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EFFECTS OF DIETARY ALUMINUM IN COMBINATION WITH REDUCED CALCIUM AND PHOSPHOROUS ON THE RING DOVE (Streptopelia risoria).

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ABSTRACT. Elevated levels of Al have been reported in surface waters and in certain aquatic organisms including aquatic insects in areas receiving acidic precipitation. It has been suggested that Al can affect avian reproduction. In this study, Ring doves were assigned to a control group fed a diet reduced in Ca and P and to a treated group fed the same diet supplemented with 0.1% Al. A four month dosing period did not result in any effect on egg production, fertility or hatchability. Eggshell permeability was decreased initially but subsequently recovered to a normal level. Dietary aluminum sulphate did not affect plasma Ca, P nor Mg levels of adults nor did it affect the pattern of growth nor the final weight of chicks fed on the same diet. There was a tendency for Al to accumulate in the sternum of growing doves fed levels up to 1500 ppm Al. Neither reproduction nor growth of this species were influenced by levels of Al equivalent to those occuring in areas receiving acid deposition. However, the results of a preliminary experiment suggest that decreasing the dietary levels of Ca and P below 0.9% and 0.5% respectively, in combination with excess Al (0.075%) caused significant impacts upon reproduction and growth. Similar experimental findings have been reported in the literature for domestic birds where levels of dietary Al exceeded those of Ca and P.

RESUME. Des niveaux élevé d'Al ont été détecté dans les eaux de surfaces et dans certains insectes aquatiques vivant dans des régions arrosée par les pluies acides. Certains travaux suggèrent que l'Al pourrait affecter la reproduction des oiseaux.

Nous examinons ici l'effet de l'Al (0.1 %) chez des tourterelles à collier placées sur un régime à teneure réduite en Ca et en P. Après 4 mois d'exposition à ce régime aucun effet sur la production d'oeuf, la fertilité ou le taux d'éclosion n'a été noté. La perméabilité de la coquille d'oeuf dans le groupe traité a d'abord diminué mais a ensuite rejoint le groupe contrôle.

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La présence d'Al dans le régime n'a pas affecté les niveaux de Ca, de P et de Mg dans le plasma des adultes et n'a pas affecté non plus la forme de la courbe de croissance et le poids final des poussins maintenus sur ce même régime. L'Al semble avoir été accumulé dans les os des jeunes tourterelles nourries à des niveaux allant jusqu'à 1500 ppm d'Al. Cependant, ni la reproduction ni la croissance n'a été affecté par l'Al dans la diète même à des niveaux similaires à ceux qu'entrainent les précipitations acides. Les résultats d'une étude préliminaire suggérent que l'Al (0.075%) administré avec une diète dont la teneur en Ca et en P est inférieure à 0.9% et 0.5% respectivement, pourrait affecter la reproduction et la croissance. Des résultats similaires ont été rapporté pour le poulet domestique nourrie d'une diète dont la teneure en Al dépasse la teneure en Ca et en P.

1. INTRODUCTION

Increased Al concentrations in surface waters due to acid precipitation have stimulated interest in the toxicity of this element to aquatic biota. Elevated levels of Al have been reported in emerging insects and in tissues of wild birds in Sweden (Nyholm and Myhrberg, 1977). Aluminum was found in the bone marrow of the pied flycatcher (Ficedula hypoleuca) nesting in areas adjacent to an acidified lake and was associated with impaired reproduction (Nyholm, 1981). The relative toxicity of dietary Al compared with other metals is low, the principal effect being the disturbance of P metabolism (Sorenson et al., 1974). Under normal conditions Al is little absorbed through the intestinal epithelium (Cam et al., 1976). In the alimentary canal, Al forms insoluble compounds with P resulting in an imbalance in the ratio of available Ca and P (Ondreicka et al., 1971). Absorption of Al along with P has been stimulated in chickens by injecting 1,25-$(OH)_2D_3$, a derivative of vitamin D (Long et al., 1980). In most vertebrates, the synthesis of this substance is mediated by the parathyroid hormone and normally produced by the kidneys when the need for Ca increases or when there is a shortage of dietary Ca. The production of 1,25-$(OH)_2D_3$ subsequently increases the synthesis of intestinal calcium-binding proteins which augment the absorption of Ca (Haussler and McCain, 1977; Norman, 1979). These proteins also increase the absorption of metals bound to the essential minerals including Pb (Shields and Mitchell, 1941; Six and Goyer, 1970) and Cd (Washko and Cousins, 1977). It has been previously noted that the absorption of many metals including Zn, Cd, Cs, and Co is enhanced when the level of vitamin D is high and when the parathyroid activity is increased (eg. during egg-laying) (Worker and Magicovsky, 1961a,b). Mayor et al., (1977) found a similar relationship between the level of parathyroid hormone and the gastrointestinal absorption of Al in the rat.

Birds stressed by a diet low in Ca and P may therefore be more sensitive to the presence of Al in the diet or may accumulate it to a greater extent. In this experiment we attempted to assess the effect of Al in concentrations similar to those likely to be encountered in prey of insectivorous birds from acid-stressed areas. The levels of dietary Ca and P were reduced from those available in standard commercial diets in an attempt to mimic the stress occuring in the environment. Sufficient Ca and P were provided to enable breeding and egg-laying.

2. MATERIALS AND METHODS

The measured parameters were chosen to identify the early signs of Al intoxication so that a means of monitoring the effects of Al stress in wild birds could be developed. Breeding pairs of Ring doves (Streptopelia risoria) were divided into two groups of twenty pairs each and both groups were fed a diet in which the Ca and P levels were set at 0.9 % and 0.5 % respectively. For the treated group, Al given as $Al_2(SO_4)_3.18H_2O$ was added to the diet in the concentration of 1000 ppm (0.1%). Aluminum sulphate was chosen because it is the most common form of Al in acidified waters (LaZerte, 1984) and soluble compounds of Al were found to be more toxic than insoluble forms to growing chicks (Storer and Nelson, 1968).

Both control and treated groups were divided into two equal subgroups of ten pairs each, in order to study in undisturbed conditions, the breeding productivity and growth in one subgroup and the egg permeability in the other subgroup.

In another study, also designed to examine the growth of juvenile ring doves exposed to dietary Al, a total of thirty 21 day-old chicks were divided into 4 groups. The control group was fed a purified diet modified to contain 0.6% Ca and 0.3% P. The other groups were given the same diet with respectively, 500 ppm, 1000 ppm and 1500 ppm Al mixed as $Al_2(SO_4)_3.18H_2O$.

3. RESULTS AND DISCUSSION

With the exception of a decline in moisture loss observed for the first eggs laid in the treated group (but followed by a recovery), none of the parameters of reproduction were significantly affected by the dosing levels of Al used here. No embryonic malformations were observed. The examination of two eggshells from each of the control and treated groups with a scanning electron microscope indicated that the number of pores and the pore area were similar between treatment groups, although one of the experimental shells had a low permeability index. Nevertheless, our findings do not confirm the field observations of Nyholm (op. cit.) of increased moisture loss and embryonic malformations.

Plasma Ca, P and Mg levels were not significantly affected by treatment. The higher levels of Ca and P in the plasma of females as compared with males were expected since they all had an egg in the oviduct when they were sacrificed. In our experiment, females from the

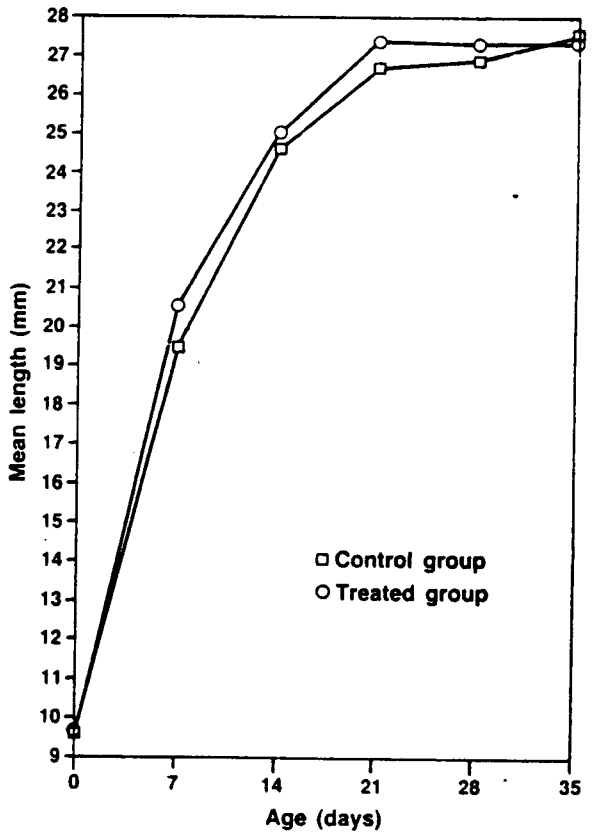

Fig.1
Growth curves of mean tarsus length of juvenile doves fed a control diet or 1000 ppm Al from 0 - 35 days.

treated group had plasma Ca levels slightly lower than control females.

Accumulation of Al occurred in at least the bones ($P<0.003$) and possibly in the kidneys of adult females (Table I). Aluminum concentrations in the pooled leg and wing bones of growing juvenile doves were not significantly affected by treatment ($P>0.05$) but a significant trend ($P<0.0136$) was found for the bones of the sternum to accumulate dietary Al (Table II). For the most part, Al was accumulated by bones of high P content. This was probably due to the tendency of Al to form stable aluminum phosphates (Nofre *et al.*, 1963).

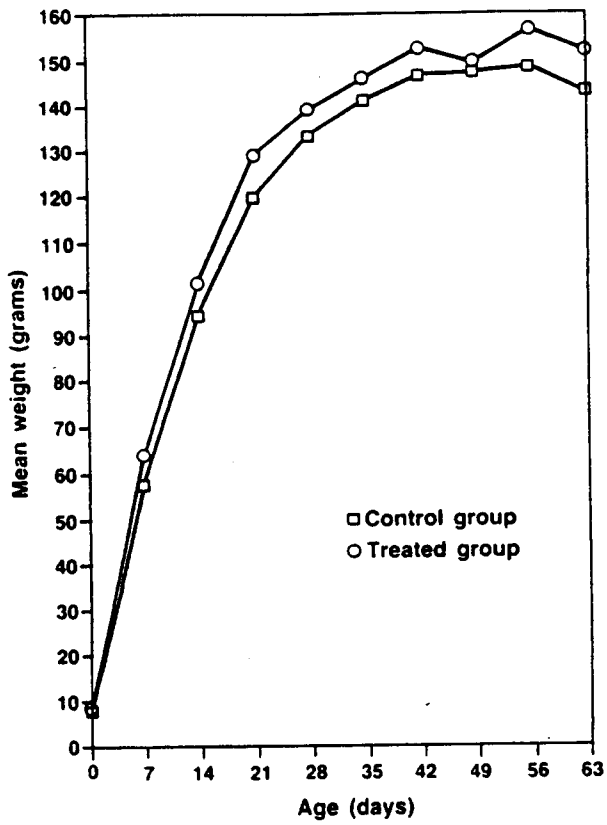

Fig.2
Mean weight increase in juvenile doves fed a control diet or 1000 ppm Al from 0 - 63 days.

In our experiment, Al treatment did not affect the growth of the doves (Figure 1). None of the dosing levels used affected the asymptotic weight or the rate of weight gain (Figure 2). For the juvenile doves fed various levels of Al, Ca and P, contents of bones were not significantly affected by treatment (Table II). The Ca:P ratio in bones was 2.1 for each of the 4 treatment groups in both the sternum and pooled leg and wing bones.

The levels of Ca and P administered in this experiment were higher than those of Al; it is considered that the effect of Al would have been greater if Ca and P conditions were deficient for growth and reproduction (Simkiss, 1961). In the course of a preliminary experiment with Ca, P and Al concentrations of 0.5%, 0.3% and 0.075%, respectively, eggshells were easily broken and crushed upon handling;

Table I. Aluminum content (ug g^{-1} on a dry weight basis) in femurae, kidneys and brain of adult ring doves.

Group	Tissue	Males	Females
Control	femurae	7.87 ± 2.51 (6/6)a	7.42 ± 2.14 (6/6)
	kidneys	0.75 (1/6)	0.97 (1/6)
	brain	n.d.	n.d.
Treated	femurae	6.75 ± 1.66 (6/6)	15.87 ± 10.30 (6/6)
	kidneys	0.92 ± 0.13 (5/6)	1.92 ± 0.47 (4/6)
	brain	n.d.	n.d.

a: mean ± s.d. (number above the detection limit out of 6 replicates)
n.d.: not detectable.

Table II. Calcium, P and Al levels (ug g^{-1} on a dry weight basis) in bones of growing ring doves administered four dietary levels of aluminum sulphate.

		Sternum	Pooled legs and wings bones
Control	Ca	169000 ± 17700 (12)a	137000 ± 16000 (12)a
	P	79800 ± 8700 (12)	64900 ± 7500 (12)
	Al	9.9 ± 3.3 (12)	6.6 ± 1.7 (12)
500ppm	Ca	158000 ± 21000 (6)	141000 ± 9300 (6)
	P	75700 ± 9300 (6)	67700 ± 7500 (6)
	Al	10.6 ± 4.2 (6)	7.0 ± 1.6 (6)
1000ppm	Ca	160000 ± 29000 (7)	129000 ± 12500 (7)
	P	76600 ± 13200 (7)	62000 ± 5300 (7)
	Al	11.3 ± 3.9 (7)	6.2 ± 1.4 (7)
1500ppm	Ca	182000 ± 23000 (5)	143000 ± 17700 (5)
	P	86400 ± 10600 (5)	69000 ± 8500 (5)
	Al	15.9 ± 6.7 (6)	6.7 ± 1.6 (5)

a: mean ± s.d. (n)

egg-laying was reduced and chick mortality was close to 100%. With the adoption of higher levels of Ca and P, no further effects were found, despite an increase in the Al added to the diet. The findings of this preliminary experiment are supported by other studies reported in the literature confirming the importance of Ca and P levels in determining Al absorption and toxicity to birds (Lipstein and Hurwitz, 1982).

4. CONCLUSIONS

No significant influence of dietary Al (0.1%) on reproduction or growth of Ring doves was observed in a laboratory experiment with adequate levels of Ca (0.9%) and P (0.5%) in the diet. The levels of Al in the diet were similar to those found in insect prey from areas impacted by acid precipitation (Hall and Likens, 1981). The difference between field observations and our experimental results may be due to species-to-species variation or the relative availability of Al and essential minerals in the diet.

Preliminary experiments with doves on diets with low levels of Ca (0.5%) and P (0.3%) in combination with Al (750 ppm) resulted in substantial effects on reproduction and growth. These findings are consistent with the literature which indicates that the ratio of Ca:P:Al is critical because of the importance of Ca and P in egg formation and chick development; the role of Al in binding P and displacing Ca in bone could have severe implications for reproduction and growth (Jones, 1938; Sorenson, op cit.).

Many areas subjected to acidification and mobilization of Al are also areas where the Ca and P levels in surface waters are low. Under these conditions, it is possible that the availability of Al could exceed those of the essential minerals in prey organisms and thereby cause reproductive impairment in avian predators.

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