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

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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 lit-
erature 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 informa-
tion 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 con-
stituted 66–68% of total stomach contents of Giraffe in a low-altitude sub-tropical lowveld/bush-
veld 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 $\alpha$-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 LEKO 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*,

### Table 2. Chemical composition of incubated feeds (g/kg DM)

| Forage legumes, trees and shrubs | Chemical composition of incubated feeds (g/kg DM) |
|----------------------------------|-------------------------------------------------|
| CPH                             | DM 944 OM 935 CP 85 NDF 617 ADF 428 ADL 102 HEM 189 CEL 328 |
| UTCPH                           | DM 627 OM 928 CP 141 NDF 615 ADF 422 ADL 105 HEM 193 CEL 312 |
| GNH                             | DM 932 OM 889 CP 109 NDF 495 ADF 386 ADL 116 HEM 110 CEL 265 |
| CMLB                            | DM 906 OM 941 CP 132 NDF 407 ADF 199 ADL - HEM 208 CEL - |
| CMLG                            | DM 918 OM 931 CP 144 NDF 470 ADF 175 ADL - HEM 295 CEL - |
| CMP                             | DM 916 OM 946 CP 195 NDF 477 ADF 197 ADL - HEM 280 CEL - |
| MPL                             | DM 917 OM 942 CP 118 NDF 607 ADF 233 ADL - HEM 374 CEL - |
| CRP                             | DM 896 OM 953 CP 78 NDF 489 ADF 98 ADL - HEM 391 CEL - |
| AQLP                            | DM 956 OM 978 CP 70 NDF 628 ADF 220 ADL - HEM 408 CEL - |
| BOAL                            | DM 908 OM 746 CP 305 NDF 363 ADF 137 ADL - HEM 226 CEL - |
| Forage grasses                  |                                                 |
| MS                              | DM 930 OM 828 CP 96 NDF 718 ADF 614 ADL 118 HEM 104 CEL 496 |
| ML                              | DM 925 OM 660 CP 102 NDF 645 ADF 559 ADL 100 HEM 86 CEL 459 |
| WS                              | DM 878 OM 800 CP 42 NDF 764 ADF 691 ADL 175 HEM 73 CEL 516 |
| EC                              | DM 931 OM 836 CP 107 NDF 815 ADF 503 ADL 130 HEM 312 CEL 373 |
| ECB                             | DM 925 OM 890 CP 128 NDF 874 ADF 615 ADL 171 HEM 259 CEL 444 |
| KG                              | DM 919 OM 833 CP 99 NDF 778 ADF 666 ADL 189 HEM 112 CEL 477 |
| VGHp1                           | DM 932 OM 887 CP 41 NDF 885 ADF 629 ADL 159 HEM 256 CEL 470 |
| VGHp2                           | DM 936 OM 882 CP 37 NDF 876 ADF 609 ADL 142 HEM 267 CEL 454 |
| DH                              | DM 970 OM 959 CP 20 NDF 880 ADF 565 ADL 78 HEM 316 CEL 485 |
| UTDH                            | DM 617 OM 968 CP 36 NDF 876 ADF 566 ADL 88 HEM 310 CEL 476 |
| ET                              | DM 969 OM 976 CP 21 NDF 796 ADF 465 ADL 67 HEM 330 CEL 397 |
| UTET                            | DM 613 OM 971 CP 47 NDF 829 ADF 485 ADL 72 HEM 344 CEL 414 |
| SE                              | DM 949 OM 954 CP 22 NDF 813 ADF 518 ADL 49 HEM 295 CEL 447 |
| UTSE                            | DM 626 OM 956 CP 49 NDF 812 ADF 541 ADL 90 HEM 270 CEL 450 |
| MIS                             | DM 954 OM 913 CP 39 NDF 816 ADF 518 ADL 130 HEM 298 CEL 394 |
| UTMIS                           | DM 619 OM 911 CP 46 NDF 799 ADF 523 ADL 118 HEM 276 CEL 406 |
| SS (whole)                      | DM 964 OM 845 CP 23 NDF 791 ADF 535 ADL 198 HEM 257 CEL 296 |
| UTSS (whole)                    | DM 624 OM 843 CP 45 NDF 773 ADF 514 ADL 189 HEM 259 CEL 331 |
| SSS                             | DM 973 OM 809 CP 40 NDF 725 ADF 440 ADL 145 HEM 285 CEL 289 |
| SSS                             | DM 962 OM 906 CP 22 NDF 731 ADF 438 ADL 100 HEM 293 CEL 332 |
| Concentrates                    |                                                 |
| MB                              | DM 919 OM 897 CP 146 NDF 513 ADF 122 ADL 63 HEM 391 CEL 61 |
| WB                              | DM 953 OM 951 CP 163 NDF 477 ADF 125 ADL 35 HEM 352 CEL 86 |
| CSC                             | DM 980 OM 948 CP 222 NDF 570 ADF 437 ADL 101 HEM 133 CEL 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*

### 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.

| 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 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.

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

| 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  |
| 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, VGHP₁: veld grass hay Pietermaritzburg area 1, VGHP₂: 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, UTMS: 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).
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...
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): $ED = a + (PD-a) \times c / (c + kp)$; 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.](image-url)
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, *N* 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.

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