Africa. Conversion of CP content to yield (kg CP/ha) demonstrated that *E. superba* presented more protein than *E. macrostachyus* and *C. ciliaris*. This clearly demonstrates its superior forage value over the other two species. The range of the chemical components ash (40–90 g/kg DM), NDF (650–860 g/kg DM), ADF (400–590 g/kg DM) and ADL (50–190 g/kg DM) found in *C. ciliaris* and *E. superba* by Kabuga and Darko (1993) compare well with those found in the leaf and stem biomass fractions of the selected grasses in this study. Additionally, NDF content of the three grass species studied here ranged between ~700 and 800 g/kg DM. This is comparable to other tropical forage grasses *C. gayana* (693 g/kg DM) and *P. clandestinum* (681 g/kg DM) (Tran *et al*. 2009).

Forage value in leafy biomass was significantly higher than in stem biomass in each of the grass species. Significant differences in the chemical component content and RFV between leaf and stem biomass fractions of the selected forage grasses indigenous to African rangelands are probably attributed to the metabolic role of the leaf and structural function of stems. Generally, leaf blades are more digestible, richer in CP and poorer in cell-wall constituents than stems; thus an increasing or decreasing forage value depends on the proportion of plant parts (Delagarde *et al*. 2000). Our results are consistent with other studies demonstrating that leaf blades have approximately twice as much CP as stems (Ferri 2011). NDF content, an estimate of the cell-wall concentration, is negatively linked to digestibility and intake potential of forages. Leaf biomass fractions had lower NDF concentration than stems in all three grass species. High digestibility of leaf compared with stem fractions has been established in temperate grass species (Terry and Tilley 1964). Leafy biomass is usually retained in the rumen for a shorter period than stems because of faster rates of NDF digestion and higher rates of passage (Delagarde *et al*. 2000). Tropical grass forage species with high leafy biomass (e.g. *E. superba*) are more nutritious and will be consumed and digested more readily

than those with a higher stem biomass proportion, such as *E. macrostachyus* and *C. ciliaris*.

Consequently, higher leaf:stem ratio in *E. superba* than in *E. macrostachyus* and *C. ciliaris* demonstrates its greater potential value for livestock production. Pastoral communities in African rangelands (e.g. Pokot and Il Chamus in Kenya) have identified *E. superba* as a key forage source for free-ranging livestock. This is attributed mainly to its role in increased milk production and fattening (Wasonga *et al*. 2003). Pastoral communities in Kenya practising reseeding to replenish depleted natural pastures have also demonstrated a preference for *E. superba* because of its high nutritional value for ruminants (Mganga *et al*. 2015). Pastoral Maasai of East Africa have observed that free-grazing livestock tend to select pasture patches dominated by *E. superba*. This observation conforms with previous studies showing leaf biomass fraction to be the best predictor of bite mass and instantaneous intake rate across different phenological stages of a grasses (Baumont *et al*. 2000).

Mean concentration of Ca in *E. superba* (1.5 g/kg DM), *E. macrostachyus* (1.2 g/kg DM) and *C. ciliaris* (1 g/kg DM) was much less than 6 g/kg DM recommended for livestock (Juknevičius and Sabiene 2007; NRC 2000; Erickson and Kalscheur 2020). Calcium requirements in growing, gestating and lactating beef cattle are up to 8, 3 and 6 g/kg DM, respectively (Greene 2000). Calcium content of the grasses was also less than in other tropical forage grasses *Pennisetum purpureum* (36 g/kg DM) and *P. maximum* (7.4 g/kg DM) reported in tropical Africa (Kambashi *et al*. 2014). Inadequate Ca content suggests that livestock grazing pastures dominated by these grasses are likely to suffer Ca deficiency. Consequently, Ca supplementation (e.g. mineral licks) is recommended when these grasses constitute the largest portion of the basal diet.

Phosphorus content of 3.5 g/kg DM has been considered optimum for livestock nutrition (Juknevičius and Sabiene 2007; NRC 2000). On average, lactating dairy cows require 3.2–4.2 g P/kg DM in their diet and calves 3.0–4.2 g/kg DM (Erickson and Kalscheur 2020) and beef cattle 2.0–4.0 g/kg DM (Greene 2000). Phosphorus concentration in all of the selected grasses (5 g/kg DM) was much higher than in *P. purpureum* (1.2 g/kg DM) and *P. maximum* (2.1 g/kg DM) (Kambashi *et al*. 2014). Natural fertilisation through manure deposition by grazers contributes significantly to increased available P in open pastures in African rangelands. This translates to high P in plant biomass. Higher P content than the critical range suggests that livestock can obtain sufficient P from all three grasses, thus not limiting production in both beef and dairy enterprises.

In addition to Ca and P, ruminants have a high K requirement to perform numerous body functions, growth and muscle development. Average K content of the analysed grasses was 5–6 g/kg DM. This is lower than the 7.5 g/kg DM recorded for *E. superba* in Kruger National Park, South Africa (Ben-Shahar and Coe 1992). Critical K levels for lactating dairy cows and calves are 15 and 5 g/kg DM, respectively (Erickson and Kalscheur 2020). On the other hand, critical K contents 6–8 g/kg DM have been established for beef cattle, for growing and fattening of steers and heifers (Greene 2000). Consequently, our results suggest that *E. superba*, *E. macrostachyus* and *C. ciliaris* are more suitable for the beef enterprise and growing and fattening of steers and heifers. Other tropical forage grasses with higher K content, such as *P. purpureum* (33.6 g/kg DM) and *P. maximum* (23.8 g/kg DM) (Kambashi *et al*. 2014), are best suited for dairy production.

Plants allocate more nutrients to leaf biomass to support growth and use only nutrients stored in stems to satisfy the needs of leaves in limited conditions. However, our results demonstrate a uniform distribution of the acquired nutrients to the more metabolically active tissues (i.e. leaves) and less active structural tissues (stems). This allocation pattern suggests that there was less demand for these nutrients in the leaf tissues during the vegetative phase to trigger their translocation from the stem tissues. Furthermore, accumulation of nutrients in stem tissues indicates a possible strategy to store nutrients for a later time when the demand is intensified (e.g. during flowering and seed production). This probably explains higher P and K content in stem than leaf biomass in *E. macrostachyus*. Unlike *E. macrostachyus* and *C. ciliaris*, *E. superba* demonstrated considerably higher Ca content in leaf than stem biomass. Delivery and allocation of Ca to biomass fractions is linked to transpiration rate. Lower transpiration rates result in lower Ca content of plant tissue (Gilliham *et al*. 2011). Accumulation of Ca in *E. superba* leaves suggests its higher transpiration rate than *E. macrostachyus* and *C. ciliaris*.

Conclusions

Indigenous grasses *E. superba*, *E. macrostachyus* and *C. ciliaris* are key sources of forage for free-ranging livestock in African rangeland environments. These forage species demonstrated different morpho-ecological characteristics and patterns of biomass allocation and forage quality in the leaf and stem fractions. *Eragrostis superba* allocated significantly more biomass to the leaf than the stem fraction, translating to two times higher leaf:stem ratio than *E. macrostachyus* and *C. ciliaris*. Furthermore, forage value (chemical and mineral components) was largely greater in leaf than stem biomass fractions in all of the selected grasses. The outcomes demonstrate that *E. superba* is a superior forage species to *E. macrostachyus* and *C. ciliaris*. These observed results relate well to indigenous technical knowledge among pastoral communities in African rangelands who have identified *E. superba* as an important forage species for pastoral livestock production systems.

Conflicts of interest

The authors declare no conflicts of interest.

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