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Only a few of the large number of papers on aluminum in nutrition have considered the effect of this element on reproduction and lactation. McCollum, Rask, and Becker (1), Myers and Mull (2), Lyman and Scott (3), and MacKenzie (4) reported no ill effects on reproduction and lactation from the addition of aluminum to the diet. The amounts of the element ingested varied from 0.02 per cent to 0.12 per cent, usually as potassium or sodium aluminum sulphate; although McCollum and co-workers employed $AlCl_3$ as the source of Al. Schaeffer and co-workers (5), using alum phosphate baking powder in bread, reported a decrease in the number of young mice born and a detrimental effect on the growth of rats and chickens.

The experiments in this paper were planned to ascertain if aluminum salts play any detrimental effect on growth, reproduction, and lactation. McCollum, Rask, and Becker (1) have reached the following conclusions regarding aluminum: 1. Aluminum is not a constituent of either plant or animal matter. 2. Aluminum compounds are not absorbed out of the stomach or intestinal tract when present in the diet. 3. Aluminum compounds when present in the alimentary tract do not form any union or compound with the stomach or intestinal walls. 4. Aluminum compounds in the diet in concentrations as high as 60 p.p.m. of the element Al exert no noticeably deleterious action on growth, reproduction, or general well-being as judged by external appearance and autopsy. They employed the spectrographic method for estimation of Al, a very sensitive method for the detection of this element. Myers and Mull (2) found traces of aluminum in normal tissues and there was a slight increase on a diet containing considerable aluminum. They observed, furthermore, that the aluminum-fed rats showed a slightly greater initial growth, otherwise the aluminum did not effect growth or reproduction. Myers and Morrison (6) reported that when aluminum compounds are administered orally to dogs, the absorption of the element is very slight. Underhill and Peterman (7) state that aluminum in the urine tends to increase after the ingestion of aluminum rich foods; and this, of course, points to absorption. Because of the conflicting data re-

ported on the absorption of aluminum, it was believed that the experiments here outlined, on high amounts of Al, would enhance our information as to whether absorption occurred if detrimental effects resulted during reproduction and lactation.

EXPERIMENTAL

The basal diet consisted of natural foodstuffs used in the feeding of our stock colony. The stock ration was composed of yellow corn 37.5 per cent, hulled oats 35.2 per cent, alfalfa meal 4.7 per cent, wheat 9.18 per cent, butter milk powder 2.6 per cent, tankage 6.0 per cent, and linseed oil meal 4.82 per cent. One per cent of bone meal and one per cent of salt were added to this mixture. $Al(NO_3)_3 . 3H_2O$ was incorporated in the stock ration at levels of 0.168 per cent Al, 0.42 per cent Al, and 0.84 per cent Al. The other salts tested were $K_2SO_4 . Al_2(SO_4)_3 . 24H_2O$, $AlCl_3 . 6H_2O$, and $Al(OH)(CH_3COO)_2$ at levels of 0.42 per cent and 0.84 per cent Al. All of the experiments were performed on rats.

Rats fed 0.168 per cent Al as $Al(NO_3)_3 . 3H_2O$ grew normally in the first generation and, after weaning, grew normally through the sixth generation. Lactation was poor in the six generations studied on this level of Al, and fertility varied between 0 and 58 per cent in five of the generations and 73 per cent in the second generation. The young showed an unusually high mortality rate and a low weaning weight; they appeared thin and shaggy before one year old. The fifth generation, consisting of four females and two males, did not begin to reproduce until they were nearly five months old; and then only two females had young. Five litters were born and weaned with an average weaning weight of 24 grams and an average mortality rate of 65.6 per cent. The reproduction period continued only a short time; and when no litters had been born for six months, the remaining animals were killed at fourteen months of age. The sixth generation, composed of only one pair of rats, gave birth to two young when nine months of age; and shortly thereafter the entire family died.

Fertility, during the first eight months, in the three generations studied on 0.42 per cent Al as $Al(NO_3)_3 . 3H_2O$ varied between 0 and 62 per cent. The first generation had previously received 0.168 per cent Al until they were eight months old. This procedure was advisable because rats placed directly on the diet containing the higher amount of $Al(NO_3)_3 . 3H_2O$ did not adapt themselves to the ration. Although fertility of the mothers, condition of the young at birth, and weaning weight were not affected, nevertheless, the mortality of the young increased from 31 per cent in the

first generation on 0.168 per cent Al as compared to 60 per cent in the corresponding generation on 0.42 per cent Al as $Al(NO_3)_3 . 3H_2O$. Although the second generation was observed for 20 months, only 55 young were born from five of the eight females on experiment; the remaining females had no young. Reproduction ceased before the animals were one year of age. The third generation was composed of four females and one male; two of these females, at eight months of age, had litters of three and four young respectively. The litters died before weaning and no more were born, although the third generation was fourteen months old when killed. The average weaning weight for the young from the first generation was 43 grams and for the young from the second generation was 29 grams. Growth after weaning was normal in all generations studied. Growth was subnormal and death occurred in two to three months when thirty day old rats from the stock colony were placed on the ration containing 0.84 per cent Al as $Al(NO_3)_3 . 3H_2O$. Even animals which had become accustomed to large amounts of Al succumbed in a short time, if the Al content was increased to 0.84 per cent as $Al(NO_3)_3 . 3H_2O$.

Animals grew normally on the ration containing 0.42 per cent Al as $AlCl_3 . 6H_2O$, but there was no reproduction and death occurred at five months. Similar results were obtained on the 0.84 per cent level of this salt.

Four generations have been obtained on the diet containing 0.42 per cent Al as $K_2SO_4 . Al_2(SO_4)_3 . 24H_2O$. Twenty-five young were weaned in the first generation with an average weaning weight of 28 grams. However, fifty per cent of the young died before they were weaned. The animals of the first generation did not reproduce after they were eight months old, although they were observed for thirteen months. The second generation consisted of four females and two males; and all of the females reproduced. From these young enough were obtained for a third generation study, so the second generation animals were killed for analytical purposes at nine months of age. The third generation, composed of ten females and three males, produced twenty-seven young, of which only four were weaned. The mortality rate of the young was 85 per cent, and the average weaning weight was 28 grams; growth after weaning was normal. The animals lived only seven months on a diet containing 0.84 per cent Al as $KAl(SO_4)_2 . 12H_2O$; one-third of the females produced young, but of the 16 young born only one was weaned at a weight of 46 grams.

Basic aluminum acetate gave much better results than the other

salts; for instance, it was possible to obtain five generations on the diet containing 0.42 per cent Al as $Al(OH)(CH_3COO)_2$. Seventy-five per cent of the young in the first generation were weaned, with an average weaning weight of 43 grams. The results in the second, third, and fourth generations have been comparable, and a fifth generation of eleven females and four males is now approaching maturity. The animals have been long-lived and in a healthy condition at the end of the experiment. The mortality of the young has increased from 25 per cent to 50 per cent, but the weaning weight has decreased little between the first and fourth generations. Growth was normal in all generations on 0.42 per cent Al as $Al(OH)(CH_3COO)_2$. Only two generations have been obtained on 0.84 per cent Al as $Al(OH)(CH_3COO)_2$. The mortality of the young from the first generation was 24 per cent and the average weaning weight 43 grams; whereas, the second generation — nine females and three males — did not reproduce in nine months; they were killed for analyses.

SUMMARY

1. The effect of feeding four different Al salts in high concentration has been studied.

2. $Al(OH)(CH_3COO)_2$ is least toxic and $AlCl_3 . 6H_2O$ most toxic; $KAl(SO_4)_2 . 12H_2O$ and $Al(NO_3)_3 . 3H_2O$ are intermediate in toxicity.

3. The time required for the manifestation of the detrimental effect of the Al salts depends on the nature and the amount of the salt administered.

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