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RHINOCEROS NUTRITION: AN OVERVIEW WITH SPECIAL REFERENCE TO BROWSERS

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While various gastrointestinal problems contribute significantly to mortality figures in all captive rhinos (KOCK and GARNIER, 1993), metabolic disorders linked with inappropriate or nutritionally imbalanced diets appear restricted to the browsing species. We can rarely duplicate actual ingredients of an animal's natural diet in managed feeding programs; however, we can duplicate nutrients in our attempt to properly satisfy physiological requirements. Thus this summary focuses on chemical constituents of browsing rhino diets. Although many field studies exist describing plants consumed by, and feeding habits of, black rhinos (*Diceros bicornis*), few include chemical analyses. Even less data are available for Sumatran rhinos (*Dicerorhinus sumatrensis*). Nutrient descriptions in this report are derived from plant chemistry information collected in 4 African countries: Kenya (GHEBREMESKEL et al., 1991; MUKINYA, 1977), Namibia (JOUBERT and ELOFF, 1971; LOUTIT et al., 1987), South Africa (HALL-MARTIN et al., 1982), and Zimbabwe (DIERENFELD et al., 1995), and limited data on plants consumed by Sumatran rhinos in Malaysia and Indonesia (DIERENFELD et al., 1994; LEE et al., 1993; VAN STRIEN, 1985). Physiological responses to diets have been measured almost exclusively in zoo rhinoceros; combining these two data sets may help us better understand feeding management of browsing rhinoceros species.

Digestive Physiology

With average body masses of 850 (Sumatran) to >1000 kg (black), rhinos spend >1/3 of the day and much of the night eating. Zoo studies quantified daily hay intake of black rhinos at 1.1% or 1.6% of body mass (14 and 21 kg for grass and alfalfa hay, respectively; FOOSE, 1982), whereas animals consuming natural browses ate up to 30 kg (2.5% of body mass; GODDARD, 1968). In nature, the Sumatran rhino consumes up to 50 kg (fresh weight) of leaves and stems from broad-leaved herbs, shrubs, and trees; monocot grazing has also been observed (VAN STRIEN, 1985). Daily dry matter (DM) intakes of approximately 1.0% (ZAINAL-ZAHARI et al., 1990) to 2.0% (DIERENFELD et al., 1994) of body mass in the Sumatran rhino agree well with published reports of food consumption for other rhinoceros species (JONES, 1979). Mean retention of ingesta ranged from 50 to about 60 hr in black rhinos (FOOSE, 1982), but has not been reported for the Sumatran.

Both digestion and fermentation processes supply energy needs of the rhionoceros. The rhino stomach, containing high concentrations of lactate and low levels of volatile fatty acids (VFA), is a primary digestion site of soluble dietary carbohydrates (CHO = sugars), and lipids (MALOIY and CLEMENS, 1991). Additionally, dietary energy is available from the fermentation of structural CHO including hemicellulose and unlignified cellulose throughout the cecum and colon, which comprise 73% of gut capacity. VFA ratios in the hindgut of rhinos are similar to those found in the rumen, indicating corresponding microbial populations and fermentation processes (MALOIY and CLEMENS, 1991). Due to analogies in digestive tract morphology, horses should probably be considered the best model for nutritional requirements of rhinoceros until more specific data are compiled.

Carbohydrates - Fiber and Soluble Sugars

Differing analytical techniques make direct comparison impossible in some instances; for the few studies that exist where both cellulose (24-36%, 19-38%) and lignin (8-14%, 6-21%) values are found (South African and Zimbabwean browses, respectively), numbers are quite comparable (Table 1). Ten native browses eaten by Sumatran rhinos contained less cellulose (14 to 23% of DM; Table 1), but even higher lignin levels (8 to 24%) than black rhino browses, suggesting that south-east Asian forages may be less digestible than African browses.

Table 1: Ranges in chemical composition of preferred rhino browse plants collected in Africa and south-east Asia. All values expressed as % of dry matter.

Sample Location	# ssp.	Crude Protein	Crude Fiber	Cellulose	Lignin	Crude Fat
		% of DM				
Black rhino browses:						
Kenya	10	4-13	4-41			1-7
Namibia	11	8.5*				2-24
South Africa	7	9-11	35-48	24-36	8-14	5-7
Zimbabwe	26	6-22		19-38	6-21	
Sumatran rhino browses:						
Indonesia	9(12)[1]	6-24				
Malaysia	10	7-18		14-23	8-24	

* Value presented as a mean of 11 species. [1] Crude protein data includes 9 individuals species and 3 mixtures of plants.
Data sources: DIERENFELD et al., 1994; DIERENFELD et al., 1995; GHEBREMESKEL et al., 1991; HALL-MARTIN et al., 1982; LOUTIT et al., 1987; MUKINYA, 1977; VAN STRIEN, 1985.

Thus both browsing rhinos consume high-fiber, highly lignified (with presumably low digestibility) forages in nature. Black rhinos in zoos digested 43% of timothy hay, and 65% of alfalfa hay-based diets (FOOSE, 1982), compared with a calculated 50% digestibility of natural forages (based on fecal lignin ratio, HALL-MARTIN et al., 1982). Overall, alfalfa hay appears excessively digestible for browsing rhinos.
It is also apparent from these limited data that while rhino browses contain more lignified tissue in cell wall constituents (CWC) than either legume (alfalfa) or grass forages in general, they also contain an intermediate hemicellulose (HC) level (see Figure 1). Hemicellulose comprises approximately 30% of CWC in native browses (n=44) compared with 20 (legumes) to 40% (grasses) in hays used in zoos, and may provide a ready source of carbohydrate energy to rhinos. HC digestion by non-ruminants equals or surpasses that in ruminant herbivores (VAN SOEST, 1994), and zoo studies have shown that while cellulose in alfalfa compared with grass hay is better digested by rhinos (54 vs. 43%), little or no difference in hemicellulose digestibility was seen (48% for alfalfa, 47% for timothy; FOOSE, 1982). Mixed grass:legume forages may thus provide more nutritionally appropriate substitutes than either hay fed separately for the browsing rhino species.
The soluble CHO content of grass (25% of DM) compared to alfalfa (11%) hay differs considerably (VAN SOEST, 1994), which may also be important for the browsing rhinos, but has not been investigated in detail. Nor has the soluble sugar content of native browses been quantified.

Protein

The crude protein content of rhino browse plants is variable and seasonal (4 to 24% of DM; see Table 1), but in general was intermediate to those considered typical of monocot (6-12%) or legume (12-25%) hays or diets typically fed in zoos (14-18%). Recent studies (DIERENFELD et al., 1994; DIERENFELD et al., 1995) which quantified crude compared with chemically-bound protein in rhino browses demonstrated that, on average, effective available protein in nature is 2 to 3% lower than crude protein content. Again, mixed grass: legume hays may better duplicate dietary protein levels found in natural forages consumed by these species. Crude protein levels considered excessive in captive rhino diets (10-13%) have been linked with laminitis (JONES, 1979) in zoo animals; protein deficiency in rhinos has never been reported. Essential amino acid deficiency was investigated in cases of skin ulceration in black rhinos in North America (n=3); no overt deficiencies were detected (Table 2, unpubl. data).

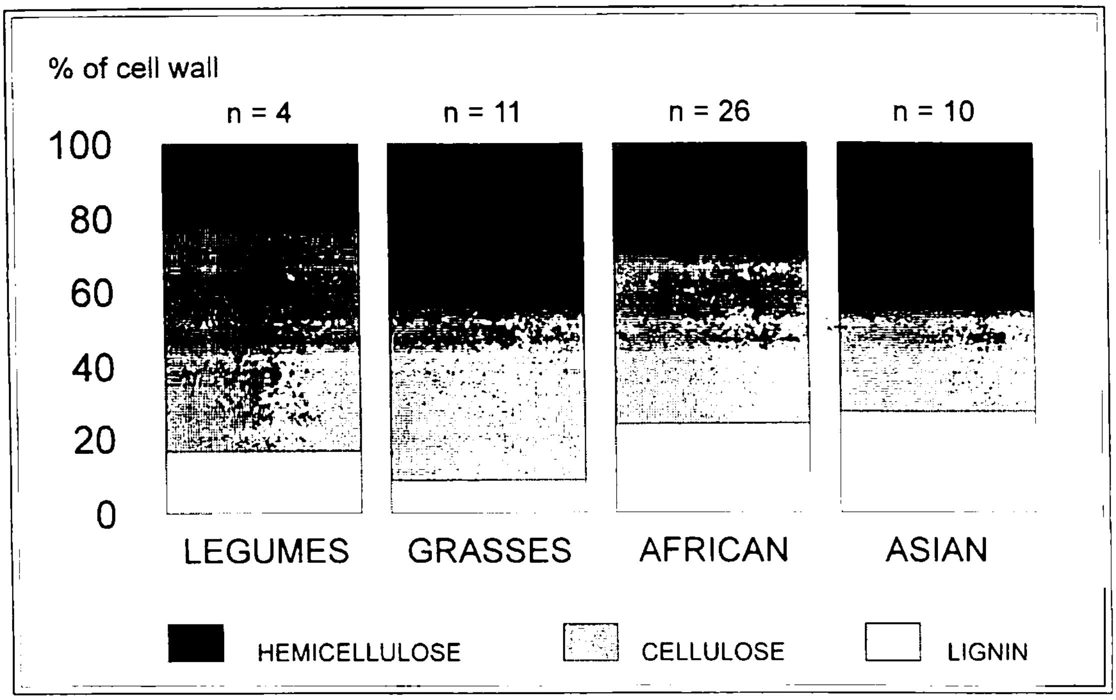

Figure 1: Cell wall constitutents in forages consumed by browsing rhinos. Summarized from: DIERENFELD et al., 1995; VAN SOEST, 1994.

Table 2: Plasma amino acid concentrations (nmol/ml) in three zoo black rhinoceros (Diceros bicornis, studbook # 251, 6068, 9109), compared with domestic livestock normals.

Amino Acid	Rhino ID			Normals		
[nmol/ml]	# 251	# 6068	# 9109	Equine	Bovine	Ovine
Alanine	207	319	210	168	252	202
Glutamine	321	286	340	679	--	180
Valine	276	352	453	282	186	182
Isoleucine	73	94	133	54	87	53
Leucine	140	204	250	150	146	98
Proline	67	84	172	98	--	--
Serine	121	73	152	186	115	154
Threonine	141	110	162	158	98	227
Methionine	20	27	19	30	28	21
Phenylalanine	89	93	122	54	38	57
Tyrosine	75	66	163	75	54	41
Aspartic Acid	6	6	9	12	68	57
Glutamic Acid	49	59	43	13	67	187
Arginine	107	96	71	107	46	174
Histidine	95	95	112	67	70	236
Lysine	143	119	102	105	73	314
Ornithine	166	219	241	36	43	92
Taurine	58	33	27	38	--	--
Glycine	686	344	477	462	419	1261

Lipids

The crude fat content of rhino browses (2 to 24%) is considerably higher than found in most dry diets for captive animals -- 2-4%, and may, in fact be the single most important nutrient group for these species. Lipogenesis in rhinos, as in other non-ruminants, probably relies heavily on glucose as a main substrate preferentially through the pentose phosphate shunt (VAN SOEST, 1994). If energy is limiting from imbalanced carbohydrate sources, lipogenesis could be impacted in rhinos. Furthermore, as fat appears to be a significant dietary constitutent in rhino browses, this nutrient category should be considered a primary focus for nutritional biochemistry research. Predominant fatty acids in black rhino browses include palmitic ([16:0], 26% by wt), linoleic ([18:2], 16% by wt), and linolenic ([18:3], 21% by wt) (GHEBREMESKEL et al., 1991), the latter two essential fatty acids (FA) not synthesized in the body. These values provide guidelines for selecting appropriate grains for formulating substitute diets, and may explain differences in health between European and North American black rhino populations. Palmitic and linolenic acid, in particular, have been shown to stabilize erythrocyte and central nervous system membranes, respectively, in other species (DELION et al., 1994), and may function similarly in the rhino. High incidence of hemolytic anemia (MILLER, 1987), ulcerative dematitis (MUNSON, 1993), and encephalomalacia (MONTALI and CITINO, 1993) in captive black rhinos may be linked with imbalances in cellular membrane stability.

Investigations of FA metabolism in browsing rhinos have been identified as a research priority, and are currently underway. Studies correlating dietary FA composition with body tissue lipids might elucidate underlying linkages. One experimental diet containing 2.5% linolenic acid precipitated a decrease in both plasma linolenic and palmitoleic acid concentrations in 2 black rhinos (unpubl. data), possibly due to an oxidative stress associated with **excess** linoleic acid relative to other FAs. Clearly other diet formulations remain to be investigated.

Comparing the FA content of grass vs. legume hays vs. rhino browses (Table 3), once again it appears that a mix of the two hays might provide the most suitable substitute forage. Stearic [18:0] and oleic [18:1] acids, lacking in dried hays compared to browse, may be provided by grains typically used in manufactured, pelleted diets.

Table 3: Fatty acid profile (% of total fatty acids) in hays, pellets, and native Kenyan browses (n=10 spp.) consumed by black rhinoceros (Diceros bicornis).[1]

Fatty Acid	Mixed (Tim/Alf)	Alfalfa Hay	Grass Hay	Pellets	Browses (n=10)
15:0	--	0.42	0.54	0.14	0.26
16:0	22.2	20.5	25.5	18.3	27.4
16:1 n-7	--	--	--	1.34	1.9
17:0	--	0.44	0.67	0.32	1.5
18:0	3.78	4.47	4.39	6.42	4.62
18:1 n-9	3.31	3.01	4.65	30.5	6.47
18:2 n-6	20.3	18.9	23.1	36.4	17.1
18:3 n-3	41.0	39.1	21.7	4.0	26.2
20:0	2.29	2.37	4.84	0.37	1.81
22:0	3.00	2.40	5.09	0.26	2.62
24:0	1.85	2.43	5.15	--	2.44
% Total Fat	1.50	2.10	1.90	6.10	2.07

[1] Summarized from GHEBREMESKEL et al., 1991 and VAN SOEST, 1994. Browses averaged as unweighted means.

Minerals

Macromineral and trace element ranges in native rhino browses fall into general ranges for horse requirements (Table 4). Sodium (Na) may be limiting in native browses (DIERENFELD et al., 1994; DIERENFELD et al., 1995), but can be readily obtained in natural salt licks (LEE et al., 1993; VAN STRIEN, 1985). Phosphorus (P) also appears to be limiting in natural rhino browses, particularly in relation to calcium content; hypophosphatemia has been associated with hemolytic and dermatits problems in captive black rhinos (KOCK and GARNIER, 1993). Se and Zn status in zoo black rhinos have been suggested to be marginal based on blood samples (n=4; GHEBREMESKEL et al., 1991), and browses sampled appear to contain low levels of these nutrients (DIERENFELD et al., 1994; DIERENFELD et al., 1995). Hemosiderosis, possibly linked with dietary mineral imbalances, has been reported in captive, but not free-ranging, black rhinos (KOCK et al., 1992; MONTALI and CITINO, 1993). Dietary mineral interactions, overall health, and nutritional status need to be investigated in these species.

Table 4: Macromineral (n=42 spp.) and trace element (n=39 spp.) concentrations in browses eaten by black and Sumatran (n=44 spp.) rhinoceros compared wtih nutrient requirements for horses (NATIONAL RESEARCH COUNCIL, 1989).

Component		Range in Native Browses		Equid
(dry wt. basis)		Black Rhino	Sumatran	Reqts.
Calcium,	%	0.7 - 6.1	0.04 - 6.76	0.3 - 0.6
Copper,	mg/kg	3.0 - 16.1	3.4 - 13.3[2]	10
Iron,	mg/kg	29 - 215	47.9 - 116.0[2]	50
Magnesium,	%	0.1 - 0.9	0.16 - 1.28	0.1
Manganese,	mg/kg	4.0 - 269	45 - 1940[2]	40
Phosphorus,	%	0.05 - 0.26	0.03 - 0.37	0.2 - 0.3
Potassium,	%	0.3 - 2.0	0.12 - 6.31	0.3-0.4
Selenium[1],	mg/kg	0.02 - 0.04	NA	0.1
Sodium,	%	0.001 - 0.65[3]	<0.01 - 0.45[3]	0.1
Zinc,	mg/kg	2.5 - 96.3	7.1 - 25.6[2]	40

Data sources: DIERENFELD et al., 1994; GHEBREMESKEL et al, 1991; JOUBERT and ELOFF, 1971. LEE et al., 1993; VAN STRIEN, 1985

[1,2] (n=10 spp.) [3] Maximum value based on single species; majority <0.05% sodium NA = not analyzed

Vitamins A and E

Due to the skin and erythrocyte-based diseases described earlier, selected fat-soluble vitamins have been evaluated in detail in black rhinos. Plasma vitamin A (retinol) levels in free-ranging black rhinos are 10-fold lower than those seen in most other mammalian species, averaging 0.04 ± 0.01 to 0.06 ± 0.03 μg/ml (n=100 animals from 4 locations). Values in zoo rhinos are somewhat higher (0.10 ± 0.10 μg/ml, n=99). If free-ranging values are to be considered normal for black rhinos, zoo animals may be showing possible vitamin A excess. β-carotene status of rhinoceros has not been investigated, but may provide a more physiologically natural source of vitamin A activity than supplements currently added to captive diet preparations.

Tissue retinol levels measured in zoo rhinos (μg/g wet weight) are reported in Table 5a. Although sample sizes are low, Indian rhinos appear to differ from other rhino species. No comparative tissue values from free-ranging animals are currently available.

Plasma vitamin E levels in free-ranging black rhinos have been shown to differ among locations, ranging from 0.23±0.07 μg/ml in Kenya (n=7) to 0.80±0.05 in Namibia (n=3) (DIERENFELD and TRABER, 1992). Most animals (n=129 from South Africa and Zimbabwe) average about 0.6 μg/ml. By comparison, zoo black rhinos (n=112) average 0.61±0.73 μg/ml α-tocopherol, and have shown significant increases (from 0.18±0.03 μg/ml, n=11; DIERENFELD et al., 1988) with dietary supplementation (recommended 200 mg/kg DM) over the past several years. Mean plasma vitamin E concentrations in zoo rhinos do not differ significantly across species, yet are still 4- to 10-fold lower compared with other herbivores, probably due to a lack of high-density carrier lipoproteins in rhinoceros (DIERENFELD and TRABER, 1992). Vitamin E levels in native browses eaten by black rhinos range from 50-200 mg/kg DM, and provide guidelines for captive diet recommendations (GHEBREMESKEL et al, 1991; DIERENFELD, 1990; Dierenfeld et al., 1995).

Table 5a: Tissue retinol levels in North American zoo rhinoceros (μg/g wet weight; X ± SEM).

Tissue	Black	White (n=7)	Indian (n=2)	Sumatran (n=2)
Liver	97.09 ± 38.92 (n=16)	109.0 ± 35.9	38.6 ± 37.2	198.1 ± 53.3
Muscle	0.15 ± 0.03 (n=16)	0.11 ± 0.04	0.03 ± 0.03	0.43 ± 0.19
Heart	0.28 ± 0.04 (n=14)	0.38 ± 0.28	0.08 ± 0.04	0.31 ± 0.12
Adipose	0.69 ± 0.21 (n=11)	0.60 ± 0.14	0.29 ± 0.09	0.38 ± 0.03

Source: Wildlife Conservation Society Nutrition Laboratory, current to 1 Jan 95.

Tissue vitamin E levels have been quantified in 19 individual rhinos representing 4 species (Table 5b). Concentrations in liver and muscle tissues are higher in browsing species compared with grazers (white, Indian rhinos), possibly due to higher dietary supplementation in the browsers. Normal tissue α-tocopherol concentrations in domestic horses do not appear to provide comparative indicators for tissue vitamin E status in rhinoceros, perhaps due to difference in fat storage and metabolism between the temperate-evolved horse and tropical rhino. α-tocopherol concentrations in free-ranging rhino tissues have not been measured, but may be essential to understand optimal captive animal nutrition. It is possible that antagonistic nutrients (pro-oxidant minerals, vitamins, fats) are being supplied in excess of animal requirements, leading to a necessity for elevated antioxidant vitamin supplementation in captive animals.

Table 5b: Tissue α-tocopherol levels in North American zoo rhinoceros (μg/g wet weight; X ± SEM).

Tissue	Black	White (n=8)	Indian (n=2)	Sumatran (n=2)
Liver	17.08 ± 5.14 (n=16)	10.06 ± 3.67	1.63 ± 0.28	20.45 ± 0.33
Muscle	6.63 ± 1.47 (n=17)	4.98 ± 1.43	1.31 ± 0.28	15.54 ± 8.08
Heart	15.41 ± 3.90 (n=15)	11.78 ± 3.57	3.60 ± 0.91	30.72 ± 5.12
Adipose	5.76 ± 1.42 (n=12)	12.81 ± 4.43	0.77 ± 0.01	6.21 ± 2.43

Horse normals: liver, 5 μg/g; muscle, 5 μg/g; adipose, 25 μg/g
Source: Wildlife Conservation Society Nutrition Laboratory, current to 1 Jan 95.

Summary

<u>Rhinoceros Nutrition: an Overview, with special Reference to Browsers</u>

Several implications for formulating better captive diets and future research thrusts for investigating nutrition of browsing rhinos have been identified. These include: 1) the use of mixed grass:legume forages in managed feeding programs to balance soluble and insoluble carbohydrates, as well as chemical characterization of browses currently fed in zoo; 2) investigation and supplementation of proper energy sources, particularly simple sugars and essential fatty acids; 3) measurement of tissue levels of specific fat-soluble nutrients including fatty acids and ß-carotene; and 4) examination of mineral status and interactions, particularly regarding the pro-oxidants Fe, Cu, and Se. Ca, P, and Na status should also be compared between captive and free-ranging animals.

Zusammenfassung

Nahrungsaufnahme bei Nashörnern - Ein allgemeiner Überblick unter besonderer Berücksichtigung der Aufnahme von Buschvegetation

Zwischen den Bemühungen um eine verbesserte Zusammensetzung des Futters für Nashömer in Zoohaltung und künftigen Forschungsrichtungen bei Untersuchungen zur Nahrungsaufnahme besteht eine Reihe von Wechselbeziehungen, und zwar vor allem in den folgenden Bereichen:
1. Verfütterung von Gemischen aus Gras und Leguminosen im Rahmen von kontrollierten Fütterungsprogrammen zur Gewährleistung eines ausgewogenen Verhältnisses zwischen löslichen und unlöslichen Kohlehydraten sowie die chemische Charakterisierung der gegenwärtig in Zoos verfütterten Gehölze;
2. Untersuchung und Supplementierung geeigneter Energieträger, besonders der Monosaccharide und der essentiellen Fettsäuren; 3. Messung der in den Geweben vorhandenen Gehalte an spezifischen fettlöslichen Nährstoffen, wie Fettsäuren und Beta-Karotin; 4. Untersuchungen zum Mineralstoffstatus und zu den Wechselwirkungen besonders zwischen den Oxidationsmitteln Eisen, Kupfer und Selen. Auch im Hinblick auf den Kalzium-, Phosphor- und Natriumstatus müßten Vergleiche zwischen Zootieren einerseits und wildlebenden Tieren andererseits angestellt werden.

Résumé

La réception de l'alimentation chez des rhinocéros - un aperçu général en tenant particulièrement compte de la réception d'une végétation de la brousse

Il existe toute une série de corrélations entre les efforts visant à améliorer la composition du fourrage pour rhinocéros gardés dans des jardins zoologiques et les orientations dans la recherche prévisionnelle pour étudier le phénomène de la réception du fourrage. Ces considérations concement surtout les domaines que voici :
1èrement, une alimentation sur la base d'un mélange d'herbes et de léguminoses dans le cadre de programmes alimentaires contrôlés afin de garantir une relation équilibrée entre carbones solubles et indissolubles ainsi que la caractérisation chimique des buissons utilisés actuellement dans les jardins zoologiques comme matière alimentaire;
2èmement, l'étude et la supplémentation de porteurs d'énergie appropriés, notamment des monosaccharides et acides gras essentiels; 3èmement, analyse des teneurs en nutriments spécifiques liposolubles tels qu'acides gras et bêta-carotine contenus dans les tissus; 4èmement, étude du status minéral et des interactions surtout entre les oxydants Fe, Cu et le sélénium. Il faudrait également établir des comparaisons entre les animaux gardés et sauvages concemant leur état de calcium, de phosphore et de sodium.

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