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Macromineral Absorption in the Black Rhinoceros (*Diceros bicornis*) Compared with the Domestic Horse[1–3]

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EXPANDED ABSTRACT

KEY WORDS: • *black rhinoceros* • *Diceros bicornis* • *horse* • *Equus caballus* • *sodium* • *potassium* • *magnesium* • *calcium* • *phosphorus* • *absorption*

There has been recent interest in the mineral status of free-ranging and captive rhinoceroses (1). Zoo diets for rhinoceroses and elephants deficient in different minerals have been recorded (2,3). Because the horse is usually considered the model animal for designing rhino diets (4), we wanted to generate data on the absorption of minerals in a rhino species, to facilitate a comparison with published data for domestic horses, and thus test the hypothesis that rhino mineral absorption resembles that of the horse.

MATERIALS AND METHODS

Feeding trials were performed with 8 black rhinoceroses (*Diceros bicornis*) from 3 zoological institutions. Ethical treatment of the animals was guaranteed in that during the trial, the usual zoo husbandry routine for these animals was applied. Animals were kept individually, food intake was recorded by weighing offered feeds and leftovers for 7 d, and fecal excretion by total collection for 5 d. Three to 5 different zoo rations, consisting of varying proportions of roughage, concentrates, and in some cases browse material, were fed (total n of trials = 32). Adaptation periods for new diets lasted at least a month. The feeding trials have been described in more detail recently (5). Representative samples of feeds and feces were analyzed for mineral content (Ca, P, Mg, Na, K). All analyses were run in duplicate. To 0.5 g of sample, 5 ml of 65% HNO_3 was added for wet ashing (1200 mega High Performance Microwave, MLS, Milestone). Mineral analysis was performed by inductively coupled plasma emission spectrometry (ICPES, JY66, Jobin Yvon). Because the results for Na were unexpected, analyses were repeated by flame photometry (EFOX 5053, Eppendorf). There was no difference between results generated by the 2 methods. Here, therefore, only ICPES results are given. Additional data for black rhinos were available from three unpublished studies (D. Paros and E. S. Dierenfeld, $n = 2$; T. Woodfine and E. S. Dierenfeld, $n = 2$; T. Froeschle and M. Clauss, $n = 14$; not all minerals analyzed in all cases). Apparent absorption (aA) of minerals was calculated using the formula aA [%] = (mineral ingested [g]– mineral excreted [g])/mineral ingested [g] × 100. Mineral content was plotted against absorbable mineral content in 100 g DM, and differences in the resulting regressions from those derived from literature data on domestic horses (6–44) as well as of calculated mean aA coefficients were tested by analysis of covariance (45) and *U*-test, respectively, using the SPSS 12.0 statistical package (SPSS Inc.). The regression slope (a) corresponds to the "true" absorption coefficient, and the negative intercept (b) to the endogenous fecal losses (EFL) (46). Significance level was set at $P < 0.05$.

RESULTS AND DISCUSSION

Dietary mineral contents, aA coefficients, and the regression equations are summarized in **Table 1**; the respective data plots

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TABLE 1

Mineral absorption characteristics in domestic horses (E. caballus) and black rhinoceroses (D. bicornis)

Mineral and Species	Observations, *n*	Dietary mineral concentration, *g/100g DM ± SD (range)*	Apparent absorption,[1] *% ± SD (range)*	a^2	b^2	R^2
Ca						
E. cab.	85	0.92 ± 0.62 (0.07, 2.66)	26^a ± 68 (−458–70)	0.41^a	−0.02	0.68***
D. bic.	50	0.82 ± 0.26 (0.36, 1.58)	80^b ± 5 (65–90)	0.84^b	−0.03	0.97***
P						
E. cab.	86	0.39 ± 0.22 (0.07, 1.39)	5^a ± 28 (−123–59)	0.45	-0.12^a	0.65***
D. bic.	36	0.37 ± 0.09 (0.19, 0.53)	23^b ± 10 (3–50)	0.32	-0.03^b	0.41***
Mg						
E. cab.	162	0.18 ± 0.07 (0.02, 0.73)	35^a ± 12 (−16–67)	0.15^a	0.03	0.17***
D. bic.	36	0.21 ± 0.06 (0.14, 0.40)	73^b ± 6 (58–84)	0.71^b	0.00	0.92***
Na						
E. cab.	163	0.24 ± 0.16 (0.01, 1.69)	56^a ± 29 (−140–95)	0.87	-0.06^a	0.87***
D. bic.	36	0.39 ± 0.16 (0.15, 0.74)	15^b ± 34 (−71–72)	0.84	-0.22^b	0.85***
K						
E. cab.	166	1.52 ± 0.85 (0.05, 3.65)	78^a ± 9 (45–94)	0.88^a	−0.11	0.98***
D. bic.	36	2.69 ± 0.78 (1.50, 4.37)	67^b ± 13 (37–88)	1.00^b	−0.83	0.93***

[1] Apparent absorption is defined as [mineral ingested (g)– mineral excreted (g)]/mineral ingested (g) × 100.

[2] According to the regression equation: apparent absorbable mineral content = *a* × mineral content + *b*, where a = the "true" absorption coefficient and b = endogenous fecal losses.

[a,b] Superscripts in a column without a common letter differ, $P < 0.001$ in the respective parameter for this mineral (apparent absorption, *U*-test; [a]ANCOVA, test for interaction; [b]ANCOVA test between groups).

*** Regression equations significant at $P < 0.001$ (regression analysis, *F*-test).

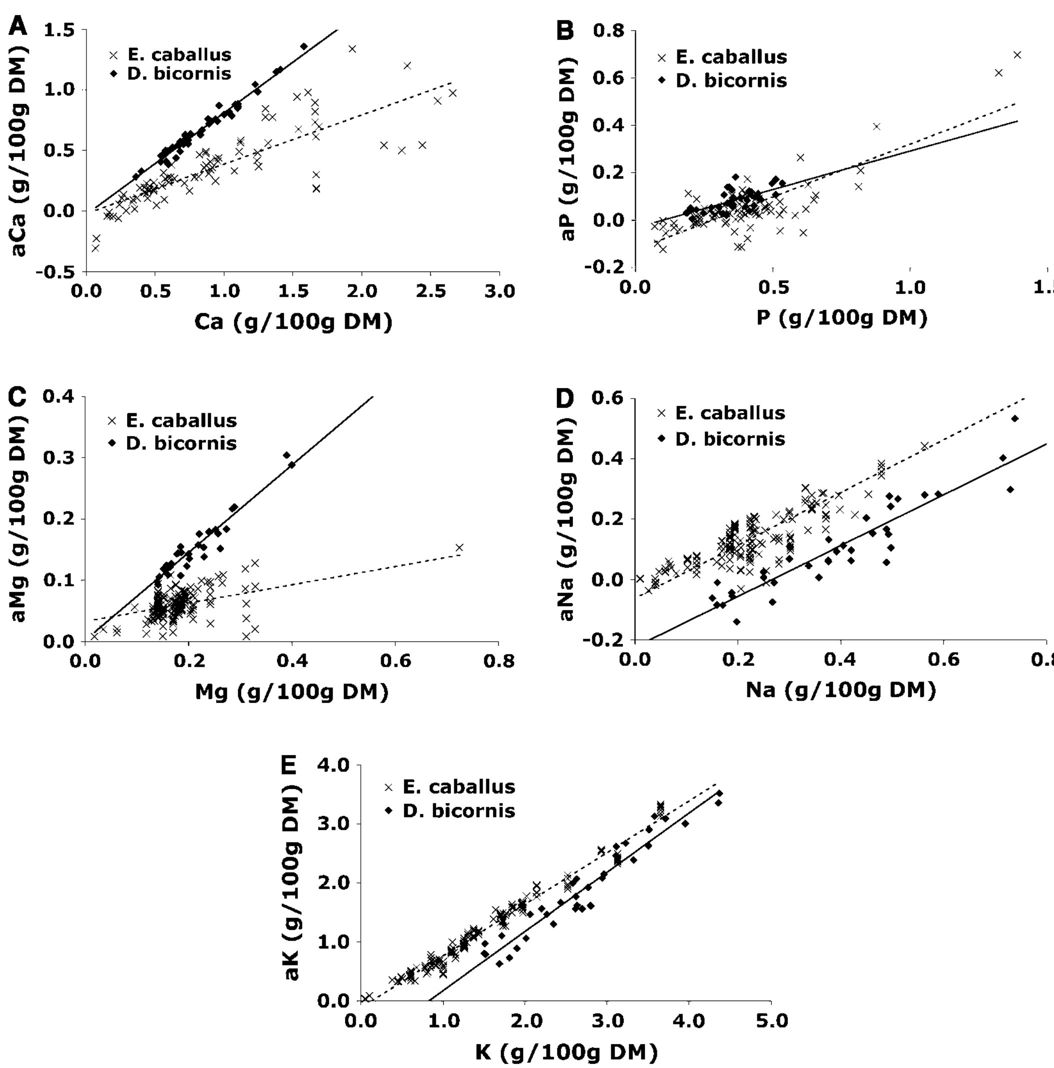

FIGURE 1 Correlations between the mineral content and the absorbable mineral content (g/100 g dry matter) in horses (*Equus caballus*) and black rhinoceroses (*Diceros bicornis*) for Ca (*A*), P (*B*), Mg (*C*), Na (*D*), and K (*E*). For significant differences between the species, see Table 1.

are depicted in **Figure 1**. The aA coefficients differed for all minerals. Black rhinos had a significantly higher "true" absorption of Ca and Mg. EFL of P were significantly lower in black rhinos (difference: 0.09 g/100 g DM). Regardless of a similar "true" absorption efficiency for Na, black rhinos had significantly higher Na EFL (difference: 0.16 g/100 g DM). K gave a similar pattern as Na, but in this case, the difference of 0.12 between the slopes was significant, and therefore, intercepts could not be compared.

These data suggest that differences in mineral absorption exist between species, even in the face of a similar digestive anatomy (47). For the management of captive rhinos, the results imply that diets designed according to horse requirements should be adequate, with the exception of Na. Therefore, salt licks should be provided to captive rhinos. Na is recognized as a limiting factor for populations of free-ranging herbivores, and natural Na lick use has been observed in many wild herbivore species (48–50). In terms of ecophysiology, the interesting question arises whether the high endogenous fecal Na losses of black rhinos are species-specific or represent an effect of increasing body size. If fecal Na excretion is considered an effect of fecal bulk (46,51), then species with generally lower apparent digestion coefficients and hence more fecal excretion, such as elephants or black rhinos as compared with white and Indian rhinos or horses (5,52,53), or browsing as compared with grazing ruminants (54), could be hypothesized to have higher Na EFL. In order to answer this question, comparable data from other wildlife species would be warranted.

LITERATURE CITED

1. Dierenfeld ES, Atkinson S, Craig AM, Walker KC, Streich WJ, Clauss M. Mineral concentrations in serum/plasma and liver tissue of captive and free-ranging rhinoceros species. Zoo Biol. 2005;24:51–72.
2. Clauss M, Polster C, Kienzle E, Wiesner H, Baumgartner K, von Houwald F, Streich WJ, Dierenfeld ES. Energy and mineral nutrition and water intake in the captive Indian rhinoceros (*Rhinoceros unicornis*). Zoo Biol. 2005;24:1–14.
3. Ange K, Crissey SD, Doyle C, Lance K, Hintz H. A survey of African (*Loxodonta africana*) and Asian (*Elephas maximus*) elephant diets and measured body dimensions compared with their estimated nutrient requirements. In: Edwards MS, Lisi KJ, Schlegel ML, Bray RE, editors. Proceedings of the Nutrition Advisory Group 4th Conference on Zoo and Wildlife Nutrition; 2001 Sep 19–23; Lake Buena Vista, FL. San Diego: Zoological Society of San Diego; 2001. p. 5–14.
4. Oftedal OT, Baer DJ, Allen ME. The feeding and nutrition of herbivores. In: Kleimann DG, Allen ME, Thompson KV, Lumpkin S, editors. Wild mammals in captivity: principles and techniques. Chicago: University of Chicago Press; 1996. p. 129–38.
5. Clauss M, Castell JC, Kienzle E, Dierenfeld ES, Flach EJ, Behlert O, Ortmann S, Streich WJ, Hummel J, Hatt JM. Digestion coefficients achieved by the black rhinoceros (*Diceros bicornis*), a large browsing hindgut fermenter. J Anim Physiol Anim Nutr (Berl). In press 2006.
6. Bertone AL, Van Soest PJ, Stashak TS. Digestion, fecal, and blood variables associated with extensive colon resection in the horse. Am J Vet Res. 1989; 50:253–8.
7. Brems R. Untersuchungen zur Verdaulichkeit verschiedener Rationen bei aktiv eingesetzten Sportpferden mit Hilfe einer modifizierten Indikatormethode und Überprüfung des Einflusses auf Gesundheit und Leistung [dissertation]. Giessen, Germany: JL-University Giessen; 1983.
8. Crozier JA, Allen VG, Jack NE, Fontenot JP, Cochran MA. Digestibility, apparent mineral absorption, and voluntary intake by horses fed alfalfa, tall fescue, and caucasian bluestem. J Anim Sci. 1997;75:1651–8.
9. Cymbaluk NF. Comparison of forage digestion by cattle and horses. Can J Anim Sci. 1990;70:601–10.
10. Cymbaluk NF, Christison GI, Leach DH. Nutrient utilization by limit- and ad libitum-fed growing horses. J Anim Sci. 1989;67:414–25.
11. Groenendyk S, English PB, Abetz I. External balance of water and electrolytes in the horse. Equine Vet J. 1988;20:189–93.
12. Gomda YM. Untersuchungen über die renale, fäkale und kutane Wasser- und Elektrolytausscheidung bei Pferden in Abhängigkeit von Fütterungszeit, Futtermenge sowie Bewegungsleistung [dissertation]. Hannover, Germany: TiHo Hannover; 1988.
13. Güldenhaupt V. Veträglichkeit und Verdaulichkeit eines Alleinfutters für Pferde in Kombination mit Stroh [dissertation]. Hannover, Germany: TiHo Hannover; 1979.
14. Günther C. Untersuchungen über die Verdaulichkeit und Verträglichkeit von Hafer, Quetschhafer, Gerste und Mais beim Pferd [dissertation]. Hannover, Germany: TiHo Hannover; 1984.
15. Hintz HF, Schryver HF. Availability to ponies of calcium and phosphorus from various supplements. J Anim Sci. 1972;34:979–80.
16. Hintz HF, Schryver HF. Magnesium, calcium and phosphorus metabolism in ponies fed varying levels of magnesium. J Anim Sci. 1973;37:927–30.
17. Hintz HF, Schryver HF. Potassium metabolism in ponies. J Anim Sci. 1976;42:637–43.
18. Kapusniak LJ, Potter GD. Calcium, magnesium and phosphorus absorption from the small and large intestine of ponies fed elevated amounts of aluminium. J Equine Vet Sci. 1988;8:305–9.
19. Krull HD. Untersuchungen über Aufnahme und Verdaulichkeit von Grünfutter beim Pferd [dissertation]. Hannover, Germany: TiHo Hannover; 1984.
20. Lindemann G. Untersuchungen über den Einfluss von Lactose- und Stärkezulagen auf die Verdaulichkeit von NH_3-aufgeschlossenem Stroh beim Pferd [dissertation]. Hannover, Germany: TiHo Hannover; 1982.
21. Meyer H, Ahlswede L. Untersuchungen über den Na-Stoffwechsel des Pferdes. Zentbl Vetmed Reihe A. 1979;26:212–20.
22. Meyer H, Schmidt M, Lindemann G, Muus H. Praecaecale und postileale Verdaulichkeit von Mengen- (Ca, P, Mg) und Spurenelementen (Cu, Zn, Mn) beim Pferd. Adv Anim Physiol Anim Nutr. 1982;13:61–9.
23. Meyer H, Stadermann B, Radicke S, Kienzle E, Nyari A. Untersuchungen zum Einfluss der Futterart auf Füllung und Zusammensetzung des Verdauungskanals sowie postprandiale Blut- und Harnparameter. Pferdeheilkd. 1993;9:15–25.
24. Mundt HC. Untersuchungen über die Verdaulichkeit von aufgeschlossenem Stroh für Pferde [dissertation]. Hannover, Germany: TiHo Hannover; 1978.
25. Nehring T. Einfluss der Futterart auf die Nettoabsorption von Calcium sowie Magnesium und Phosphor beim Pferd [dissertation]. Hannover, Germany: TiHo Hannover; 1991.
26. Ott EA, Feater JP, Panco PJ. Effect of calcium and phosphorus levels on availability of trace minerals. Proc Equine Nutr Physiol Symp. 1975;4:61–7.
27. Perez Noriega HR. Untersuchungen über den postprandialen Wasser- und Elektrolythaushalt des Pferdes unter Variation des Wasser- und Futterangebotes [dissertation]. Hannover, Germany: TiHo Hannover; 1989.
28. Pferdekamp M. Einfluss steigender Proteinmengen auf den Stoffwechsel des Pferdes [dissertation]. Hannover, Germany: TiHo Hannover; 1978.
29. Scheunert A, Schattke A, Weise M. Über den Kalk- und Phosphorsäurestoffwechsel des Pferdes bei normaler Fütterung. Biochem Z. 1923;139:1–10.
30. Schmidt M. Untersuchungen über die Verträglichkeit und Verdaulichkeit eines pelletierten Mischfutters für Pferde in Kombination mit Heu und NH_3-aufgeschlossenem Stroh [dissertation]. Hannover, Germany: TiHo Hannover; 1980.
31. Schryver HF, Craig PH, Hintz HF. Calcium metabolism in ponies fed varying levels of calcium. J Nutr. 1970;100:955–64.
32. Schryver HF, Hintz HF, Craig PH. Calcium metabolism in ponies fed a high phosphorus diet. J Nutr. 1971;101:259–64.
33. Schulze K. Untersuchungen zur Verdaulichkeit und Energiebewertung von Mischfuttermitteln für Pferde [dissertation]. Hannover, Germany: TiHo Hannover; 1987.
34. Smiley LK, Greene LW, Potter GD, Arnold FF. Digestibility of calcium in alfalfa hay in the equine small intestine. Proc Equine Nutr Physiol Symp. 1985;9:124–8.
35. Stürmer K. Untersuchungen zum Einfluss der Fütterung auf den Säure-Basen-Haushalt bei Ponies [dissertation]. Munich, Germany: LM-University Munich; 2005.
36. Swartzman JA, Hintz HF, Schryver HF. Inhibition of calcium absorption in ponies fed diets containing oxalic acid. Am J Vet Res. 1978;39:1621–3.
37. Tangl F. Zur Kenntnis des P-, Ca-, und Mg-umsatzes bei Pflanzenfressern. Pflügers Arch Eur J Physiol 1902;89:227–39.
38. Teleb H. Untersuchungen über den intestinalen Ca-Stoffwechsel bei Pferd nach variierender Ca-Zufuhr und einer Oxalatzulage. [dissertation]. Hannover, Germany: TiHo Hannover; 1984.
39. Verthein B. Auswirkungen einer Enzymgabe auf die Futterverdaulichkeit beim Pferd. [dissertation]. Hannover, Germany: TiHo Hannover; 1981.
40. v Wedemeyer HC. Untersuchungen zum Calcium-, Phosphor- und Natrium-Umsatz des erwachsenen Pferdes. [dissertation]. Göttingen, Germany: University of Göttingen; 1970.
41. Weidenhaupt K. Untersuchungen zum Kaliumstoffwechsel des Pferden. [dissertation]. Hannover, Germany: TiHo Hannover; 1977.
42. Whitlock RH, Schryver HF, Krook L, Hintz HF, Craig PH. The effects of dietary calcium in horses. Proc Am Assoc Equine Pract. 1970;16:127–34.
43. Wolff E. Pferde-Fütterungsversuche, 13. Bericht: Vergleichende Versuche mit Pferd und Hammel über die Verdaulichkeit von Wiesenheu und Kleeheu, nebst Beobachtungen über die Ausscheidung der Mineralstoffe bei Pferden. Landw Jb. 1884;13:271–90.
44. Wolff E. Pferde-Fütterungsversuche, 15. Bericht: Versuche über die Leistungsfähigkeit des Pferdes bei stickstoffreicherem und stickstoffärmeren Futter, sowie über den Kreislauf der Mineralstoffe im Körper dieses Tieres. Landw Jb. 1887; 16 (Suppl 3): 1,49,95.
45. Huitema BE. The analysis of covariance and alternatives. New York: John Wiley & Sons; 1980.
46. Robbins CT. Wildlife feeding and nutrition. San Diego: Academic Press; 1993.
47. Stevens CE, Hume ID. Comparative physiology of the vertebrate digestive system. Cambridge: Cambridge University Press; 1995.
48. Denton D. The hunger for salt. Berlin: Springer; 1984.

49. Jones RL, Hanson HC. Mineral licks, geophagy, and biogeochemistry of North American ungulates. Ames: Iowa State University Press; 1985.

50. Bowell RJ, Warren A, Redmond I. Formation of cave salts and utilization by elephants in the Mount Elgon region, Kenya. In: Appleton JD, Fuge R, McCall GJH, editors. Environmental geochemistry and health. Geological Soceity Special Publicaton No. 113, 1996, p. 63–79.

51. Kienzle E, Wichert B, Dobenecker B, Schuster S. Effect of fecal water and dry matter excretion on fecal mineral excretion in dogs studied in a fiber model. J Nutr.2001S3S.

52. Clauss M, Loehlein W, Kienzle E, Wiesner H. Studies on feed digestibilities in captive Asian elephants (*Elephas maximus*). J Anim Physiol Anim Nutr (Berl). 2003;87:160–73.

53. Clauss M, Polster C, Kienzle E, Wiesner H, Baumgartner K, von Houwald F, Ortmann S, Streich WJ, Dierenfeld ES. Studies on digestive physiology and feed digestibilities in captive Indian rhinoceros (*Rhinoceros unicornis*). J Anim Physiol Anim Nutr (Berl). 2005;89:229–37.

54. Pérez-Barbería F, Elston D, Gordon I, Illius A. The evolution of phylogenetic differences in the efficiency of digestion in ruminants. Proc Biol Sci. 2004;271: 1081–90.