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Influence of Methionine and Other Dietary Additions on the Performance of Chicks Fed Bird Resistant Sorghum Grain Diets[1]

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ABSTRACT Studies were conducted on the performance of chicks fed diets containing the bird resistant sorghums BR64 and IS8260 as compared to chicks fed diets containing the non-resistant sorghums RS610 and RS671 and to observe the effects on chick performance and leg scores of various dietary supplements. Feeding bird resistant sorghum grains BR64 and IS8260 resulted in significantly poorer growth and feed efficiency as compared to that noted when non-resistant sorghum grains RS610 and RS671 were fed. Supplementation of bird resistant sorghums BR64 and IS8260 with methionine resulted in a marked improvement in chick growth and feed efficiency to levels comparable to those noted with the non-resistant sorghums. Supplementation of the bird resistant sorghums with choline did not result in an improvement in chick growth or feed efficiency. Methionine supplementation did not overcome the growth depressing effects noted when 1.0% commercial tannic acid was added to the sorghum RS671 diet. Additions of 1.0% polyvinylpyrrolidone overcame the depressing effects of commercial tannic acid additions to sorghum RS671 diets as well as the tannin provided by the bird resistant sorghum BR64.

An increased incidence and severity of a leg abnormality was noted in the more rapidly growing chicks fed the bird resistant sorghum BR64 and IS8260 diets supplemented with methionine. Supplementation of the non-resistant sorghum diets with methionine did not result in an increased incidence or severity of the leg abnormality. Dietary supplementations of lysine, carnitine or a mineral mix containing calcium, manganese and zinc failed to alleviate the problem.

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INTRODUCTION

STUDIES by Chang and Fuller (1964), Fuller *et al.* (1967), Connor *et al.* (1969) and Rayudu *et al.* (1970a) have shown that additions of methionine, choline and other methyl group donors helped to overcome the growth depression caused by dietary tannic acid, the extent of the improvement being related to the level of dietary tannic acid. In some studies, chicks fed diets containing little or no tannic acid also responded with increased performance when the diets were supplemented with these methyl group donors. Potter and Fuller (1968) have shown that tannic acid is hydrolyzed to gallic acid and that a large portion of this is methylated and excreted in the urine as 4-0-methyl gallic acid. This offers a possible explanation why additions of methionine, choline and other methyl group donors have beneficial effects when fed in diets containing tannic acid.

Vohra *et al.* (1966) and Glick and

[1] Journal paper no. 4964, Purdue University Agricultural Experiment Station. This investigation supported in part by the U. S. Agency for International Development under contract csd/1175—"Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (Linn.) Moench."

Joslyn (1970) concluded that the decreased feed intake resulting from feeding tannic acid cannot completely explain the depression in growth. Vohra *et al.* (1966) showed that some of the growth depression was due to a reduction in nitrogen retention.

Studies by Rayudu *et al.* (1970b) have shown that slurry forms of Na_2CO_3 and $Ca(OH)_2$, Tween 80 and polyvinylpyrrolidone (PVP) are effective in reducing the growth depressing effect of tannic acid. These workers suggest that non-ionic polymers like Tween 80 and PVP bind to tannic acid *in vivo* as they do *in vitro* and prevent them from precipitating proteins, being absorbed or being metabolized to other absorbable products.

Rostagno *et al.* (1973) observed an abnormal leg condition in the young growing chick when fed diets containing sorghum grains at sub-optimal protein levels. The incidence and severity of this condition was greater in chicks fed the bird resistant sorghum grain BR64 as compared to chicks fed the non-resistant sorghum grain RS610 or corn diets.

The present study was conducted to determine the extent to which methionine, choline and polyvinylpyrrolidone could reverse the detrimental effects on chick performance of commercial and sorghum tannins. Two high-tannin sorghum grains, BR64 and IS8260, were compared to two low-tannin sorghum grains, RS610 and RS671, in these studies. The results of attempts to overcome a leg problem noted when high-tannin sorghum grains supplemented with methionine were fed by additions of lysine, carnitine and a mineral mixture to the diet are also presented.

EXPERIMENTAL PROCEDURE

Male, White Mountain chicks were randomly alloted to treatments at one day of age in the four experiments. Each chick was weighed, wing banded and placed in an electrically heated battery brooder with raised wire floors. Eight chicks were placed in each pen with four replicates per treatment. No two replicates of the same treatment appeared in the same battery or the same deck level of another battery. Feed and water were provided *ad libitum*.

The protein content of the sorghum grain and soybean meal was determined by the Kjeldahl procedure (A.O.A.C., 1960). The tannic acid equivalents of the grains was determined by the Folin-Denis Method as described by Burns (1963). Protein and tannic acid equivalents, respectively, of the sorghum grains used in these studies were as follows: RS610, 9.8%, 0.33%; RS671, 8.8%, 0.37%; BR64, 9.0%, 1.57%; IS8260, 7.4%, 2.66%. The different grains were compared on an isonitrogenous basis except in Experiment 2 in which the two high-tannin sorghums, BR64 and IS8260, were compared on an equal weight basis. The dietary protein contents in Experiments 1, 3, and 4 were 15.6%, 15.2 and 14.5%, respectively. No adjustment in total nitrogen was made when amino acids were added to certain diets. Composition of the experimental diets are shown in Tables 1-4.

A subjective leg score was used at the end of each experiment in an attempt to quantitatively evaluate the extent of an abnormal leg condition. The determination was based on the following: 1-normal; 2-slightly abnormal; 3-severely abnormal; and 4-unable to stand.

The analysis of plasma free amino acids was determined by ion exchange chromatography[2] following the procedure described by Cromwell *et al.* (1967). Norleucine was added to each sample as an internal standard. Plasma calcium con-

[2] Technicon Amino Acid Analyzer, Technicon Corporation, Ardsley, New York.

TABLE 1.—*Composition of diets and the effect of tannic acid, methionine, choline, and mineral supplementation of sorghum grains on weight gain, feed conversion, and leg score of chicks. (Experiment 1)*

Ingredients (%)	Diets							
	1	2	3	4	5	6	7	8
Sorghum BR-64 (9.0)[1]	70.5	70.5	70.5	—	—	—	—	—
Sorghum RS-610 (9.8)	—	—	—	64.7	64.7	64.7	64.7	64.7
Corn oil	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Glucose monohydrate	1.87	1.46	1.14	7.67	6.82	7.26	6.41	6.94
Soybean meal (52.2)	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75
Premix[2]	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
$MnSO_4$	—	0.0424	—	—	—	0.0424	0.0424	—
$CaCO_3$	—	0.36	—	—	—	0.36	0.36	—
ZnO	—	0.0079	—	—	—	0.0079	0.0079	—
DL-Methionine[3]	—	—	0.31	—	—	—	—	0.31
Choline chloride[4]	—	—	0.42	—	—	—	—	0.42
Tannic acid[5]	—	—	—	—	0.846	—	0.846	—
Weight gain (g.)[6]	241[d]	305[d]	636[a]	440[c]	253[d]	429[c]	268[d]	548[b]
Feed/gain ratios (g.)[6]	2.93[a]	2.79[ab]	2.12[c]	2.13[c]	2.65[b]	2.16[c]	2.59[b]	1.68[d]
Leg scores[6,7]	1.1[b]	1.3[b]	2.0[a]	1.3[b]	1.1[b]	1.3[b]	1.3[b]	1.2[b]

[1] Figures in parentheses represent the protein contents expressed as a percentage of air-dried feedstuff.
[2] The premix provided the following ingredients (in %): dicalcium phosphate, 2.1; limestone, 1.5; sodiun chloride (iodized), 0.45; manganese sulfate $\cdot H_2O$, 0.01692; zinc oxide, 0.006; butylated hydroxytoluene, 0.0125; vitamin supplement, 0.7935. The vitamin supplement contained the following (in units/kg.): choline chloride, 2000 mg.; vitamin A, 5000 I.U.; vitamin D_3, 2250 I.C.U.; riboflavin, 8.8 mg.; calcium pantothenate, 17.6 mg.; niacin, 39.6 mg.; d-alpha tocopherol acetate, 8.8 I.U.; menadione sodium bisulfite, 1.4 mg.; vitamin B_{12}, 11.0 μg.
[3] 98% pure.
[4] 25% pure.
[5] Tannic acid added to bring tannin level up to that of Diet 1.
[6] Mean values for 5-week old chicks. Means bearing the same superscripts are not significantly different. ($P > .05$).
[7] Values assigned for leg condition: 1.—Normal; 2.—Slightly abnormal; 3.—Severely abnormal; 4.—Unable to stand.

centrations were determined by atomic absorption spectrophotometry.

In Experiment 1, BR64, a bird resistant sorghum grain, and RS610, a non-resistant grain, were compared on an isonitrogenous basis in diets containing sub-optimal protein levels (Table 1). Dietary additons of DL-methionine, choline, calcium, manganese, zinc and commercially available tannic acid[3] were studied to determine their effects on chick performance when supplemented to either the sorghum BR64 or RS610 diets. At the end of this five week study, leg scores were assigned to all the birds. Blood samples were collected from six birds from treatments 1, 3, 4, and 8 for analysis of the plasma free amino acid composition. Plasma from two chicks were pooled providing three analyses per treatment.

Experiment 2 was conducted to determine if the response in Experiment 1 from methionine and choline supplementation was due to the use of methionine for protein synthesis or as a source of methyl groups. DL-methionine and choline were supplemented to diets containing sorghums RS610, BR64 and IS8260 individually and in combination on an isomethyl group basis (Table 2). Sorghums BR64 and IS8260 were fed on an equal weight basis while BR64 and RS610 were compared on an isonitrogenous basis in diets containing sub-optimal levels of pro-

[3] Tannic Acid, Fluffy Powder, Sigma Chemical Company, St. Louis, Missouri.

TABLE 2.—*Composition of diets and the effect of methionine and choline supplementation of sorghum grains on weight gain, feed conversion, and leg score of chicks. (Experiment 2)*

Ingredients %	Diets											
	1	2	3	4	5	6	7	8	9	10	11	12
Sorghum BR-64 (9.0)[1]	70.5	70.5	70.5	70.5	—	—	—	—	—	—	—	—
Sorghum IS-8260 (7.4)	—	—	—	—	70.5	70.5	70.5	70.5	—	—	—	—
Sorghum RS-610 (9.8)	—	—	—	—	—	—	—	—	64.7	64.7	64.7	64.7
Corn oil	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Glucose monohydrate	1.87	1.56	1.47	1.51	1.87	1.56	1.47	1.51	7.67	7.36	7.27	7.31
Soybean meal (52.2)	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75
Premix[2]	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
DL-Methionine[3]	—	.31	—	.155	—	.31	—	.155	—	.31	—	.155
Choline[4]	—	—	.40	.20	—	—	.40	.20	—	—	.40	.20
Total Protein (%)	15.6	15.6	15.6	15.6	14.5	14.5	14.5	14.5	15.6	15.6	15.6	15.6
Weight gain (g.)[5]	155^{c}	267^{ab}	160^{c}	274^{ab}	118^{e}	265^{ab}	116^{e}	258^{ab}	213^{b}	264^{ab}	246^{ab}	294^{a}
Feed/gain ratios (g.)[5]	2.45^{b}	1.92^{cd}	2.52^{b}	1.94^{cd}	2.74^{a}	2.07^{c}	2.81^{a}	2.08^{c}	1.92^{cd}	1.80^{d}	1.89^{cd}	1.75^{d}
Leg scores[5,6]	1.1^{b}	1.3^{b}	1.1^{b}	1.2^{b}	1.1^{b}	2.0^{a}	1.1^{b}	2.0^{a}	1.1^{b}	1.2^{b}	1.2^{b}	1.1^{b}

[1,2,3,4] See footnotes in Table 1.
[5] Mean values for 21-day old chicks. Means bearing the same superscripts are not significantly different ($P > .05$).
[6] See footnote 7, Table 1.

tein. Leg scores were assigned to the chicks at the end of the 21-day study.

In Experiment 3, sorghum RS671, a non-resistant sorghum grain, and sorghum BR64 were compared on an isonitrogenous basis at sub-optimal protein levels in diets containing additions of DL-methionine, polyvinylpyrrolidone,[4] and/or tannic acid (Table 3). Sorghum RS610 was included in this study as a positive control. This experiment was conducted to determine if the growth depressing effect of both commercial and sorghum tannic acid could be alleviated by either methionine or polyvinylpyrrolidone. Leg score values were assigned to chicks in treatments 4 and 10 at the end of the 21-day study.

The effects of additions of DL-methionine, L-lysine and DL-carnitine[5] were observed when supplemented to diets containing sorghum IS8260 at sub-optimal protein levels in Experiment 4 (Table 4). Sorghum RS610 was also fed as a positive

[4] Polyvinylpyrrolidone, Powder, Sigma Chemical Co., St. Louis, Missouri.

[5] DL-Carnitine HCl, Powder, Sigma Chemical Co. St. Louis, Missouri.

TABLE 3.—*Composition of diets and the effect of tannic acid, methionine, and polyvinylpyrrolidone supplementation of sorghum grains on weight gain, feed conversion, and leg score of chicks. (Experiment 3)*

Ingredients %	Diets									
	1	2	3	4	5	6	7	8	9	10
Sorghum RS-610 (9.8)[1]	62.87	—	—	—	—	—	—	—	—	—
Sorghum RS-671 (8.8)	—	70.37	70.37	70.37	70.37	70.37	70.37	—	—	—
Sorghum BR-64 (9.0)	—	—	—	—	—	—	—	68.31	68.81	68.81
Corn oil	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Glucose monohydrate	9.50	2.00	1.00	1.85	0.85	1.00	—	3.56	2.56	3.41
Soybean meal (52.2)	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75	17.75
Premix[2]	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
Tannic acid[3]	—	—	1.00	—	1.00	—	1.00	—	—	—
DL-Methionine[4]	—	—	—	0.15	0.15	—	—	—	—	0.15
Polyvinylpyrrolidone	—	—	—	—	—	1.00	1.00	—	1.00	—
Weight gain (g.)[5]	216^{bc}	234^{bc}	125^{d}	296^{a}	151^{d}	242^{bc}	207^{c}	154^{d}	248^{b}	277^{a}
Feed/gain ratios (g.)[5]	1.91^{de}	1.94^{ce}	2.46^{a}	1.72^{f}	2.24^{b}	1.88^{e}	2.01^{cde}	2.31^{a}	2.04^{cd}	2.06^{cd}
Leg scores[5,6]	—	—	—	1.0^{a}	—	—	—	—	—	1.4^{b}

[1,2] See footnotes in Table 1.
[3] See footnote 5, Table 1.
[4] 98% pure.
[5] See footnote 5, Table 2.
[6] See footnote 7, Table 1.

TABLE 4.—*Composition of diets and the effect of methionine, lysine, and carnitine supplementation of sorghum grains on weight gain, feed conversion, and leg score of chicks. (Experiment 4)*

Ingredients %	Diets					
	1	2	3	4	5	6
Sorghum RS-610 (9.8)[1]	55.78	—	—	—	—	—
Sorghum IS-8260 (7.4)	—	71.82	71.82	71.82	71.82	71.82
Corn oil	5.0	5.0	5.0	5.0	5.0	5.0
Glucose monohydrate	16.59	0.55	0.40	0.20	0.20	—
Soybean meal (52.2)	17.75	17.75	17.75	17.75	17.75	17.75
Premix[2,3]	4.88	4.88	4.88	4.88	4.88	4.88
DL-Methionine[4]	—	—	0.15	0.15	0.15	0.15
Lysine	—	—	—	0.20	—	0.20
Carnitine	—	—	—	—	0.20	0.20
Weight gain (g.)[5]	216[b]	138[c]	258[a]	238[ab]	228[ab]	241[ab]
Feed/gain ratios (g.)[5]	1.94[c]	2.76[a]	2.09[bc]	2.12[bc]	2.23[b]	2.08[bc]
Leg scores[5,6]	1.3[b]	1.3[b]	2.0[a]	1.9[a]	2.1[a]	1.9[a]

[1,2] See footnotes in Table 1.
[3] B-vitamins were added as follows (mg./kg. diet): thiamine, 1.8; pyridoxine, 3.0; biotin, 0.09; folic acid, 1.0.
[4] 98% pure.
[5] See footnote 5, Table 2.
[6] See footnote 7, Table 1.

control. This experiment was designed to measure the effect of these supplements on the abnormal leg condition observed in previous experiments. Leg scores were assigned to all chicks at the end of this 21-day experiment.

Analysis of variance (Steel and Torrie, 1960) was used to statistically analyze final chick weight gain, feed conversion and leg scores. In testing the main effects, the treatment × replication interaction was used. Individual treatment differences were tested by the Newman-Keuls multiple range test (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Sorghum RS610, a non-resistant sorghum grain, produced significantly better weight gain and feed conversion ($P<0.05$) than did sorghum BR64, a bird resistant sorghum grain, when fed on an isonitrogenous basis at sub-optimal levels of protein in Experiment 1 (Table 1). These results agree with the reports of several workers (Chang and Fuller, 1964; Connor *et al.*, 1969; and Rostagno *et al.*, 1972) who observed that weight gain and feed conversion were reduced when high-tannin sorghum grains were fed to chicks. The addition of tannic acid to the sorghum RS610 diet (Diet 5) to bring the tannic acid level up to that supplied by sorghum BR64 reduced weight gain to a level similar to that produced by sorghum BR64. The reduced weight gain and feed conversion noted in this group was significantly different ($P<0.05$) from that observed with the sorghum RS610 unsupplemented diet. Supplementation of both sorghum grain diets with methionine and choline resulted in significant ($P < 0.05$) improvements in weight gain and feed conversion. The magnitude of the weight gain (approximately 2.6 fold) with chicks fed the sorghum BR64 was much greater than that for chicks fed sorghum RS610. Nevertheless, the feed/gain ratio for chicks fed the supplemented sorghum BR64 diet was no better than that for chicks fed the unsupplemented sorghum RS610 diets. The beneficial effects noted for methionine and choline in these studies agree with those described by Chang and Fuller (1964) and Connor *et al.* (1969).

Another objective of this experiment

was to determine if the addition of a mineral mix containing calcium, manganese and zinc would aid in alleviating a leg problem previously noted in our laboratories (Rostagno *et al.*, 1973) in chicks fed high-tannin sorghum grain diets. A significant incidence of leg problems in this experiment was noted only in chicks fed the sorghum BR64 diet supplemented with methionine and choline, so it was impossible to determine from this study whether the mineral supplementation had any beneficial influence or not. No improvement in weight gain or feed efficiency was noted, however, when the minerals were added to the sorghum BR64, sorghum RS610 or sorghum RS610 plus tannic acid diets. The abnormal leg condition is characterized by an outward bowing of the legs with an enlargement of the hock joint. An afflicted chick as well as a normal chick are shown in Figure 1. The tibia from these two chicks are shown in Figure 2. Note the curvative of the bone from the afflicted chick particularly in the area adjacent to the hock joint.

Blood was taken from birds on treatments 1, 3, 4 and 8 for determination of calcium and plasma free amino acids.

FIG. 1. A chick fed a non-resistant sorghum RS-610 diet (Diet 8, Experiment 1) on the left and a chick fed a bird resistant BR-64 sorghum diet (Diet 3, Experiment 1) on the right.

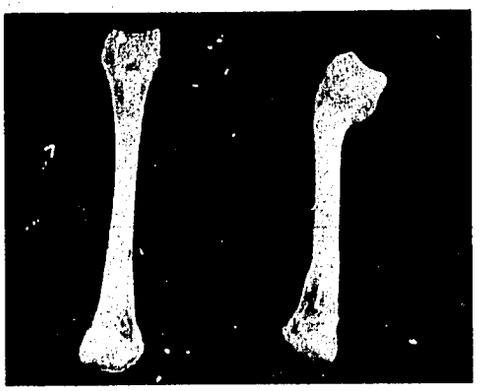

FIG. 2. Tibia from the chick in Figure 1 fed the non-resistant sorghum RS-610 diet (left) and the tibia from the chick in Figure 1 fed the bird resistant sorghum BR-64 diet (right). Note the abnormal curvature of the tibia from the chick fed the bird resistant sorghum diet.

Calcium levels were similar in chicks from all four treatments. The total plasma free amino acid concentrations (mg. of amino acid/100 ml. of plasma) of these blood samples were: BR64, 56.8; BR64 + methionine, 36.8; RS610, 46.7; and RS610 + methionine, 43.6. The concentrations are inversely related to growth rate and are consistent with the concept that lower concentrations are associated with efficient utilization of the dietary amino acids.

Experiment 2 was conducted to determine if the response from supplementation of methionine and choline in Experiment 1 was due to methionine or choline alone or from the combination of these two methyl group donors. Diets containing two bird resistant sorghums, BR64 and IS8260, were compared on an equal weight basis while sorghums BR64 and RS610 were compared on an isonitrogenous basis at sub-optimal levels of protein (Table 2). Methionine and choline were compared alone on an equal methyl group basis as well as together with each providing one-half of the methyl groups. Methionine supplementation alone and in combination with choline produced

significant improvements ($P < 0.05$) in weight gain and feed conversion when added to the bird resistant sorghums BR64 and IS8260. These same additions to the sorghum RS610 diets resulted in improvements in weight gain and feed conversion, but they were not of the same magnitude as noted with the bird resistant grains and were not always statistically significant ($P > 0.05$). The additions of choline to the three grain diets had no effect on weight gain or feed conversion. These results suggest that the methionine was serving in some capacity other than as a methyl group donor, and that the positive response from methionine and choline together was probably due to the methionine. As was the case in Experiment 1, the methionine supplementation of the bird resistant sorghums BR64 and IS8260 resulted in an increased incidence and severity of the observed leg problem. However, the increased leg scores were statistically ($P < 0.05$) higher only with the sorghum IS8260.

In Experiment 3, when sorghum RS671 was supplemented with 1% tannic acid, there was a significant depression ($P < 0.05$) in weight gain and feed conversion when compared with a sorghum RS671 unsupplemented diet (Table 3). The growth rate and feed conversion observed with this treatment were similar to those observed from the bird resistant sorghum BR64 diet. As in previous experiments, supplementation of sorghum BR64 and RS671 diets with methionine significantly improved ($P < 0.05$) weight gain and feed conversion over the unsupplemented diets. As was true in the first two experiments, the improvements were of a greater magnitude in the bird resistant sorghum diets than in the nonresistant sorghum diets. When the sorghum RS671 plus tannic acid diet was supplemented with methionine, the improvement in weight gain was not significant ($P > 0.05$) from that of RS671 plus tannic acid without methionine. The reason for the lack of response from methionine supplementation in this case remains unexplained; however, the feed conversion was significantly improved ($P < 0.05$) with added methionine. Chicks fed sorghum RS671 performed equally with those fed sorghum RS610, and therefore either of these two grains were used as controls in future experiments.

The depression in weight gain and feed conversion caused by both exogenous (sorghum RS671 + 1% tannic acid) and endogenous (sorghum BR64) tannic acid was almost completely alleviated by supplementation of 1% polyvinylpyrrolidone (PVP). This agrees with the work of Rayudu *et al.* (1970b) who observed that PVP and other compounds would reduce the growth depressing effect of tannic acid. These workers suggested that PVP in some way combines with the tannic acid and renders it ineffective.

At the end of the trial, leg scores were assigned only to chicks fed the sorghum BR64 and RS671 diets that were supplemented with methionine. As in previous observations, the birds fed the sorghum BR64 plus methionine diet had significantly higher ($P < 0.05$) leg scores than chicks fed the sorghum RS671 plus methionine diet. These two groups of chicks were fed a commercial diet for two additional weeks and the leg scores did not differ from the 3-week scores. This indicated that the early growing period of the chick was the critical period for prevention of this abnormal leg condition.

In Experiment 4, chicks fed the bird resistant sorghum IS8260 exhibited significantly ($P < 0.05$) poorer growth and feed conversion as compared to chicks

fed the sorghum RS610 diet (Table 4). Supplementation of the sorghum IS8260 diet with methionine resulted in chick growth which was significantly ($P < 0.05$) better than that of chicks fed the sorghum RS610. An increased leg score was noted, however, in these chicks. Supplemental thiamine, pyridoxine, biotin and folic acid (see footnote 3, Table 4) were added to all diets in this experiment to insure that none were deficient. The similar results noted in this experiment as compared to previous experiments indicated that this was not the case. Carnitine and its precursor lysine were evaluated in this experiment because of the known role of carnitine in fatty acid oxidation and the reported increased lipid content of bone resulting from a lysine deficiency (Rohdenburg, 1958; Braham *et al.*, 1961). Additions of lysine and carnitine alone or in combination to the sorghum IS8260 plus methionine diet failed to exert any beneficial effect toward correcting the leg problems.

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