THE DIETARY LEVELS OF RIBOFLAVIN, PANTOTHENIC ACID, NIACIN, CHOLINE AND FOLIC ACID REQUIRED BY CHICKS FED A HIGH ENERGY RATION

By

JOE P. DAVIS

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1949

Submitted to the Faculty of the Graduate School of

the Oklahoma Agricultural and Mechanical College

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

1951

THE DIETARY LEVELS OF RIBOFLAVIN, PANTOTHENIC ACID, NIACIN,

CHOLINE AND FOLIC ACID REQUIRED BY CHICKS FED A HIGH ENERGY RATION

JOE P. DAVIS

MASTER OF SCIENCE

1951

THESIS AND ABSTRACT APPROVED:

Rollin H. Thayer
Thesis Adviser

R B Thompson
Faculty Representative

D. C. McIntosh
Dean of the Graduate School

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to Rollin H. Thayer, Associate Professor of Poultry Husbandry and Major Adviser, for his supervision and valuable suggestions in conducting this study.

Acknowledgement is also due Professor R. B. Thompson and George F. Godfrey, Associate Professor of Poultry Husbandry, for their assistance in the organization and writing of this manuscript.

THE DIETARY LEVELS OF RIBOFLAVIN, PANTOTHENIC ACID, NIACIN, CHOLINE AND FOLIC ACID REQUIRED BY CHICKS FED A HIGH ENERGY RATION

TABLE OF CONTENTS

INTRODUCTION

As the high energy ration came into prominent use the value of the vitamins of the B-G complex became more fully realized. The use of a synthetic source of these vitamins to supplement the low-vitamin, high energy feeds has made possible the use of the high energy broiler ration on a commercial scale. Unless the vitamins of the B-G complex are added, inefficient use is made of the high energy feed and vitamin deficiencies become apparent.

The vitamin levels which had proven satisfactory for the low energy ration were inadequate to support the increased rate of growth produced by the ration high in dietary energy. So little was known concerning the increased requirement that higher levels of the B-G complex vitamins were indiscriminately added to the high energy ration.

It was found that the more rapidly growing chick not only required a higher level of nutrients but had an increased need for a diet which supplied all the essential nutrients in the correct proportion. It is not yet certain that the increased rate of gain resulting from feeding the high energy ration demands a higher level of all vitamins. Furthermore, it is generally believed that age has a direct influence upon the vitamin requirement of the chick.

It would be highly desirable to obtain more exacting information concerning the vitamin requirements of chicks fed a high energy ration. The purposes of this study are as follows:

(1) Primarily, to determine if the dietary requirements for riboflavin, pantothenic acid, niacin, choline and folic acid are increased when the chick is fed a high energy ration.

(2) To gain some general idea of the practical levels of the above-named vitamins which should be included in the high energy ration.

(3) To examine some of the problems, such as effect of substituting the corn with grain sorghum as a source of energy, which are related to the primary purpose of this study.

REVIEW OF LITERATURE

Although a great interest has been shown in research dealing with the vitamins of the B-G complex very little attention has been given to the vitamin need of chicks fed a high energy ration. Most of the information available has come from experiments designed to solve other problems. Much of the research of this nature concerns the medicinal value of the vitamins.

Mishler, Carrick, Roberts and Hauge (1946) found the corn-soybean meal type of ration lacked riboflavin, pantothenic acid, choline and niacin. Mill products, substituted for corn in the ration, depressed growth. The modern high energy ration contains little more than corn, soybean meal, vitamins, and minerals. Corn usually comprises about 50 to 70 percent of the ration.

Sure and Romans (1948) found that a deficiency of the B-G complex caused a gross decrease in feed intake and feed utilization. They found a great reduction in growth when the vitamins were omitted from the rat ration.

Ackerson and co-workers (1950), on the other hand, reported that they could find no advantage for feeding added levels of the vitamins of the B-G complex to a ration similar to the high energy type. They kept the chicks in individual feeding cages and accurately determined body weights. Nitrogen, calcium, and phosphorus retention was determined. The ration used contained 3 percent dried buttermilk and other sources of the B-G complex. The rate of gain was about 180 grams at four weeks which is very low in comparison to results obtained from a good high energy ration.

Hegsted (1948) working with vitamin requirements concluded that a large number of chicks were required to demonstrate small, though significant, differences. He pointed out that many of the additive growth effects of certain levels were very small. There is a tendency to set the vitamin requirements too low because with a small group of chicks an appreciable difference might appear inconsequential.

After a brief review of literature which discloses the need for vitamins of the B-G complex and some of the problems connected with the feeding of the high energy ration, the literature dealing with each specific vitamin will be examined. Table I shows a summarization of the levels of vitamins studied in this review, the vitamin content of two high energy broiler rations which have given excellent results and some recommended levels compiled by nutritionists.

RIBOFLAVIN

The levels of riboflavin recommended in the literature are far below the levels generally used in a high energy ration. The effect exerted by increased growth and the feeding of B_{12} and antibiotics upon the riboflavin requirement has not yet been determined.

Norris, Wilgus, Ringrose and Heiman (1936) published the first work on the quantitative requirement of the chick for riboflavin. Their data showed that because of body reserves no good estimate could be made of the requirement for riboflavin during the first two weeks of the growing period. The requirement for maximum growth to four weeks was found to be 1.46 mg. per pound. The requirements for maximum growth to the sixth and eighth weeks of age were 1.35 mg. per pound and 1.3 mg. per pound, respectively.

In another study Heuser, Wilgus and Norris (1938) gave the optimum requirement based upon the age of the chick. They found that the chick could best utilize a ration containing 1.58 mg. of riboflavin per pound during the first two weeks of its life, 1 mg. per pound during the fourth week, 0.7 mg. per pound during the sixth week and 0.45 mg. per pound during the eighth week.

Results obtained by Lepkovsky, Taylor, Jukes, and Almquist (1938) indicated that the minimum riboflavin requirement for all classes and ages of poultry is 1.5 mg. per pound but they did not report what the optimum levels should be.

Bird, Asmundson, Kratzer and Lepkovsky (1946) stated that the riboflavin requirement of the chick for optimal growth to four weeks of age is between 1.23 and 1.46 mg. per pound of ration. In addition, they reported the level for optimum growth to be below the level necessary to prevent curled-toe paralysis. The optimal growth as reported in this experiment is far below the gains which are consistently obtained with high energy broiler rations.

Bethke and Record (1942) found that a synthetic source of riboflavin was equally as effective as a natural source. They found it required 1.1 mg. per pound of ration for maximum growth but 1.35 mg. per pound was necessary for the prevention of deficiency symptoms.

Evans, Slinger and Marcellus (1943) using crystalline and natural sources of riboflavin set the minimum level at 1.3 mg. per pound and recommended that 1.7 mg. per pound be included in the ration. They observed some improvement in feather development when the natural source was fed.

Wilgus and Zander (1945) successfully replaced dried whey as a source of riboflavin with crystalline riboflavin but limited the recommendation for feeding the synthetic form to one-half the total requirement.

Patrick and Morgan (1944) found much of the riboflavin from a natural source as determined by the fluorometric method to be unavailable to the chick. This indicates that the chick biological test might be the best measure upon which to base feeding recommendations.

Reiser and Pearson (1946) found that more riboflavin is required when the diet is high in fat and explained that the unsaturated fatty acids interfere with the intestinal synthesis of riboflavin. Intestinal synthesis is probably of little importance in meeting vitamin requirements when high energy rations are fed.

PANTOTHENIC ACID

The use of added levels of pantothenic acid in poultry rations is relatively new. The levels as given in this review are for the low energy type of ration. Bauernfeind, Norris and Heuser (1942) reported that White Leghorn chicks required 2.24 mg. of pantothenic acid per pound of ration for the prevention of deficiency symptoms and 2.7 mg. per pound for maximum growth. Rhode Island Reds were found less susceptible to a pantothenic acid deficiency and required only about 0.33 mg. per pound of diet. A diet treated with heat to eliminate the natural occurring vitamin was used to determine the requirement of pantothenic acid for the chick. They concluded that a pantothenic acid supplement, in addition to the pantothenic acid naturally occurring in the diet, is not necessary because the practical ration contained an amount far above the requirement. The maximum growth as reported for these chicks is about one-half the growth expected from rations used in this study.

Cline (1945) in an experiment using distillers dried solubles indicated that for the higher rate of growth obtained with the high energy ration, a synthetic supplement of pantothenic acid is necessary. He did not indicate the necessary level.

Lepkovsky, Bird, Kratzer, and Asmundson (1945) used heated diets to destroy the naturally occurring pantothenic acid. The feed was extracted with charcoal absorbate to remove all traces of the vitamin. Through the use of a synthetic source they determined that the chick required 4.1 mg. per pound of diet.

Ram (1949) produced experimentally and reported many of the symptoms resulting from a pantothenic acid deficiency in the chick. He found about 4.3 mg. per pound a safe level to prevent deficiency symptoms.

Pearson, Melass and Sherwood (1946) analyzed the tissue and bone in the chick for pantothenic acid content in an effort to determine the proper dietary level. They set 7.1 mg. per pound as the amount of pantothenic acid necessary to maintain the normal blood level. The feeding of an adequate level of the vitamin to chicks depleted by a low pantothenic acid ration caused a rapid rise in the pantothenic acid level of the muscle tissue.

Jukes and McElroy (1943) used a heated diet containing natural feedstuffs depleted of their pantothenic acid content. They found that the requirement levels were very variable for rations containing different feedstuffs. They state that the average requirement was 4.5 mg. per pound of diet and that a ration containing one-half this amount produced some deficiency symptoms.

Hegsted and Riggs (1949) reviewed the literature on requirements for pantothenic acid and conducted experiments with various levels in the diet. They pointed out that only about 66 percent of the pantothenic acid in the ration is available to the chick. They found little difference in gain when levels above 4.5 mg. per pound were fed.

Bird and Rubin (1946) observed that 9 mg. per pound of calcium pantothenate and 675 mg. per pound of choline chloride gave a very favorable growth response. This experiment indicates that the chick can tolerate an excessive level of pantothenic acid in the diet. The authors stated that the level of choline in this ration was high.

Groschke and Evans (1951) reported that B_{12} had a depressing effect on the storage of pantothenic acid in the liver and that penicillin reduced the requirement for pantothenic acid.

Yacowitz, Norris and Heuser (1950) reported a sparing effect of B_{12} on the requirement of pantothenic acid for the chick. It was also found that the addition of B_{12} to a ration low in riboflavin intensified the riboflavin deficiency. It is possible that this report and the preceding one are not contradictory. The B_{12} might in some way activate the pantothenic acid in the liver and by increasing its utilization lower the required dietary level for pantothenic acid.

NIACIN

Great interest has been shown in the niacin requirement of the chick fed a high corn ration. It has been impossible to definitely establish the optimum dietary levels of niacin in the high energy ration because it is related in its function to several of the nutrients in the ration. Briggs, Mills, Elvehjem and Hart (1942) found that chicks required a dietary source of niacin for optimal growth. They described the symptoms of a deficiency and established the minimum level at 8.1 mg. per pound. They claimed the same activity for niacin amide as for niacin. They were, however, working with a ration relatively low in energy.

Scott, Singsen and Matterson (1946) working with a high energy ration containing corn found that if no supplementary additions of niacin were made very poor growth and a high incidence of perosis occurred. There was nearly a 100 percent increase in gain due to the niacin supplementation. The supplemented ration did not produce any perotic chicks. The supplementary level used was 9 mg. per pound in addition to 6 mg. per pound from a natural source. The amount of corn used in this ration was higher than is now used in most high energy rations.

Sarma and Elvehjem (1946) found corn grits at a 40 percent level to be growth depressing even when fed with three different levels of proteins. In all cases the growth depression was prevented by the addition of niacin in the ration.

Salmon (1946) discovered that fat had a sparing effect on the niacin requirement of rats when they were fed a corn diet. He concluded that niacin must function in carbohydrate metabolism and that the sparing effect is caused by a decrease in the rate of carbohydrate metabolism. If this is true, it seems logical to assume that the niacin requirement would rise when a high carbohydrate diet is fed.

Hundley (1949) using rats found that a great variation in niacin requirements resulted from the use of different types of carbohydrates. He found that rations containing large amounts of dextrins and starch require about one-third less niacin than rations containing fructose, galactose and sucrose. In another report (1947) he stated that the growth depression due to a high level of corn is corrected by the use of either niacin or tryptophane. He demonstrated that rats deficient in tryptophane showed a marked increase in niacin synthesis. Generally a ration high in protein would be expected to require less niacin because of the sparing effect of tryptophane.

Briggs (1945) showed that a New Hampshire strain of chicks fed a ration high in corn required at least 22.5 mg. per pound of diet when the tryptophane content of the ration is low. They found gelatin about three times more active than corn in depressing growth in a low niacin ration.

Mishler, Carrick, Roberts and Hauge (1946) observed a growth depressing effect from feeding 22 mg. per pound of niacin in a corn-soybean oil meal type of ration.

Denton, Kellogg and Bird (1947) conducted tests to determine the factors which affect niacin storage in the tissue of the chick. They found that the quantity of niacin in the tissue depended on the level of dietary intake and the age of the chick. The storage level of all tissue declined slightly, but consistently as the chick grew older. They could increase the niacin in the body tissue storage by increasing the level in the diet.

It has been shown that the chick can synthesize some of the niacin needed. Dann and Handler (1941) found that the chick contained about 10 to 20 times as much niacin as the egg. The chick is, therefore, well fortified with niacin for the first part of its life. Briggs (1942) found that roughly one-sixth of the niacin requirement is provided by intestinal synthesis during the first four weeks of the chick's life.

CHOLINE

Due to the interrelationships with other nutrients, experiments with choline are very difficult to interpret. Research seems to suggest that the role as a methylating agent is the important function of choline. Muntz (1950) suggested that choline does not transfer its methyl groups directly but must be converted to betaine before transmethylation can occur.

That choline is related to both B_{12} and betaine is shown in a report by Gillis and Norris (1949). They found that B_{12} has a sparing effect on choline. They were able to substitute an equal amount of betaine for the 0.2 percent choline in the ration and receive equally as good results. B_{12}, substituted for all the choline in the ration, produced as good a gain as a combination of B_{12} and choline.

Schaefer, Salmon and Strength (1949) reported that in using a purified diet the choline requirement was 0.6 percent for maximum growth but if

3 micrograms of B_{12} per pound were added the choline requirement dropped to 0.2 percent or about 900 mg. per pound.

Jukes (1949) in experiments involving the methylating compounds found that a decrease in growth resulted from feeding 1 percent choline (4,500 mg. per pound). This amount is about five times the levels contained in the high energy ration referred to in Table I.

Gerry, Carrick and Hauge (1948) found that choline in the ration had a sparing effect on methionine. Good results were obtained when both were fed at either a 0.25 percent or a 0.50 percent level.

Melass, Pearson and Sherwood (1946) found 0.5 percent adequate for maximum growth. The addition of 1 percent decreased gain from 10 to 15 percent and levels from 2 to 4 percent decreased gains from 14 to 24 percent. They observed that in feeding higher choline levels, less fat was deposited in the tissue.

Record and Bethke (1942) claim that 0.15 percent choline is ample for maximum growth for chicks fed a practical ration. They found soybean lecithin an effective substitute for choline.

Marvel, Carrick, Roberts and Hauge (1945) conducted an experiment using a corn-soybean meal ration similar to a high energy ration. Distillers dried solubles contributed most of the natural choline to the ration. Excellent weight gains were produced by adding 0.15 percent of choline to this practical ration to make a total of 0.29 percent of the ration.

Both the natural and synthetic choline appears to be very stable. Cooley and Christiansen (1948) found the choline content of mixed feed almost unchanged after six months storage. Addition of an appreciable amount to a ration as a safety factor does not seem necessary.

FOLIC ACID

The need of a supplemental addition of folic acid to the normal or practical poultry ration has not yet been demonstrated. Most of the practical rations contain an estimate of 1 mg. of folic acid per pound of ration from a natural source. Synthetic sources are available and varied benefits are reported from their use.

Very little work has been completed on the quantitative analysis of the common feedstuffs for folic acid. Lillie (1947b) (1950a) reports figures on some of the more commonly used ingredients and by their use an estimation of the natural level in the ration may be determined.

Lillie and Briggs (1947a) experimenting with New Hampshire chicks found that a minimum of 0.68 mg. of folic acid per pound of diet was necessary for optimum growth and 0.9 mg. per pound was necessary for normal feathering. This experiment was made using a completely purified diet and is the first record that better gains could be made on a purified diet than on a practical ration. At a folic acid level of 0.05 mg. per pound, Leghorn chicks gave a greater growth response than did New Hampshire chicks, but with higher levels up to 0.135 mg. per pound the results were reversed. These authors believe that some folic acid should be added to the practical starting ration for optimum growth.

Lillie, Combs and Briggs (1950b) have made an extensive investigation of the requirements of poultry for folic acid. They reported that there was a sexual difference in the folic acid requirement. The male required a larger amount as indicated by feather pigmentation comparisons. They found a higher level of folic acid was necessary for proper feather pigmentation than for proper feather structure. They also found that the feeding of a folic acid deficient ration during the first two weeks produced a much greater incidence of abnormal feather pigmentation at six weeks than when an ample diet was fed the entire period. This seems to definitely stress the importance of folic acid in the early life of the chick.

Robertson, Daniels, Farmer, Norris and Heuser (1946) reported that 0.11 mg. per pound of diet is necessary for survival to six weeks of age. They favored 0.2 mg. per pound as the level necessary for normal growth to four weeks. According to their results, 0.137 mg. per pound was necessary for normal hemoglobin level and 0.25 mg. per pound was necessary for proper feather pigmentation. The level necessary for maximum growth response was 0.2 mg. per pound. They conclude that about 0.45 mg. per pound is a safe level for a practical growing ration.

Hill and Briggs (1951) used a synthetic ration containing about 56 percent cerelose and produced chicks weighing about 260 to 270 grams at four weeks. They found 1 mg. per pound of diet gave good results and that 0.5 mg. per pound was too low. Growth about one-third better than that reported by Hill and Briggs should be expected from a high energy ration.

Luckey, Moore, Elvehjem and Hart (1946) concluded that the nature of the constituents of a ration had a great effect on the folic acid requirement. They found that 0.045 mg. per pound permitted maximum growth when a high protein diet was used. They reported that feather development cannot be correlated with either the level of folic acid in the diet or rate of growth when a low level of folic acid is fed in the diet.

EXPERIMENTAL PROCEDURE AND RESULTS

General

One thousand and forty New Hampshire straight-run chicks were used in three experiments. Each chick was wingbanded for the purpose of identification. The initial and weekly body weights were recorded. Daily mortality records were kept. The amount of feed consumed per pen was recorded at weekly intervals. The feed was removed from the pens the night before the chicks were to be weighed. The duration of each feeding trial varied as given in the Experimental Procedure for each experiment. The conditions in all pens were kept as nearly uniform as possible.

Basal rations were used as much as possible to insure uniformity. Levels of the vitamins naturally occurring in the rations were computed using the latest and most applicable tables. The synthetic vitamins added to the rations were carefully weighed on a gram balance and mixed with a suitable carrier in a ball mill for twenty minutes. The vitamin supplement was then mixed with the proper basal ration for another twenty minutes. Fresh feed was mixed for each four-week period and was screened at the end of the first week to prevent lumping.

The various experimental levels of the vitamins of the B-G complex fed in this study are given in tables accompanying each experiment. The basis for the selection of these levels is found in the Review of Literature and is summarized in Table I. The lower levels closely follow the recommendations for the low energy starter ration and the higher levels are based upon experimental data and the amounts contained in some typical high energy rations.

Chicks were not depleted for these tests and the parental stock was fed a good practical ration considered ample in all known vitamins. All rations used in these experiments were the all-mash type and no supplements or injections were used in addition to the mash. Feed and water were available at all times during the growing period, except for periods previous to body weight determinations. Appropriate size feeders were supplied as needed and the feed wasted was negligible.

Feed samples were collected from each ration and chemical determinations of protein, ash, water, fat, fiber, nitrogen-free extract, calcium and phosphorus were made in order to check for possible error in mixing the ration. Very little variation in the chemical content of the different rations was noted and the computed values and analytical values agreed very closely.

Each trial was planned in such a manner that proper statistical analyses might be made. Chicks for each pen were randomly selected and the rations of each comparison group were randomly assigned to pens.

An analysis of variance was computed for each comparison group for each week of the experiment. Significant differences were isolated using the t-test as described by Snedecor (1946). Gain in grams is the unit of measure used throughout the experiments. Total gain represents the gain made by all chicks alive at the termination of the test.

A pen is used in this study to represent a group kept in a common enclosure and a lot is one or more pens fed the same ration. Replicate pens compose a lot.

Experiment I

Experimental Procedure

The first approach in this study was exploratory. Control, high and low levels of riboflavin, pantothenic acid, niacin, choline and folic acid as selected and used in the various test rations are listed in Table II. Table III gives the semi-purified ration used to mix the eleven rations used in this experiment.

Twelve lots of twenty chicks each were grown on the floor of a colony type house equipped with a hot water brooding system. Pens were approximately 6 x 8 feet and separated with wire partitions. New litter was placed in the pens at the beginning of the experiment and additions were made when necessary.

The eight-week experimental period started December 26, 1950, and ended February 21, 1951. The sex of each chick was recorded at the termination of the test.

Results

The total and weekly weight gains for the lots in Experiment I are given in Table IV. There were no significant differences in the weekly gains of any lot until the fourth week of the growing period.

A distinct advantage in favor of the high level of riboflavin as compared with the low level existed in the weekly gains for the first two weeks of the test. The gains of the high riboflavin lot for the fourth, fifth and sixth weeks were significantly higher than the gain produced by the low level lot. During the seventh and eighth weeks the lot fed the high level of riboflavin maintained a non-significant advantage over the low level. This advantage approached significance when the sex gains were used instead of the mean lot gains. This was due to the small number of males in the high riboflavin lot and was the only instance in the experiment when the sex and lot mean differed appreciably.

The chicks fed a high level of pantothenic acid produced a gain during the fourth week which was significantly higher than the gains of the chicks fed the control level and appreciably higher than the gains produced by low level feeding of pantothenic acid. Very little difference was noted between the high and low levels until the eighth week when the weekly gain of the high pantothenic acid lot was significantly higher than the gain produced by the chicks fed the low level. During this same period the ration containing a low pantothenic acid level produced a significantly lower gain than did the control group. For the total gain of the entire experiment there was an appreciable, but non-significant advantage in favor of the high pantothenic level over the lower levels.

Even during the second and third weeks, the high level of niacin appeared above optimum. From the fourth to the eighth week the lot fed a low level of niacin consistently produced better gains than did the high level lot. The gain of the low level lot was almost as good as the gain produced by the control group. The gain made by the high niacin lot during the fifth week was significantly lower than the gain produced by the control lot. The total gains for the entire period showed that the lot fed the high niacin level produced gains significantly lower than the gains made by the control lot. The difference between the total gains of lots fed the high and low levels of niacin approached significance in favor of the low level. All these results seem to definitely point out that the ration containing a low level of niacin was as effective in producing gain as the ration containing the higher levels.

The lot fed a low level of choline made as good a gain and sometimes exceeded the gain produced by the high choline lot. No real difference existed in the weekly gain of the different choline lots except during the fifth week when the low level excelled and in the eighth week when the results produced by the high level were best. No important difference existed in the total gains but a comparison with the control lot indicated that an intermediate level might be the most effective in a high energy ration.

During the first and eighth week the lot fed a high level of folic acid made a slight, but non-significant greater gain than did the lot fed the low folic acid level. On the other hand, the group fed the low folic acid ration produced better gains for all other periods of the experiment. For the total gain the advantage of the low level folic acid lot was significant when compared with the results obtained from the feeding of a high folic acid level. During the fourth week the lot fed the control level of folic acid made a significantly greater gain than the gain produced by the group fed the ration containing a higher level of that vitamin.

Experiment II

Experiment II was designed to gain some information pertaining to the effect of feeding low and high levels of an individual vitamin when the other vitamins of the B-G complex were varied. The experiment was divided into four comparison groups. The vitamin levels fed in Part A were basically high and in Part B all except one vitamin in each ration were fed at a low level. Part C dealt with some intermediate levels in addition to the high and low levels of each vitamin. Part D gave the comparison of Dwarf White Kafir and corn in a series of rations with variable vitamin levels. Experiment II was conducted during the four-week period from March 19 to April 19, 1951.

Part A

Experimental Procedure

This part of this experiment was designed to test the value of feeding a low level of a B-G vitamin combined with a high level of each of the other vitamins of the B-G complex.

The semi-purified basal used in Experiment I and as listed in Table III was used for all lots. Vitamin supplements were added to make the dietary levels conform to the total levels given in Table V.

Twelve pens of ten chicks each were used to test six rations. One ration was used as a high vitamin control. All pens were kept in new multi-section electric battery brooders.

Results

The results of this section of the study are given in Table VI. There was no significant difference in the weekly lot means during the first three weeks.

The low weekly gains made by the lot fed Ration 1, although not significantly different from the control, strongly suggest that a high level of riboflavin was necessary for proper growth to four weeks. The gain made by the low riboflavin pens during the fourth week was significantly lower than any lot in this comparison group except the control lot.

The gains made by the low pantothenic acid pens were surprisingly high when results of Experiment I are reviewed. The erratic growth of these pens should be noted. This should leave little doubt that a high level of pantothenic acid is desirable in the high energy ration.

The lots which were fed low levels of niacin, choline and folic acid consistently produced better gains than the control containing the high levels of these vitamins. These differences were significant at the fourth week and in the total gains. This indicated that the poor gains produced by the control lot were probably due to a high level of either choline, niacin or folic acid rather than a high level of riboflavin or pantothenic acid.

Part B

Experimental Procedure

This part of the experiment involved the addition of a high level of a vitamin of the B-G complex to a ration containing a low level of each of the other vitamins concerned in this experiment.

The semi-purified basal listed in Table III was used for all pens. Table VII shows the total vitamin content of each of the rations.

Twelve pens of ten chicks each were used to test six rations. One ration was used as a low vitamin control. All pens were kept in new multi-section electric battery brooders.

Results

Statistical analysis of each weekly period reveals no real difference in the lot means until the fourth week. At that time the gains made by the pens fed the high level of pantothenic acid were significantly better than the gains produced by the low vitamin control lot.

There was no significant difference in the lot means of the total gains. Although not significant these results do give some good indication of certain trends. There seems to be a distinct advantage in feeding the higher level of riboflavin and pantothenic acid when compared to lower levels in the control lots. When compared with the results of the control lot the feeding of a high level of choline, folic acid and possibly niacin seems undesirable. The results of this part of the experiment are given in Table VIII.

There seems to be little advantage in feeding a high level of a given vitamin if a low level of the others is fed. It is worthwhile to note the erratic weekly gain of the pens fed the same ration. It is reasonable to expect such results with an improperly balanced vitamin content.

Part C

Experimental Procedure

This part of the experiment was designed to test some high and low levels of the vitamins of the B-G complex and in addition some levels of an intermediate nature.

The semi-purified basal listed in Table III was used for all pens. Vitamin supplements were used to make the total content of vitamins conform to levels listed in Table IX.

Twenty-two pens of ten chicks each were used to test eleven rations. All pens were kept in new multi-section electric battery brooders.

Results

The results of this part of the study were distorted by a sinus infection during the fourth week. Statistical analysis was used on the weekly gain for the first three weeks. The total and weekly gains are recorded in Table X.

The control level of riboflavin appeared to be sufficient for the first three weeks but inferior for the fourth. The total gain favors the intermediate level.

The pens fed a high and intermediate levels of pantothenic acid made significantly better gains during the second week as compared with the control lot. The intermediate level continued to carry its advantage to the fourth week but the high level did not make as favorable results.

The low levels of niacin and choline were sufficient up to the end of the second week but during the latter period of the experiment the intermediate levels slightly improved.

The intermediate level of folic acid produced a distinct advantage over both the control and low levels. The low level produced results slightly superior to the control level. During the second week the gain produced by the intermediate level was significantly greater than either the control or low level.

Part D

Experimental Procedure

Fourteen pens of ten chicks each were used as a preliminary attempt to apply the results obtained in Experiment I to a practical high energy ration. Rations in which grain sorghum was substituted for yellow corn were fed to seven pens. Dwarf White Kafir was the grain sorghum used.

The basal corn and grain sorghum rations are listed in Table XI. The total vitamin levels are given in Table XII. All lots were kept in a multi-section electric battery brooder.

Results

The results for this part of the experiment are to be found in Table XIII. Statistical analysis revealed no real difference in the weekly gains until the fourth week. At that time the high vitamin control lot produced gains significantly lower than the control lot. It should be noted that the pen fed the high vitamin level containing grain sorghum made very poor gains. It would have been highly desirable to have a replicate of these pens to determine whether the difference was entirely nutritional.

The results obtained from feeding a high level of riboflavin indicated that 6.4 mg. per pound was not desirable when low levels of other vitamins are fed.

The differences in the total gains of the pens fed the high level of pantothenic barely missed the significant level and pointed out the need for a high level of pantothenic acid in the diet.

A low level of niacin apparently did not significantly affect the total gains for the four-week period. It might be pointed out that the gain during the fourth week was as good on the low niacin rations as on the higher level.

The rations low in choline gave consistent results throughout the entire four weeks. While this does not indicate that the optimum level of each vitamin was present, it does strongly suggest that there was a good balance in the levels of each constituent vitamin. The significant difference in the gain of the low choline pens over the high choline level of the control pen indicated a possible toxic effect from the latter level.

The feeding of a high level of folic acid showed that lower levels of folic acid were as effective. The poor gain made by pens fed Ration 5 seems to have indicated a depressing effect due to the higher level of folic acid. The greatest depression was in the ration containing corn but the highly significant difference in the corn and grain sorghum pens fed a high level of folic acid suggest a difference in their supplementary need for the vitamin. The effect of the high level of folic acid was less depressing during the first two or three weeks of the experiment.

An examination of the results indicated that the high level of pantothenic acid was responsible for growth improvement in the high vitamin pen containing corn.

A comparison of the results secured from corn and grain sorghum should be briefly reviewed. Most of the difference between the pens occurred during the third week. Based on the total gains it seems logical to assume that the corn basal required a higher level of riboflavin, pantothenic acid and choline. The grain sorghum basal seemed to utilize folic acid supplementation to a good advantage. With the exception of the high folic acid and the high vitamin pens practically no difference existed between the gains of the corn and grain sorghum lots during the fourth week.

Experiment III

Experimental Procedure

This portion of the study was an attempt to apply the data from the previous experiments to a practical high energy ration and to verify the results obtained from the semi-purified diet.

The corn-soybean oil meal basal is given in Table XI. Additional vitamins were added to the basal so that the levels complied with the total figure listed in Table XIV.

Five rations were fed to ten pens containing twenty chicks each. All pens were kept in one multi-section electric battery brooder. The four-week experiment started May 14 and terminated June 11, 1951.

Results

Growth in this experiment was not as good as in those conducted earlier. Probably the chief reason was the higher and more variable temperature of the late spring period. Total and weekly gains were recorded in Table XV.

Feed consumption and utilization records were compiled in Table XVI and since there was no mortality in this test these figures should be very accurate.

The levels of riboflavin fed in this experiment seemed to have made but little difference in terms of body growth. A slight advantage in gain from feeding a high level of riboflavin was made during the fourth week. The rations having a higher level of riboflavin had a distinct advantage in feed utilization.

The high level of pantothenic acid seemed to have had an advantage in terms of growth during the fourth week. The results of Pen 6 was not consistent with the results found in other experiments of this study and suggest that Pen 2 was a better measure of the results expected from Ration 2.

The results from Ration 3 suggested that the intermediate level of all the vitamins was not the solution to the problem of finding the optimum dietary levels for the high energy ration.

The good gains produced consistently by Ration 4 should be noted. There was very little variation in the gains of pens fed this ration. The feed efficiency of this pen was excellent.

The pens fed the high level of all vitamins gave inconsistent results. Growth was erratic as though a series of depletions had occurred. There seemed to be no advantage in feeding a high level of all vitamins in view of the total gains.

DISCUSSION

The most consistent trend observed in this study was the intermittent periods of good gain produced by rations believed to contain an imbalance of vitamins or a high level of all vitamins. This was probably due to the rapid depletion of the available nutrients. It was noted that the more rapid the growth rate the more spasmodic the rate of gain. There was usually an accompanying irregularity in feed intake.

The results sought were not the effect of the various levels of any single vitamin but what effect that level exerted when combined with the various levels of the other vitamins of the B-G complex. The interaction of the combinations of vitamins makes it difficult to isolate and assign the small increase due to the small change in the dietary level of any certain vitamin. This small increase in growth is dependent on so many factors, some of which are not nutritional in nature, that it is very difficult to consistently demonstrate it. Unless a large number of chicks are used and the differential growth due to sex is isolated the consistent trends are the chief basis for securing information.

The various vitamin levels fed during the first two weeks seemed to have had little or no effect upon weekly gains. In extreme cases, this might not be true. Probably the body reserves of the chick were sufficient for the need up to about two weeks of age. A toxic level of a vitamin in the ration might not exert its effect during that time because of the lack of ability of the chick to utilize the dietary vitamins. It is probably during the third week that the chick begins to utilize the dietary source to the extent that a much greater measure of dependence is upon that source. This would seem to explain some of the erratic results obtained during the third week of the experiments.

A large amount of energy which is properly supplemented seemed to be the primary factor that produces an increased growth response when the high energy is fed. Panda and Combs (1950) found a minimum of 84 therms of productive energy per 100 pounds of ration necessary for good growth. Rations now used contain from 90 to 95 therms of productive energy per 100 pounds of ration. The higher level of energy, by increasing growth response, apparently also increases the requirement for all vitamins. It seems logical to assume that the sparing effects of certain nutrients might make some of the vitamins of the B-G complex unnecessary and even toxic.

The effect of the interrelationship of B_{12} and antibiotics with the vitamins of the B-G complex should not be overlooked as a suggested explanation of some of the results obtained in this study. Experimental evidence seems to indicate that B_{12} and antibiotics have a sparing effect on folic acid, choline and possibly niacin and their inclusion in the ration would lower the levels of these vitamins required in the ration.

The suggestion that the chick requires more riboflavin and pantothenic acid as the result of added growth response from feeding B_{12} and antibiotics seemed to be verified in these feeding trials.

The general trend of these experiments seemed to emphasize the need for a higher level of riboflavin and pantothenic acid in the high energy ration. The greatest benefits from feeding a high level of these vitamins were derived during the third and fourth weeks. The requirement in terms of mg. per pound of feed seemed to have lessened slightly as the eighth week was approached. Almost all of the increased growth due to folic acid in the diet was obtained during the third and fourth weeks.

The requirements for choline and niacin apparently remain fairly stable up to eight weeks. In this study, the low levels of these vitamins generally produced equal or larger gains than the higher levels. The requirement for niacin was probably low because of the inclusion of an ample supply of tryptophane. The level of several nutrients in the ration such as B_{12}, methionine, antibiotics and cystine might have affected the choline requirement.

An interpretation of these results seemed to indicate that the required level of pantothenic acid was not as specific as the other vitamins of the B-G complex. Good results may be secured with highly variable levels in the ration. On the other hand, a depressing effect seemed to have been produced by levels of niacin, choline and folic acid not greatly exceeding the control levels. This suggests that poor growth on a high energy ration for the first three or four weeks might be attributed to the depressing effect of some of these factors rather than a deficiency of nutrients.

The greatest difference between corn and grain sorghums in the ration did not seem to involve their supplemental requirements for vitamins of the B-G complex. However, the indication that practically the only difference in gain occurred during the third week suggested that a differential vitamin need may be part of the problem. Some interesting differences in corn and grain sorghums in their relationship to the B-G complex vitamins have been suggested. The results of this study suggested that corn rations have a critical need for pantothenic acid and that grain sorghum rations are greatly improved by folic acid supplementation.

Generally, the efficiency of the utilization of the feed varied directly in proportion to the rate of gain. There seemed to be a general trend throughout the experiment that the amount of gain produced per pound of feed was increased by feeding a ration containing a high level of the B-G vitamins. This was especially true in the feeding of high levels of riboflavin and pantothenic acid.

CONCLUSIONS

The following conclusions are based upon the results and conditions of this experiment.

1. The dietary level of riboflavin, pantothenic acid, niacin, choline and folic acid fed during the first two weeks of the life of the chick, as measured by mean weekly gain during that period, was apparently of little importance.
2. That the critical period in vitamin nutrition began during the third week.
3. There was a depressing effect in the feeding of high levels of choline, niacin and folic acid.
4. The inclusion of a high level of any vitamin of the B-G complex with a low level of the other vitamins of the B-G complex did not improve the effectiveness of the ration.
5. The feeding of low levels of riboflavin or pantothenic acid or a high level of all vitamins caused erratic gains.
6. The grain sorghum used in this test had a critical need for folic acid.
7. The most practical levels of the vitamins of the B-G complex for the rations used in these experiments are as follows:

Riboflavin	5.6 - 6.4 mg. per pound
Pantothenic acid	6.25 - 7.5 mg. per pound
Niacin	12.0 - 16.0 mg. per pound
Choline	700 - 800 mg. per pound
Folic acid	1.0 - 1.5 mg. per pound

TABLE I

SUMMARY OF THE B COMPLEX VITAMIN REQUIREMENTS
FOR GROWING CHICKS IN MILLIGRAMS PER POUND OF TOTAL RATION

Source of Information	Riboflavin	Pantothenic Acid	Niacin	Choline	Folic Acid
National Research Council (1946)	1.60	5.00	8.0	700	-
Titus (1949)					
Low Protein Starter	1.70	5.00	7.0	650	.250
High Protein Starter	2.20	6.50	9.0	800	
Oklahoma Broiler Ration (Godfrey, Thayer and Thompson, 1951)	2.42	6.33	22.9	804	.958
Connecticut Broiler Ration (Singsen and Matterson, 1951)	5.76	4.22	23.7	615	-
Levels reviewed in this study	1.30-1.46	0.33	8.1	900	.200
	0.45-1.58	7.10	15.0	2700[1]	.450
	1.50	4.50	22.5	900	.680
	1.23-1.46	4.50	22.5	2250	.900
	1.70	4.30		675	1.000
		9.0[2]		1125-2250	

1 Choline Chloride

2 Calcium Pantothenate

TABLE II

DIETARY LEVELS OF B COMPLEX VITAMINS FED IN EXPERIMENT I
(mg./lb.)

Relative Vitamin Level	Riboflavin High	Riboflavin Low	Pantothenic Acid High	Pantothenic Acid Low	Niacin High	Niacin Low	Choline High	Choline Low	Folic Acid High	Folic Acid Low	Control	Control
Ration Number	1	2	3	4	5	6	7	8	9	10	11	12
Lot Number	4	12	5	1	8	6	9	10	11	7	2	3
Riboflavin	6.4	1.6	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Pantothenic Acid	5.0	5.0	7.5	2.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Niacin	16.0	16.0	16.0	16.0	24.0	8.0	16.0	16.0	16.0	16.0	16.0	16.0
Choline	900	900	900	900	900	900	1400	700	900	900	900	900
Folic Acid	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	5.0	1.25	2.5	2.5

TABLE III

SEMI-PURIFIED RATION

Ingredient	Percent
Cerelose	45.4
Dl Methionine	.1
T Cake (Wheat gluten hydrolysate)	1.0
Soybean Meal (Low-fiber, 50% protein)	41.0
Mineral Mix No. I	5.0
Vitamin Mix No. I	2.5
Soybean Oil	5.0

Mineral Mix No. I	
Ingredient	Percent
$CaCO_3$	29.40
$CaHPO_4 \cdot 2H_2O$	35.58
K_2HPO_4	15.73
NaCl	11.24
$MgSO_4 \cdot 7H_2O$	9.36
$Fe(SO_4)_3 \cdot 7H_2O$	1.03
$MnSO_4 \cdot 4H_2O$	0.54
KI	0.062
$CuSO_4 \cdot 5H_2O$	0.028
$ZnCl_2$	0.018
$CoCl_2 \cdot 6H_2O$	0.0037

Vitamin Mix No. I	
Ingredient	Amount
Vitamin A Oil (6000 I.U./gm.)	.2 lb.
Vitamin D (2000 A.O.A.C./gm.)	.1 lb.
Tocopherol Concentrate (10 mg. of Alpha Tocopherol/gm.)	19 c.c.
Menadione	.018 gm.
Thiamin Hypochloride	.227 gm.
Biotin	.0045 gm.
Pyridoxine	.227 gm.
Mercks B_{12} and Antibiotic Supplement (12 mg. B_{12}/lb. and 3 gm. procaine penicillin/lb.)	51 gm.
Cerelose	4.5 lbs.

TABLE IV

SUMMARY OF RESULTS OF EXPERIMENT I

Relative Vitamin Level	Riboflavin		Pantothenic Acid		Niacin		Choline		Folic Acid		Control	
	High	Low	High	Low	High	Low	High	Low	High	Low		
Lot	4	12	5	1	8	6	9	10	11	7	2	3
						Grams Of Gain In Body Weight						
Growth Interval By Weeks												
0-1												
Ave. Male	38.0	33.0	38.9	40.2	39.2	38.4	39.5	39.2	44.3	39.0	42.5	42.1
Ave. Female	35.9	27.8	34.3	32.1	31.3	38.3	35.5	36.4	37.7	36.9	37.4	36.1
Lot Mean	36.4	29.9	36.3	36.4	34.9	38.4	37.6	37.7	40.7	38.2	39.4	38.8
1-2												
Ave. Male	75.8	66.5	70.9	68.7	57.0	71.0	70.7	75.1	69.0	71.1	68.8	76.5
Ave. Female	66.5	61.9	59.2	55.2	49.5	66.1	63.4	65.8	60.4	67.6	63.6	64.5
Lot Mean	68.8	63.4	64.5	62.3	52.9	68.3	67.2	70.0	64.2	69.7	65.7	70.0
2-3												
Ave. Male	105.8	108.5	106.1	103.2	86.4	105.8	99.5	98.2	108.1	110.9	112.5	108.1
Ave. Female	91.7	87.3	85.7	81.4	75.0	88.7	91.8	78.4	93.4	103.0	101.4	97.5
Lot Mean	95.3	95.8	94.9	92.9	80.2	96.5	95.8	87.3	100.0	107.8	105.9	102.3
3-4												
Ave. Male	122.4	100.0	151.1	144.1	120.9	118.3	116.7	113.2	78.2	90.0	104.3	121.1
Ave. Female	110.5	68.3	128.3	112.0	103.1	86.7	71.6	89.8	56.3	77.8	94.8	92.5
Lot Mean	113.5	80.9	138.6	128.9	111.6	101.0	95.5	99.3	66.2	85.1	98.6	105.4
4-5												
Ave. Male	148.8	108.8	127.6	133.4	106.9	127.3	124.4	143.4	132.2	139.8	156.9	145.9
Ave. Female	172.6	124.6	146.8	153.8	112.8	150.0	131.0	168.2	147.1	148.1	166.8	168.5
Lot Mean	148.8	108.8	127.6	133.4	106.9	127.3	124.4	143.4	132.2	139.8	156.9	145.9
5-6												
Ave. Male	156.2	136.2	165.6	160.9	159.0	174.1	162.1	156.6	147.2	167.8	157.2	189.7
Ave. Female	116.8	99.7	116.4	127.8	124.7	143.2	118.3	123.9	116.9	141.5	134.7	134.5
Lot Mean	126.7	114.3	138.6	145.2	140.1	156.6	140.2	138.7	136.5	157.3	143.8	159.4
6-7												
Ave. Male	254.8	208.8	244.4	224.2	210.7	238.6	235.8	255.2	225.8	229.7	220.8	251.6
Ave. Female	186.7	169.7	177.7	169.6	169.9	186.3	173.0	190.7	160.6	164.9	194.5	174.2
Lot Mean	203.7	185.3	207.8	198.4	188.3	209.8	217.5	219.8	191.5	203.8	204.9	209.0
7-8												
Ave. Male	200.4	170.8	194.2	144.0	197.2	192.0	193.7	142.1	205.4	173.6	181.4	199.2
Ave. Female	129.3	122.2	137.5	114.1	119.4	133.7	130.0	78.5	137.6	138.6	131.8	132.4
Lot Mean	147.1	141.6	163.0	129.8	154.4	160.0	163.5	107.1	169.7	159.6	151.6	162.2
0-8												
Ave. Male	1,106.0	948.5	1,118.1	1,039.3	983.3	1,088.0	1,027.2	1,059.4	1,024.8	1,038.3	1,053.9	1,135.3
Ave. Female	879.8	735.0	853.1	800.0	779.4	852.0	806.1	784.6	773.5	870.1	908.5	859.4
Lot Mean	936.4	820.4	972.4	925.8	871.2	958.2	922.5	908.3	892.6	971.1	966.6	983.6
						Pound Of Feed Per Pound Of Gain						
0-8	2.69	2.55	2.50	2.64	2.47	2.63	2.60	2.50	2.64	2.67	2.61	2.81

TABLE V

DIETARY LEVELS OF B COMPLEX VITAMINS
FED IN EXPERIMENT II-A
(mg./lb.)

Relative Vitamin Level	Riboflavin Low	Pantothenic Acid Low	Niacin Low	Choline Low	Folic Acid Low	Control High
Ration Number	1	2	3	4	5	6
Pen Number	6 11	12 22	10 24	3 13	18 20	4 14
Riboflavin	1.6	6.4	6.4	6.4	6.4	6.4
Pantothenic Acid	7.5	2.5	7.5	7.5	7.5	7.5
Niacin	24	24	8	24	24	24
Choline	1400	1400	1400	700	1400	1400
Folic Acid	5.0	5.0	5.0	5.0	1.25	5.0

TABLE VI

SUMMARY OF RESULTS OF EXPERIMENT II-A

Relative Vitamin Level	Riboflavin Low		Pantothenic Acid Low		Niacin Low		Choline Low		Folic Acid Low		Control High	
Ration Number	1		2		3		4		5		6	
Pen Number	6	11	12	22	10	24	3	13	18	20	4	14
	Grams Of Gain In Body Weight											
Growth Interval By Weeks												
0-1												
Pen Mean	45.6	44.8	40.2	36.1	36.2	39.1	40.6	38.9	39.2	43.7	38.5	35.2
Lot Mean	45.2		38.1		38.5		39.7		41.4		36.8	
1-2												
Pen Mean	58.6	62.9	60.6	54.1	66.4	64.6	69.4	67.6	67.7	64.8	63.8	58.9
Lot Mean	60.7		57.2		65.6		68.5		66.2		61.2	
2-3												
Pen Mean	69.0	82.6	77.0	57.8	85.1	79.1	69.6	85.7	72.6	58.8	75.9	63.1
Lot Mean	75.9		66.9		82.4		78.0		65.7		69.1	
3-4												
Pen Mean	118.7	79.5	111.2	134.1	119.0	111.9	126.6	121.2	128.9	106.8	106.3	99.7
Lot Mean	98.0		122.7		115.8		123.8		117.8		102.8	
0-4												
Pen Mean	291.4	269.8	290.2	282.1	307.6	295.4	269.7	313.1	308.4	278.7	269.9	256.9
Lot Mean	280.0		286.0		302.2		292.5		293.6		263.0	
	Pounds Of Feed Per Pound Of Gain											
0-4	2.20		2.00		2.04		2.21		1.78		2.25	

TABLE VII

DIETARY LEVELS OF B COMPLEX VITAMINS
FED IN EXPERIMENT II-B
(mg./lb.)

Relative Vitamin Level	Riboflavin High	Pantothenic Acid High	Niacin High	Choline High	Folic Acid High	Control Low
Ration Number	1	2	3	4	5	6
Pen Number	1 5	8 19	3 7	15 17	9 23	16 21
Riboflavin	6.4	1.6	1.6	1.6	1.6	1.6
Pantothenic Acid	2.5	7.5	2.5	2.5	2.5	2.5
Niacin	8	8	24	8	8	8
Choline	700	700	700	1400	700	700
Folic Acid	1.25	1.25	1.25	1.25	5.0	1.25

TABLE VIII

SUMMARY OF RESULTS OF EXPERIMENT II-B

Relative Vitamin Level	Riboflavin High		Pantothenic Acid High		Niacin High		Choline High		Folic Acid High		Control Low	
Ration Number	1		2		3		4		5		6	
Pen Number	1	5	8	19	3	7	15	17	9	23	16	21
Grams Of Gain In Body Weight												
Growth Interval By Weeks												
0-1												
Pen Mean	42.4	34.2	40.1	29.0	35.0	39.1	34.7	41.4	40.0	41.0	38.1	34.5
Lot Mean	38.1		34.8		36.9		38.6		40.5		36.4	
1-2												
Pen Mean	62.9	64.8	62.0	59.5	56.4	66.1	62.9	54.6	64.3	56.1	58.9	70.2
Lot Mean	63.9		60.8		61.3		59.0		60.2		64.2	
2-3												
Pen Mean	83.8	79.9	59.4	67.6	78.0	62.1	82.2	45.6	57.9	79.4	65.5	83.1
Lot Mean	81.8		63.3		70.1		68.4		68.6		73.8	
3-4												
Pen Mean	99.0	112.1	123.8	115.4	104.8	107.1	83.7	121.3	127.8	84.0	97.0	109.1
Lot Mean	105.8		120.1		105.9		101.5		105.9		102.5	
0-4												
Pen Mean	285.9	290.9	285.2	279.9	277.6	281.8	263.5	263.0	290.0	260.5	260.0	289.3
Lot Mean	288.5		282.9		279.7		263.0		275.2		274.7	
Pounds Of Feed Per Pound Of Gain												
0-4	2.40		2.27		2.40		2.18		2.05		2.28	

TABLE IX

DIETARY LEVELS OF B COMPLEX VITAMINS FED IN EXPERIMENT II-C
(mg./lb.)

Relative Vitamin Level[3]	Riboflavin		Pantothenic Acid		Niacin		Choline		Folic Acid		Control
	H	I	H	I	L	I	L	I	L	I	
Ration Number	1	2	3	4	5	6	7	8	9	10	11
Pen Number	2 15	10 18	13 17	5 8	14 22	12 20	16 21	9 11	6 7	1 3	4 19
Riboflavin	6.4	5.6	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Pantothenic Acid	5.0	5.0	7.5	6.25	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Niacin	16	16	16	16	8	12	16	16	16	16	16
Choline	900	900	900	900	900	900	700	800	900	900	900
Folic Acid	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.25	1.85	2.5

---

3 H = High level
L = Low level
I = Intermediate level

TABLE X

SUMMARY OF RESULTS OF EXPERIMENT II-C

Relative Vitamin Level[4]	Riboflavin		Pantothenic Acid		Niacin		Choline		Folic Acid		Control
	H	I	H	I	L	I	L	I	L	I	
Ration No.	1	2	3	4	5	6	7	8	9	10	11
Pen No.	2, 15	10, 18	13, 17	5, 8	14, 22	12, 20	16, 21	9, 11	6, 7	1, 3	4, 19
Growth Interval By Weeks	**Grams Of Gain In Body Weight (Pen and Lot Means)**										
0-1 (pens)	35.8, 38.8	35.3, 35.4	40.9, 35.3	37.7, 41.5	35.3, 42.2	34.9, 38.0	34.9, 34.2	38.3, 32.7	34.3, 35.6	33.3, 42.7	34.3, 37.1
0-1 (lot)	37.3	35.4	37.9	39.6	38.8	36.5	34.5	35.5	35.0	37.7	35.8
1-2 (pens)	58.1, 68.0	61.0, 70.1	80.0, 63.0	66.7, 67.5	59.6, 61.3	64.8, 68.1	56.0, 65.9	67.4, 55.3	56.7, 64.5	67.4, 75.7	65.0, 59.4
1-2 (lot)	63.1	65.3	71.0	67.1	60.4	66.5	60.7	61.4	60.6	71.4	62.0
2-3 (pens)	73.0, 59.1	44.7, 76.6	94.0, 42.0	66.4, 90.9	61.0, 63.2	76.3, 79.9	65.3, 71.8	78.6, 67.9	67.9, 54.6	84.8, 98.2	50.0, 87.6
2-3 (lot)	66.0	59.6	66.6	78.6	62.1	78.2	68.4	73.2	61.1	91.2	68.8
3-4 (pens)	109.1, 82.4	97.6, 123.4	88.5, 96.5	113.4, 83.1	84.0, 87.6	87.5, 101.6	68.3, 54.6	101.5, 105.7	104.3, 130.3	88.7, 75.7	91.4, 84.7
3-4 (lot)	94.2	115.9	94.1	98.2	85.7	94.6	61.5	103.6	119.3	78.8	87.1
0-4 (pens)	281.4, 248.3	245.4, 305.0	304.6, 237.3	284.2, 285.0	239.9, 254.2	263.6, 240.6	224.0, 274.3	308.4, 281.1	269.8, 291.0	274.2, 347.0	237.9, 271.4
0-4 (lot)	263.0	275.1	267.2	284.6	247.0	251.5	247.8	295.7	284.0	306.6	255.6
	Pounds Of Feed Per Pound Of Gain										
0-4	2.41	2.35	2.64	2.06	2.24	2.47	2.45	2.40	2.20	2.30	2.62

4 H = High level
L = Low level
I = Intermediate level

TABLE XI

BASALS FOR PRACTICAL HIGH ENERGY RATIONS

Corn Basal

Ingredient	Percent
Ground Yellow Corn	55.0
Pulverized Oats	5.0
Corn Gluten Meal	5.0
Fish Meal (60% protein)	5.0
Soybean Oil Meal (41% protein)	25.0
Vitamin A Oil (6000 I.U./gm.)	0.13
Dry D (2000 A.O.A.C./gm.)	0.05
Manganese Sulfate	0.013
Salt	1.0
Calcium Carbonate	1.0
Steamed Bone Meal	2.0
Mercks B_{12} and Antibiotic Supplement (12 mg. B_{12}/lb. and 3 gm. procaine penicillin/lb.)	0.2

Grain Sorghum Basal

The Grain Sorghum Basal is the same as above except grain sorghum is substituted pound for pound for corn.

TABLE XII

DIETARY LEVELS OF B COMPLEX VITAMINS FED IN EXPERIMENT II-D
(mg./lb.)

Relative Vitamin Level	Riboflavin High		Pantothenic Acid High		Niacin Low		Choline Low		Folic Acid High		Control		Control High	
Ration Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pen Number														
Corn basal	4		14		12		10		5		8		2	
Grain sorghum basal		6		3		1		13		11		9		7
Riboflavin	6.4		4.8		4.8		4.8		4.8		4.8		6.4	
Pantothenic Acid	5.0		7.5		5.0		5.0		5.0		5.0		7.5	
Niacin	16		16		8		16		16		16		24	
Choline	900		900		900		700		900		900		1400	
Folic Acid	1.0		1.0		1.0		1.0		2.5		1.0		2.5	

TABLE XIII

SUMMARY OF RESULTS OF EXPERIMENT II-D

Relative Vitamin Level	Riboflavin High		Pantothenic Acid High		Niacin Low		Choline Low		Folic Acid High		Control		Control High	
Ration Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pen Number														
Corn basal	4		14		12		10		5		8		2	
Grain sorghum basal		6		3		1		13		11		9		7
Grams Of Gain In Body Weight														
Growth Interval By Weeks														
0-1														
Pen Mean	35.2	30.3	34.2	35.5	28.1	31.6	30.7	37.4	34.7	35.0	29.9	33.9	36.8	33.6
Lot Mean	32.7		34.8		29.9		34.2		34.8		31.8		35.2	
1-2														
Pen Mean	61.2	61.2	66.7	53.6	49.1	58.0	58.4	66.9	56.4	57.6	58.5	50.0	62.2	61.8
Lot Mean	61.2		60.1		53.6		62.9		57.0		54.5		62.0	
2-3														
Pen Mean	70.0	66.7	89.7	63.2	75.6	78.4	84.6	78.9	83.5	77.1	85.4	57.8	90.5	63.7
Lot Mean	68.4		76.4		77.0		81.6		80.3		72.4		76.3	
3-4														
Pen Mean	95.8	88.4	103.7	100.1	110.2	100.8	95.4	96.0	74.9	95.2	99.1	102.0	107.9	56.8
Lot Mean	92.1		101.9		105.3		95.7		84.5		100.5		81.0	
0-4														
Pen Mean	258.6	244.1	294.3	252.4	268.4	268.8	269.1	279.2	249.5	281.2	273.2	236.6	298.0	216.9
Lot Mean	251.7		273.4		268.6		274.4		264.5		256.0		255.3	
Pounds Of Feed Per Pound Of Gain														
0-4	2.23	2.61	2.16	2.27	2.14	2.45	2.63	2.27	2.79	2.26	2.16	2.76	2.10	2.43

TABLE XIV

DIETARY LEVELS OF B COMPLEX VITAMINS
FED IN EXPERIMENT III
(mg./lb.)

Ration Number	1	2	3	4	5
Pen Number	3 8	6 2	10 5	9 7	1 4
Riboflavin	4.8	6.4	5.6	6.4	6.4
Pantothenic Acid	5.0	7.5	6.25	7.5	7.5
Niacin	20	12	16	16	24
Choline	900	700	800	800	1400
Folic Acid	1.0	1.0	1.5	1.5	2.0

TABLE XV

SUMMARY OF RESULTS OF EXPERIMENT III

Grams Of Gain In Body Weight

Ration Number	1		2		3		4		5	
Pen Number	3	8	6	2	10	5	9	7	1	4
Growth Interval By Weeks										
0-1										
Pen Mean	24.0	20.4	21.6	19.5	21.4	19.7	19.4	21.6	20.8	26.0
Lot Mean	22.2		20.5		20.6		20.5		23.4	
1-2										
Pen Mean	53.3	55.8	34.6	55.6	54.4	49.4	56.0	54.9	58.2	55.6
Lot Mean	54.6		45.1		52.0		55.4		56.9	
2-3										
Pen Mean	80.6	84.8	80.0	85.0	80.8	78.6	84.2	77.2	72.4	66.7
Lot Mean	82.7		82.5		79.8		80.7		69.6	
3-4										
Pen Mean	126.6	114.0	119.8	130.1	119.2	120.9	123.6	122.0	129.2	118.2
Lot Mean	119.3		125.0		120.0		122.8		123.7	
0-4										
Pen Mean	282.4	275.0	254.5	290.2	275.8	263.7	283.2	275.9	280.8	270.4
Lot Mean	278.7		272.3		269.8		279.5		275.6	

TABLE XVI

FEED CONSUMPTION AND FEED UTILIZATION DATA
FROM EXPERIMENT III

Ration Number	1		2		3		4		5	
Pen Number	3	8	6	2	10	5	9	7	1	4
				Pounds Of Feed Consumed						
Growth Interval By Weeks										
0-1	2.3	1.9	2.4	1.9	2.1	1.8	2.0	2.0	2.5	2.2
1-2	4.5	4.7	3.3	4.7	4.7	6.3	4.6	4.5	4.8	2.9
2-3	7.3	7.6	7.0	7.4	7.7	7.3	7.7	7.4	6.9	6.8
3-4	10.2	11.9	9.5	9.7	9.3	9.8	8.2	9.6	10.3	10.6
0-4	24.3	26.1	22.2	23.7	23.8	25.2	22.5	23.5	24.5	22.5
Lot Mean	25.2		22.9		24.5		23.0		23.5	
				Pounds Of Feed Per Pound Of Gain						
0-4	2.05		1.91		2.06		1.87		1.94	

BIBLIOGRAPHY

Ackerson, C. W., R. L. Borchers, John E. Temper and F. E. Mussehl, 1950. The utilization of food elements by growing chicks, XII. The effect of additions of iodocasein and vitamin concentrate to the ration. Poultry Sci. 29: 640-643.

Bauernfeind, J. C., L. C. Norris and G. F. Heuser, 1942. The pantothenic acid requirement of chicks. Poultry Sci. 21: 142-146.

Bethke, R. M., P. R. Record, 1942. The relation of riboflavin to growth and curled-toe paralysis in chickens. Poultry Sci. 21: 147-154.

Bird, F. H., V. S. Asmundson, F. H. Kratzer and S. Lepkovsky, 1946. The comparative requirements of chicks and turkey poults for riboflavin. Poultry Sci. 25: 47.

Bird, H. R. and Max Rubin, 1946. Value of high levels of calcium pantothenate and pyridoxine hydrochloride in chick diets. Poultry Sci. 25: 87-89.

Briggs, G. M., Jr., R. C. Mills, C. A. Elvehjem and E. B. Hart, 1942. Nicotinic acid in chick nutrition. Proc. Soc. Expt. Biol. Med. 51: 59-61.

Briggs, G. M., Jr., 1945. Influence of gelatin and tryptophane on nicotinic acid requirement of chicks. Journal of Biol. Chem. 161: 749.

Cline, M. A., 1945. Distillers dried solubles as a source of pantothenic acid in poultry rations. Master's Thesis. Purdue University. Lafayette, Ind.

Cooley, M. L. and J. B. Christiansen, 1948. Stability of choline in feed mixtures. Poultry Sci. 27: 822.

Dann, W. J. and P. Handler, 1941. Synthesis of nicotinic acid by the chick embryo. Journal of Biol. Chem. 140: 935.

Denton, C. A., W. L. Kellogg and H. R. Bird, 1947. The effect of diet, age and sex on the nicotinic acid content of tissues of the chicken. Poultry Sci. 26: 299-303.

Evans, E. V., S. J. Slinger and F. N. Marcellus, 1943. Use of crystalline riboflavin in practical poultry rations. I. Growth studies. Poultry Sci. 22: 433-437.

Gerry, R. W., C. W. Carrick and S. M. Hauge, 1948. Some relationships between choline and methionine. Poultry Sci. 27: 663-664.

Gillis, M. B. and L. C. Norris, 1949. Vitamin B_{12} and the requirement of chicks for methylating compounds. Poultry Sci. 28: 749-750.

Godfrey, G. F., R. H. Thayer and R. B. Thompson, 1951. Broiler growing can be profitable. Okla. Agri. Expt. Bulletin B-365.

Groschke, A. C., R. J. Evans and Helen A. Butt, 1951. Further studies of the interrelationship of vitamin B_{12} and pantothenic acid in the nutrition of the chick. Nutrition Conference, Cleveland, Ohio. Aug. 29, 1951.

Hegsted, D. M., 1948. The determination of the minimum vitamin requirement for growth. Journal of Nutr. 35: 399-409.

Hegsted, D. M. and T. R. Riggs, 1949. The pantothenic acid requirement for chicks. Journal of Nutr. 37: 361-367.

Heuser, G. F., H. S. Wilgus and L. C. Norris, 1938. The quantitative vitamin G requirements for chicks. Poultry Sci. 17: 105-108.

Hundley, J. M., 1947. Production of niacin deficiency in rats. Journal of Nutr. 34: 253-261.

Hundley, J. M., 1949. Influence of fructose and other carbohydrates on the niacin requirement of the rat. Journal of Biol. Chem. 181: 1-10.

Hill, E. G. and G. M. Briggs, Jr., 1951. Replacement of pteroylglutamic acid by folinic acid for the chick. Prod. Soc. Expt. Biol. Med. 76: 417-418.

Jukes, T. H. and L. W. McElroy, 1943. Observations on the pantothenic acid requirements for chicks. Poultry Sci. 22: 428-441.

Jukes, T. H., 1949. Choline, methionine and betaine in nutrition of chickens. Feedstuffs. 21: 24.

Lepkovsky, S., L. W. Taylor, T. H. Jukes and H. J. Almquist, 1938. The effect of riboflavin and the filtrate factor on egg production and hatchability. Hilgardia. 11: 19.

Lepkovsky, S., F. H. Bird, F. H. Kratzer and V. S. Asmundson, 1945. The comparative requirement of chicks and turkey poults for pantothenic acid. Poultry Sci. 24: 335-339.

Lillie, R. J. and G. M. Briggs, Jr., 1947a. Folic acid requirement of New Hampshire chicks receiving a synthetic diet. Poultry Sci. 26: 295-298.

Lillie, R. J. and G. M. Briggs, Jr., 1947b. Biological assay for folic acid activity in common feedstuffs. Poultry Science 26: 289-294.

Lillie, R. J., G. F. Combs and G. M. Briggs, Jr., 1950a. Folic acid in poultry nutrition. I. The critical need for folic acid by laying pullets. Poultry Sci. 29: 115-121.

Lillie, R. J., G. F. Combs and G. M. Briggs, Jr., 1950b. Folic acid in poultry nutrition. II. Effects of maternal diet and chick diet on mortality, growth and feathering of progeny. Poultry Sci. 29: 122-129.

Luckey, T. D., P. R. Moore, C. A. Elvehjem and E. B. Hart, 1946. Effect of diet on the response of chicks to folic acid. Prod. Soc. Expt. Biol. Med. 62: 307-312.

Marvel, J. A., C. W. Carrick, Roy E. Roberts and S. M. Hauge, 1945. The value of choline additions to a corn and soybean oil meal chick ration containing distillers dried solubles. Poultry Sci. 24: 181.

Melass, V. H., P. B. Pearson and R. M. Sherwood, 1946. Toxicity of choline in the diet of the growing chicken. Proc. Soc. Expt. Biol. Med. 62: 174-177.

Mishler, D. M., C. W. Carrick, R. E. Roberts and S. M. Hauge, 1946. Synthetic and natural vitamin supplements for the corn and soybean oil meal chick rations. Poultry Sci. 25: 479-485.

Muntz, J. A., 1950. The inability of choline to transfer a methyl group directly to homocysteine for methionine formation. Journal Biol. Chem. 182: 489-499.

National Research Council, 1946. Recommended Nutrient Allowances for Domestic Animals. No. 1 (Revised leaflet).

Norris, L. C., H. S. Wilgus, Jr., A. T. Ringrose, Victor Heiman and G. F. Heuser, 1936. The vitamin G requirement for poultry. Cornell Agr. Exp. Sta. Bul. 660.

Panda, J. N. and G. F. Combs, 1950. Studies on the energy requirements for rapid growth. Poultry Sci. 29: 774.

Patrick, H. and C. L. Morgan, 1944. The comparative biological value of crystalline riboflavin, alfalfa leaf meal and lespedeza meal as a source of riboflavin for chicks. Poultry Sci. 23: 142-145.

Pearson, P. B., V. H. Melass and R. M. Sherwood, 1946. The pantothenic acid content of the blood and tissue of the chick as influenced by the level in the diet. Journal of Nutr. 32: 187-193.

Ram, Tulsa, 1949. The histopathologic study of chicks deficient in pantothenic acid. Poultry Sci. 25: 87-89.

Record, P. R. and R. M. Bethke, 1942. Further observations on choline and yeast in chick nutrition. Poultry Sci. 21: 271-275.

Reiser, Raymond and P. B. Pearson, 1949. The influence of high levels of fat with suboptimum levels of riboflavin on the growth of the chick. Journal of Nutr. 38: 247-256.

Robertson, E. I., L. J. Daniels, F. A. Farmer, L. C. Norris and G. F. Heuser, 1946. The folic acid requirement of chick for growth, feathering and hemoglobin formation. Proc. Soc. Expt. Biol. Med. 62: 97-101.

Salmon, W. D., 1946. Relation of corn products to the requirements for the rat for dietary nicotinic acid. Journal of Nutr. 33: 169-175.

Sarma, P. S. and C. A. Elvehjem, 1946. Growth inhibitions of chicks on rations containing corn grits. Poultry Sci. 25: 39-40.

Schaefer, A. E., W. D. Salmon and D. R. Strength, 1949. Interrelationships of vitamin B_{12} and choline. II. Effect on growth of the chick. Proc. Soc. Expt. Biol. Med. 72: 202.

Scott, H. M., E. P. Singsen and L. D. Matterson, 1946. The influence of nicotinic acid in response of chicks receiving a diet high in corn. Poultry Sci. 25: 303-304.

Singsen, E. P. and L. D. Matterson, 1950. The Connecticut broiler ration and experiments with high efficiency rations. Storrs Agr. Expt. Station. Information series, No. 4.

Snedecor, G. W., 1946. Statistical Methods, 4th ed. Ames. Iowa State College Press.

Sure, Barnett and Freeland Romans, 1948. Influence of the concentration of mixtures of various components of the vitamin B complex on the biological value of casein and on economy of food utilization. Journal of Nutr. 36: 727-737.

Titus, H. M., 1949. The Scientific Feeding of Chickens, 2nd ed. Dansville, Ill. The Interstate.

Wilgus, H. S., Jr., and D. V. Zander, 1945. The quantity of animal protein required to supplement soybean oil meal for growth. Poultry Sci. 24: 41-45.

Yacowitz, H., L. C. Norris and G. F. Heuser, 1950. Evidence of the interrelationship between vitamin B_{12} and riboflavin, pyridoxine and pantothenic acid. Poultry Sci. 29: 787.

TYPIST PAGE

THESIS TITLE: THE DIETARY LEVELS OF RIBOFLAVIN, PANTOTHENIC ACID, NIACIN, CHOLINE AND FOLIC ACID REQUIRED BY CHICKS FED A HIGH ENERGY RATION

NAME OF AUTHOR: JOE P. DAVIS

THESIS ADVISER: ROLLIN H. THAYER

The content and form have been checked and approved by the author and thesis adviser. "Instructions for Typing and Arranging the Thesis" are available in the Graduate School office. Changes or corrections in the thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

NAME OF TYPIST: JOYCE DAVIS