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Evaluation and Prediction of the Nutritive Value of Underutilised Forages as Potential Feeds for Ruminants

Mehluli Moyo, Siyabonga T. Bhiya,
Masande Katamzi and Ignatius V. Nsahlai

Additional information is available at the end of the chapter

Abstract

The aim of the chapter was to evaluate and predict the nutritive and feeding value of unknown and underutilised forages. Underutilised forages were collected from various regions. Chemical composition and degradability of forages in the rumen were determined. A dataset was created bearing degradability parameters of feeds from 40 studies. Using the dataset, a step-wise regression procedure was used to develop regression equations to predict rumen degradability. Of the underutilised forages, crude protein content tended to be double for *Brassica oleracea var. acephala* compared to *Colophospermum mopane* leaves and pods. Forage grasses tended to have very low crude protein contents compared to legumes and concentrates. Underutilised *Brassica oleracea var. acephala* tended to have higher crude protein levels compared to commonly used protein sources. The regression model for predicting the soluble fraction accounted for 59% (development) and 71% (validation) of the variation. The regression model for predicting the potential degradability accounted for 65% (development) and 24% (validation) of the variation. In conclusion, the nutritive value of underutilised forages was good, high in crude protein and high potential degradability. After correcting for factors that significantly affected degradability parameters, predicted solubility and effective degradability lay near the ideal prediction line, giving good predictions.

Keywords: *Afzelia quanzensis*, *Brassica oleracea var. acephala*, *Colophospermum mopane*, degradability, feeding value

1. Introduction

Ruminants such as cattle, goats and sheep are important livestock for resource-limited farmers around the world because of their ability to utilise readily available and cheap fibrous feeds that are otherwise not consumed by humans and monogastric livestock. Key to their ability to utilise feeds of high fibre content is the presence of fibrolytic bacteria in the rumen. There are a large number of plant species that have the potential of being used as forage for ruminants. Among them are a wide range of plants that are unknown to the public domain and some that are underutilised because of inadequate information on their feeding value. Exploration of these plant species is important in increasing the forage base for livestock farmers under gradually changing climatic conditions that are projected to reduce forage availability, quantity and quality. Determination of whether a forage crop can be a potential feed for a ruminant entails evaluation of its feeding value. Feeding value and quality of forages as feed for ruminants are evaluated through determining chemical composition, intake, palatability, acceptability and digestibility in vivo or in sacco. Degradability of feeds in sacco is one of the most widely used techniques to determine how much feed is digested in the rumen [1] and is important in determining feed intake. In developing countries, lack of rumen cannulated animals and/or nylon bags may hinder assessment of forage quality using rumen degradability of forages in sacco. There is a need for the development of simpler methods for the prediction of rumen degradation of forages. Simulation of digestibility of forages that has never been studied before is crucial for preliminary identification and selection of relatively unknown forages as a feed source for ruminants.

The broad objective of this chapter was to review, evaluate and predict the nutritive and feeding value of unknown and underutilised forages that have a potential of being ruminant feeds. The aim of this study was to: (1) evaluate rumen degradation of legume forages (*Colophospermum mopane* leaf meal and pods, cowpea haulms, *Mucuna pruriens*, cassava peels and *Afzelia quanzensis* legume pods), grass forages (millet stover, maize stover, maize leaves, veld grass hay and wheat straw) and *Brassica oleracea var. acephala*; and (2) predict the rumen degradation of the above-mentioned forages based on chemical composition of plant material and animal properties.

2. Review of relatively underutilised plants for feeding ruminants in sub-Saharan Africa

Non-conventional feeds and forages are feed resources used locally by farmers or have not been traditionally used in commercial or local feeding of livestock. These feeds can be available mostly with smallholder farmers and are used for short period of time, especially during the dry season when there is shortage of feeds. Literature has shown that non-conventional feeds (e.g. home waste) and forages (some forbs) are mainly used by smallholder farmers to cope during the dry season [2–4]. Although these non-convention forages are used occasionally, some of them have shown good quality attributes, which can sustain any ruminant livestock

if they are provided a good quantity throughout the year. For example, bitter leaf (Vernonia), corn plant, snake weed and commelina [5] have an acceptable metabolisable energy (ME) of >7 MJ/kg DM, which is comparable to well-known Lucerne hay (7.8 MJ/kg DM; [6]). Browse plants include *Gmelina arborea*, *Myrianthus arboreus*, *Terminalia catappa*, *Dacroydes edulis*, *Parkia filicoidea* and *Tephrosia bracteolata* [7], *Moringa oleifera* (Adediran, A per com.) and accession of *Sesbania sesban*. The young leaves of *Myrianthus arboreus* (native of Angola, Cameroon, Congo, Cote d'Ivoire, Kenya, Sudan, Tanzania, Uganda and Nigeria) are popularly consumed in West Africa as vegetables and contain appreciable levels of protein, calcium, iron and phosphorous [8]. Nutrient profile of the fresh leaves of *Gmelina arborea* (originates from Southeast Asia but is planted in tropical Africa) revealed appreciable levels of crude protein (146 g/kg DM) and ether extract (127 g/kg DM) [9]. *Dacroydes edulis* can substitute 40–60% maize in poultry without any effect on production, yet it is rich in alkaloids [7]. Other energy- and protein-rich feeds are *Guizotia abyssinica* (Noug seed cake), *Hevea brasiliensis* (Rubber seed cake), *Leucaena leucocephala* leaves and pods, citrus pulp, jackfruit, palm kernel meal, tea waste, millet (seeds, bran, stover) and coconut pith. Banana leaves and pseudostems [10], cassava and cacti (high in water use efficiency, high in insoluble carbohydrates, calcium, potassium and vitamin A, but are low in crude fibre and crude protein), pineapple waste and palm oil mill effluents can be considered as a source of water for ruminants raised under harsh environments [11, 12]. Other feeds with considerable amount of water are potato peeling waste, sugar cane tops, tomato waste, apple waste, cassava peels, starch and milk waste, cocoa pods, mango seed meal and corn steep liquor.

The improvement of these feed resources could increase its availability year-round and reduce the length of the critical period when feed is in short supply. However, a cursory review of literature has depicted a paucity of information on efforts to improve and promote new options related to these feeds. Notwithstanding little is known about non-conventional feeds, it is not easy to encapsulate technological challenges on these feeds. Nonetheless, anecdotal information shows that technological challenges to include these feeds are related to (1) less interest on these feeds; many plant breeders are much more interested in food crops than forages, leading to poor testing and selection of the best-bet forages among the latter based on their agronomic aspects, (2) lack of information on these feeds at local prevailing conditions and on their potentiality (biomass production and nutrient value). Some of these underutilised forages are described below.

2.1. *Colophospermum mopane*

Mopane trees are widely distributed in the hot arid steppe areas of Southern Africa and are mainly concentrated between Southwestern Zimbabwe and Northeastern Botswana. Mopane shrubs grow in hot, dry, low-lying areas with alkaline soils. During periods of feed scarcity, cattle, goats and sheep tend to browse on Mopani tree leaves and pods. Goats prefer to browse on Mopane leaves and pods when they are reddish-brown in colour probably coinciding with high pH > 5 and low levels of condensed tannins. *Colophospermum mopane* leaves and fruits constituted 66–68% of total stomach contents of Giraffe in a low-altitude sub-tropical lowveld/bushveld mostly on the savanna habitat in winter [13]. Studies have evaluated Mopane leaf meals as

a potential protein source for monogastrics, mainly in pig diets [14, 15]. Crude protein content of Mopane leaves is about 85.6 [16] and 139·6 g/kg [14]. *Colophospermum mopane* leaves had significantly lower fibre-bound proanthocyanidins (2.4 vs. 2.9 g/kg) and ytterbium-perceptible phenolic (203.8 vs. 428 g/kg) content compared to the commonly studied legume tree species such as *Acacia karroo* [14]. Few studies including Lukhele and Van Ryssen [17] and Dambe et al. [18] have evaluated the potential of *Colophospermum mopane* leaves as a feed source for ruminants, but did not determine its degradability in the rumen. This suggests that *Colophospermum mopane* forage may well be a good source of supplementary dietary protein for ruminants although more research needs to be done to increase knowledge on its feeding value for ruminants.

2.2. *Brassica oleracea var. acephala*

Commonly known as African kale, Chou Moellier and/or chomollier, this plant species thrives in well-drained soils with good soil quality and may be grown after turning in a green manure such as vetch or clover. Predominantly grown as a vegetable crop for human consumption [19, 20], little is known of the nutritional value of Chou Moellier leaves as a supplement feed source for ruminants, especially goats and sheep. There are claims that dairy cattle farmers in some parts of Australia and New Zealand use *Brassica oleracea var. acephala* leaves as a supplementary forage for dairy cows. Crude protein content of *Brassica oleracea* ranges from 15.7–25% [21, 22]. Few studies, including Barry et al. [23] and Cassida et al. [24], have evaluated the potential use of *Brassica oleracea* spp. as feed for sheep. However, the authors [25] claim that lamb growth performance (100–150 g/day) was inferior relative to the high nutritive value of *Brassica oleracea* leaves. Body weight gains of lambs grazing on *Brassica oleracea* were slightly lower than those of lambs grazing on a popular protein source, Lucerne hay (62 vs. 91 g/day) [23]. Total tract digestibility of organic matter was high for *Brassica oleracea* diets (875 g/kg) compared to Lucerne hay (731 g/kg) [23].

2.3. *Manihot esculenta*

Although the cassava root remains a good source of food for humans, cassava peels and chips may be fed to ruminants as household waste to provide supplementary nutrients. Tested in cattle, the a-fraction and effective degradability of dry matter, organic matter and crude protein were highest for cassava chips compared to generally preferred energy concentrates namely, ground corn, broken rice, rice bran and rice pollard [26]. Supplementation of rice straw with sun-dried cassava (at 1% body weight) foliage increased dry matter intake (+1341 g/d), crude protein intake (+239 g/d) and average daily gain (+201 g/d) compared to unsupplemented rice straw fed heifers [27]. In addition, molar proportions of propionic acid were higher in cattle supplemented with cassava at 2 and 3% body weight, leading to significantly low acetate: propionate ratio in the rumen [28]. Fermentation shifts towards propionic acid production are implicated in reduction in methane emissions from the rumen. The response of microbial nitrogen supply to increased levels of supplementation of cassava was a positive quadratic peaking (186.6 ± 0.85 gN/d) at 2% BW supplementation. Wanapat and Khampa [28] recommended the use of a cost-effective option to supplement using cassava at inclusion rates of 2% body weight by smallholder beef and dairy farmers. Cassava may thus play a critical role in

improving the nutritional status of ruminants in tropical and sub-tropical areas coupled by its environmentally friendly role of reducing methane emissions.

2.4. *Sclerocarya birrea* ssp. *caffra*

The Marula tree fruit is a common feed supplement for ruminants in parts of Northwestern Nigeria [29], but generally not fully exploited in most parts of Southern Africa, given its abundance in the region. Full exploitation of Marula oil cake (MOC) as a supplement in ruminant diets may be limited by the scarcity of its feeding value for ruminants. Crude protein content of MOC is about 324–472 g/kg [30, 31] and may be comparable with those of commonly used protein supplements, soya bean meal (SBM) and sunflower cake (SFC) [32]. Several studies have evaluated the potential benefits of MOC as a supplement for ruminants with positive results; substitution of urea with MOC as a source of nitrogen in fattening rations had no undesirable effects on dry matter feed intake (fattening ration plus urea = 6.38 vs. fattening ration plus MOC = 6.84 kg/day) and growth rate (fattening ration plus urea = 1.62 kg/d vs. fattening ration plus MOC = 1.75 kg/d) of feedlot cattle, while a combination of equal amounts of urea and MOC in the fattening ration tended to maintain similar intakes (7.07 kg/day), but yielding better growth rates (1.82 kg/d) in feedlot cattle [33]. Potential degradability (PD) of MOC in the rumen was 723–857 g/kg for dry matter, while the PD of crude protein was 844–963 g/kg [32] in goats. Nitrogen retention was higher in goats that fed grass hay supplemented with MOC (2.8 g/d) compared to SBM (1.1 g/d) and SFC (−0.6 g/d) [32]. This suggests that *Sclerocarya birrea* ssp. *caffra* could well be a good source of supplementary dietary protein for ruminants.

2.5. *Mucuna pruriens*

With appreciable amounts of crude protein of 180–255 g/kg [34], pre-suckling kids grazing and supplemented with *Mucuna pruriens* bean had superior body weight gain (+130 vs. +86 g/day) compared to unsupplemented grazing kids, while growing lambs grazing and supplemented with *Mucuna pruriens* bean had superior body weight gain (+95 vs. +63 g/day) compared to unsupplemented grazing [35]. At similar dietary crude protein levels, *Mucuna pruriens* (inclusion level = 242 g/kg) had higher microbial protein (MP) yields (57.0 vs. 41.8 g/day) and superior microbial efficiency (70.8 vs. 51.2 g MP/kg digestible organic matter) compared to soya bean meal (inclusion level = 84.9 g/kg) [36]. Supplementation of dairy cows grazing on Napier grass with *Mucuna pruriens* increased milk yield by 32.5% compared to unsupplemented cows [37]. This suggests that *Mucuna pruriens* may well be a good source of supplementary dietary protein for all classes of ruminants.

2.6. *Strychnos* spp.

Commonly known as Monkey orange, *Strychnos* spp., fruit is indigenous to tropical and sub-tropical Africa [38]. This plant species is drought tolerant, and grows well on drained sandy soils and rocky hills [39]. Although the fruit possesses health benefits to humans, particularly children and women [40], its carbohydrate content ranges between 154 and 161 g/kg DM [41] with an average crude protein content of 128 g/kg DM [42]. The water

content of the fruit ranges between 600 and 910 g/kg DM [43, 44] hence may serve as a potential water source for ruminants in arid and semi-arid regions during periods of water scarcity. There is little evidence to show that ruminants eat the Monkey orange fruit and its hard pod covering makes it an unfavourable feed for non-bipedal animals. There is limited information on the nutritional value of the Monkey orange fruit as a feed source for livestock. Given the potential of the fruit to be used as supplementary water source, evaluation of the feeding value of the fruit may render its use as a potential dual purpose feed for ruminants and other livestock.

3. Nutritive value of some underutilised forage crops

3.1. Evaluation of the nutritional value of underutilised forages and roughages

3.1.1. Materials and methods

Underutilised forage legumes and forage trees and shrubs (non-leguminous) were collected from various regions. These forages included *Colophospermum mopane* leaves and pods (Mangwe district; 20°36′57.5″S 27°45′39.7″E), and *Brassica oleracea var. acephala* (Bulawayo; 20°09′52.1″S 28°35′00.4″E) harvested in Southwestern Zimbabwe, and *Afzelia quanzensis* legume pods (Pietermaritzburg; 29°39′45.6″S 30°24′17.9″E) harvested in South Africa.

Eleven commonly used forages (10 forage grasses and 1 legume forage) were collected in KwaZulu-Natal, South Africa. These roughages included cowpea leaves and stems (*Mucuna pruriens*), maize stover, maize leaves, maize stalks (*Zea mays*), wheat straw (*Tritium aestivum*), kikuyu grass (*Pennisetum clandestinum*), weeping love grass at mature and bloom stages (*Eragrostis curvula*), bean straw, veld grass hay (Pietermaritzburg; 29°39′45.6″S 30°24′17.9″E), veld grass hay (Dundee; 28°09′17.2″S 30°12′42.8″E) and veld grass hay (Camperdown; 29°43′40.4″S 30°31′34.9″E). The forage hays were air-dried under a shade at ambient temperature and stored.

Moisture, dry matter (Method 934.01), organic matter and ash content (Method 942.05) of these forages and roughages were analysed using the procedures described by the Association of Official Analytical Chemists [45]. Nitrogen content was determined using the LECO TruSpec nitrogen analyser (LECO FP2000, LECO, Pretoria, South Africa). Crude protein content was calculated by multiplying the nitrogen content by a factor of 6.25 (crude protein = nitrogen content × 6.25). Neutral detergent fibre, acid detergent fibre and acid detergent lignin were analysed using ANKOM A220 fibre analyser (ANKOM Technology, New York, USA). Hemicellulose content was calculated as the difference between neutral detergent fibre and acid detergent fibre content (hemicellulose = neutral detergent fibre—acid detergent fibre). The cellulose and acid detergent lignin content were determined using the method of Van Soest and Wine [46].

The nylon bag technique [1] was used to determine the degradability of forages and roughages in the rumen. Dried forages were milled to pass through a 2-mm screen using a hammer mill (Scientec hammer mill 400, Lab World Pty Ltd., Johannesburg, South Africa). Approximately 4 g

of each ground forage sample was weighed into ANKOM nylon bags (ANKOM Co, Fairport, New York, USA; internal dimensions: 5 × 9 cm; pore size 50 μm) and sequentially incubated (in triplicates per time interval) in the rumen for 120, 96, 72, 48, 24, 9, 6, and 3 hours using four non-lactating Jersey cows (body weight = 330 ± 19.97). The cows were fed on veld hay (*Themeda triandra*) and supplemented with 2 kg Lucerne hay per day (**Table 1**) at Ukulinga Research Farm, Pietermaritzburg, South Africa (29°39′45.6″S 30°24′17.9″E). Incubated bags were removed and washed together with the unincubated (zero hour) bags for 30 minutes (6 cycles each lasting 5 minutes) using a semi-automatic washing machine. Washed bags were oven-dried for 48 hours at 80°C and weighed.

3.1.2. Mathematical procedures

Degradability of forages was determined using dry matter loss (DML) in nylon bags. A curve for DML against incubation time was plotted and used to inspect for outliers. The model of McDonald [47] was fitted on Statistical Analysis System 9.3 (SAS Institute Inc., Cary, NC, USA) to generate degradation parameters of the forages. The model used was as follows: $Y = a + b(1-e^{-c(t-L)})$, where Y is the degradability at time (t), a is the intercept, b is the potentially degradable fraction, c is the rate of degradation of b and L is the lag time. Effective degradability (ED) was calculated using a predicted passage rates for each forage. The passage rate of solid was predicted using models developed by Moyo et al. [48].

3.2. Results

Of the underutilised forages, the crude protein content tended to be double as much for *Brassica oleracea var. acephala* compared to *Colophospermum mopane* leaves and pods (**Table 2**). Forage grasses (62.9 ± 34 g/kgDM) tended to have very low crude protein contents compared to legumes (137.6 ± 69) and concentrates (177 ± 39.9). Underutilised *Brassica oleracea var. acephala* (305 g/kgDM) tended to have higher crude protein levels compared to commonly used protein sources (CSC = 222 g/kgDM).

There was not much of a difference between the potential degradability of forage grasses (651 ± 111 g/kgDM), concentrates (756 ± 95.4 g/kgDM), and forage legumes, trees and shrubs (745 ± 110.2 g/kgDM) (**Tables 3–5**).

Diets	Chemical composition of feeds and diets fed to cows (g/kg DM)							
Forages	DM	OM	CP	NDF	ADF	ADL	HEM	CEL
IPR	727	922	89	745	415	-	330	-
LH	906	911	136	524	361	-	163	-
Roughages								
Diet 1 (VGH)	933	867	69	795	603	190	192	413
LH	895	564	165	487	356	77	131	279
Diet 2 (VGH + 33% LH)	920	767	101	693	521	153	172	369
Diet 3 (VGH + 50% LH)	914	716	117	641	480	134	162	346

Table 1. Chemical composition of experimental feeds and diets fed to cows during nylon bag degradability.

DM: dry matter, OM: organic matter, N: nitrogen, NDF: neutral detergent fibre, ADF: acid detergent, ADL: acid detergent lignin, HEM: hemicellulose, CEL: cellulose, VGH: veld grass hay, LH: lucerne hay.

CMLB: *Colophospermum mopane* leaves brown, CMLG: *Colophospermum mopane* leaves green CMP: *Colophospermum mopane* pods, DH: *Diheteropogon hagerupii*, ET: *Eragrostis tremula*,

Group	Chemical composition of incubated feeds (g/kg DM)							
Forage legumes, trees and shrubs	DM	OM	CP	NDF	ADF	ADL	HEM	CEL
CPH	944	935	85	617	428	102	189	328
UTCPH	627	928	141	615	422	105	193	312
GNH	932	889	109	495	386	116	110	265
CMLB	906	941	132	407	199	-	208	-
CMLG	918	931	144	470	175	-	295	-
CMP	916	946	195	477	197	-	280	-
MPL	917	942	118	607	233	-	374	-
CRP	896	953	78	489	98	-	391	-
AQLP	956	978	70	628	220	-	408	-
BOAL	908	746	305	363	137	-	226	-
Forage grasses								
MS	930	828	96	718	614	118	104	496
ML	925	660	102	645	559	100	86	459
WS	878	800	42	764	691	175	73	516
EC	931	836	107	815	503	130	312	373
ECB	925	890	128	874	615	171	259	444
KG	919	833	99	778	666	189	112	477
VGHD	932	887	41	885	629	159	256	470
VGHC	929	866	41	834	564	110	270	454
VGHP$_1$	932	877	51	849	619	189	230	430
VGHP$_2$	936	882	37	876	609	142	267	467
DH	970	959	20	880	565	78	316	485
UTDH	617	968	36	876	566	88	310	476
ET	969	976	21	796	465	67	330	397
UTET	613	971	47	829	485	72	344	414
SE	949	954	22	813	518	49	295	447
UTSE	626	956	49	812	541	90	270	450
MIS	954	913	39	816	518	130	298	394
UTMIS	619	911	46	799	523	118	276	406
SS (whole)	964	845	23	791	535	198	257	296
UTSS (whole)	624	843	45	773	514	189	259	331
SSLS	973	809	40	725	440	145	285	289
SSS	962	906	22	731	438	100	293	332
Concentrates								
MB	919	897	146	513	122	63	391	61
WB	953	951	163	477	125	35	352	86
CSC	980	948	222	570	437	101	133	339

Table 2. Chemical composition of incubated forages.

MPL: *Mucuna pruriens* leaves, MOC: marula oil cake, AQLP: *Afzelia quanzensis* legume pods, BOAL: *Brassica oleracea var. acephala* leaves, MS: maize stover, ML: maize leaves, MT: maize stalks, MIS: millet stover, UTMIS: urea-treated millet stover, WS: wheat straw, EC: *Eragrostis*

	Rumen degradation of feeds						
	CPH	UTCPH	GNH	CMLB	CMLG	CMP	
a (g/kg)	234	236	305	519	358	398	
b (g/kg)	466	483	457	224	361	286	
c (h⁻¹)	0.15	0.08	0.14	0.06	0.07	0.11	
PD (g/kg)	700	719	762	743	719	684	
ED (g/kg)	556	505	621	668	611	623	
tL (h)	-	-	-	7.1	0	1.9	
	MPL	CRP	AQLP	BOAL	CSC	MB	WB
a (g/kg)	178	293	278	351	276	449	457
b (g/kg)	550	600	274	600	371	374	342
c (h⁻¹)	0.08	0.22	0.05	0.15	0.05	0.29	0.22
PD (g/kg)	728	893	552	951	647	823	799
ED (g/kg)	578	821	449	851	439	755	722
tL (h)	0	0	2.0	0	-	-	-

Table 3. Nylon bag degradation of forage legumes, forage trees and shrubs (non-leguminous), and concentrates. ED was calculated at kp: rate of passage of particles in the rumen = 0.03 per h.

Diet 1 (100% veld hay)										
	MS	ML	WS	ECM	ECB	KG	GHD	GHC	GHP₁	GHP₂
a (g/kg)	194	158	17	86	43	76	53	44	39	174
b (g/kg)	445	454	373	518	491	430	475	400	446	439
c (h⁻¹)	0.049	0.049	0.033	0.048	0.037	0.047	0.027	0.032	0.026	0.029
PD (g/kg)	639	612	391	604	534	506	499	445	486	613
ED (g/kg)	645	637	351	622	454	339	405	398	385	351
Diet 2 (67% veld hay: 33% lucerne hay)										
a (g/kg)	194	158	16	87	44	76	24	43	51	28
b (g/kg)	592	623	534	726	818	577	869	622	521	647
c (h⁻¹)	0.039	0.043	0.016	0.033	0.017	0.017	0.008	0.018	0.029	0.017
PD (g/kg)	786	780	556	813	819	652	894	665	572	676
ED (g/kg)	531	524	201	467	289	272	212	258	285	265
Diet 2 (50% veld hay: 50% lucerne hay)										
a (g/kg)	194	158	16	87	44	76	24	43	40	173
b (g/kg)	607	659	489	727	647	507	593	591	543	428
c (h⁻¹)	0.052	0.051	0.033	0.042	0.029	0.03	0.019	0.024	0.025	0.03
PD (g/kg)	801	817	505	814	691	582	616	634	583	600
ED (g/kg)	579	572	269	512	365	329	256	299	285	387

Table 4. Nylon bag degradability of forage grasses (roughages) in cows fed with three different diets. ED was calculated at kp: rate of passage of particles in the rumen = 0.03 per h.

Rumen degradation of feeds						
	DH	UTDH	ET	UTET	SE	UTSE
a (g/kg)	99	129	136	165	91	157
b (g/kg)	572	529	521	538	564	525
c (h⁻¹)	0.02	0.02	0.02	0.02	0.02	0.03
PD (g/kg)	671	658	657	703	655	682
ED (g/kg)	224	248	267	271	238	307
	MS	UTMS	SS (whole)	UTSS (whole)	SSLS	SSS
a (g/kg)	131	182	223	251	217	206
b (g/kg)	552	437	507	470	548	421
c (h⁻¹)	0.01	0.02	0.02	0.02	0.03	0.02
PD (g/kg)	683	619	730	721	765	627
ED (g/kg)	214	298	330	362	376	313

Table 5. Nylon bag degradability of urea treated and untreated forage grasses (roughages) in cows fed kikuyu pasture.

curvula, ECB: *Eragrostis curvula* at bloom stage, KG: kikuyu grass, SE: *Schizachyrium exile*, VGHD: veld grass hay from Dundee, VGHC: veld grass hay Camperdown, VGHP$_1$: veld grass hay Pietermaritzburg area 1, VGHP$_2$: veld grass hay from the Pietermaritzburg area 2, CPH: cowpea husks, CRP: cassava root peels, GNH: groundnut haulms, UTCPH: urea-treated cowpea husks, UTDH: urea-treated *Diheteropogon hagerupii*, UTET: urea-treated *Eragrostis tremula*, UTSE: urea-treated *Schizachyrium exile*, UTMIS: urea-treated maize stover, SS: sorghum stover, UTSS: urea-treated sorghum stover, SSLS: sorghum stover leaves and sheath, SSS: sorghum stover stems, MB: millet bran, WB: wheat bran, and CSC: cottonseed cake.

CMLB: *Colophospermum mopane* leaves—brown, CMLG: *Colophospermum mopane* leaves - green, CMPG: *Colophospermum mopane* pods, CPH: cowpea husks, CRP: cassava root peels, GNH: groundnut haulms, MPL: *Mucuna pruriens* leaves, AQLP: *Afzelia quanzensis* legume pods, BOAL: *Brassica oleraceae var. acephala* leaves, UTCPH: urea-treated cowpea husks, MB: millet bran, WB: wheat bran, CSC: cottonseed cake, a: rapidly degradable fraction, b: slowly degradable fraction, c: rate of degradation, PD: potential degradability, and ED: effective degradability.

MS: maize stover, ML: maize leaves, MT: maize stalks, WS: wheat straw, EC: *Eragrostis curvula*, ECB: *Eragrostis curvula* at bloom stage, KG: kikuyu grass, VGHD: veld grass hay from Dundee, VGHC: veld grass hay Camperdown, VGHP1: veld grass hay Pietermaritzburg area 1, VGHP2: veld grass hay from the Pietermaritzburg area 2, kp: rate of passage of particles in the rumen, a: rapidly degradable fraction, b: slowly degradable fraction, c: rate of degradation, PD: potential degradability, and ED: effective degradability.

MS: maize stover, ML: maize leaves, MT: maize stalks, WS: wheat straw, EC: *Eragrostis curvula*, ECB: *Eragrostis curvula* at bloom stage, KG: kikuyu grass, VGHD: veld grass hay.

4. Is it possible to predict the rumen digestibility (feeding value) of unknown and underutilised forages?

4.1. Prediction of degradation of forages in the rumen using feed and animal properties

4.1.1. Materials and methods

Data were collected from studies that reported at least average values for in sacco (nylon bag technique) degradability parameters (a, soluble fraction; b, slowly degradable fraction and c, rate of degradation) of roughages and stated the diet, feeds and feed supplements given to animals. A dataset was created bearing degradability parameters from wild and domesticated ruminants from 40 studies. Factors affecting degradability were identified in each of these studies and were categorised into two main groups: (1) diet properties (i.e. fed to the animal) and (2) feed sample properties (i.e. incubated in the rumen). Diet properties were used to account for the effects of rumen ecology on fermentation and included neutral detergent fibre (NDF), starch (STA) and crude protein (CP) contents of entire diet (all in g/kg), level of concentrate supplementation (%) and provision of a urea supplement in the form of a lick (presence = 1, absence = 0). Feed sample properties included urea treatment (%) of sample and feed compositional attributes (DM, dry matter; CP, crude protein; NDF, neutral detergent fibre, ADF, acid detergent fibre; HEM, hemicellulose and ash all in g/kg). Starch content of the diet fed to animals was calculated using the formula: STA = 1000–(NDF + CP). Potential degradability (PD) and hemicellulose (HEM) content were calculated in studies that did not report them using the formulae: PD = a + b; and HEM = NDF—ADF, respectively. Studies that did not report dietary composition of feeds but mentioned names of feeds used had their composition looked up in studies that reported them. These factors were used as input parameters to develop regression models for predicting degradability of feeds in the rumen.

A step-wise regression procedure on the Statistical Analysis System 9.3 (SAS Institute Inc., Cary, NC, USA) was used to select parameters that qualified to develop regression equations to predict (1) rapidly degradable fraction of fibre (a), (2) potential degradability (PD), (3) time lag for fermentation to occur (tL), and (4) rate of degradation (c) in the rumen. One parameter from a pair of correlated parameters was dropped in model development when both correlated parameters significantly influence degradation parameters. Those parameters that qualified for model development were CP and NDF content of feed sample (model for soluble fraction of fibre); ADF content of feed sample and STA content of diet (model for potential degradability); ADF, CP and ash content of feed sample, and STA content of diet (model for time-lag); NDF and CP content of feed sample, and, STA and DNDF content of diet (model for degradation rate).

Regression models were used to simulate the rumen degradability of *Colophospermum mopane* leaves and pods, *Diheteropogon hagerupii*, *Eragrostis tremula*, *Mucuna pruriens* leaves, Marula oil cake, *Afzelia quanzensis* legume pods, *Brassica oleraceae var. acephala* leaves, maize stover, leaves and stalks, millet stover, wheat straw, *Eragrostis curvula*, Kikuyu grass, *Schizachyrium exile*, veld grass hay, cowpea husks, cassava root peels, groundnut haulms, *Eragrostis tremula*,

sorghum stover, leaves and sheath, and stems, millet bran, wheat bran, and cottonseed cake. The effective degradability of these forages was calculated using the model of McDonald [47].

4.1.2. Statistical analyses

For all evaluations, regression analyses of observed against predicted degradability were carried out using the linear regression procedure. Coefficients of determination (R^2) were used to evaluate the precision of regression lines in approximating real data points of models and standard error of the mean (SEM) was used to determine the accuracy of prediction.

4.2. Results

4.2.1. Model development

From the step-wise regression procedure for all prediction models, level of concentrate supplementation, provision of a urea supplement in the form of a lick and urea treatment of feed sample were rejected in model development.

The regression model for predicting the soluble fraction (a) was a = 558.12(±62.45) + 0.27 (±0.133) CP–0.57(±0.07) NDF (n = 113, SEM = 6.86), accounting for 59% of the variation in development.

The regression model for predicting the potential degradability (PD) was PD = 1025.96(±66.64) –0.91(±0.10) ADF + 0.32(±0.08) STA (n = 113, SEM = 9.27), accounting for 65% of the variation in development.

The regression model for predicting the time-lag (tL) was tL = −11.33(±1.89) + 0.030(±0.002) ADF + 0.01(±0.003) CP–0.006(±0.001) STA + 0.02(±0.007) ASH (n = 113, SEM = 0.17), accounting for 77% of the variation in development.

The regression model for predicting the rate of degradation (c) was c = 0.12(±0.05) + 0.00013 (±0.00002) CP–0.00012(±0.00006) STA–0.00002(±0.00001) NDF–0.00008(±0.00005) DNDF (n = 113, SEM = 0.0009), accounting for 55% of the variation in development.

4.2.2. Model predictions

The regression model for predicting the soluble fraction of feeds accounted for 70% of the variation in prediction for forage legumes, trees and shrubs, forage grasses and concentrates (**Figure 1**).

The regression model for predicting the potential degradability accounted for 24% of the variation in prediction for forage legumes, trees and shrubs, forage grasses and concentrates (**Figure 2**).

The regression model for predicting the slowly degradable fraction of feeds for forage legumes, trees and shrubs, forage grasses and concentrates (**Figure 3**).

The regression model for predicting the rate of degradation accounted for 4% of the variation in prediction for forage legumes, trees and shrubs, forage grasses and concentrates (**Figure 4**).
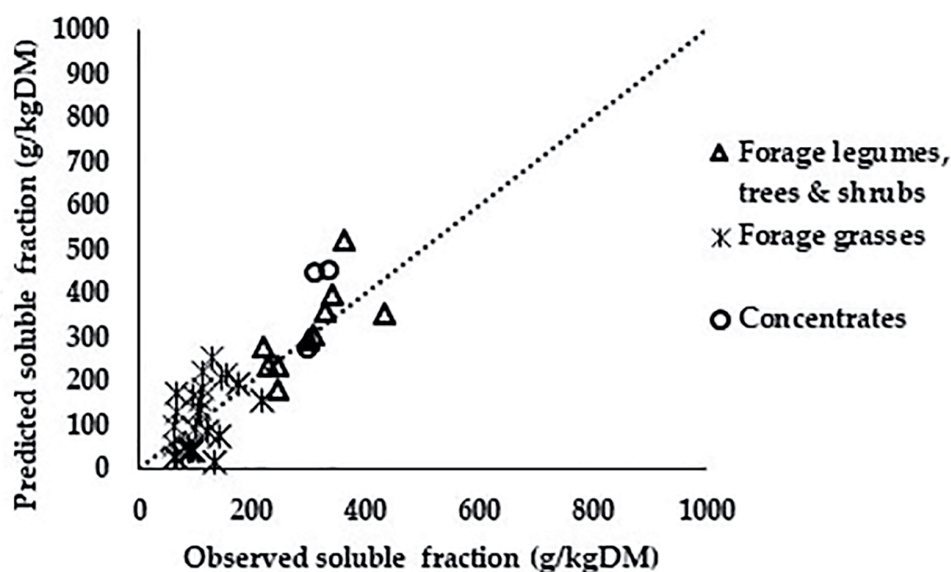
Figure 1. Relationship between observed and predicted degradability of soluble fraction.
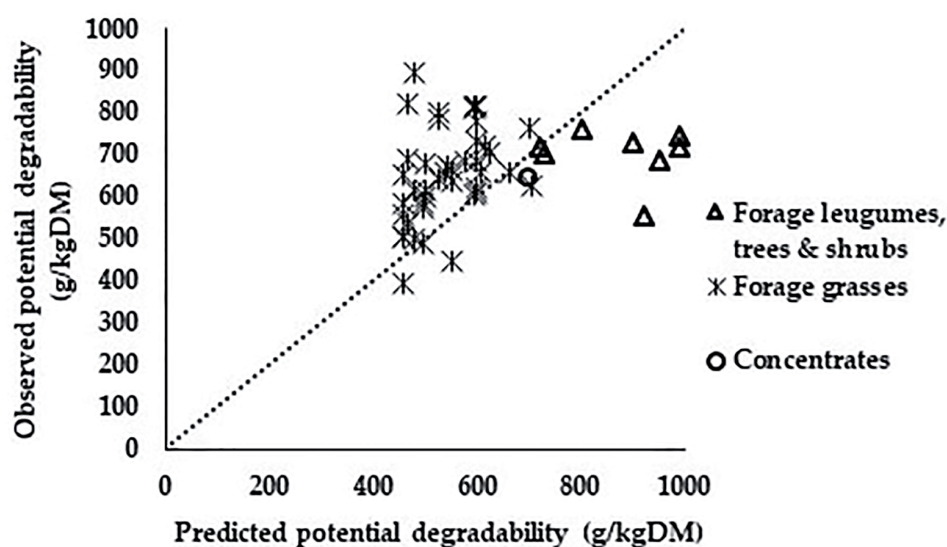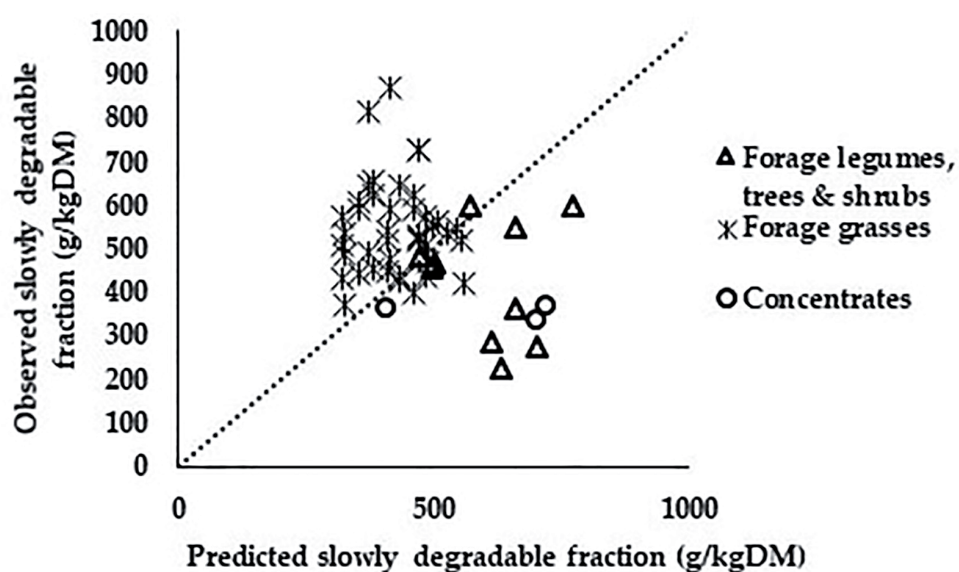

Figure 2. Relationship between observed and predicted potential degradability.

The regression model for predicting the effective degradability of feeds accounted for 57% of the variation in prediction for forage legumes, trees and shrubs, forage grasses and concentrates (**Figure 5**).

4.3. Discussion

Among the forage legumes, trees and shrubs, *Brassica oleracea var. acephala* leaves had a superior crude protein content and the lowest neutral and acid detergent fibre contents. The CP content of *Brassica oleracea var. acephala* is slightly higher than those reported by McDonald et al. [21] and Barry et al. [22]. The rate of degradation of *Colophospermum mopane* pods was similar to that of *Brassica oleracea var. acephala*. High levels of degradability of these feeds were partly due to

Figure 3. Relationship between observed and predicted degradability of slowly degradable fraction.
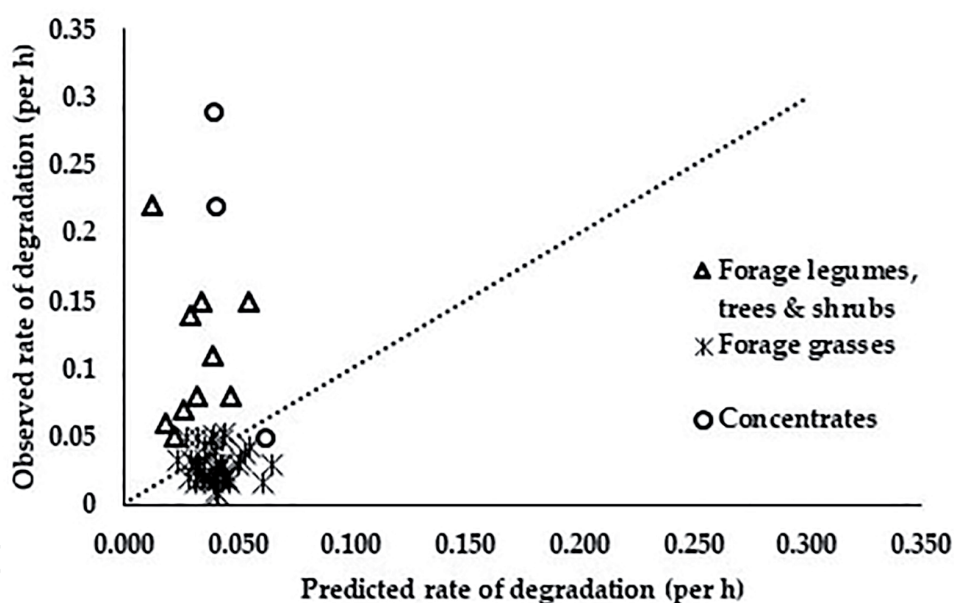

Figure 4. Relationship between observed and predicted rates of degradation .

high levels of crude protein, which could help in the proliferation of microbial populations in the rumen, increasing ED and rate of degradation of these forages. Faster rates of degradation may suggest faster rates of passage of these feeds in the rumen, which could increase microbial protein supply for host animals in the hindgut, improving animal's nutritional status. The CP level in *Colophospermum mopane* leaves was comparable to results of Halimani et al. [14], while NDF contents tended to be comparably higher than those reported by other authors [14, 17].

Compared to concentrates used in the study, *Brassica oleracea var. acephala* leaves tended to have superior crude protein levels than the 'brans' and cotton seed cake. Despite this trend,

the brans tended to have faster degradation rates than cotton seed cake and *Brassica oleracea var. acephala* leaves. *Colophospermum mopane* leaves and pods had comparable CP and NDF levels compared to maize and wheat brans, suggesting that *Brassica oleracea var. acephala* and, *Colophospermum mopane* can be used as good sources of supplementary protein to ruminants.

Relationships between two variables are said to be ideal when the coefficient of determination (R^2) is in unity; any deviation from the unity degree indicates the degree of imperfection. The above parameters were used to determine the effective degradability (ED): (ED = a + (PD−a) × c/ (c + kp); where 'a' is a soluble fraction, PD is the potential degradability, 'c' is the rate of degradation and kp is the rate of passage of particles through the rumen. Effective degradability is equivalent to digestibility in the rumen. The predicted effective degradability indicated in **Figure 5** followed the expected trends, suggesting that these models (for predicting 'a', PD, and 'c') in the meantime can be used for this purpose. The overall trend between the observed and the predicted digestibility is positive, though accounting for just 36–52% of the total variation [49], which does not compare favourably with R^2 of 70% obtained with the application of the simulation model to temperate roughages [43] and those from this study. The amount of variation accounted for in observed against predicted digestibility for simulations by Nsahlai and Apaloo [49, 50] was comparably higher than those reported in empirical studies by Shem et al. [10], Kibon and Orskov [51] and Umunna et al. [52].

The rather low precision in predicting the rate of degradation (mainly for concentrates, legume forages, trees and shrubs) and the potential degradability (concentrates) of feeds in this study may have been due to the fact that the studies that were used in model development reported data on degradation of roughages grasses only, which are generally of low quality, and did not use data on concentrates, legume forages, trees and shrubs. Despite this, simulations of solubility and effective degradability were good, suggesting that slight modification of model parameters may give better prediction of all degradability (nutritive value) of a large number and classes of forage crops. Generally, there is a poor simulation of
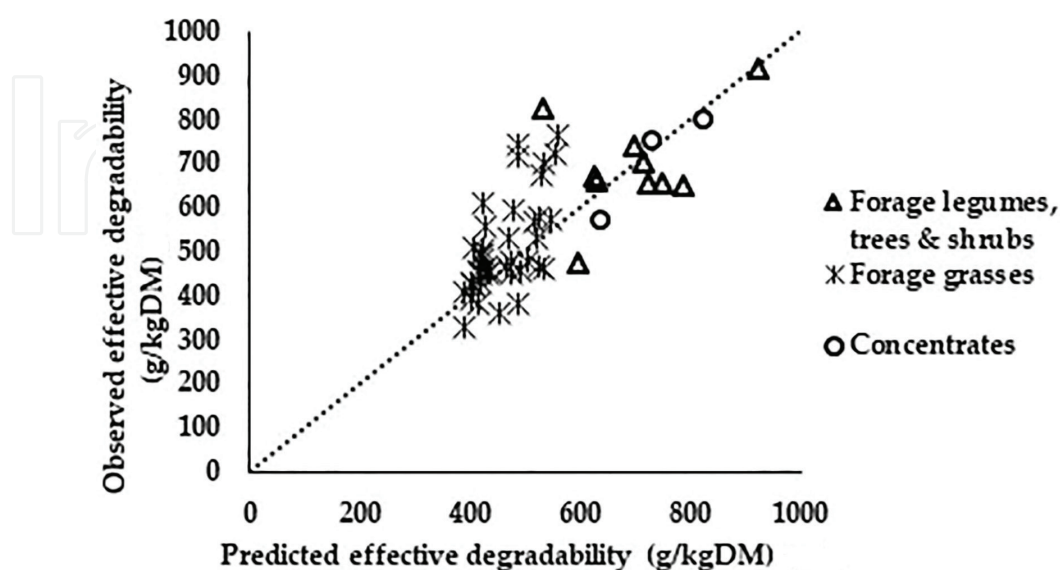

Figure 5. Relationship between observed and predicted effective degradability.

digestibility for low quality roughages, which are commonly grazed and fed to ruminants in the tropics. Ambient temperature grossly affects the digestibility of plant material through its influence on lignin deposition in plants. Studies should focus on development of digestibility models that account for variability in diet quality as brought about by ambient temperature. Future studies may need to account for the type of model used in computation of degradation parameters.

5. Conclusions

The nutritive value of underutilised forages, *Brassica oleracea var. acephala* and, *N̈* leaf meal and pods was good with high levels of crude protein and potential degradability in the rumen, suggesting their potential use as ruminant feeds during the dry season. Predicted solubility and effective degradability lay near the ideal prediction line, giving good predictions for these parameters. However, some adjustments in the inputs for prediction of potential degradability and rate of degradation are needed to improve predictions.

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Conflict of interest and declaration

The authors declare that they have no competing interests. We affirm that all the authors of this manuscript agree to the submission, and the manuscript has not been submitted to be published in or considered for publication anywhere else. The views expressed in the paper are those of the authors and not of the National Research Foundation (NRF) of the Republic of South Africa.

Author details

Mehluli Moyo, Siyabonga T. Bhiya, Masande Katamzi and Ignatius V. Nsahlai*

*Address all correspondence to: nsahlaii@ukzn.ac.za

Animal and Poultry Science, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa

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