Review Articles

Recent progress in exploring the essentiality of the ultratrace element cadmium to the nutrition of animals and man

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Abstract

Cadmium-poor nutrition (< 15 μg Cd/kg feed dry matter (DM)) did not affect feed intake and growth rate, while it affected reproduction performance. Intrauterinally cadmium-depleted kids were often phlegmatic, too lazy to eat and drink, and died of muscle weakness. With oral application of the control feed (300 μg Cd/kg DM), they slowly regained their mobility. Feeding them 65 μg Cd/kg feed DM prevented myasthenia. The normative cadmium requirement of goats (and animals in general) amounts to < 20 μg/kg diet DM. The daily requirement of humans might be < 3 μg.

Keywords : cadmium, essentiality for animals, geological influences, intake by man, foodstuffs

Introduction

Cadmium is well known as a toxic element. Its essentiality is disputed. Smith [1] noted that, although a specific function for cadmium is not known, this metal is a good candidate for essentiality. First results regarding the essentiality of cadmium in goats and rats were published 1977 [2, 3, 4]. In rats, cadmium supplementation (50 to 100 μg/kg feed dry matter, DM) increased the growth rate in one experiment, whereas in other examinations it did not influence the development.

Better evidence of the essentiality of cadmium is available after ten repetitions of cadmium deficiency experiments with growing, pregnant and lactating goats and their kids, and the discovery of a cadmium-specific carboanhydrase in the diatom Thallasia sira weissflogii [5], which is involved in acquiring inorganic carbon. On the other hand, cadmium mimics the in-vivo effects of estrogen in the uterus and mammary glands of rats [6]. Women with estrogen contraceptives excreted significantly more cadmium with the faeces than those without such contraceptives [2].

Informations to material and methods are given bei Anke et al., Res. Trace Elemens, 16 : 2005.

Essentiality of cadmium for animals

The essentiality of cadmium was investigated systematically in control goats with 300 μg Cd/kg feed DM, and in corresponding cadmium-deficient animals with < 15 μg/kg feed DM (Table 1). Cadmium-poor nutrition did not have any effect on feed intake (629 and 644 g/day, respectively). Live weight gain (18.2 and 16.8 kg by day 91 of life, respectively) was not affected by cadmium-poor nutrition, whereas cadmium deficiency had a significant effect on first insemination, rate of abortion and number of services per gravidity. The cadmium-poor nutrition of mothers affected the activity of the kids. The intrauterinely cadmium-depleted kids were often very phlegmatic, moved very little, were too lazy to eat and drink, and had problems holding their heads erect (Figure 1). The symptoms of impaired mobility occurred at different times of the lactation period. Of nine kids (6 males, 3 females) from cadmium-deficient goats, all showed clinical deficiency symptoms in the form of muscular weakness about 6 weeks after weaning. Subsequently, six of the cadmium-deficient kids died. The last three survivors were then given the feed of control animals,

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with 300 μg Cd/kg DM matter, by means of an esophageal tube, and slowly regained their mobility and achieved their normal body weight. Myasthenia also occurred due to nutrition depletion in lactating goats, and, without cadmium supplementation, led to death. Feeding cadmium (65 μg/kg feed DM) prevented the occurrence of cadmium-deficiency symptoms [2, 7, 8, 9].

The liver, muscles, heart, kidneys and cerebrum of cadmium-deficient goats were examined with regard to their ultrastructure. Primarily, the mitochondria appeared to be damaged and their size increased, with degenerative changes especially in mitochondria of the liver and kidneys. Christolysis and enlargements were also detected. The mitochondria were only detectable because of their double membrane and detectable isolated christae - changes which could not be found in other organs. Within these organs, the considerable increase in regularly arranged christae was impressive. There were also striking reductions in the contractile apparatus of the cardiac and skeletal muscles. Such findings point to reduced protein synthesis or, in lactating goats, to increased protein mobilization from muscles. This hypothesis might explain the reduction of the contractile system, but not the increased mitochondrial size. Such hyperplasia was found when there was an insufficiency of mitochondria, and might represent compensatory hypertrophy [8, 9, 10].

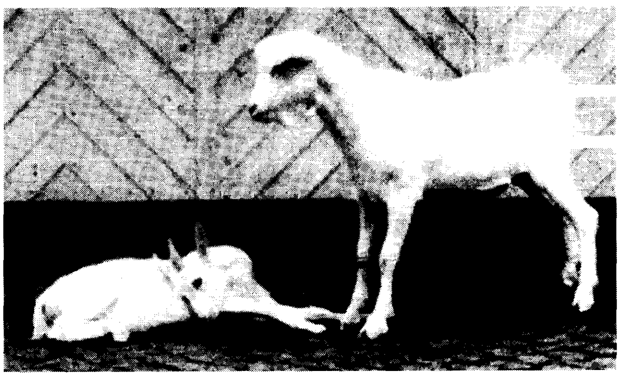

Figure 1 Left : cadmium-deficient kid ; right : control kid

The normative cadmium requirement of goats and animals amounts to < 20 μg/kg DM. Primary cadmium deficiency is not to be expected in animals, as the normal intake is considerably above this range [11].

Influence of the geological origin of the soil on the cadmium content of the vegetation

The acid weathering soils of granite rock transferred most cadmium into the food chain in Germany and Europe, whereas the more neutral soils of Muschelkalk, Keuper and loess and humus-rich boglands produce a significantly cadmium-poor flora (Table 2). The cadmium content in the flora may increase twentyfold in the vicinity of non-ferrous metal smelteries and cadmium producing and processing plants [12, 13].

Cadmium intake by humans

The cadmium intake by adult Germans with mixed diets has decreased by about > 10% over the last 12 years and is quite low. In Mexico, the cadmium con-

Table 1 Influence of Cd-poor nutrition on feed intake, growth, reproduction, mortality and milk performance

Parameter			Control goats	Cd-deficient goats	$p^{2)}$	$\%^{1)}$
Cd-content of the feed		μg/kg DM	< 300	< 15	< 0.001	< 5
Feed intake	First year of life	g/day	687	679	>0.05	99
	Adult goats	g/day	629	644	< 0.05	102
Growth	Birth weight < 1.6 kg	%	0	5	< 0.05	-
	Live weight 91st day	kg	18.2	16.8	>0.05	92
	Live weight 101st-268th day	g	86	78	> 0.05	91
Reproduction performance	Success of first insemination	%	73	46	< 0.001	-
	Conception rate	%	85	72	>0.05	-
	Abortion rate	%	0	12	< 0.01	-
	Service per gravidity		1.2	2.2	< 0.001	-
	Sex ratio (female = 1)		1.4	1.5	> 0.05	-
Mortality	Kids 7th to 91th day	%	8	43	< 0.001	-
	Adult goats 1st and 2nd year		30	41	< 0.001	-
Milk performance	Amount of milk	ml/day	1010	730	< 0.001	72
	Milk of 4% fat	ml/day	882	581	< 0.001	66
	Fat	g/day	35	23	< 0.001	66
	Protein	g/day	28	22	< 0.001	79

$\%^{1)}$ Control goats = 100 %, Cadmium deficiency goats = x %; $p^{2)}$ = Significance level, Student test

Table 2 Influence of the geological origin of the site on the relative cadmium contents of the flora in Central Europe

Geological origin of the site	Relative index
Granite weathering soils	100
Rotliegende weathering soils	90
Boulder clay	86
Phyllite weathering soils	82
Slate weathering soils (Devonian, Silurian, Culm)	81
Gneiss weathering soils	79
Bunter weathering soils	75
Alluvial riverside soils	71
Diluvial sands	70
Muschelkalk weathering soils	69
Keuper weathering soils	67
Loess	60
Bogs, peat soils	52

Table 3 Cadmium intake by German and Mexican adults with mixed and ovolacto-vegetarian diets depending on time and gender (μg/day) ($n^{2)}$ = 1750)

Form of diet, country	Women		Men		Fp[1)]	%
	s	x	s	x	p	
Mixed diet (MD) Germany (G) 1.	12	8.4	10	9.1	< 0.001	119
Germany 4.	6.2	9.2	12	8.7		130
Germany 8.	4.4	7.1	8.8	5.1		124
Mexico (M) 8.	2.7	4.8	5.8	3.3	< 0.001	121
Vegetarian (V) Germany 8.	6.8	11	17	13	< 0.001	155
Fp p MDG 1.: MDG 8.	< 0.001					
MDG 8.: MDM 8.	< 0.001		< 0.001			
MDG 8. : VG 8.	< 0.001		< 0.001			
% MDG 1. : MDG 8.	85		88		–	
MDG 8. : MDM 8.	68		66			
MDG 8. : VG 8.	155		193			

Fp[1)] = Significance level in one- or multifactorial variance analysis; n[2)] = Number

Table 4 The cadmium contents of foods (μg/kg dry matter) and beverages (μg/L) (n 1506)

Vegetable foods		Animal foods		Beverages	
Sugar-rich products	2.5-5.0	Cheese	1.0-5.0	Drinking water	0.5
Starch	5.0-10	Infant formulas	1.0-10	Brandy	0.9
Fruits	5.0-40	Marine fish	2.0-25	Cola, lemonade	1.0
Bread, cake	10-55	Sausage	3.0-28	Wine	1.0
Prepared cereals, flour	5-50	Meat	2.0-20	Beer	1.2
Vegetables	13-550	Curd, milk	4.0-10	Juice	1.4
Herbs, spices	500-1800	Kidneys, cattle	800	Advokaat	1.6

sumption is one third lower than in Germany, and ovolacto-vegetarians eat 50 to 90% more cadmium than people with mixed diets (Table 3). Their higher cadmium intake is only partly due to their higher dry matter consumption. Vegetable foodstuffs contain more cadmium than animal foodstuffs (except kidney and liver).

On average, the cadmium intake in Germany and Japan is similar [10, 14, 15, 16, 17].

Cadmium contents of foodstuffs and beverages

The cadmium contents of the foodstuffs examined were comparable with results of recent studies carried out in Europe and Japan [18, 19] (Table 4). In Europe, sugar and sugar-rich products, starch, as well as milk and dairy products contain 1 to 10 μg Cd/kg dry matter (DM). The cadmium contents of fruits, meat, marine fish and sausage deliver, on average 2 to 30 μg Cd/kg DM to the food chain of Europeans. Bread, cake, prepared cereals, and flour are relatively rich in cadmium, storing 10 to 50 μg Cd/kg DM.

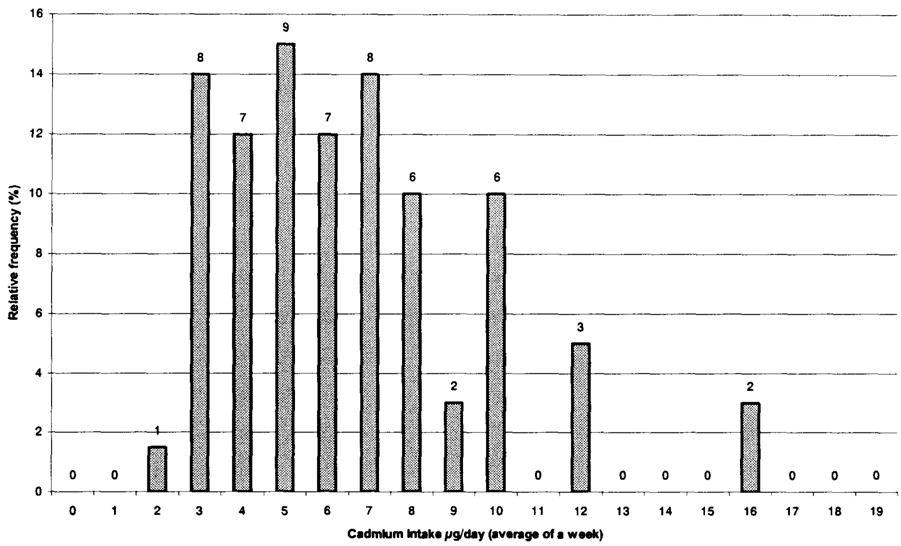

Figure 2 Frequency distribution of the daily cadmium intake by women

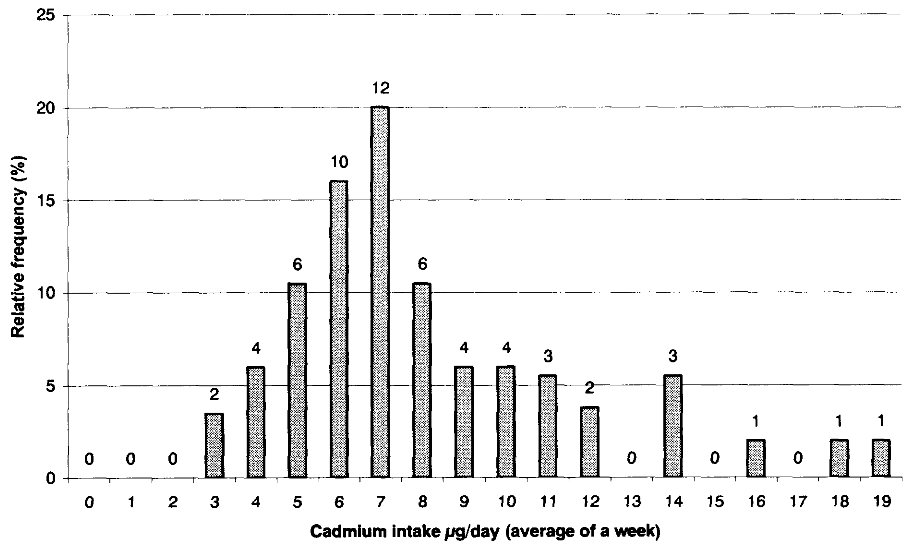

Figure 3 Frequency distribution of the daily cadmium intake by men

Vegetables contain extremely different cadmium levels. Pulses (beans, peas, lentils) store only 10 to 25 μg Cd/kg DM. Red and white cabbage, sauerkraut, asparagus, cauliflower, tomatoes, potatoes and mixed mushrooms deliver 30 to 100 μg cadmium to the food chain, whereas cucumber, kohlrabi, carrots and especially lettuce provide 100 to 600 μg Cd/kg DM. Herbs (chive, parsley, dill) accumulate between 500 and 2000 μg Cd/kg DM.

Beverages in Germany are relatively poor in cadmium, containing between 0.5 and 1.6 μg Cd/L.

Discussion

On the average of a week, the German test subjects consumed 2 to 16 μg Cd/day (women) and 3 to 9 μg Cd/day (men), respectively (Figures 2, 3). These cadmium intakes are far from harmful. In case of cadmium being essential for man, the normative requirement may be $>$ 3 μg Cd/day, while that of animals is $<$ 20 μg/kg feed dry matter.

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