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NUTRIENT COMPOSITION OF SELECTED BROWSES CONSUMED BY BLACK RHINOCEROS (*DICEROS BICORNIS*) IN THE ZAMBEZI VALLEY, ZIMBABWE

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Abstract. Moisture, crude and bound protein, cell wall constituents (neutral and acid detergent fiber [NDF and ADF], lignin [Lig]), vitamin E, total ash, macrominerals, and selected trace elements were analyzed in 26 browse species eaten by black rhinoceros (*Diceros bicornis*) in the Zambezi Valley, Zimbabwe. Leaves contained higher levels of water, protein, and ash than did stem fractions of the same plant and lower levels of all cell wall constituents. Browses consumed by black rhinoceros comprised on a dry matter (DM) basis 4–20% available protein, 34–72% NDF, 21–53% ADF, 7–21% Lig, and 3–12% ash. Lig:NDF was 14–32%; Lig:ADF was 18–47%; differences in lignification index between leaves and twigs were not significant. Vitamin E concentrations ranged from 9.6 to 286.7 IU/kg DM and were higher in leaves than in twigs of the same species. Mineral concentrations (DM basis) varied widely: Ca (0.55–4.27%), K (0.28–1.77%), and Mg (0.12–0.65%) appeared present in relative excess, but Na (0.001–0.094%), P (0.06–0.19%), and Zn (2.5–67.4 μg/g DM) were marginal to low compared with known dietary requirements for domestic herbivores. Cu (3.0–12.2 μg/g DM), Fe (29.0–215.0 μg/g DM), and Mn (10.8–269.0 μg/g DM) levels encompassed ranges known to adequately support livestock and wildlife. Although specific nutrient requirements of rhinoceros are currently unknown, chemical analyses from field samples may provide useful guidelines for dietary management of this species.

Key words: Browse, fiber, minerals, nutrition, black rhinoceros, *Diceros bicornis*, vitamin E.

INTRODUCTION

Studies of dietary habits of free-ranging black rhinoceros (*Diceros bicornis*) indicate that these animals consume woody and or succulent plants (trees, herbs, and shrubs) in preference to grasses regardless of season.[5,12,13,15,17,18,20,24] Browsing is a distinct contrast to documented feeding patterns of the grazing white (*Ceratotherium simum*) or Indian (*Rhinoceros unicornis*) rhinoceros, and chemical constituents of foods may impose differing digestive strategies and or physiologies among rhinoceros species.[21]

Earlier reports have summarized the proximate composition of a limited number of rhinoceros browse or fecal samples from southern Africa[13,17,18,22] or East Africa;[10,24] however, this is the first detailed study from Zimbabwe. Additionally, we document and discuss nutrient levels not previously published for forages consumed by these animals. Such baseline investigations can provide insight into animal digestive physiology as well as habitat assessment and may be useful in the development of optimal diets for managed populations of black rhinoceros.

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MATERIALS AND METHODS

Plants samples

African browse specimens were collected in September 1989 in the Zambezi Valley (16°00'S, 29°30'E), Zimbabwe. Prior to recent poaching, the area of sample collection supported some of the highest densities of black rhinoceros in Zimbabwe (up to 0.3 animals/km²); this area contains a diversity of herbaceous and woody browse species growing on a fertile mix of colluvial and alluvial soils along the southern Zambezi escarpment. The time of the study coincided with the early spring flush and flowering period in the late dry season, prior to the November–March rainy season. During this period, body condition of Zimbabwean black rhinoceros begins to improve following the nutritional constraints inherent in the predominantly deciduous plant communities during the dry season.

The ends of branches that have been browsed by black rhinoceros show a characteristic neatly pruned appearance, in contrast to the shredded appearance of branches that have been utilized by elephants. This distinctive rhinoceros browsing, combined with observations of the diet selection of rhinoceros that had been penned in this area during capture operations, enabled a range of preferred browse species to be identified. A black rhinoceros uses its prehensile upper lip to pull a branch into its mouth, cuts off the branch (generally about 1.0 cm in diameter) with its teeth, and then steadily chews it from the proximal end with a sideways grinding action, which moves the branch laterally into the mouth until the tips are consumed. The selection of samples in the Zambezi Valley attempted to approximate a black rhinoceros's diet selection; typical bite-sized portions were cut off a range of preferred species (26 species from 15 families) along rhinoceros trails, and subsamples were taken from the leaf and stem portions of each browse sample. The identity of plant specimens was confirmed at the National Herbarium, Harare, and nomenclature follows the national plant species list maintained by the Herbarium.[3]

Ten to 50 g of fresh material was selected from a minimum of five plants per species, placed in plastic bags, and stored at < 10°C until processing within 6 hr. Leaf:twig (L:T) ratios were determined in woody browses by weighing separated fractions of the entire sample; herbaceous species or fruits were not separated into distinct fractions prior to analysis. Vitamin extractions were conducted immediately upon subsamples of fresh tissues, and remaining samples were weighed and air dried until further laboratory processing.

Chemical analyses

Water content was determined by oven drying to a constant weight at 60°C. The plant samples were then ground in a Wiley mill through a 2-mm screen and analyzed according to AOAC methods.[16] Crude protein (CP) values were determined as total nitrogen × 6.25 using a macro-Kjeldahl method with a copper catalyst; acid detergent–nitrogen × 6.25 (AD-CP) was evaluated as a measure of unavailable protein.[14] Neutral detergent fiber (NDF), acid detergent fiber (ADF), and sulfuric acid lignin (Lig) values were quantified using the methods of Goering and Van Soest, with no pretreatments or enzymes.[11] Total ash content was obtained by heating samples (0.5 g) to 550°C overnight in a muffle furnace. Where appropriate, leaves were analyzed separately from twig fractions; chemical composition of browses as consumed was determined by recalculating based on quantified L:T ratios (dry matter [DM] basis).

Dry samples were recombined in appropriate L:T ratios and mineral content was determined by inductively coupled argon plasma emission spectroscopy using a modification of methods previously described.[29] Triplicate samples of plant material (0.5 g) were weighed into 30-ml screw-cap teflon vials (Savillex Corp., Minnetonka, Minnesota 55343, USA) and mixed with 5 ml concentrated HNO_3. The caps were tightened firmly, and the samples digested overnight at 95–100°C. The digests were quantitatively transferred to 25-ml volumetric flasks, mixed with 2.5 ml of yttrium (100 ppm), and diluted to volume. A 0.5-g sample of NIST SRM 1572 citrus leaves (National Institute of Standards and Technology, Gaithersburg, Maryland 20879, USA) was prepared as above for assurance of accuracy of the mineral values. Elements were analyzed on a Jarrell-Ash 955 Atomcomp ICP-AES spectrometer using wavelengths and operating parameters previously described.[29]

Vitamin E

Extraction of lipid-soluble components was conducted in duplicate or triplicate under field laboratory conditions, using modified procedures.[1] Half-gram subsamples of

Table 1. Chemical composition of browses consumed by black rhinoceros (*Diceros bicornis*) in the Zambezi Valley, Zimbabwe.

Plant species	Plant part or ratio[a]	Water (%)	Dry matter (%)[b]					
			CP	AD-CP	NDF	ADF	Lig	Ash
Acanthaceae								
Dicliptera crenata (Lindau) P. G. Meyer	L, T	40.0	13.6	1.1	47.2	29.4	6.7	15.5
Annonaceae								
Friesodielsia obovata (Benth.) Verdc.	L, T	42.9	13.5	2.3	53.4	30.8	10.6	6.1
Apocynaceae								
Diplorhynchus condylocarpon (Muell. Arg.) Pichon	I	46.5	8.8	1.7	41.2	27.6	11.4	5.7
	T	43.1	6.5	1.5	58.3	42.3	13.4	4.7
	57:43	45.0	7.8	1.6	48.6	33.9	12.3	5.2
Balanitaceae								
Balanites maughamii Sprague	L, T	68.1	21.8	1.9	64.5	40.4	13.9	7.4
Bignoniaceae								
Kigelia africana (Lam.) Benth.	FR	89.5	14.8	5.8	40.0	28.3	10.0	8.0
Markhamia zanzibarica (D.C.) K. Schum.	L	39.2	16.3	2.0	38.2	19.3	7.5	10.8
	T	46.0	9.0	1.8	66.9	51.1	18.3	4.8
	42:58	43.1	12.0	1.9	54.8	37.7	13.8	7.3
Capparaceae								
Boscia mossambicensis Klotzsch	L	41.1	18.4	1.3	48.9	40.0	9.5	9.3
	T	38.8	14.6	3.6	71.9	45.4	18.5	5.6
	56:44	40.1	16.7	2.3	59.0	42.4	13.4	7.7
Combretaceae								
Combretum apiculatum Sond.	L	42.3	9.3	1.3	36.1	22.5	5.0	6.3
	T	29.5	6.9	1.1	72.0	49.5	12.4	4.0
	49:51	35.8	7.9	1.2	56.2	37.6	9.1	5.0
C. elaeagnoides Klotzsch	L	21.8	17.3	2.4	40.1	25.1	11.2	5.6
	T	33.4	7.4	1.6	75.2	58.4	18.1	2.6
	48:52	27.8	12.5	2.0	56.9	41.1	14.5	4.1
C. mossambicense (Klotzsch) Engl.	L	51.5	19.6	1.3	32.0	21.4	4.7	12.3
	T	44.3	12.7	2.4	72.1	54.2	16.8	5.9
	FL	71.6	12.5	1.4	54.9	35.1	10.2	9.5
	41:43:16	51.6	15.5	1.9	52.9	37.7	10.7	9.0
Ebenaceae								
Diospyros quiloensis (Hiern) F. White	I	32.7	19.0	1.2	30.1	14.4	7.4	3.8
	T	29.1	10.8	2.6	78.3	58.1	23.0	2.7
	30:70	30.2	13.1	2.2	64.4	45.4	18.5	3.0
D. senensis (Klotzsch)	L	46.5	11.4	2.0	59.1	40.5	14.0	7.8
	T	33.2	10.9	2.3	64.2	45.3	16.1	7.7
	28:72	36.9	11.0	2.2	63.0	44.2	15.6	7.7
Euphorbiaceae								
Euphorbia cooperi A. Berger	L, T	81.1	9.7	2.6	41.3	34.5	6.3	6.7
Flueggea virosa (Willd.) Voigt	L	62.5	38.4	ND	ND	ND	ND	10.0
	T	56.8	10.8	1.6	69.6	52.7	14.3	5.7
	19:81	57.9						
Leguminosae								
Caesalpinioideae								
Bauhinia tomentosa (L.)	L	37.2	22.1	2.3	32.6	14.4	6.7	10.8

Table 1. Continued

Plant species	Plant part or ratio[a]	Water (%)	Dry matter (%)[b]					
			CP	AD-CP	NDF	ADF	Lig	Ash
	I	33.9	9.9	1.4	70.0	47.2	13.9	3.8
	33:67	35.0	13.7	1.7	58.4	37.0	11.7	6.0
Colophospermum mopane (Benth.) J. Leonard	I	43.1	11.6	1.7	34.3	21.2	8.6	5.8
Papilionoidae								
Dalbergia melanoxylon Guill. & Perr.	L	40.6	17.9	2.2	47.1	23.6	9.1	8.8
	T	34.1	3.5	2.0	76.9	52.6	17.8	3.6
	19:81	35.3	6.1	2.0	71.5	47.4	16.3	4.6
Lonchocarpus capassa Rolfe	I	73.5	21.4	4.1	63.7	43.9	21.6	8.3
	SH	37.2	12.1	1.7	67.4	49.4	15.9	4.7
	69:31	62.2	18.4	3.7	64.3	44.6	20.8	7.8
Pterocarpus brenanii Barbosa & Torre	L	34.2	13.4	1.8	33.9	21.0	7.1	14.2
	I	37.0	7.9	1.8	72.8	55.3	19.2	7.1
	60:40	35.3	9.6	1.8	60.7	44.6	15.5	11.4
Olacaceae								
Ximinia americana L.	L, SH	43.7	7.9	2.4	51.5	37.5	15.7	5.7
Rhamnaceae								
Ziziphus abyssinica A. Rich.	I	50.9	14.2	1.9	36.3	21.4	9.9	9.3
	T	37.9	6.6	2.0	68.0	52.5	18.0	6.3
	40:60	43.1	9.2	2.0	57.2	41.9	15.3	7.3
Rubiaceae								
Canthium frangula S. Moore	I	37.5	11.3	1.5	21.7	18.5	9.6	14.8
	I	38.6	8.0	1.8	75.1	59.8	19.9	3.5
	17:83	38.4	8.6	1.8	66.0	52.8	18.1	5.4
Gardenia resiniflua Hiern	I	30.7	9.2	1.4	32.4	20.2	5.3	8.0
	I	28.2	7.5	1.5	71.7	50.7	17.4	5.6
	3:97	28.3	7.5	1.5	70.5	49.8	17.1	5.6
Tiliaceae								
Grewia bicolor Juss.	I	39.0	18.1	2.0	52.5	24.1	9.4	13.3
	T	37.3	10.5	2.3	69.1	49.9	15.0	10.8
	54:46	38.2	14.7	2.2	61.6	38.3	10.6	11.9
G. flavescens Juss.	I	35.0	14.7	2.2	41.1	23.9	10.0	9.2
	I	30.1	7.4	1.4	75.0	54.1	18.3	3.5
	17:83	30.9	8.5	1.6	69.1	49.6	17.0	4.4
Verbenaceae								
Karomia tettensis (Klotzsch) R. Fernandes	I	46.5	14.3	1.3	34.9	20.4	6.6	8.2
	I	43.1	10.0	1.8	75.3	55.8	23.1	3.5
	19:81	43.7	10.8	1.7	68.0	49.5	20.1	4.4
L, T paired comparisons		•	•••	ns	•••	•••	•••	•••

[a] L = leaf, T = twig, FR = fruit, FL = flower, SH = shoot, ratio = proportion of whole plant sample as consumed by black rhinoceros.

[b] CP = crude protein, AD-CP = acid detergent CP (bound protein), NDF = neutral detergent fiber, ADF = acid detergent fiber, Lig = sulfuric acid lignin, ND = not determined.

[c] *P* levels: • = < 0.05, ••• = < 0.001.

coarsely macerated plant tissue were mixed with 20 mg sodium ascorbate and 5 ml distilled water and homogenized. Solutions were transferred to 15-ml capped polystyrene tubes; 2 ml of 0.1 M sodium dodecylsulfate, 5 ml of ethanol (EtOH), and 3 ml of hexane were added to each tube and mixed by inversion. Following separation by grav-

Table 2. α-, γ-, and δ-tocopherols and vitamin E concentrations in browses consumed by black rhinoceros (*Diceros bicornis*) in the Zambezi Valley, Zimbabwe.

Plant species	Plant part or ratio[a]	Tocopherols (μg/g DM) α	γ	δ	Calculated vitamin E activity (IU/kg DM)[b]
Diospyros virgatum (Acanthaceae)	L, T	10.85	1.30		16.30
Fresodielsia elevata (Annonaceae)	L, T	158.60	6.94		237.00
Diplorhynchus condylocarpon (Apocynaceae)	L	71.96	1.99		
	T	11.95	1.09		
	57:43	46.14	1.60		68.91
Balanites maughamii (Balanitaceae)	L, T	7.34	7.96	2.96	11.79
Kigelia africana (Bignoniaceae)	FR	12.19	1.71		18.31
Markhamia zanzibarica (Bignoniaceae)	L	94.06	0.99		
	T	13.48	1.71		
	42:58	50.55	6.59	1.65	76.01
Boscia mossambicensis (Capparaceae)	L	29.44	1.49		
	T	13.94	0.38		
	56:44	22.63	1.00		33.82
Combretum apiculatum (Combretaceae)	L	214.14	10.17		
	T	7.76	0.35		
	49:51	98.55	4.67		147.31
C. elaeagnoides (Combretaceae)	L	83.30	17.08		
	T	6.11	0.18		
	48:52	46.23	8.97		69.78
C. mossambicense (Combretaceae)	L	289.28		19.34	
	T	26.61	0.93		
	FL	7.43	4.58		
	41:43:16	144.82	0.51	8.70	216.01
Diospyros quiloensis (Ebenaceae)	L	17.98	0.92		
	T	6.39	0.72		
	30:70	9.75	0.78		14.61
D. senensis (Ebenaceae)	L	129.20	14.86		
	T	16.74	0.66		
	28:72	42.59	3.93		63.85
Euphorbia cooperi (Euphorbiaceae)	L, T	23.33	1.48	0.16	34.91
Flueggea virosa (Euphorbiaceae)	L	57.33	3.84		
	T	4.79	3.63		
	19:81	13.73	3.67		20.82
Bauhinia tomentosa (Leguminosae)	L	178.92	56.69		
	T	4.90			
	33:67	58.88	17.57		89.49
Colophospermum mopane (Leguminosae)	L	100.14	8.92		150.10
Dalbergia melanoxylon (Leguminosae)	L	61.57	2.98		
	T	20.04	0.49		
	19:81	27.53	0.94		41.11
Lonchocarpus capassa (Leguminosae)	L	13.24	1.85		
	SH				
	69:31	14.53	1.59		21.81
Pterocarpus brenanii (Leguminosae)	L	44.79	1.19		
	T	4.38	0.19		
	60:40	29.01	0.80		43.30
Ximnia americana L. (Olacaceae)	L, SH	26.63	1.08		39.79
Ziziphus abyssinica (Rhamnaceae)	L	26.74	0.90	0.20	
	T	6.28			
	40:60	13.24	0.31	0.13	19.76
Canthium frangula (Rubiaceae)	L	42.03	2.42	0.18	

Table 2. Continued

Plant species	Plant part or ratio[a]	Tocopherols (μg/g DM) α	γ	δ	Calculated vitamin E activity (IU/kg DM)[b]
	L	11.99	1.14	0.24	
	17:83	17.10	1.36	0.23	25.62
Gardenia resiniflua (Rubiaceae)	L	17.52	1.41		
	T	6.02	0.60		
	3:97	6.37	0.62		9.55
Grewia bicolor (Tiliaceae)	L	341.61	15.02		
	T	7.33	1.41		
	54:46	191.84	8.90		286.73
G. flavescens (Tiliaceae)	L	63.03	2.58	0.20	
	T	19.37	0.84	0.21	
	17:83	25.91	1.10	0.19	38.72
Karomia lettensis (Verbenaceae)	L	100.15	5.19		
	T	2.65			
	19:81	20.17	0.93		30.15

[a] L = leaf, T = twig, FR = fruit, FL = flower, SH = shoot, ratio = proportion of whole plant sample as consumed by black rhinoceros.

[b] Vitamin E activity calculated as [(α-tocopherol × 1.49) + (γ-tocopherol × 0.1) + (δ-tocopherol × 0.015)].

ity, 1 ml of the hexane layer was collected and evaporated to dryness under N_2. Aliquots were reconstituted with 1 ml EtOH containing 0.2% butylated hydroxytoluene, sealed, and stored at −0°C until laboratory analysis via high-performance liquid chromatography (HPLC).

α-, γ-, and δ-tocopherol concentrations were monitored by fluorescence detection with the excitation wavelength set at 280 nm and emission at 310 nm using a Series 400 system (Perkin-Elmer, Norwalk, Connecticut 06856, USA). HPLC-grade methanol and water in a 98:2 (vol/vol) mixture was used as the mobile phase; flow rate was 2.0 ml/min, and a 15-cm C18 reversed-phase column was used for separation. Vitamin E activity was calculated by summing assay values (1 mg RRR α-tocopherol = 1.49 IU; 1 mg γ-tocopherol = 0.1 IU; 1 mg δ-tocopherol = 0.015 IU).[8]

Paired comparisons of nutrient concentrations in leaf versus twig fractions were performed using the SYSTAT computer software package.[11]

RESULTS

Leaves contained higher levels of water, CP, and ash than did twig fractions of the same plants ($n = 19$), as well as lower levels of all cell wall constituents ($n = 18$) (Table 1). Percent bound protein (AD-CP; range, 1.1–4.1%) did not differ between leaves and twigs. Lignification (Lig NDF) of cell walls averaged 23.6% ± 5.0% ($n = 25$); differences in percent lignification between leaves (range, 14–44%) and twigs (range, 17–32%) were not significant ($n = 18$; $P = 0.45$). Lig/ADF was 22–52% in leaves ($n = 26$) and 25–41% in twigs ($n = 19$); differences in percent lignification between leaves and twigs were not significant ($P = 0.10$) in paired ($n = 24$) comparison.

For vitamin E concentrations in browse samples, (Table 2), leaves contained more α- and γ-tocopherol than did twig fractions of the same plant ($P < 0.001$, $n = 20$; $P < 0.003$, $n = 15$, respectively). Coefficients of variation among replicates were 22% for α-tocopherol, 20% for γ-tocopherol, and 10% for δ-tocopherol. Mineral levels of browses as consumed are displayed in Table 3.

DISCUSSION

In view of the considerable diversity of plants eaten by black rhinoceros, combined with the structural and chemical variation in different parts of the same plants and

Table 3. Macromineral and trace element concentrations in browse species consumed by black rhinoceros (*Diceros bicornis*) in the Zambezi Valley, Zimbabwe.

Plant species	Macrominerals (% DM)					Trace elements (μg/g DM)			
	Ca	K	Mg	Na	P	Cu	Fe	Mn	Zn
Balanites maughamii	0.77	1.77	0.40	0.026	0.18	3.5	150	17.7	10.8
Boscia mossambicensis	0.55	1.57	0.26	0.002	0.10	4.6	104	19.1	10.6
Combretum apiculatum	1.46	0.65	0.29	0.003	0.06	6.7	41	52.6	17.2
C. elaeagnoides	1.06	0.73	0.24	0.003	0.13	4.9	97	26.9	20.0
C. mossambicense	1.99	1.39	0.26	0.006	0.12	5.9	95	107	14.9
Colospermum mopane	1.89	0.98	0.15	0.002	0.08	3.8	71	52.1	67.4
Dalbergia melanoxylon	1.51	0.28	0.27	0.044	0.10	3.0	155	12.5	3.7
Diplorhynchus condylocarpon	1.26	0.52	0.48	0.009	0.20	3.8	45	60.8	14.0
Diospyros quiloensis	0.79	0.58	0.12	0.003	0.08	10.2	89	151	21.0
D. senensis	3.10	0.55	0.15	0.006	0.09	5.5	164	87.5	18.4
Friesodielsia obovata	1.94	0.47	0.12	0.009	0.14	7.0	129	54.6	14.5
Gardenia resiniflua	1.85	0.80	0.14	0.001	0.07	6.6	29	10.8	5.7
Grewia bicolor	4.02	1.00	0.29	0.006	0.18	12.2	165	84.0	20.8
Lonchocarpus capassa	0.74	1.19	0.16	0.003	0.15	8.9	107	79.1	25.2
Markhamia zanzibarica	1.64	0.78	0.65	0.005	0.14	11.0	215	160	17.3
Pterocarpus brenanii	4.27	0.54	0.52	0.002	0.12	4.5	124	31.7	2.5
Ximinia americana	1.07	1.36	0.18	0.094	0.19	5.5	164	87.5	18.4
Ziziphus abyssinica	2.89	0.43	0.20	0.021	0.13	9.2	97	91.8	19.9

phenologic changes in nutrient values, there are several practical constraints to any plant sampling procedure that attempts to precisely replicate a black rhinoceros's natural diet. Thus, in this study, the sampling procedure was intended merely to be a reasonable indication of the nutrient composition of components in the black rhinoceros diet during one time of year in one African area where the megaherbivore is indigenous.

Crude protein levels (6–22% of DM) in browses measured in our study were quite comparable to values reported from other studies (4–18%). Higher average (n = 7 species) CP values (up to 11%) have been documented in browses collected during spring than during other seasons.[15,17] Average CP levels of 8.5% (n = 11 species) were reported for rhinoceros browses sampled during the dry season in Namibia,[20] whereas values reported at the end of the rainy season in Kenya averaged 6.2% (n = 10 species).[10] ADCP comprised about 2% of DM, regardless of plant fraction. Thus, the effective available CP level of rhinoceros browses can be lower than indicated from a simple CP assay and should be considered when evaluating browse species. Analyses of protein (6–10%) in rhinoceros fecal samples, which have been used as an indicator of seasonal forage CP quality,[13] might also be enhanced through separate assays of bound versus available protein.

The bound values measured in our study provide a direct indicator of protein availability, which is useful in interpreting CP determinations of browses in general. ADCP may reflect the physiochemical influence of condensed tannins upon dietary protein or may be evidence of nitrogen as an integral component of lignified tissues in general.[30] Because twig fractions contain less CP than leaves, the impact of bound protein becomes even greater in evaluating protein quality in woody plants. Available protein levels measured in these rhinoceros browses were intermediate between those considered typical of monocot (6–12%) and of legume (12–25%) hays.[30]

Regarding tannins, no evidence was found of rhinoceros feeding selectivity against browses containing levels of soluble tannins

felt to be detrimental to animal preferences;[3] however, the role of secondary compounds in diet selection of the black rhinoceros has not been examined in detail. In other studies with African ungulates, condensed, rather than soluble, tannins have been shown to more strongly influence browse utilization.[3]

Browses eaten by black rhinoceros in Zimbabwe were highly fibrous, containing up to 70% NDF. Although leaves contain significantly lower levels of dietary fiber than do twig fractions, animals did not appear to preferentially consume leaves. The availability of leaves is much reduced during the dry season in the Zambezi Valley (June–October) because many of the woody species are deciduous. Furthermore, in this study the degree of lignification in leaves did not differ from that measured in woody fractions.

Although fiber is generally considered a negative index of feed quality, ruminant and nonruminant herbivores such as the rhinoceros derive a major portion of dietary energy from the fermentation of cell wall constituents.[2,3,11] Because lignin constitutes a theoretically indigestible fiber fraction, the degree of cell wall lignification is a critical determinant of fiber quality and potential fermentability.[30] Quantity and quality of dietary fiber must both be considered in evaluating nutritive value of browses. Quality may be more important in providing a suitable substrate for enhanced hindgut fermentation by large herbivores.[21] Browses in this study contained fiber levels more highly lignified but intermediate to those typically found in either legume (28–66% NDF) or grass (54–80% NDF) hays commonly fed as forage substitutes to captive black rhinoceros.[2,3]

Total cell wall constituents measured in this survey cannot be directly compared with the crude fiber levels in previous studies of rhinoceros browse composition because of differences in analyses.[30] Other authors have reported seasonal and species variation in crude fiber, with mean values ranging from 22% to 47% of DM.[10,15,17,20] However, cellulose and lignin levels of approximately 31% and 11%, respectively, were summarized from seven species collected in South Africa.[15] These values correspond with the 11–38% cellulose (ADF-Lig) and 7–21% lignin in our Zimbabwean plant samples.

Leaves consistently contained higher concentrations of tocopherols than did twig fractions (Table 2), as has been reported previously.[3,5] α-tocopherol increases with chlorophyll degradation during plant maturation as phytol chains are integrated into the tocopherol molecules.[22] Photosynthetic tissues (leaves) would thus be expected to contain higher levels of vitamin E activity than would less active tissues (structural or fruit); mature plants also contain higher levels of vitamin E activity than do immature stages.[22] Conditions that increase leafiness and maturation of browses should be incorporated into pasture management plans if optimization of vitamin E nutrition is a goal.

Vitamin E levels quantified in 26 plants eaten by black rhinoceros ranged from 10 to almost 300 IU kg DM (Table 2), values higher than those previously reported for 10 browses eaten by rhinoceros in Kenya (0.4–153.0 μg/g = 0.6–228 IU/kg vitamin E; α-tocopherol data only).[10] Ten of 26 (39%) samples from this study, and six of 10 (60%) browses examined in Kenya[10] contained vitamin E levels greater than current NRC dietary recommendations (50 IU kg) for equids.[26]

Previous laboratory studies have documented differences in plasma α-tocopherol levels among free-ranging populations of black rhinoceros[3] and between captive (zoo) and free-ranging rhinoceros.[4,5] Because plasma and available dietary levels of α-tocopherol are closely correlated, it would have been interesting to have simultaneously obtained blood, as well as browse, samples from the Zambezi rhinoceros. Our previous analyses of circulating α-tocopherol levels in Zimbabwean rhinoceros (0.61 ± 0.23 μg/ml, n = 85; Dierenfeld et al., unpubl. data)

involved samples from animals captured in the same area from which our plant sampling was undertaken, also in the dry season. Seasonal variation in plasma tocopherol concentrations has not been examined in rhinoceros but might be expected to fluctuate with plant phenology. Based upon both browse composition and plasma data, NRC recommendations for vitamin E should be considered minimal levels for use in formulating diets for managed rhinoceros populations.

Ash ranged from 3% to 16% of DM (Tables 1, 3). Potential environmental contamination of samples was not controlled in collections, thus the possibility of sand or soil contributing to mineral concentrations must be considered. However, all samples were treated identically in the field and laboratory and represent forages available to free-ranging rhinceros. The Ca (0.6–4.27%) and P (0.06–0.19%) levels documented in this study were very similar (identical for *Combretum apiculatum* sampled in September) to values reported in other detailed publications describing rhinoceros browse mineral concentrations (Ca, 0.7–4.9%; P, 0.04–0.26%).[17,19]

Fecal Ca (2.1–6.5%) excretion by black rhinoceros was substantially higher than that of normal livestock values, whereas P levels (0.6–1.6%) were within expected ranges for livestock.[20] These Ca excretion values were attributed to highly calcified soil substrate; however, they might also be attributed to elevated dietary Ca concentrations in native forages. Our data support the finding that Ca is likely not limiting from these plants; however, Ca:P ratios appear out of balance from an optimal 2:1 suggested for most animals,[21] and P requirements may not be met by many of these forages.[28]

Dietary macroelement requirements established for various livestock species would appear to be satisfied for Mg (0.3–0.5%); however, K may be present in comparative excess (0.2–0.6%) and Na in insufficient amounts (minimum 0.1%) in browses consumed by black rhinoceros.[21,26] Specific mineral requirements of the rhinoceros have not been established; furthermore, unweighted means of these values do not represent actual animal intake. Nonetheless, it would be prudent to ensure the presence of natural or provisioned salt for managed black rhinoceros populations.

Trace element nutrition has also not been examined in detail for rhinoceros, although limited data from Kenyan plants do exist.[10,22] Mineral levels are known to vary with soil type, plant species, and/or plant phenology, but values in Table 3 invite some speculations. Based on broad dietary requirements for Cu (4–8 μg/g), Fe (25–125 μg/g), Mn (5–20 μg/g), and Zn (30–50 μg/g) in domestic herbivores, plants consumed by black rhinoceros in the Zambezi Valley appear to provide generally adequate levels but may be marginally deficient in Zn.[23] However, mineral interactions and numerous unquantified factors must be considered for proper evaluation of mineral status; these data should be considered preliminary.

SUMMARY

Because of similarities in digestive tract anatomy and physiology, equids should be considered the most appropriate model for estimating the nutritional requirements of rhinoceros until more specific data are compiled. Browses available to black rhinoceros in Zimbabwe contained higher indigestible fiber and lower available protein levels than grass and legume hays commonly fed these herbivores in managed feeding programs. Vitamin E and mineral concentrations varied widely, and some nutrients (Na, P, Zn) would appear to be relatively deficient in rhinoceros browses, based on equid requirements. These data, in combination with other studies of feeding ecology and diet composition, may enhance our ability to understand and meet the nutritional needs of black rhinoceros.

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ANESTHESIA OF PRZEWALSKI'S HORSES (*EQUUS PRZEWALSKII PRZEWALSKII*) WITH MEDETOMIDINE/KETAMINE AND ANTAGONISM WITH ATIPAMEZOLE

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Abstract: Eleven of 14 mature Przewalski's horses (*Equus przewalskii przewalskii*) were successfully anesthetized for routine hoof trimming, vaccination, and blood sampling with a combination of medetomidine (0.07–0.1 mg/kg, x̄ = 0.09 mg/kg) and ketamine (1.8–2.6 mg/kg, x̄ = 2.1 mg/kg) administered i.m. with a rifle and metal projectile dart. Mean induction time (time from dart administration to recumbency) was 11 min (SD = 6 min). Atipamezole (0.17–0.23 mg/kg, x̄ = 0.19 mg/kg) was administered approximately 30 min after darting to reverse the effects of medetomidine. The mean standing time (time to standing after administration of atipamezole) was 13 min (SD = 5 min), and total recumbency time was 28–62 min (x̄ = 46 min). Heart rate, respiratory rate, blood pressure, temperature, hemoglobin saturation, pH, $Paco_2$, and Pao_2 were measured and recorded during recumbency. Some bradycardia and transient decrease in Pao_2 occurred, however no complications were recognized. The three horses that were not successfully immobilized were obviously sedated but were not manageable for the intended procedure. A higher atipamezole dose than used in this study is recommended to decrease the recovery time.

Key words: *Equus przewalskii przewalskii*, Mongolian wild horse, medetomidine, ketamine, atipamezole, immobilization.

INTRODUCTION

Immobilization of wild equids has always been difficult to perform safely and effectively. Several combinations of drugs have been used[1,3,7,11,13,16,18] with varying results. Although effective for this use, etorphine[16,18] is no longer available,[15] which has led to investigation of other drug combinations such as carfentanil,[3] xylazine/butorphanol/tiletamine–zolazepam,[11] and romifidine–tiletamine–zolazepam.[21]

Many combinations of $alpha_2$ agonists (such as xylazine, detomidine, or romifidine) with ketamine or tiletamine–zolazepam have been used to anesthetize horses, ponies, mules, and donkeys.[6,13,14,17] Other adjunct drugs such as the benzodiazepines[15] and butorphanol[9] have been investigated in an attempt to improve sedation, muscle relaxation, induction, and recovery. Medetomidine is a newer but not yet commercially available $alpha_2$ agonist that produces sedation and analgesia. Investigations of its use in the horse indicate that it produces ataxia, which is undesirable when used alone for standing procedures.[4] However, a report of the use of medetomidine with ketamine in Przewalski's horses (*Equus przewalskii przewalskii*) indicated satisfactory immobilization in five horses.[5] The purpose of this study was to investigate the use of medetomidine/ketamine combination for immobilization of 14 Przewalski's horses with antagonism by atipamezole while monitoring important cardiopulmonary variables.

MATERIALS AND METHODS

All immobilizations were performed at the Minnesota Zoo in July 1993. Eleven adult Przewalski's horses (five male, six female) 5–18 years of age (x̄ = 13 yr) and 283–373 kg (x̄ = 340 kg) were immobilized with 0.09 mg/kg medetomidine (range = 0.07–0.1 mg/kg) (Wildlife Pharmaceuticals, Fort Collins, Colorado 80524, USA) 10 mg/ml and 2.1 mg/kg ketamine (range = 1.8–2.6

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