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Nickel Toxicity in Growing Chicks [1]

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ABSTRACT Two experiments have been conducted with chicks to determine the effects of high levels of dietary nickel on growth and nutrient utilization. Dietary nickel was supplied as either the acetate or sulfate salt at levels up to 1300 ppm in a basal diet calculated to be adequate in all known nutrients. Growth of chicks to 4 weeks of age was significantly depressed at 700 ppm nickel and above.

Metabolizable energy determinations on the respective experimental diets suggested an impairment in energy metabolism at the higher levels of dietary nickel. Fat retentions were not affected by nickel, but a marked reduction in nitrogen retention was obtained with the higher dietary levels of nickel.

In a second experiment, 1100 ppm nickel were incorporated into a basal diet and control diets pair-fed to delineate the effects associated with feed consumption and nickel toxicity per se. No significant differences in growth rate were obtained with either 1100 ppm nickel as the sulfate or acetate in comparison with the pair-fed controls. Nitrogen retention values were depressed in birds fed 1100 ppm nickel.

The effects of nickel have been clearly defined in rats, guinea pigs and mice. In a study with rats, it was found that levels of 250, 500 and 1000 ppm of nickel in three different forms did not significantly affect growth rate or reproduction (1). Approximately 71 to 91% of ingested Ni was found in the feces. Appreciable quantities were also retained in the tissues. In a further study, young rats fed on a diet containing 250 ppm of added Ni for 16 months grew normally (2). They found that maximum Ni levels occurred after 8 months and gradually decreased thereafter, probably because of decreased absorption of the nickel together with continued excretion. Low molar concentrations of nickel given to white mice by means of intraperitoneal injection were found to be lethal (3). Nickel given to guinea pigs by subcutaneous injections over a period of 120 days showed that the nickel was present in all organs investigated, and was eliminated primarily by the kidneys (4). Studies on the effect of Ni on various physiological systems have shown that Ni does activate arginase (5), carboxylase (6) and trypsin (7). Acid phosphatase under certain conditions was inhibited (8).

In view of the lack of information relating to the toxicity of nickel in poultry and the difficulties of extrapolating data from studies with rats and mice to chickens, the present study was initiated to evaluate the effects of high levels of this element on growth and the utilization of protein, fat and energy in the chick.

EXPERIMENTAL

Two studies were carried out with Hubbard broiler chicks grown to 4 weeks of age in batteries with raised wire floors. In the first experiment, nickel sulfate or nickel acetate was fed in amounts to supply zero, 100, 300, 500, 700, 900, 1100 and 1300 ppm added nickel to the basal diet. These experimental diets were supplied ad libitum.

In a second study, the 1100 ppm level of nickel was fed as the sulfate or acetate, and the basal diet was pair-fed with these diets to evaluate the separate effects of nickel on feed consumption and protein utilization. An additional treatment employed the basal diet fed ad libitum.

In each of the experiments, three replicate groups of 8 chicks each (4 males and 4 females) were fed each of the experimental diets. The basal diet (table 1) used in these studies was calculated to be adequate in all essential nutrients.

In addition to body weight gain and feed consumption data, feces samples

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TABLE 1

Diet of nickel sulfate and acetate used in chick growth study

Ingredient	% of diet
Fish meal	5.00
Alfalfa meal (17% protein)	2.00
Whey, dried	1.00
Corn, diet, dried sol.	1.00
Animal fat	5.00
Ground yellow corn	49.50
Soybean meal (44% protein)	31.15
Dicalcium phosphate	1.00
Calcium carbonate	0.75
Salt	0.20
Manganese dioxide	0.02
DL-Methionine	0.10
Vitamin mix [1]	2.50
Chromium oxide	0.20
Total	100.00

[1] Supplied the following per kilogram of diet: (in mg) ascorbic acid, 12.5; thiamine·HCl, 12.5; niacin, 100.0; riboflavin, 20.0; pyridoxine·HCl, 12.5; *d*-biotin, 1.25; Ca D-pantothenate, 75.0; vitamin B_{12} (0.1%), 10.0; folic acid, 4.00; *d*-α-tocopheryl acetate, 200.0; menadione (2-methyl-naphthoquinone), 1.25; ethoxyquin, 500.0; *i*-inositol, 500.0; *p*-aminobenzoic acid, 25.0; oxytetracycline, 25.0; (in IU) vitamin A palmitate (stabilized), 14,000; and vitamin D_3, 1,500.

were collected during the fourth week of each experiment to determine the effects of the nickel on nitrogen, calcium, phosphorus and fat retentions and on dietary metabolizable energy values.

A 0.20% level of chromium oxide (Cr_2O_3) was mixed into the experimental rations as an inert marker and the ratio of this material to the analysis values obtained for the nutrients listed above was used to calculate retentions according to the formula:

$$\% \text{ retention of "X"} = 100 - 100 \frac{(Cr_2O_3 \text{ feed} \quad \text{"X" feces})}{(Cr_2O_3 \text{ feces} \quad \text{"X" feed})}$$

Chromium oxide was determined on feed and feces samples by $HNO_3 - HClO_4$ digestion as outlined by Edwards and Gillis (9). The perchloric acid digest from the above determination was used for the determination of calcium by flame photometry employing a phosphorus correction (10) and for the determination of total phosphorus (11). The A.O.A.C. Kjeldahl method was used for nitrogen determinations while combustible energy values were determined with the Parr oxygen bomb calorimeter.

All data, where applicable, were subjected to statistical analysis by analysis of variance and the means separated by Duncan's multiple range test (12).

RESULTS AND DISCUSSION

No significant differences were obtained in the growth of chicks fed the two forms of nickel (tables 2 and 3). The birds fed nickel sulfate showed no significant differences in body weights up to the 300 ppm level, but the feeding of 500 to 700 ppm Ni significantly depressed weight gains in comparison with the control birds (table 2). A further progressive growth reduction occurred at the 900 to 1300 ppm levels of nickel. Feed conversion was not altered up to the 900 ppm level, at which point it was increased with each increasing level of nickel.

Nickel acetate gave results similar to those of nickel sulfate (table 3). No significant differences in body weights occurred up to the 500 ppm level but body weights were reduced at the 900 ppm level of nickel. Thus, nickel caused a progressive growth depression when fed as either the acetate or sulfate salts. Feed conversions were apparently not affected up to the 900 ppm nickel level but were depressed at both the 1300 ppm levels. Calculated amounts of nickel consumed per bird were quite similar for the two sources (tables 2 and 3). The 500 to 700 ppm levels appeared to be in a plateau region of intake. These results suggested that the amount of nickel ingested controlled the level of feed consumption. The amount of nickel ingested per bird, calculated as milligrams consumed per gram of gain, gave opposing data (tables 2 and 3). These data showed that as the birds ingested increasing amounts of nickel, body weight decreased in a direct relationship and that the effect of nickel was in addition to reduced feed intake. This problem was further examined in studying the metabolism of feed nutrients.

The effects of nickel on the utilization of dietary nutrients was investigated by means of Cr_2O_3 marker techniques. No great differences were found in metabolizable energy values or percent fat absorption with birds fed nickel sulfate (table 4). Metabolizable energy values were unal-

TABLE 2

Effect of dietary nickel sulfate on body weights, feed utilization and levels of nickel ingested in chicks

Nickel added as nickel sulfate	Body wt, 4 weeks	Feed conversion	Calculated nickel ingested to gain	Calculated nickel consumed per bird
ppm	*g*		*mg/g*	*mg*
0	565 [a 1]	1.78	T [2]	T
100	534 [a]	1.73	151	87
300	568 [a]	1.68	453	269
500	467 [ab]	1.69	687	406
700	376 [b]	1.97	794	412
900	247 [c]	2.11	837	396
1100	180 [c]	2.38	889	373
1300	179 [c]	2.82	1,347	478

[1] Means having different superscripts are statistically different at the 0.05 level of probability.
[2] T = trace.

TABLE 3

Effects of dietary nickel acetate on body weights, feed utilization and levels of nickel ingested in chicks

Nickel added as nickel acetate	Body wt, 4 weeks	Feed conversion	Calculated nickel ingested to gain	Calculated nickel consumed per bird
ppm	*g*		*mg/g*	*mg*
0	565 [a 1]	1.78	T [2]	T
100	514 [a]	1.79	152	85
300	559 [a]	1.66	429	259
500	484 [ab]	1.71	656	383
700	390 [b]	1.79	795	444
900	259 [c]	2.13	870	409
1100	256 [c]	2.04	1009	483
1300	173 [c]	2.54	1155	454

[1] Means having different superscripts are statistically different at the 0.05 level of probability.
[2] T = trace.

TABLE 4

Effect of nickel sulfate on the metabolism of some dietary nutrients

Nickel added	Gross energy retention	Metabolizable energy	Fat retention	Nitrogen retained	Protein efficiency ratio
ppm	%	*kcal/g feed*	%	%	
0	64.83	2.72	69.46	41.16	2.44
100	63.96	2.68	67.06	41.64	2.51
300	65.66	2.76	69.58	41.58	2.59
500	62.29	2.61	64.80	33.00	2.57
700	56.37	2.37	68.33	19.57	2.21
900	58.03	2.44	72.50	16.17	2.06
1100	56.06	2.35	75.75	12.50	1.83
1300	52.05	2.19	71.79	11.27	1.54

tered up to the 500 ppm level of nickel sulfate but appeared to be decreasing at levels above 500 ppm. Percent nitrogen retentions showed a decrease between the 300 to 500 ppm nickel levels. Nitrogen retentions dropped from 41% at the 300 ppm level to 33% at the 500 ppm level. It was further observed that as the level of nickel increased, the amount of nitrogen retained decreased. Protein efficiency ratios were found to decrease with higher levels of nickel sulfate. Above the 500

ppm level of the diet a decrease occurred in the PER with each increasing amount of nickel fed above this level.

Nickel acetate, when compared with nickel sulfate, showed no significant alterations in either the gross energy or fat retained (table 5). The metabolizable energy was unaffected by nickel acetate up to the 1100 ppm Ni level. The feeding of 1300 ppm Ni did not further lower the metabolizable energy figures. Percent nitrogen retained was decreased by nickel acetate feeding but no differences occurred until a 900 ppm Ni level was fed, and for each increment added thereafter, a further reduction occurred. The PER values of nickel acetate were found to be slightly different from those of nickel sulfate in that a decrease did not occur until the 900 ppm Ni level was fed. A further reduction in PER values occurred with higher levels of nickel acetate (table 5).

These results do not agree with the in vitro work of Sugai (7) who found an increase in trypsin activity with nickel. Our experimental data would suggest a reduction of proteolytic enzyme activity or increased protein catabolism. The question of whether the availability of nickel from the two sources was a factor in the differences noted between the sulfate and acetate salts or whether the sulfate ions were responsible for the differences in results noted cannot be resolved at this point.

In view of the apparent effects of dietary nickel on both feed consumption and nitrogen utilization, an additional experiment involving the feeding of 1100 ppm nickel was conducted. In this study, control groups were pair-fed at a level equivalent to the feed consumption of birds on the nickel-containing diets. When feed intake was equalized, there was no signifi-

TABLE 5

Effect of nickel acetate on the metabolism of some dietary nutrients

Nickel added	Gross energy retention	Metabolizable energy	Fat retention	Nitrogen retained	Protein efficiency ratio
ppm	%	*kcal/g feed*	%	%	
0	64.83	2.72	69.46	41.16	2.44
100	63.43	2.66	69.78	33.96	2.43
300	63.89	2.68	64.97	36.99	2.62
500	65.80	2.76	71.79	36.67	2.54
700	64.56	2.71	72.49	36.11	2.43
900	62.56	2.63	79.06	28.28	2.04
1100	58.33	2.45	73.03	20.34	2.08
1300	58.48	2.46	75.26	15.82	1.71

TABLE 6

Effect of dietary nickel on pair-fed chicks

Dietary treatment	Avg body wt 4 weeks	Feed consumed per bird	Feed conversion	Nitrogen retention
	g	*g*		%
1. Basal diet ad libitum	570 [a,1]	905	1.74	54.4
2. 1100 ppm Ni as nickel acetate ad libitum	304 [b]	538	2.12	44.9
3. Basal diet pair-fed with treatment 2	292 [b]	501	2.07	58.1
4. 1100 ppm Ni as nickel sulfate ad libitum	262 [b]	490	2.31	46.5
5. Basal diet pair-fed with treatment 4	259 [b]	451	2.16	63.4

[1] Means having different superscripts are statistically different at the 0.05 level of probability.

cant effect of dietary nickel on the growth rate of chicks to 4 weeks of age (table 6). No significant differences were noted between the acetate and sulfate salts. Feed conversions were slightly better in the pair-fed groups not receiving nickel. Nitrogen retentions were decreased with the feeding of 1100 ppm nickel, as either the acetate or sulfate, in comparison with the pair-fed control groups (table 6).

These data, along with the results obtained in the previous study, suggest that nickel, in addition to having an effect on feed intake, was detrimental to nitrogen retention. A striking difference in nitrogen retention values was obtained with nickel supplementation between the two experiments. The birds in the second study showed much higher nitrogen retention values at 1100 ppm nickel than in the first experiment. These differences are explained.

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