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EFFECT OF AN ALUMINUM SUPPLEMENT ON NUTRIENT DIGESTIBILITY AND MINERAL METABOLISM IN THOROUGHBRED HORSES

K. A. ROOSE, K. E. HOEKSTRA, J. D. PAGAN, R. J. GEOR
Kentucky Equine Research, Inc., Versailles, KY

Summary

The effect of aluminum supplementation on nutrient digestibility and macro- and micromineral balance was studied in balance trials in mature Thoroughbred horses (n=4) in a replicated 2 X 2 Latin square experiment, with each period lasting four weeks. A 5-day complete digestion trial was performed at the end of each period. The treatments were: 1) a basal diet that consisted of 2 kg/d unfortified sweet feed, 6.8 kg/d mixed hay and 1 oz sodium chloride, and containing 159.90 ppm of aluminum; and 2) the basal diet plus 224 g of an aluminum-containing supplement (30301 ppm aluminum in the form of dihydroxy-aluminum sodium carbonate and aluminum phosphate), and providing 931 ppm aluminum. There was no effect of aluminum supplementation on nutrient digestibility or the metabolism of calcium, phosphorus, magnesium, zinc, copper and boron. However, urinary iron excretion was higher ($P < 0.05$) for the aluminum-supplemented diet compared to the basal diet. It is concluded that short-term consumption of a diet containing 930 ppm aluminum has negligible effect on nutrient digestibility and mineral metabolism in horses.

Introduction

In ruminants and horses, it has been reported that high levels of aluminum in the diet adversely affect the metabolism of other minerals, particularly calcium and phosphorus (Allen, 1984; Schryver et al., 1986). Allen (1984) reported that diets containing greater than 1500 ppm aluminum (as $AlCl_3$) reduced phosphorus absorption and increased the dietary phosphorus requirement in sheep. Allen (1984) also found that a single large dose of aluminum in ruminants resulted in a significant decrease in phosphorus incorporation into tissue, including blood, liver, kidney, brain, muscle and bone. In ponies, Schryver et al.(1986) demonstrated a 30% decrease in phosphorus absorption in ponies fed a diet containing 4500 ppm aluminum. Although calcium absorption was unaffected by this level of aluminum intake, the ponies were in negative calcium balance because of greater urinary excretion of calcium compared to the basal diet. These authors speculated that the increase in urinary loss of calcium was due to reduced use of calcium in the formation of hydroxyapatite, presumably because of the lack of phosphate. On the other hand, aluminum intake of 1500 ppm or less does not appear to adversely affect mineral metabolism in horses. In the study by Schryver et al. (1986), a diet containing 1370 ppm aluminum had no effect on macro- or micromineral balance. Similarly, in ruminants, there was little effect of aluminum on mineral metabolism at levels of aluminum intake below 1000 ppm.

Gastric ulceration is common in horses, particularly those in race training. Antacids, basic compounds that neutralize acid in the gastric lumen, are frequently administered to horses for the treatment and prevention of gastric ulcers (MacAllister, 1999). An antacid specifically formulated for horses has recently become available (Neigh-Lox™). As the active ingredient in this product contains aluminum, one concern is the effect of high aluminum intake on mineral metabolism. Therefore, the current study was undertaken to determine the effects of ingestion of this aluminum-containing product on nutrient digestibility and mineral balance in Thoroughbred horses.

Materials and Methods

Four mature Thoroughbred geldings (mean age of 12 years, mean body weight 568 kg), were used in a replicated 2 x 2 Latin square design. Each dietary period consisted of a 21-day adaptation period and a five day complete collection digestion trial. Horses were turned out into paddocks during the day with muzzles to prevent grazing (0830 to 1600) and were housed in 3.0 m x 3.0 m stalls overnight (1600 to 0830). The basal diet (CON) consisted of 6.8 kg mixed hay, 2 kg unfortified sweet feed and 1 oz sodium chloride (39.34% sodium and 60.66% chloride) (Table 1). The grain ration was divided into two equal feedings (0700 and 1600 h), and forage was provided at 0700, 1600 and 2200 h. Fresh water was available at all times. The treatment (AL) diet was the basal diet plus 8 oz per day (4 oz in each grain meal) of an aluminum-containing supplement (Neigh-Lox™), KPT Technology Inc., Midway, KY) (Table 1). The basal and aluminum-supplemented diets were 159 and 931 ppm aluminum per kg of feed, respectively, and provided approximately 1 and 12 mg of aluminum/kg body weight/day.

After a 3-week period on each diet, the horses were fitted with collection harnesses (Equisan PTY Ltd., Melbourne, Australia) that allowed complete and separate collection of urine and feces. Intake of feed and water and excretion of feces and urine were measured daily for 5 days (during the last week of each dietary period). Composite samples of feed, feces and urine representing the 5 days of collection were prepared. Blood samples for determination of serum biochemistry were taken before and after each dietary period. Feed and feces were analyzed for dry matter, crude protein, acid detergent fiber, neutral detergent fiber, hemicellulose, fat, nonstructural carbohydrates, calcium, phosphorus,

TABLE 1. Nutrient composition of the diet.

Nutrient	Grain[2]	Forage	Supplement*
Dry matter, %	85.88	90.77	91.65
Crude protein (CP), %[1]	0.98	19.50	8.76
Acid detergent fiber (ADF), %[1]	8.92	26.67	2.20
Neutral detergent fiber (NDF), %[1]	22.20	42.83	8.11
Hemicellulose, %[1,3]	13.28	16.16	5.91
Fat, %[1]	4.53	1.92	6.88
Ash, %[1]	3.00	8.82	18.73
Nonstructural carbohydrates (NSC),%[1,4]	9.29	6.93	57.52
Calcium, %[1]	0.14	1.19	1.04
Phosphorus, %[1]	0.33	0.31	2.53
Magnesium, %[1]	0.17	0.16	0.11
Potassium, %[1]	0.87	2.41	0.64
Sodium, %[1]	0.08	0.02	1.67
Chloride, %[1]	0.00	0.00	0.00
Iron, ppm[1]	119.00	141	421
Zinc, ppm[1]	29.00	18.7	6.20
Copper, ppm[1]	10.10	8.90	10.40
Manganese, ppm[1]	24.50	53.40	31.40
Aluminum, ppm[1]	79.60	80.30	30301.40
Boron, ppm[1]	6.125	27.24	4.412

[1] 100% dry matter basis
[2] 45% cracked corn, 45% whole oats, 10% molasses
[3] Hemicellulose = NDF - ADF
[4] NSC = 100 - (CP + NDF + Fat + Ash)
* Neigh-Lox™

magnesium, potassium, sodium, chloride, iron, zinc, copper, manganese, aluminum and boron. Urine samples were analyzed for calcium, phosphorus, magnesium, potassium, sodium, chloride, iron, zinc, copper, manganese, aluminum and boron (Rock River, Watertown, WI, USA). The apparent digestibility of each nutrient was calculated. Serum chemistry measurements were made using an automated analyzer (Cobas Mira Analyzer, Rood and Riddle, Lexington, KY, USA).

Data were analyzed by analysis of variance with general linear model procedures. The model included horse, period and treatment as main effects. Treatment comparisons were made by a paired student t-test.

TABLE 2. Apparent digestibility of horses receiving the control diet or the diet supplemented with aluminum.

% Digestibility	Treatment CONTROL (n = 4)	Treatment ALUMINUM[1] (n = 4)	SEM
Dry matter	58.65	58.09	0.78
Crude protein (CP)	67.61*	65.97	0.24
Acid detergent fiber (ADF)	21.11	19.28	1.55
Neutral detergent fiber (NDF)	35.72	34.45	1.71
Hemicellulose	57.18	56.55	2.02
Fat	28.91	32.00	4.40
Ash	35.23	30.61	1.83
Nonstructural carbohydrates (NSC)	86.83	87.52	0.25
Calcium	35.55	40.90	1.00
Phosphorus	-35.75	-28.75	2.42
Magnesium	-6.52	-5.50	2.47
Potassium	62.54	58.75	1.35
Sodium	18.20	24.86	4.28
Chloride	77.77	75.98	1.90
Iron	-155.34	-131.89	33.55
Zinc	-262.53	-187.78	15.62
Copper	-189.86	-155.78	26.00
Manganese	-147.65	-151.44	6.94
Aluminum	-303.15*	563.64	37.25
Boron	-58.85	-39.83	10.79

[1]Neigh-Lox™

*Significant difference between Control and Aluminum-supplemented diet, $P < 0.05$ (SEM, standard error of the mean)

TABLE 3. Urinary mineral excretion in horses receiving the control diet or the diet supplemented with aluminum.

	Treatment CONTROL (n = 4)	Treatment ALUMINUM[1] (n = 4)	SEM
Calcium (g)	19.07	20.57	1.94
Phosphorus (g)	0.30	0.33	0.02
Magnesium (g)	3.83	4.21	0.32
Potassium (g)	102.00	98.29	2.05
Sodium (g)	5.89	6.33	0.70
Chloride (g)	71.16	68.39	2.09
Iron (mg)	201.40	255.70*	6.00
Zinc (mg)	41.73	43.97	3.90
Copper (mg)	37.18	38.17	4.63
Manganese (mg)	4.81	5.87	0.53
Aluminum (mg)	205.75	198.10	18.94
Boron (mg)	114.45	127.56	10.08

[1]Neigh-Lox™

*Significantly greater ($P < 0.05$) compared with Control treatment

TABLE 4. Effect of basal and high aluminum intakes on mineral metabolism in horses fed the two diets.

Aluminum Treatment	Intake	Urine	Feces	Retained
		Calcium		
Basal	135.2	34.0	85.8	15.4
High	138.0	36.3	82.6	19.1
		Phosphorus		
Basal	44.2	0.50	60.2	-16.5
High	53.3	0.60	68.6	-16.0
		Magnesium		
Basal	22.8	6.8	24.1	-8.2
High	23.1	7.4	24.5	-8.9
		Potassium		
Basal	291.7	180.9	108.4	2.3
High	292.0	173.2	123.1	-4.3
		Sodium		
Basal	24.5	10.6	19.3	-5.4
High	30.6	11.2	23.5	-4.1
		Chloride		
Basal	140.1	126.4	31.4	-17.7
High	140.2	121.2	34.1	-15.1
		Iron		
Basal	1.92	0.36	4.95	-3.40
High	2.06	0.46	5.15	-3.55
		Zinc		
Basal	295.8	71.6	1020.7	-796.5
High	314.9	79.9	945.2	-710.2
		Copper		
Basal	128.7	67.9	245.9	-185.1
High	131.8	66.7	219.2	-154.0
		Manganese		
Basal	662.2	8.7	1215.6	-562.1
High	669.3	10.6	1276.9	-618.1
		Aluminum		
Basal	1.12	0.36	4.10	-3.34
High	12.32	0.36	16.1	-4.10
		Boron		
Basal	318.4	201.9	240.1	-123.6
High	317.7	229.9	185.1	97.2

Calcium, phosphorus, magnesium, potassium, sodium, chloride, iron and aluminum values are mg/kg of body weight/day. Values for zinc, copper, manganese and boron are µg/kg body weight/day.

TABLE 5. Serum biochemistry values in horses receiving the control diet or the diet supplemented with aluminum.

	Treatment		
	CONTROL (n = 4)	ALUMINUM[1] (n = 4)	SEM
Blood urea nitrogen (mg/dl)	17.75	19.00	1.60
Creatinine (mg/dl)	1.42	1.45	0.10
Aspartate aminotransferase (iu/l)	259.50	425.75	189.09
Total bilirubin (mg/dl)	2.20*	1.62	0.09
Direct bilirubin (mg/dl)	0.40	0.28	0.07
Alkaline phosphatase (iu/l)	77.25	65.25	4.14
Lactate dehydrogenase (iu/l)	190.25	253.00	85.14
Creatine phosphokinase (iu/l)	149.25	938.75	803.13
Sorbitol dehydrogenase (iu/l)	142.50	160.50	60.7
g-glutamyl transferase (iu/l)	13.75	11.75	0.71
Albumin (g/dl)	3.50	3.43	0.08
Calcium (mg/dl)	3.65	13.4	0.24
Phosphorus (mg/dl)	3.73	3.50	0.22
Glucose (mg/dl)	88.25	88.00	5.80
Sodium (mmol/l)	137.00*	133.75	0.25
Potassium (mmol/l)	3.50	3.63	0.05
Chloride (mmol/l)	100.00	98.25	0.63
HCO_3 (mmol/l)	25.00	24.00	0.41

[1]Neigh-Lox™
*Significantly greater (P < 0.05) compared with Aluminum treatment

Results

Consumption of a diet with a moderately high aluminum content (930 ppm) had minimal effect on nutrient digestibility and mineral balance. High aluminum intake resulted in a significant (P<0.05) reduction in the apparent digestibility of crude protein, but this difference was very small (67.61% in CON vs. 65.97% in AL) (Table 2). In general, external balance of the macro- and microminerals also was unaffected by the high aluminum intake. However, urinary excretion of iron was significantly (P<0.05) greater when the horses consumed the high aluminum diet (Table 3). There was no effect of high aluminum intake on the absorption, excretion or retention of calcium, phosphorus, sodium, potassium, chloride, magnesium, zinc, copper, manganese and boron (Table 4). Retention of aluminum was not affected by the level of aluminum in the diet. For both dietary periods, serum biochemical variables were within reference limits for the analytical laboratory (Table 5). Serum sodium and total bilirubin were significantly (P<0.05) higher for the control diet compared to the aluminum-supplemented diet.

Discussion

The results of this study indicate that short-term consumption (one month) of a diet containing moderately high levels of aluminum (930 ppm) has negligible effect on nutrient digestibility and external mineral balance in horses. These findings are consistent with the results of a previous study in ponies, wherein an aluminum intake of 1370 ppm had no effect on mineral metabolism (Schryver et al., 1986). Furthermore, aluminum intakes of less than 1000 ppm in ruminants do not adversely affect mineral metabolism (Allen, 1984). The primary concern with high aluminum intake is reduced phosphorus absorption (Allen 1984; Schryver et al., 1986). Although the mechanism for this inhibition of phosphorus absorption has not been determined, it has been hypothesized that insoluble, nonabsorbable aluminum-phosphate complexes form in the intestinal tract (Allen, 1984). Importantly, 50% of the aluminum in the supplement fed in the present study was in the form of aluminum phosphate. This form of aluminum would be expected to have minimal effect on the digestion and absorption of dietary phosphorus. It should also be emphasized that, in equids, adverse effects of dietary aluminum on calcium and phosphorus metabolism have only been documented at extremely high levels of intake (4500 ppm or more than four times greater than the aluminum intake in the present study).

In summary, the results of this study indicate that short-term consumption of an aluminum-containing nutritional supplement, when fed at the manufacturer's recommended level of intake, has negligible effect on nutrient digestibility and external mineral balance in mature horses.

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