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Feed Intake, Diet Utilization, and Composition of Browses Consumed by the Sumatran Rhino (*Dicerorhinus sumatrensis*) in a North American Zoo

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The Sumatran rhino (*Dicerorhinus sumatrensis*), presently indigenous to the Malay peninsula and the islands of Sumatra and Borneo, is faced with extinction. It is estimated that fewer than 400 individuals still exist in the wild. In response, concerted efforts have been made to maintain and breed this species in captivity, and proper diet and nutrition underlie reproduction. The present feeding trial characterizes a diet fed to three Sumatran rhinos at the Cincinnati Zoo and Botanical Garden. The diet consists of mixed alfalfa/orchard grass hay, a variety of browses, grain pellets, produce (apples and bananas), and a vitamin E supplement. All three rhinos maintained body weight (614–761 kg), regular patterns of bowel movements, and fecal consistency and composition throughout the three 5-day trials. Dry matter intake (DMI) ranged from 1.40 to 2.49% of body mass. Browse contributed by far the majority of nutrients to the diets in this study, from 62 to 83% of DMI. The nutrient composition of six species of subtropically grown browses (two from differing locations, for a total of eight browses characterized) showed that leaves did not differ from twigs in water or lignin content, but leaves contained higher concentrations of protein (both crude and bound) and ash, as well as lower fiber fractions. Of the macrominerals analyzed, only phosphorus differed between leaves and twigs, with twigs containing significantly more. No differences were seen between leaves and twigs in iron, molybdenum, or zinc content, but leaves contained lower concentrations of copper and higher concentrations of manganese and selenium compared with twigs from the

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same plants. Dry matter digestibility averaged approximately 50%. The only overt imbalances detected when comparing rhino diets with nutrient recommendations for domestic equids were excess calcium relative to phosphorus intake and low copper intake. These data, combined with information on native browse composition, intake, and digestibility, should greatly assist in providing suitable diets for this highly endangered species. Zoo Biol 19:169–180, 2000.

Key words: rhinoceros; herbivore nutrition; browse

INTRODUCTION

Although its historical range spanned the foothills of the Himalayas in Bhutan and eastern India through the tropical forests of Burma and Thailand, and possibly Vietnam and China [Van Strien, 1974], current population estimates for the endangered Sumatran rhinoceros (*Dicerorhinus sumatrensis*) number fewer than 400 animals, limited to the Malay Peninsula and the islands of Sumatra and Borneo, Indonesia, and Malaysia. In response to this habitat and population decline, the Sumatran rhino has been the focus of concerted captive husbandry and breeding efforts [Prasetyo et al., 1990].

Similar to other browsing rhinos in North American facilities, the health of the Sumatran or "hairy" rhinoceros in captivity appears strongly linked to dietary husbandry [Dierenfeld, 1995]. Historically, diets fed to this species under intensive management contain herbivore pellets (formulated either for monogastrics or ruminants), high-quality legume hay (alfalfa or red clover), some produce (both fruits and vegetables), and fresh locally available browse species.

Stool consistency problems, gastric torsion, and metabolic imbalances have been reported, possibly owing to inappropriate captive diets [M. Campbell, personal communication]. After prolonged diet refinement to improve stool consistency, recommended feeding management included high-fiber herbivore pellets, mixed grass/legume hay, and available browses such that diets more closely duplicated natural forage composition [Dierenfeld et al., 1994]. This study was conducted to evaluate the chemical composition and utilization of diets currently fed to captive Sumatran rhinos in North America in an effort to define better diet suitability for improved captive dietary management and nutrition of the species.

METHODS

Animals

The Cincinnati Zoo and Botanical Garden currently maintains three (1.2) Sumatran rhinos. A mature male, Ipuh, was captured July 23, 1990, in Ipuh, Benkulu, southwestern Sumatra, Indonesia. He was transferred to San Diego on April 10, 1991, and to Cincinnati on October 25, 1991. One of the two mature females, Rapunzel, was captured on August 26, 1989, in Morini, Riau, central eastern Sumatra. She was transferred to Los Angeles Zoo on November 29, 1989, to the Bronx Zoo on May 16, 1990, and to Cincinnati on February 6, 1993. The second female, Emi, was captured March 6, 1991, in Ipuh, Benkulu, Sumatra. She was transferred to Los Angeles on November 23, 1991, and to Cincinnati on August 5, 1995. Ipuh and Rapunzel were both mature and possibly aged animals when captured. Emi, by her size when captured, was thought to be a sub-adult animal.

Feeding Trial

Feeding trials commenced in January 1997 for three consecutive 5-day periods. Rhinos were individually housed and fed in adjacent pens throughout the trials; normal zoo routines were not significantly altered. Rhinos were maintained indoors throughout the trials. Body weight, total wet fecal mass, and dietary intake were measured daily. The rhinos were fed and pens cleaned twice daily, at 0900 and 1600 hours. Diet ingredients and amounts fed are given in Table 1. Morning diets consisted of leaves and twigs of weeping fig (*Ficus benjamina*, Florida origin), mixed orchard grass (*Dactylis glomerata*)/alfalfa (*Medicago sativa*) hay, produce consisting of apple slices (Washington Red Delicious) and unpeeled bananas (Premium Turbana #4011), and a vitamin E supplement (3,000 IU), which was integrated into a banana piece. Afternoon diets contained additional varieties of browse (Table 2), hay, a pelleted low-fiber concentrate, and produce. Produce, pellets, and the supplement were fed on top of hay laid on freshly cleaned concrete slabs within the pens. Browse was trimmed of branches >2 cm in diameter, weighed, and fed in a pile next to the hay. Tap water and trace mineralized salt blocks (Champions Choice, Cargill, Inc., Minneapolis, MN, U.S.A.) were provided without restriction during the trial. Unconsumed food from the previous meal was collected at each feeding and weighed to the nearest tenth of a kilogram.

Sample Collection

Representative samples of browse species offered during the trial, hay, pellets, and the trace mineralized salt block were bagged and stored at 0°C for approxi-

TABLE 1. Diets offered to Sumatran rhinoceros (*Dicerorhimus sumatrensis*) during feeding trials at the Cincinnati Zoo, Cincinnati, OH, USA, 1997

Feeding	Individual	Diet component	Amount
AM diet	All rhinos	*Ficus benjamina* (FL origin)	1/3 box
		Orchard grass/alfalfa mix hay	1 flake
		Bananas with peel	7
		Apples	7
		Vitamin E supplement[a]	3000 IU
PM diet	Ipuh	*Ficus benjamina* (FL origin)	1 box
		Ficus sp (CA origin)	1 box
		Orchard grass/alfalfa mix hay	2 flakes
		Herbivore pellets[b]	1.8 kg
		Bananas with peel	8
		Apples	8
	Rapunzel	*Ficus benjamina* (FL origin)	1/3 box
		Ficus sp (CA origin)	1 box
		Orchard grass/alfalfa mix hay	2 flakes
		Herbivore pellets[b]	1.8 kg
		Bananas with peel	8
		Apples	8
	Emi	*Ficus benjamina* (FL origin)	2/3
		Ficus sp (CA origin)	1 box
		Orchard grass/alfalfa mix hay	2 flakes
		Herbivore pellets[b]	1.8 kg
		Bananas with peel	8
		Apples	8

[a]Emcelle vitamin E, Stuart Products, Bedford, TX, U.S.A.
[b]Mazuri ADF-16 large pellets, PMI, St. Louis, MO, U.S.A.

TABLE 2. Browses offered to Sumatran rhinoceros (*Dicerorhinus sumatrensis*) during feeding trials at the Cincinnati Zoo, Cincinnati, OH, USA, 1997

Scientific name (common name)	Origin
Ficus benjaminia (weeping fig)	West Palm, FL, U.S.A.
	San Diego, CA, U.S.A.
Ficus microcarpa retusa (Indian laurel fig)	San Diego, CA, U.S.A.
Ficus microcarpa nitida (green gem)	San Diego, CA, U.S.A.
	Los Angeles, CA, U.S.A.
Ficus rubiginosa (rusty leafed fig)	San Diego, CA, U.S.A.
Ficus thonningii (South African fig)	San Diego, CA, U.S.A.
Ficus nekbuda (Zulu fig)	San Diego, CA, U.S.A.
Harpephyllum caffrum (kaffir plum)	Los Angeles, CA, U.S.A.

mately 6–8 weeks before overnight shipment on ice to the Wildlife Nutrition Laboratory at the Wildlife Conservation Society. Frozen fecal samples were shipped to this location separately.

Fecal samples were obtained during the morning cleaning of the rhino pens. After total collections, approximately 1.0-kg sub-samples of feces were obtained from each animal daily and stored at 0°C.

Chemical Assessment

Browse samples were separated into leaf and twig fractions for the determination of leaf:twig ratio (L:T) by weight (as-fed basis), then dried to a constant weight at 60°C before being ground in a Wiley mill to pass through a 2-mm screen. Leaves and twigs were analyzed separately. Moisture, crude and bound protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), sulfuric acid lignin, total ash, and macro- and micromineral concentrations were determined on browses, pellets, and hay using methods described by Dierenfeld et al. [1995] for browses or according to AOAC [1996] methodology for dry feeds. Minerals assessed included calcium, phosphorus, magnesium, potassium, sodium, sulfur, copper, iron, manganese, molybdenum, selenium, and zinc using inductively coupled plasma-atomic emission spectroscopy [Stahr, 1991]. The nutrient composition of produce (apples and bananas) was estimated utilizing commercial diet balancing software (Food Processor IV, ESHA Research, Salem, OR, U.S.A.).

After weighing and freeze-drying to determine moisture content, daily fecal samples for individual rhinos were pooled for the first, second, and third 5-day pseudoreplicates of the feeding trial. Fecal samples were ground to pass a 2-mm screen and subjected to identical chemical analysis as previously described for feed constituents. Metabolic fecal nitrogen (MFN) was calculated in fecal samples as the difference between total fecal nitrogen and the residual nitrogen in neutral-detergent residue.

Statistical Applications

Data from the three feeding trials were analyzed by analysis of variance (ANOVA) to determine whether significant differences existed within individuals or among trials for all chemical analyses. When ANOVA determined significant differences, Bonferroni's multiple-comparison post hoc test was utilized to determine differences in means. Student *t*-tests were performed to compare composition between leaves and twigs in the browse, with the *a* level set at 0.05.

RESULTS

Body Weight, Fecal Production, and Diet Consumption

No remarkable anomalies were apparent during the trial, and animals maintained body condition and health. Body weights fluctuated normally during the feeding trial in relation to the timing and quantity of bowel movements; daily fecal output averaged 3.2 to 4.7% of body mass on a wet basis, 0.7 to 1.0% of body mass on a dry basis (Tables 3 and 4). Fecal output and diet consumption followed expected patterns. Bowel movements for all three rhinos were regular and predictable, with no incidences of either constipation or watery stools. Fecal output and body weight for each rhino did not vary among the three trials.

Dry matter intake (DMI) for Sumatran rhinos in this trial ranged from 1.40 to 2.49% of body mass. Rhinos consumed produce first, followed (in order) by browse, pellets, and hay. Produce and pellets were consistently and completely consumed, whereas some hay and browse remained for each rhino on various days. Produce contributed only 5 (Ipuh) to 9% (both females) of DMI, whereas pellets made up 10 (Ipuh) to 17% (Emi) of DMI in these trials. Browse contributed by far the majority of nutrients to the diets in this study, expressed on either a DM (62–83%) or as-fed (62–80%) basis (Rapunzel and Ipuh, respectively, with Emi intermediate). Rhinos ate between 50 and 70% of browse offered, in a proportion of 2/3 leaf to 1/3 twig. In general, hay consumption was minimal between the A.M. and P.M. feedings and varied among individual rhinos overnight. Rapunzel often ate a greater proportion of hay offered than either Ipuh or Emi, but total amounts were not significantly different. As a percentage of DMI, however, hay contributed 14% of Rapunzel's diet compared with 2 to 7% for Ipuh and Emi, respectively.

Diet Composition

The chemical compositions of dietary ingredients and browses eaten in this study are presented in Tables 4 and 5. Browse leaves did not differ from twigs in water or lignin content ($P > 0.05$) but contained higher concentrations of protein (both crude and bound, $P < 0.001$) and ash ($P < 0.01$), and lower fiber fractions ($P <$

TABLE 3. Average body weights, daily fecal production, and daily diet consumption (kg as-fed basis and as a percentage of body weights) of Sumatran rhinoceros (*Dicerorhinus sumatrensis*) during feeding trials at the Cincinnati Zoo, Cincinnati, OH, USA, 1997

Animal	Ipuh	Rapunzel	Emi
Body weight (kg)	719.9 ± 6.4	614.0 ± 3.5	760.5 ± 7.3
Feces (kg)	34.1 ± 2.1	19.6 ± 1.4	27.3 ± 5.5
(range)	(32.2–38.3)	(18.0–22.2)	(21.5–39.1)
Produce consumed (kg)[a]	4.9 ± 1.4	4.5 ± 1.7	4.8 ± 1.8
Pellets consumed (kg)[b]	1.9 ± 0.2	1.8 ± 0.1	1.9 ± 0.1
Hay consumed (kg)[c]	0.4 ± 0.7	1.5 ± 0.9	0.9 ± 0.8
Browse consumed (kg)[d]	29.7 ± 4.4	12.9 ± 0.6	14.2 ± 2.4
Dry matter intake (% of body mass)	2.49	1.70	1.40

[a]Bananas, 55%, apples, 45%, weight:weight basis.
[b]Mazuri ADF-16 large pellets, PMI, St. Louis, MO, U.S.A.
[c]Orchardgrass/alfalfa mix.
[d]A variety of *Ficus* species harvested in Florida and California were offered.

TABLE 4. Chemical composition of non-browse diet components fed to Sumatran rhinos (*Dicerorhinus sumatrensis*) at the Cincinnati Zoo, 1997

Nutrient	Orchard grass/ alfalfa mixed hay	Herbivore pellets[a]	Apple[b]	Banana[b]	Mineralized salt block
Water (%)	6.5	7.7	84.0	75	3.1
Crude protein (%)	12.4	19.0	1.2	4.2	0.2
AD-CP (%)	1.2	1.2	n.d.	n.d.	0.1
Crude fat (%)	3.6	4.2	2.2	1.9	0.2
NDF (%)	58.9	27.3	7.6	n.d.	n.d.
ADF (%)	38.9	16.0	4.8	n.d.	n.d.
Acid lignin (%)	4.9	4.5	0.1	n.d.	n.d.
Ash (%)	10.4	7.9	1.6	3.2	99.6
Ca (%)	0.60	1.02	0.04	0.02	0.17
K (%)	2.95	1.69	0.71	1.58	n.d.
Mg (%)	0.34	0.29	0.03	0.12	0.06
Na (%)	0.02	0.47	0.00	0.01	40.1
P (%)	0.42	0.67	0.04	0.08	0.05
S (%)	0.21	0.25	n.d.	n.d.	0.01
Cu (mg/kg)	9.0	22.0	2.7	4.2	152.0
Fe (mg/kg)	110.0	390.0	11.2	12.3	1660.0
Mn (mg/kg)	118.0	143.0	312.0	116.0	909.0
Mo (mg/kg)	4.1	4.1	n.d.	n.d.	n.d.
Se (mg/kg)	0.05	0.5	0.02	0.04	0.84
Zn (mg/kg)	21.0	158.0	2.0	6.0	2270.0

[a]ADF-16 low-fiber Herbivore pellets, PMI, St. Louis, MO, U.S.A.
[b]Estimated using Food Processor IV, ESHA Research, Salem, OR, U.S.A.
All nutrients except water expressed on a dry matter basis. AD-CP, acid detergent crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; n.d., not determined.

0.001 for both NDF and ADF). Of the macrominerals analyzed, only P differed between leaves and twigs, with twigs containing significantly more ($P < 0.001$). No differences were seen between leaves and twigs in iron, molybdenum, or zinc content, but leaves contained lower concentrations of copper ($P < 0.01$), and higher concentrations of manganese ($P < 0.01$) and selenium ($P = 0.05$) compared with twigs from the same plants.

The total nutrient composition of the diets, weighted by percentage intakes for each individual rhino, are presented in Table 6 along with comparisons of recommended dietary nutrients for horses [NRC, 1989]. Browses consumed consisted of approximately one half *Ficus benjamina* (FL origin), and one half an average of the other species offered (Tables 1, 2, and 5), with nutrients weighted by L:T ratios as above (2/3 leaves, 1/3 twigs). Crude protein was within ranges recommended for adult equine maintenance, although marginal for reproduction (10–13% of DM). Furthermore, when one subtracts chemically unavailable protein (AD-CP, found in the lignin fraction of browses) from crude protein, dietary protein levels may actually be deficient. Calcium, potassium, and magnesium were above recommended levels for horse, whereas sodium and phosphorus appeared marginally adequate (mineral values calculated without any contribution from the trace mineral blocks, available free choice). Copper levels were low for all three rhinos compared with equine requirements, whereas iron was excessive. Zinc may have been marginally adequate, but again, was calculated without the addition of the mineral supplement block. Average fecal composition and digestion coefficients are found in Tables 7 and 8, respectively.

TABLE 5. **Chemical composition of browses fed to Sumatran rhinos (*Dicerorhinus sumatrensis*) at the Cincinnati Zoo, 1997**

Browse species nutrient	*F. benjaminia* (FL)		*F. benamina* (SD)		*F microcarpa nitida* (LA)		*F. microcarpa nitida* (SD)		*F. nekbuda*		*f. rubiginosa*		*F. thonningii*		*Harpephyllum caffrum*	
	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
Leaf:twig ratio (%)	45	55	51	49	63	37	47	53	62	38	62	38	33	67	42	58
Water (%)	40.5	49.2	54.6	56.7	59.9	57.9	66.2	63.3	67.6	64.2	67.7	69.1	66.3	69.5	54.6	62.3
Crude protein (%)	8.0	3.5	9.6	5.8	9.4	5.6	10.8	5.0	11.4	8.9	12.5	9.1	17.5	9.6	7.1	2.7
AD-CP (%)	2.8	1.1	3.0	1.4	4.5	1.5	4.6	1.8	4.2	3.9	2.7	2.9	6.1	3.9	3.5	2.1
NDF (%)	43.3	66.2	42.3	63.2	44.3	66.1	42.0	60.1	41.9	44.9	42.0	54.0	43.5	50.7	31.7	52.8
ADF (%)	42.2	55.0	36.8	54.4	38.4	57.3	35.5	56.7	39.2	43.1	40.9	52.1	38.4	49.8	21.6	49.7
Acid lignin (%)	14.5	19.5	17.2	16.8	16.5	15	17.5	18.3	18.0	21.2	20.9	18.6	17.5	25.3	22.9	14.9
Ash (%)	17.3	8.7	9.1	6.8	15.4	8.7	13.0	8.5	15.8	12.9	10.8	9.1	11.0	10.5	17.2	7.5
Ca (%)	3.84	2.58	2.28	1.66	3.75	1.83	2.96	1.96	2.91	3.1	1.29	1.23	1.34	2.12	5.83	1.84
K (%)	0.71	0.68	0.93	0.98	1.85	1.44	1.80	1.33	1.82	1.62	1.33	1.95	2.63	2.26	0.78	1.01
Mg (%)	0.37	0.22	0.24	0.19	0.34	0.23	0.33	0.20	0.24	0.63	0.34	0.24	0.19	0.22	0.38	0.2
Na (%)	0.09	0.07	0.12	0.05	0.05	0.02	0.36	0.38	0.09	0.05	0.42	0.23	0.04	0.02	0.02	0.01
P(%)	0.07	0.12	0.11	0.22	0.14	0.21	0.15	0.35	0.16	0.29	0.14	0.27	0.3	0.39	0.11	0.17
Cu (mg/kg)	3	7	4	10	5	7	3	8	3	12	4	5	10	13	6	9
Fe (mg/kg)	33	46	73	93	180	61	74	128	83	86	253	169	88	102	105	45
Mn (mg/kg)	17	9	20	10	28	6	16	11	14	13	34	16	22	13	30	20
Mo (mg/kg)	<1.0	<1.0	<1.0	<1.0	1.0	1.3	1.0	1.3	1.1	7.2	<1.0	1.0	2.2	3.5	1	<1.0
Se (mg/kg)	<0.03	<0.03	0.1	0.05	0.24	0.15	0.07	<0.03	<0.03	<0.03	<0.03	<0.03	0.2	0.14	0.12	0.11
Zn (mg/kg)	6	13	12	27	33	17	13	30	15	25	20	14	28	37	13	33

All nutrients except water rexpressed on a dry matter basis.
Abbreviations FL, Florida, CA, California; SD, San Diego, CA, U.S.A. origin; LA, Los Angeles, CA, U.S.A. origin; AD-CP, acid detergent crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber, L, leaf; T, twig.

TABLE 6. Chemical composition of diets consumed by Sumatran rhinos (*Dicerorhinus sumatrensis*) in three 5-day feeding trials at the Cincinnati Zoo, 1997

Nutrient	Ipuh	Rapunzel	Emi	Horse requirement[a]
Water (%)	49.1	41.7	44.3	n.a.
Crude protein (%)	9.0	9.9	9.7	8.0–13.0
AD-CP (%)	2.5	2.1	2.2	n.a.
Crude fat (%)	0.6+	1.3+	1.2+	n.a.
NDF (%)	44.1	42.5	41.7	n.a.
ADF (%)	38.7	35.1	35.1	n.a.
Acid lignin (%)	15.1	12.4	13.0	n.a.
Ash (%)	12.0	11.0	11.1	n.a.
Ca (%)	2.6	2.1	2.2	0.3–0.4
K (%)	1.2	1.5	1.4	0.3–0.4
Mg (%)	0.3	0.3	0.3	0.1
Na (%)	0.14	0.15	0.15	0.15
P (%)	0.2	0.3	0.2	0.2–0.3
Cu (mg/kg)	6.9	8.3	8.2	10
Fe (mg/kg)	103.6	124.7	124.2	50
Mn (mg/kg)	42.2	67.7	64.0	40
Mo (mg/kg)	1.6	2.1	1.9	n.a.
Se (mg/kg)	0.11	0.13	0.13	0.1
Zn (mg/kg)	28.4	37.6	37.9	40

[a]Requirements for maintenance and reproduction, National Research Council, 1989.
All nutrients except water expressed on a dry matter basis.
NDF, neutral detergent fiber; ADF, acid detergent fiber; AD-CP, acid detergent crude protein; n.a., not available.

TABLE 7. Composition of feces produced by Sumatran rhinos (*Dicerorhinus sumatrensis*) during three 5-day feeding trials at the Cincinnati Zoo, 1997

Nutrient	Ipuh	Rapunzel	Emi
Water (%)	78.3 ± 2.55	75.2 ± 0.98	80.7 ± 2.55
Crude protein (%)	12.3 ± 1.15	12.1 ± 0.21	10.1 ± 1.15
AD-CP (%)	3.53 ± 0.21	1.96 ± 0.32	2.03 ± 0.21
Crude fat (%)	4.50 ± 0.26	4.60 ± 0.26	5.20 ± 0.26
NDF (%)	59.5 ± 1.16	66.0 ± 1.15	65.8 ± 1.16
ADF (%)	55.87 ± 2.04	54.23 ± 5.15	58.3 ± 2.04
Acid lignin (%)	24.50 ± 0.68	19.6 ± 1.05	20.90 ± 0.68
Ash (%)	9.74 ± 0.64	8.78 ± 0.21	8.97 ± 0.64
Ca (%)	1.69 ± 0.13	1.75 ± 0.18	1.67 ± 0.21
K (%)	1.09 ± 0.01	1.23 ± 0.11	0.82 ± 0.10
Mg (%)	0.18 ± 0.01	0.27 ± 0.04	0.15 ± 0.02
Na (%)	0.10 ± 0.01	0.11 ± 0.03	0.04 ± 0.02
P (%)	0.47 ± 0.06	0.43 ± 0.02	0.42 ± 0.70
S (%)	0.14 ± 0.01	0.13 ± 0.03	0.12 ± 0.03
Cu (mg/kg)	14.0 ± 2.6	14.0 ± 2.0	11.0 ± 0.0
Fe (mg/kg)	295.3 ± 25.5	279.9 ± 4.0	399.3 ± 20.0
Mn (mg/kg)	99.3 ± 19.4	122.0 ± 11.3	140.6 ± 37.1
Mo (mg/kg)	2.33 ± 1.4	3.5 ± 0.8	3.0 ± 0.8
Se (mg/kg)	0.13 ± 0.26	0.11 ± 0.23	0.20 ± 0.70
Zn (mg/kg)	68.0 ± 2.0	80.3 ± 9.01	89.7 ± 15.3

[a]All nutrients except water expressed on a dry matter basis.
NDF, neutral detergent fiber; ADF, acid detergent fiber; AD-CP, acid detergent crude protein.

TABLE 8. Digestion coefficients calculated for Sumatran rhinos (*Dicerorhinus sumatrensis*) from three 5-day feeding trials at the Cincinnati Zoo, 1997

Nuetrient	Ipuh	Rapunzel	Emi
Dry matter (%)	52.90	53.36	50.56
Crude protein (% apparent)	35.31	43.18	48.66
Crude protein (% true)	81.44	90.79	89.69
Metabolic fecal (N, %)	0.66	0.76	0.64
NDF (%)	36.49	27.51	21.92
HC (%)	68.35	25.74	43.49
ADF (%)	32.04	27.89	17.89
Cellulose (%)	37.45	28.80	16.40
Acid lignin (%)	20.42	26.21	23.58

Expressed on a dry matter basis.
NDF, neutral detergent fiber; HC, hemicellulos; ADF, acid detergent fiber.

DISCUSSION

All rhinos in this study consumed more DM than reported from other studies with this species (expected approximately 1% of body mass) [Zainal-Zahari et al., 1990; Michael, unpublished], with the male eating considerably more than either female. Although good body condition was maintained throughout the trials in all animals, the rhinos displayed clear individual food preferences that resulted in differences in the nutrient composition of diets consumed (Table 6) as well as their utilization (Table 8). Rapunzel, for example, consumed the most hay throughout the study and showed both the highest DM digestibility (DMD) as well as MFN components. The MFN, indicative of microbial contributions to the feces, may indicate a more dense (or diverse) gastrointestinal fauna in this animal compared with the others, but microbiology was not examined. Perhaps also digestive tract passage characteristics may have differed among the individuals to influence both digestibility and microbial parameters. It is interesting to note that Emi, who consumed the highest level of pellets, displayed a somewhat lower dietary DMD. Estimation of passage time in future studies would assist with interpretation of the subtle differences among individuals, as intake, passage, and digestibility were correlated in other studies with Sumatran rhinos [Michael, unpublished].

The DMD of diets consumed by the Sumatran rhinos in Cincinnati (52%) was lower than that reported for Sumatran rhinos fed native browses (65%, leaves only) [Michael, unpublished]. However, values were intermediate to those reported for another browsing rhino species, the black rhinoceros (*Diceros bicornis*) fed grass hay (43% DMD) or legume hay (65% DMD) in zoo studies [Foose, 1982], and more similar to those reported for black rhinos fed native browses (28–50% DMD) [Atkinson et al., 1997]. Given the composition of native food plants eaten, excessively digestible diets are not considered appropriate for browsing rhinoceros species in captivity. The high proportion of browse in the current diet likely contributed to the DMD coefficients. Lignification of cell wall constituents lowers digestibility, as lignin is defined as a chemically unavailable fiber fraction. The overall diets consumed by these rhinos were approximately 31% lignified (acid lignin as a proportion of NDF), which compares favorably with the average lignification index of the browses offered (32%) as well as native browses eaten by Sumatran rhinos (27%) in Indonesia [Dierenfeld et al., 1994].

The Cincinnati Zoo currently maintains the only Sumatran rhinos in captivity in North America and is one of only a few facilities to maintain this species globally. When the rhinos were originally captured in Sumatra, they were fed solely native browses and slowly conditioned to accept alfalfa hay as a browse substitute. To facilitate this process, the alfalfa was soaked in water and small amounts were combined with fresh browse to improve acceptability. Over time, the percentage of alfalfa was increased; the rhinos adapted to alfalfa hay soaked in water with no browse added, then gradually to dry alfalfa. It is clear, however, from published information [Van Strien, 1974; Dierenfeld et al., 1994; Dierenfeld, 1995] and the data in Tables 4 and 5 that domestic hays can be very different in chemical composition to tropical or sub-tropical browses consumed by this species. Alfalfa hays fed in the United States tend to be much higher in crude protein content and contain very different fiber and mineral constituencies compared with browses eaten by Sumatran rhinoceros in Indonesia [Dierenfeld, 1995]. In general, native browses have been shown to have a similar protein content as the hay fed in this study (approximately 12% overall crude protein, with 9% measured as available crude protein), but a much different fiber content.

In particular, the hemicellulose (HC) content of native browses from Indonesia (approximately 30% of total cell wall constituents) is higher than found in alfalfa (20%) or the browses fed in this study (11%). HC digestibility by rhinoceros (47–48% in zoo studies [Foose, 1982]) equals or surpasses that in ruminant herbivores and may be a ready source of carbohydrate energy to rhinos. The HC content of grasses compared with legume forages was a primary consideration in the recommendation of mixed grass:legume hays as more nutritionally appropriate substitute forages than either hay fed separately for the browsing rhino species [Dierenfeld et al., 1995]. Indeed, the digestibility of the HC fraction in our study ranged widely (26–68%), but averaged 46%.

The inclusion of a high proportion of sub-tropical browse in the diets also appears to contribute to the successful maintenance of this species at Cincinnati. Over the years, the male (Ipuh) has been fed a variety of temperate browses when available (along with herbivore pellets and alfalfa hay), but appetite was limited and preferences were distinct for mulberry (*Morus*), hackberry (*Celtis*), and willow (*Salix*) species. After the arrival of Rapunzel in 1993, a change to a higher-fiber browser pellet and mixed grass:legume hay was implemented successfully for 1 year, then the male showed depressed appetite for 6 months, went recumbent, and stopped eating for 4 days. The emergency acquisition of fresh *Ficus* browse (four species) from California stimulated his appetite immediately. The rhino consumed 20 kg of browse within the first 2 hours, continued to eat 32 to 40 kg/d, and regained 100 kg in 1 week. Fresh browse has also stimulated appetite in both females.

The current diet appears to be an appropriate amount that can be fed to maintain good health in Sumatran rhinoceros; increases will result in obesity. Weights should be monitored daily, particularly in colder months when animals have less outdoor access and activity. Overweight rhinos become lethargic and show signs of discomfort in the gut, which can be eliminated by removing pellets from the diet, limiting hay, and adjusting the quantities of fresh browse fed to meet appetite [Romo, personal observation].

Although the current diet appears to be suitable for non-reproductive maintenance of Sumatran rhinos, possible nutritional imbalances were identified from this detailed study. The browses offered, and particularly the preferred species *F.*

benjamina, appear low in available protein (crude protein minus AD-CP) compared with both native Indonesian browses and equine nutrient requirements. Additionally, the U.S.-grown browses are very low in HC compared with native browses from Indonesia (mean, 5% [*n* = 6 species] compared with 23% of DM [*n* = 10 species], respectively). HC content may be a function of species, growing conditions, age at harvest, or other factors and might be an important consideration in terms of digestibility and energetics.

More critically, however, the mineral constituents of the imported browses appear to differ considerably from those in Indonesian browses examined [Dierenfeld, 1995]. Although Ca ranges are similar between the two data sets (0.04–6.8% of DM), the overall mean for the North American browses (2.7% of DM; 2/3 leaves, 1/3 twigs, six species) is more than twofold higher than that summarized from 40 species examined in native food plants (1.2% of DM) [Van Strien, 1985; Lee et al., 1993; Dierenfeld et al., 1995]. Sodium may be limiting North American browses as it is in nature but can be readily obtained from available salt licks. Phosphorus appears to be limiting in browses, particularly in relation to calcium content. Hypophosphatemia, associated with health problems in captive black rhinoceros, has not been reported as a concern for Sumatran rhinos. Other macrominerals (potassium, magnesium) appear present in more than adequate concentrations. Of trace elements evaluated, copper, manganese, selenium, and zinc may be low in the North American browses; similar low copper, selenium, and zinc ranges were also found in native browses. Iron concentration was lowest in the preferred species *F. benjamina*; the mean for the North American browses (104 mg/kg DM) was approximately twice the average reported from Indonesia.

Overall diets consumed by Sumatran rhinos in the Cincinnati Zoo appear marginal in protein and zinc content, and possibly low in copper, but must be extrapolated with caution as the consumption of trace mineral salt supplements and water, available free-choice, was not quantified. Physiological measures including circulating plasma (or other tissue) nutrient concentrations and/or enzyme activity assessments are warranted to evaluate further mineral status.

CONCLUSIONS

1. Sumatran rhinos (*n* = 3) at the Cincinnati Zoo maintained body mass and condition on a diet containing produce (5–9% of DMI), mixed grass/alfalfa hay (2–14% of DMI), herbivore pellets (10–17% of DMI), and sub-tropical browses (62–83% of DMI) at a consumption level of 1.4 to 2.5% of body mass.

2. The nutrient composition of six species of sub-tropically grown browses showed that leaves did not differ from twigs in water or lignin content, but leaves had higher concentrations of protein (both crude and bound) and ash, and lower NDF and ADF concentrations compared with twigs. In evaluating the nutrient composition of diets consumed by browsing herbivores, separate sampling and analysis of leaf and twig fractions are imperative for accurate quantification of nutrient contributions.

3. Rhinos consumed browses with a leaf:twig ratio of approximately 2:1(wt:wt), which further weighted the nutrient contribution of the different plant fractions to the diet. Overall dietary DMD averaged 52%.

4. Although fresh browse is thought to be an integral part of the successful

management of the rhinos at Cincinnati, overall diets were found to be marginal in protein and zinc content and possibly low in copper relative to equine dietary recommendations. Contributions of a trace mineral supplement salt and water, available ad libitum, were not factored into this analysis, and other assessments of mineral status are suggested. All sources of minerals should be quantified and blood or other tissue samples analyzed to evaluate mineral-dependent enzymes and physiological status.

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