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Seasonal dynamics on nutritive value, chemical estimates and in vitro dry matter degradability of some woody species found in rangelands of South Africa

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Abstract Unlocking browse species in semi-arid regions can be a key to improving the livestock productivity. The research was conducted to assess the browse species variation in chemical composition and in vitro dry matter degradability as influenced by seasonal (summer and winter) changes. Leaves from ten randomly selected browsable trees from sixteen species (*Vachellia karroo, Senegalia nigrescens, Vachellia nilotica, Balanites maughamii, Berchemia discolor, Berchemia zeyheri, Bridelia mollis, Combretum collinum, Combretum imberbe, Dalbergia melanoxylon, Dichrostachys cinerea, Grewia monticola, Grewia occidentalis, Melia azedarach, Ormocarpum kirkii* and *Ziziphus mucronata*) were harvested before defoliation from the site in two seasons (summer and winter) and dried at room temperature and then ground for analysis. Two-way analysis was used to analyse chemical composition and in vitro ruminal dry matter degradability. *Melia azedarach* (343.7 g/kg DM) had the highest ($p < 0.0001$) CP content in summer. In winter, *B. maughamii* (210.3 g/kg DM) had the highest ($p < 0.05$) crude protein content. *Combretum collinum* (2.90 Mcal/kg) had a highest ($p < 0.0001$) metabolizable energy value in summer. *Bridelia mollis, B. maughamii, B. discolor, C. collinum, C. imberbe, O. kirkii, S. nigrescens, V. nilotica, G. occidentalis* and *B. zeyheri* had the same ($p > 0.0001$) dry matter degradability (DMD) 48 values across two seasons. In both seasons, most of these browse species have the potential to supplement low quality natural grasses because they go beyond the minimum requirement of protein and have coherent amounts of fibre concentration. There is a need to assess the bioactive compounds found in these browse species for the amelioration and also to maximize browsing of these species.

Keywords Ruminants · Crude protein · Browse · Semi-arid · Season

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Introduction

Livestock play a significant role in rural livelihoods and the economies of developing countries (Enahoro et al., 2019), and these livestock depend on rangelands mostly in semi-arid areas. Browse species as forage are used in the feeding of domestic (e.g., goats) and wilderness ruminants and are generally regarded as the cheapest source of nutrients for these ruminants.

The relationship between season and plants and livestock has been observed around the world especially in semi-arid areas (Hassen et al., 2017; Mudzengi et al., 2020; Castro et al., 2021). This is due to the fact that climatic conditions in semi-arid regions are likely to increase the competition of resources among livestock (Mudzengi et al., 2020). Due to seasonal variation, plant growth and accumulation of leaves can be affected negatively or postively which will either lead to a shortage or an abundance of available forage for livestock (Hassen et al., 2017). For example, during the drought season herbaceous layer tends to deteriorate its nutritional content and livestock happen to rely on browse species for nutritional needs. This will normally have an influence on ruminal fermentation of substrates, and the ruminants exposed on these low-quality forages will have difficulties meeting their maintenance requirements on certain seasons leading to low feed intake and ruminal fermentation on ruminants and this may lead to poor growth rate (Ravhuhali et al., 2011). The browse species are useful and inexpensive source of nutrients for livestock especially during drought seasons and they can be the alternative to commercial feed resources in most communal areas.

The nutritional value of forage depends on the amount of proteins, the concentration of acid detergent lignin and digestible carbohydrates, and these nutrients normally vary with seasons. Ravhuhali et al. (2020) stressed that leaves of many browse species have crude protein concentration of above 10%. With the comparison to conventional diets, browse leaves are known to have the potential to be used as protein supplements to diets that have low protein and fermentable energy values (El Hassan et al., 2000). Apart from the crude protein content of plants species, the chemical estimates such as dry matter digestibility (DMDigest), total digestible nutrients (TDN), relative feeding values (RFV), digestible energy and metabolisable energy vary with the kind of ruminant livestock and are of great importance for the animal's nutritional demands (NRC, 1985). Forages with high concentration of lignin are also known to have a low TDN than other fodder crops. The chemical estimates which are related to chemical composition varies widely among the woody species. Dry matter digestibility of browse species ranges from 58 to 75% (Boufennara et al., 2012; Mokoboki et al., 2019), total digestible nutrients of 50–65% and relative feeding value of up to 95% (Mokoboki et al. 2019).

However, in spite of their abundance, many wild browse species have been generally undervalued mainly because of insufficient knowledge about their potential feeding value in different seasons. Exploring the nutritional value of the resources available in different seasons for browsing livestock is considered as one of the keys to the efficient and sustainable production of animals (Minson, 1990). Some of the ligneous species studied here are consumed to a certain degree by small ruminants (Kababya et al., 1998). There is a need for a laboratory analysis for better understanding nutritional composition and utilization of these indigenous browse woody species. Therefore, the objective of the study was to assess the effect of season and species on nutritive value and in vitro ruminal dry matter degradability of browse species found in the selected rangelands areas in semi-arid South Africa, while hypothesizing that there would be a variation in the parameters.

Materials and methods

Harvesting site and leaves

The study was carried out at Thulamela Local Municipality (Limpopo) with a very high number of indigenous ruminants (goats and cattle) that rely entirely on rangelands. The tree species were harvested in communal areas of Thulamela Municipality around Vhembe District in Limpopo province. The communal areas (Makuya and Lamvi S 22°39′49.85″ and E 30°45′21.88) are located in the 40 to 50 km from Kruger National Park. In summer time annual temperatures is 34 °C and the winter time is 13 °C (SAWS, 2020). In December and early June 2019 leaves (ten tree per species) from randomly selected sixteen trees species (*Vachellia karroo; Senegalia nigrescens; Vachellia nilotica; Balanites maughamii; Berchemia discolor; Berchemia zeyheri; Bridelia mollis; Combretum collinum; Combretum imberbe; Dalbergia melanoxylon; Dichrostachys cinerea subsp. africana; Grewia monticola; Grewia occidentalis; Melia azedarach; Ziziphus mucronata* and *Ormocarpum kirkii*) were harvested before defoliation from the site by hand at a height of not more than 1.5 m. The samples were harvested from the same trees in the same area for summer and winter. Each of the samples was stored separately in labelled brown paper bag. Samples were dried at room temperature and transferred to the oven set at a temperature of 60 °C overnight, after which they were ground to pass a 1 mm sieve and kept in a tight plastic container for chemical analyses. Harvested species were also grouped according to growth form and herbivory (Table 1). Van Wyk et al. (2012) book was used to identify the species. Information on the woody species utilization was obtained from local farmers and herders from the respective grazing communal areas.

Chemical analyses

Organic matter (OM), ash and nitrogen content (Micro-Kjedahl method) were determined (AOAC, 1999). Crude protein was calculated by multiplying nitrogen value with a factor 6.25. Fibre fraction (neutral detergent fibre and acid detergent fibre) was determined using ANKOM^{2000} according to Van Soest et al. (1991) using ANKOM F57 bags. Acid detergent fibre (ADF) bags were soaked on 72% of sulphuric acid for ADL determination. The formula used to predict total digestible nutrients (TDN) was $82.38 - (0.7515 \times ADF)$ as described by Bath & Marble (1989). The formula for dry matter digestibility was DMDigest% = $88.9 - (0.779 \times \%ADF)$. Dry matter intake (DMI) was calculated using the NDF concentration and 2.5% of animal body weight as described by Mertens (2002). Relative feed value (RFV) was calculated using the following method: RFV = $(\%DMDigest \times \%DMI)/1.29$ (Jeranyama & Garcia, 2004). The equation for estimated digestible energy (DE Mcal/kg) = $0.27 + 0.0428(DMDigest\%)$ as reported by Fonnesbeck et al. (1984). DE values were converted to ME using the formula reported by Khalil et al. (1986) ME (Mcal/kg) = $0.821 \times DE(Mcal/kg)$.

In vitro *ruminal degradation*

The in vitro ruminal DM degradability of leaf samples was determined using the DaisyII incubator consisting of a thermostatic chamber (39 °C) with four rotating jars according to ANKOM Technology for in vitro true digestibility. Ground samples were weighed into ANKOM F57 bags (0.45–0.5 g), heat sealed and placed in the digestion jars. Two buffer solutions were prepared in advance and combined at a ratio of 1:5,

Table 1 Scientific and common names, growth form, herbivory and browse form of browse species identified in semi-arid areas of Limpopo province

Species	Common name	Growth form	Herbivores	PPP
Vachellia karroo	Sweet thorn	Shrub	Cattle and goats	L, P
Senegalia nigrescens	Knob thorn	Tree	Cattle and goats	L, P
Vachellia nilotica	Scented pod	Tree	Goats and game	L, P
Balanites maughamii	Torchwood	Tree	Game and cattle and goats	L, F,S
Berchemia discolor	Brown ivory	Tree	Game and cattle and goats	L, F, S
Berchemia zeyheri	Red ivory	Tree	Game and cattle and goats	L, F, S
Bridelia mollis	Velvet Sweet-Berry	Shrub	Cattle, goats and game	L, F, T
Combretum collinum	Weeping bush willow	Tree	Cattle and goats, game	L
Combretum imberbe	Lead wood	Tree	Cattle and goats	L
Dalbergia melanoxylon	African black wood	Shrub	Cattle, goats and game	F, L
Dichrostachys cinerea subsp. africana;	Sickle bush	Shrub	Goat	L, P
Grewia monticola	Silver raisin	Shrub	Goats	L
Grewia occidentalis	Four corners	Shrub	Goats	L
Melia azedarach	China berry	Tree	Cattle and goats	L
Ormocarpum kirkii	Caterpillar bush	Shrub	Goats and game	L
Ziziphus mucronata	Buffalo thorn	Tree	Cattle and goats	L, P

PPP = preferred plant parts; *L* = leaves; *F* = fruits, *P* = pods; *S* = seeds; *T* = twigs according to ANKOM Technology, and 1600 mL of the combined buffer was transferred to each of the four jars and warmed. Rumen inoculum was collected in the morning before feeding from a ruminally cannulated Bonsmara cow (metabolic weight = 550 kg). The cannulated cow was kept in a stall and had access to Buffalo grass and Lucerne. Strained rumen fluid was held at 39 °C under a stream of carbon dioxide gas. ANKOM F57 bags containing samples, were inoculated by adding 400 mL of rumen inoculum to each digestion jar containing buffer. Each jar was purged with CO_2 before being covered and placed in the incubation chamber. Filter bags were withdrawn at 24, 36 and 48 h after inoculation and were washed with cold water for 20 min and dried for 12 h at 105 °C. The ethical approval certificate was acquired from the North West University Animal Research Ethic Committee (NWU-00126-13-A9). The animal was cared for according to the guidelines of the institution and Federation of Animal Science Societies (FASS, 2010) for the use of agricultural livestock in teaching and research activities.

Statistical analysis

Browse species data were analysed using a two-way factorial treatment design in a completely randomised design SAS (2010). The general linear model used was as follows:

$$Yijk = u + Bi + Sj + (BxS)ij + \varepsilon ijk$$

where *u* was the overall mean, *S* was the effect of variation between species; *Sj* was effect of season; *BxS* was the interaction effect, and εijk is random error. The probability of difference (PDIFF) option in the LS means statement of SAS was used to compare the least square means.

Results

The differences ($p < 0.0001$) were observed on the effect of species, season and the interaction between species and season on ash, OM, CP, ADF, ADL, DMDigest, TDN, DE, ME and DMD36 (Tables 2, 3, 4 and 5). The significance differences were observed on the effect of species and season on NDF, DMI and RFV. The crude protein content ranged from 149 g/kg DM in *B. mollis* to 343.7 g/kg DM in *M. azedarach* in the summer season (Table 2), and ranges from 133 g/kg DM in *Z. mucronata* to 210.3 g/kg DM in *B. maughamii* in the winter season. *Dichrostachy cinerea, B. discolor, C. collinum, D. melanoxylon, G. monticola, C. imberbe, V. karroo, M. azedarach, V. nigrescens* and *B. zeyheri* had higher ($p < 0.0001$; $F = 9187.6$) CP content in summer than the same species in winter. In Table 3 NDF content ranged from 392 g/kg DM in *M. azedarach* to 572 g/kg DM in the summer, and in winter it ranged from 283 g/kg DM in *B. zeyheri* to 576 g/kg DM in *V. karroo*. With an exception to *D. cinerea, G. occidentalis, V. karroo* and *M. azedarach;* all other browse species had higher ($p < 0.0001$; $F = 8.6$) NDF in summer when compared to the same species in winter. Summer season greatly influenced ($p < 0.0001$; $F = 45.2$) ADL content of *B. mollis,* (502.3 g/kg DM); *S. nigrescens* (321.0 g/kg DM), *V. nilotica* (325.2 g/kg DM) while in winter *D. cinerea* (355.8 g/kg DM) had the highest ($p < 0.0001$; $F = 502.7$) ADL content. *Bridelia mollis, B. maughamii, D. melanoxylon; C. imberbe, V. karroo, O. kirkii, M. azedarach, S. nigrescens; V. nilotica, G. occidentalis* and *B. zeyheri* had higher ($p < 0.0001$; $F = 502.7$) ADL content in summer than the same species in the winter season.

For chemical estimates predictions in Table 4, *C. collinum* had the highest ($p < 0.0001$; $F = 227.8$) DMDigest % in summer. Within each species, in summer *D. cinerea, B. discolor, D. melanoxylon, C. collinum; C. imberbe, G. monticola, V. karroo; O. kirkii, M. azedarach, V. nilotica*; and *Z. mucronata* had the highest ($p < 0.0001$; $F = 227.8$) dry matter digestibility as compared to winter on the same species.

In summer, *C. collinum* had the highest ($p < 0.0001$; $F = 11.4$) TDN value and *D. melanoxylon* had higher ($p < 0.0001$; $F = 11.4$) TDN in winter.

The ME content ranged from 2.1 Mcal/kg in *G. monticola* and *S. nigrescens* to 2.9 in *C. collinum* in the summer season and 1.9 Mcal/kg in *D. cinerea* to 2.8 Mcal/kg in *D. melanoxylon* in the winter season (Table 5). In Table 6 *B. discolor; B. zeyheri* and *O. kirkii* had better ($p < 0.0001$; $F = 11.3$) DMD values after 36 h withdrawal period in winter. *Dichrostachys cinerea* and *G. monticola* had the least ($p < 0.0001$; $F = 11.3$) DMD36 values post 36-h withdrawal period in winter samples. *Bridelia mollis, B. discolor, C. collinum, C. imberbe, O. kirkii, S. nigrescens, V. nilotica, G. occidentalis* and *B. zeyheri* had the same

Table 2 Effect of species and season on ash (g/kg DM), organic matter (g/kg DM) and crude protein (g/kg DM) on browse species found in semi-arid rangelands of South Africa

	Ash		OM		CP	
Species	Summer	Winter	Summer	Winter	Summer	Winter
B. mollis	55.5^{hB}	81.3^{hA}	885.9^{cA}	869.1^{cB}	148.6^{mB}	198.7^{bA}
D. cinerea	53.5^{hiB}	80.3^{hA}	892.9^{abA}	866.2^{cB}	202.9^{efA}	156.6^{hB}
B. maughamii	111.8^{aA}	69.1^{jB}	851.4^{gB}	874.9^{bA}	202.6^{fB}	210.3^{aA}
B. discolor	63.7^{fB}	106.6^{dA}	889.3^{bcA}	848.5^{deB}	231.8^{bA}	195.5^{cB}
C. collinum	53.6^{hiB}	58.4^{lA}	895.4^{aA}	895.2^{aA}	178.9^{hA}	163.7^{gB}
D. melanoxylon	50.3^{jkB}	143.0^{bA}	896.5^{aA}	812.5^{fB}	210.3^{dA}	172.4^{eB}
G. monticola	62.8^{fgB}	70.5^{ijA}	879.2^{dA}	877.7^{bA}	167.0^{jA}	147.8^{jB}
C. imberbe	52.2^{ijB}	57.5^{lA}	896.7^{aA}	893.4^{aA}	163.1^{kA}	147.4^{jB}
V. karroo	55.8^{hB}	72.7^{iA}	893.7^{abA}	876.3^{bB}	220.7^{cA}	145.5^{kB}
O. kirkii	70.5^{eB}	99.9^{fA}	874.6^{deA}	849.4 ^{dB}	159.2^{lB}	167.8^{fA}
M. azedarach	100.4^{bB}	163.0^{aA}	853.8^{gA}	793.2^{gB}	343.7^{aA}	139.4^{lB}
S. nigrescens	60.4^{gB}	66.1^{kA}	879.2^{dA}	875.0^{bA}	158.2^{lA}	152.8^{iB}
V. nilotica	48.2^{kB}	91.3^{gA}	895.4^{aA}	867.1^{cB}	185.1^{gB}	192.4^{dA}
G. occidentalis	82.6^{cA}	81.6^{hA}	861.3^{fA}	864.1^{cA}	203.9^{eA}	167.6^{fB}
Z. mucronata	73.7 ^{dB}	103.3^{eA}	870.4^{eA}	843.5^{eB}	201.9^{fA}	132.8^{mB}
B. zeyheri	71.3^{deB}	125.7^{cA}	869.56^{eA}	817.6^{fB}	169.8^{iA}	146.9^{jB}
SE	1.05		1.98		0.41	

^{abcdefghijklm} Shared lower case superscript letters within a column indicates a non-significant difference between browse species ($p > 0.05$)

^{AB} Shared lower case superscript letters within a row indicates a non-significant difference between seasons ($p > 0.05$); *OM*, organic matter; *CP*, crude protein; *SE*, standard error

($p > 0.0001$; $F = 5.9$) DMD48 values across two seasons.

Discussion

Chemical composition of browse species

Browse plants remain the major source of feed during the period of scarcity because they are capable of surviving and retaining most of their nutritional value during the dry season in most arid and semi-arid regions (Aruwayo & Adeleke, 2019). This qualifies them to be an alternative source of feed for ruminants as they are also easily accessible to farmers in communal areas who are financially constrained to buy commercial feeds. The browse species are diverse and have numerous fodder components which include leaves (green/brown), twigs, flowers and fruits of which have a much longer period of availability throughout all seasons. Chemical composition differences have been noted among different African vegetation types in semi-arid areas (Nsubuga et al., 2020). In this study a wide variation was noted among browse species in all parameters measured which is in line with Abebe et al. (2012). The current study revealed that, the ash concentration was better in winter than summer, with a range between 48 and 163 g/kg DM. These results are in line with those reported by Aganga et al. (2005) (32.5–95.8 g/kg DM). The summer result on *Z. mucronata* is higher than the one reported by Ravhuhali et al. (2020) (39.4 g/kg DM). Therefore, the high ash content found in these species gives an overall representation of the mineral content (organic) present in the feed material that is essential for improving growth in animals (Msiza et al., 2021). Seasonal change is vital in the overall availability of forage for animal consumption, especially during the months when plant growth is less active. Plant growth tends to be slower in the winter season because of the negative effect of low ambient temperatures on growth (Hassen et al., 2007), thus low rainfall (a limiting factor) and other climatic conditions impose additional constrains for the process of photosynthesis to take place, therefore less forage yield is produced and CP content is likely to be lower. From this study *M. azedarach* in the summer (343.7 g/kg DM) season was higher than that of Mokoboki et al. (2019) (206.7 g/kg DM) in the same season. *Berchemia discolor* species recorded a CP content of 231.8 g/kg DM (summer) and 195.5 g/kg DM (winter). These results were comparable to the one reported by Osuga et al. (2012) (195 g/kg DM). In this study all the browse species had CP

Table 3 Effect of species and season on neutral and acid detergent fibres (NDF, ADF, g/kg DM) and acid detergent lignin (ADL, g/kg DM) of browse species found in semi-arid rangelands of South Africa

	NDF		ADF		ADL	
Species	Summer	Winter	Summer	Winter	Summer	Winter
B. mollis	447.9^{efgA}	356.2^{deB}	395.9^{bA}	334.2^{deB}	321.6^{aA}	268.3 ^{dB}
D. cinerea	423.7^{fgB}	522.4^{abA}	243.3^{gB}	433.6^{bA}	234.9^{eB}	355.8^{aA}
B. maughamii	520.5^{abcdA}	397.8^{cdB}	390.7^{bA}	273.3^{hiB}	202.1^{hA}	186.9^{hB}
B. discolor	452.0^{efA}	298.5^{fgB}	286.3^{eA}	294.8^{ghA}	182.9^{iB}	220.3^{gA}
C. collinum	448.5^{efgA}	354.8^{defB}	287.1^{eA}	284.8^{ghiA}	162.1^{jB}	223.4^{gA}
D. melanoxylon	557.2^{aA}	368.9^{cdeB}	246.3^{fgA}	202.4^{kB}	215.6^{gA}	112.4^{jB}
G. monticola	547.9^{abA}	509.1^{bA}	467.4^{aB}	502.3^{aA}	292.0^{bB}	320.0^{bA}
C. imberbe	471.7^{cdefA}	296.4^{gB}	279.8^{efA}	231.7^{jB}	210.6^{gA}	89.0^{kB}
V. karroo	522.3^{abcA}	575.9^{aA}	265.5^{efgB}	405.5^{cA}	244.7^{dA}	232.0^{fB}
O. kirkii	464.5^{defA}	392.8^{cdeB}	323.7^{dA}	273.5^{hB}	282.3^{cA}	114.3^{jB}
M. azedarach	392.6^{gA}	338.2^{efgA}	330.9^{cdA}	319.9^{efA}	223.2^{fA}	192.8^{hB}
S. nigrescens	572.1^{aA}	422.8^{cB}	461.2^{aA}	402.0^{cB}	321.0^{aA}	310.7^{cB}
V. nilotica	483.5^{cdefA}	370.0^{cdeB}	375.5^{bcA}	354.1^{dA}	325.2^{aA}	260.5^{eB}
G. occidentalis	473.1^{cdefA}	407.3^{cdB}	321.9^{dA}	225.3^{jkB}	203.0^{hA}	121.7^{iB}
Z. mucronata	484.7^{cdeA}	338.4^{efgB}	317.2^{dA}	302.8^{fgA}	216.5^{gB}	260.7^{eA}
B. zeyheri	496.4^{bcdeA}	283.0^{gB}	326.8^{dA}	263.5^{iB}	251.1^{dA}	222.2^{gB}
SE	20.20		8.12		2.33	

^{abcdefghij} Shared lower case superscript letters within a column indicates a non-significant difference between browse species ($p > 0.05$)

^{AB} Shared lower case superscript letters within a row indicates a non-significant difference between seasons ($p > 0.05$)

NDF, neutral detergent fibre; *ADF*, acid detergent fibre; *ADL*, lignin detergent fibre; *SE*, standard error

concentrations higher than the minimum level in both seasons (above 85 g/kg DM/day in goats during maintenance stage) (NRC, 2000) and they can have the potential to be used as a protein supplement to grass-based diets. Neutral detergent fibre (NDF) content for the browse leaves ranged between 283.0 and 575.9 g/kg DM, with summer tending to be generally much higher than winter except for *D. cinerea*. This finding was in line with Fentahun et al. (2020) who also reported a higher NDF concentration for the browse in dry seasons than in rainy seasons. The NDF concentration in winter is higher than summer because of the high intensity of solar radiation and the less amount of rainfall caused faster maturation during the winter season, of which it resulted in higher cell wall contents than those in the summer season (Aruwayo & Adeleke, 2019). Low NDF concentration on *M. azedarach* and *B. zeyheri* (392.6 g/kg DM and 283 g/kg DM, respectively) in both seasons is within the recommended ones for browsers and grazers (30–40% DM) and this can have a direct relationship with DMI (Van Saun, 2016). The significance of DM intake lies in the utilization of forage by the animal and it is a determining factor of energy and performance in ruminants. The ADF results in this study were within a range of 202.4–502.3 g/kg DM and this was within the range of that reported by Gemeda & Hassen (2015) (273.3–495.1 g/kg DM) and lower than that reported by Anele et al. (2008) (604–607 g/kg DM). Saleem et al. (2012) agrees that the ADF concentration level in browse species can positively or negatively affect the digestibility. The lignin content in most of the browse species in our study were ranging between 89 to 355.8 g/kg DM for both seasons and was much higher in summer than in the winter season. Tjelele (2007) reported similar findings highlighting that lignin content in browse leaves varies based on the season, such that in warmer temperatures (summer) the lignin content increases and in lower temperatures (winter) lignin content decreases because

Table 4 Effect of species and season on dry matter intake (kg/day), dry matter digestibility (%) and total digestible nutrients (%) of browse species found in semi-arid rangelands of South Africa

	DMI		DMDigest		TDN	
Species	Summer	Winter	Summer	Winter	Summer	Winter
B. mollis	13.9^{B}	16.2^{bcdeA}	55.5^{hA}	55.6^{deA}	50.2^{hB}	61.2^{efA}
D. cinerea	12.7^{A}	12.5^{efgA}	69.9^{bcA}	43.1^{gB}	64.1^{cdA}	48.2^{iB}
B. maughamii	10.9^{B}	13.6^{defgA}	58.2^{gB}	61.8^{bcA}	52.7^{gB}	67.6^{cdA}
B. discolor	12.0^{B}	18.0^{abcdA}	66.6^{dA}	60.3^{cB}	60.9^{eB}	66.0^{dA}
C. collinum	12.0^{B}	18.3^{abcA}	76.3^{aA}	57.5 ^{dB}	70.2^{aA}	63.1^{eB}
D. melanoxylon	9.7^{B}	14.6^{bcdefA}	69.7^{cdA}	67.2^{aB}	63.9^{cdB}	73.1^{aA}
G. monticola	10.0^{A}	10.6^{fgA}	52.5^{iA}	44.6^{gB}	47.3^{iB}	49.8^{iA}
C. imberbe	11.5^{B}	18.2^{abcA}	68.7^{cdA}	65.0^{aB}	62.9^{deB}	70.9^{bA}
V. karroo	10.3^{A}	9.4^{gA}	68.2^{cdA}	51.9^{fB}	62.4^{deA}	57.3^{gB}
O. kirkii	12.1^{A}	14.2^{cdefA}	63.7^{eA}	61.8^{bcB}	58.1^{fB}	67.6^{cdA}
M. azedarach	13.8^{B}	16.9^{abcdeA}	71.5^{bcA}	57.0 ^{dB}	65.6^{cA}	62.6^{eB}
S. nigrescens	9.4^{B}	12.8^{efgA}	53.0^{iA}	52.2^{fA}	47.7^{iB}	57.6^{gA}
V. nilotica	11.2^{B}	15.3^{bcdeA}	63.6^{eA}	54.6^{eB}	57.9^{fB}	60.1^{fA}
G. occidentalis	11.4^{A}	13.3^{efgA}	63.8^{eB}	65.5^{aA}	58.2^{fB}	71.4^{abA}
Z. mucronata	11.1^{B}	20.7^{aA}	72.0^{bA}	56.9 ^{dB}	66.1^{bA}	62.5^{eB}
B. zeyheri	10.9^{B}	19.1^{abA}	63.4^{eA}	62.6^{bA}	57.8^{fB}	68.4^{cA}
SE	0.81		0.40		0.39	

^{abcdefghi} Shared lower case superscript letters within a column indicates a non-significant difference between browse species ($p > 0.05$)

^{AB} Shared lower case superscript letters within a row indicates a non-significant difference between seasons ($p > 0.05$)

DMDigest, dry matter digestibility; *DMI*, dry matter intake; *TDN*, total digestible nutrients; *SE*, standard error

of limited light for plant development. Mokoboki et al. (2019) stated that lignin has an ability to reduce the nitrogen balance of animals by increasing endogenous and microbial nitrogen loss in faeces. Moreover, when plants have lower ADL level, the microflora is able to properly break down the low lignified leaves in the digestive tract of the ruminant because it is not resistant to chemical and enzymatic degradation (Ramantsi et al., 2020).

The digestibility of the substrates is normally influenced by the amount of ADF and most of the species had higher DM digestibility in summer when compared to winter. The DMDigest results in this study were ranging from 52.5 to 76.3 g/kg DM in summer and 43.1–67.2 g/kg DM in winter. Factors that may influence the variation of digestibility among woody species include nitrogen, cell wall content, lignin and bioactive compounds (Mlambo et al., 2015). It is essential to understand the manner in which ruminants use ME for their metabolizable functions due to their different efficiencies that are based on their nutritional requirements including their physiological stage (pregnancy, gestation, growth) and general maintenance (Filho et al., 2011). The ME of the studied species ranged between 1.91 and 2.79 Mcal/kg. Most browse species in this study had lower ME values in summer than in winter, this result is lower than that reported by Nsubuga et al. (2020) (above 3 Mcal/kg). The ME of these species shows that they can be able to support the maintenance and high activity of goats (0.57–2.78 Mcal/kg) and other livestock such as dairy and beef cattle (NRC, 1985).

In vitro *dry matter degradability*

A lot of research has given a detailed account on the nutritive value and degradability of browse leaves (Ramantsi et al., 2020; Ravhuhali et al. 2020). The latter authors added that rumen degradability is capable of reaching up to > 600 g/kg when there is

Table 5 Effect of species and season on relative feeding value (g/kg DM), digestible energy (Mcal/kg) and metabolizable energy (Mcal/kg) of browse species found in semi-arid rangelands of South Africa

	RFV		DE		ME	
Species	Summer	Winter	Summer	Winter	Summer	Winter
B. mollis	769.7^{abcdeB}	988.7^{bcA}	2.6^{hB}	2.9^{fgA}	2.2^{iB}	2.4^{deA}
D. cinerea	891.4^{abcB}	$600.7^{\ dB}$	3.3^{bcdB}	2.3^{iA}	2.7^{cA}	1.9^{gB}
B. maughamii	631.4^{cdeB}	917.9^{bcA}	2.8^{gB}	3.2^{cdA}	2.3^{hB}	2.6^{cA}
B. discolor	796.5^{abcdB}	1189.8^{abA}	3.1^{eA}	3.1^{dA}	2.6^{fA}	2.5^{cA}
C. collinum	918.4^{abB}	1151.2^{abA}	3.5^{aA}	3.0^{eB}	2.9^{aA}	$2.4^{\ dB}$
D. melanoxylon	675.7^{bcdeB}	1070.5^{abA}	3.3^{cdB}	3.4^{aA}	2.7^{cdB}	2.8^{aA}
G. monticola	526.3^{deA}	527.9^{dA}	2.5^{iA}	2.4^{iB}	2.1^{jA}	2.0^{gB}
C. imberbe	787.1^{abcdB}	1290.7^{aA}	3.2^{deB}	3.3^{bA}	2.6^{deB}	2.7^{bA}
V. karroo	705.3^{abcdeA}	$537.6^{\ dB}$	3.2^{deA}	2.7^{hB}	2.6^{eA}	2.2^{fB}
O. kirkii	767.8^{abcdeB}	961.9^{bcA}	3.0^{fB}	3.2^{cdA}	2.5^{gB}	2.6^{cA}
M. azedarach	983.6^{aA}	1057.0^{abA}	3.3^{bcA}	3.0^{efB}	2.7^{bA}	$2.4^{\ dB}$
S. nigrescens	500.2^{eB}	735.5^{cdA}	2.5^{iB}	2.7^{hA}	2.1^{jB}	2.3^{fA}
V. nilotica	710.0^{abcdeB}	916.7^{bcA}	3.0^{fA}	2.8^{gB}	2.5^{gA}	2.3^{eB}
G. occidentalis	728.5^{abcdeB}	946.0^{bcA}	3.0^{fB}	3.3^{abA}	2.5^{gB}	2.7^{abA}
Z. mucronata	802.6^{abcdB}	1295.5^{aA}	3.4^{bA}	3.0^{fB}	2.8^{bA}	$2.4^{\ dB}$
B. zeyheri	690.1^{bcdB}	1306.5^{aA}	3.0^{fB}	3.2^{cA}	2.5^{gB}	2.6^{cA}
SE	50.09		0.02		0.01	

^{abcdefghij} Shared lower case superscript letters within a column indicates a non-significant difference between browse species ($p > 0.05$)

^{AB} Shared lower case superscript letters within a row indicates a non-significant difference between seasons ($p > 0.05$)

RFV, relative feeding value; *DE*, digestible energy; *ME*, metabolizable energy; *SE*, standard error

a higher concentration of CP than fibres in the feed diet. According to Fentahun et al. (2020) a high to medium DM degradability suggests that there is great value in feeding these browse species to livestock mostly in the winter season. The degradability of browse species increased with an increase in the incubation time meaning that it needs more time to be broken down by microbes which maybe a result of its high fibre contents of the species. Indeed, various extent and rate at which tropical browse species respond to rumen degradability is expected because of their different chemical composition profile and the season (Ma et al., 2019). The degradability was ranging from 315.1 to 605.7 g/kg DM (summer) and 223.1 to 611.6 g/kg DM (winter). In vitro DM degradability of this study was within Belachew et al. (2013) for tropical species leaves (264.6–824.9 g/kg DM), of which it is sufficient enough to satisfy the energy demands of less productive animals with lower production levels (Mokoboki et al., 2005). Even though in this study, tannins and phenolics were not studied, we cannot shy away from the association of lignin and tannin concentrations and their influence on effectively reducing the fermentation and digestion of the browse leaves (Gemeda & Hassen, 2015).

Conclusions

Results from the current study, indicate that seasonal dynamics on browse species have an effect on the nutritive value, chemical estimates and in vitro dry matter degradability of indigenous woody species. In both seasons, most of these browse species have the potential to supplement low quality natural grasses because they go beyond the minimum requirement of protein and have reasonable amounts of fibre concentration. The overall assessment of these species indicates their outstanding nutritive traits which make

Table 6 Effect of species and season on the in vitro dry matter degradability (DMD g/kg) (DMD24, DMD36, DMD48) of browse species found in semi-arid rangelands of South Africa

	DMD24		DMD36		DMD48	
Species	Summer	Winter	Summer	Winter	Summer	Winter
B. mollis	268.1^{efgA}	263.6^{efgA}	298.0^{ghB}	339.7^{deA}	355.5^{fghiA}	356.0^{efgA}
D. cinerea	248.4^{fgA}	213.4^{fgA}	270.4^{hA}	226.8^{fB}	338.0^{ghiA}	260.9^{ghB}
B. maughamii	374.6^{bcdA}	376.3^{cA}	407.8^{deA}	425.1^{bcA}	$466,9^{bcdefgA}$	449.9^{bcdefA}
B. discolor	524.5^{aA}	468.4^{aB}	536.1^{abA}	515.7^{aA}	581.5^{abA}	556.0^{abcA}
C. collinum	353.1^{bcdeB}	404.8^{abcA}	380.4^{defB}	426.8^{bcA}	$449.4^{cdefghA}$	472.9^{bcdeA}
D. melanoxylon	312.8^{cdeB}	464.5^{abA}	316.7^{fghB}	487.3^{abA}	362.7^{efghiB}	504.2^{abcdA}
G. monticola	225.8^{gA}	185.0^{gA}	243.6^{hA}	194.7^{fB}	326.8^{efghiA}	223.1^{hB}
C. imberbe	366.4^{bcdA}	379.3^{bcA}	354.6^{efgB}	411.6^{bcdA}	$403.4^{defghiA}$	452.9^{bcdefA}
V. karroo	255.6^{fgA}	272.4^{defA}	294.5^{ghB}	346.2^{cdeA}	347.5^{ghiB}	444.2^{bcdefA}
O. kirkii	475.2^{aA}	471.7^{aA}	507.7^{abcA}	534.8^{aA}	559.8^{abcA}	611.6^{aA}
M. azedarach	497.7^{aA}	351.2^{cdB}	537.5^{aB}	404.3^{cdA}	605.7^{aA}	434.2^{cdefB}
S. nigrescens	256.5^{fgA}	269.3^{defgA}	299.8^{fghA}	319.0^{eA}	344.0^{ghiA}	373.0^{efgA}
V. nilotica	292.8^{defgA}	246.1^{fgB}	297.2^{ghA}	318.8^{eA}	315.1^{iA}	329.0^{fghA}
G. occidentalis	384.5^{bcA}	374.9^{cA}	417.2^{deA}	386.0^{cdeA}	$483.3^{abcdefA}$	444.6^{bcdefA}
Z. mucronata	352.7^{bcdeA}	339.6^{cdeA}	432.3^{cdeA}	369.0^{cdeB}	492.2^{abcdeA}	404.1^{defB}
B. zeyheri	438.5^{abA}	428.1^{abcA}	455.1^{bcdB}	529.2^{aA}	516.4^{abcdA}	567.4^{abA}
SE	15.38		14.50		23.18	

^{abcdefghi} Shared lower case superscript letters within a column indicates a non-significant difference between browse species ($p > 0.05$)

^{AB} Shared lower case superscript letters within a row indicates a non-significant difference between seasons ($p > 0.05$); *DMD24*, in vitro dry matter degradability at 24 h; *DMD36*, in vitro dry matter degradability at 36 h; *DMD48*, in vitro dry matter degradability at 48 h; *SE,* standard error

them suitable for their use in ruminant diets and can be given first preference for ruminants to browse them. Further studies need to be taken to investigate the level of bioactive compounds found in these woody species for amelioration and maximizing browsing of these species.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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