CASSAVA (<u>MANIHOT</u> <u>ESCULANTA</u> CRANTZ): A SOURCE OF ENERGY IN DIETS FOR BROILER CHICKENS

A Thesis

Presented to

The Faculty of Graduate Studies

of

The University of Guelph

by

G. E. SYDNEY WILLIAMS

In partial fulfilment of requirements

for the degree of

Doctor of Philosophy

November, 1974

ABSTRACT

CASSAVA (MANIHOT ESCULANTA CRANTZ): A SOURCE OF ENERGY IN DIETS FOR BROILER CHICKENS

G. E. Sydney Williams, Ph.D.
University of Guelph, 1974

Supervisor:
Professor J. D. Summers

Three experiments were conducted to evaluate cassava, a tropical root crop, as a source of energy in diets containing all vegetable protein or 5% fish meal which is a source of readily available essential amino acids required by growing chicks.

The biological metabolizable energy (ME) was determined replacing part of the basal diet with the test materials (cassava meal Grades I and II combined and Grade III. Grades I and II have little of the rind and outer cover whereas Grade III contained more of the rind and outer cover.) The ME's were corrected for the nitrogen retained and the values with their standard errors obtained for Grades I and II combined were 3.59 Kcal/g ± 0.03 and those for Grade III were 3.20 Kcal/g ± 0.04.

The diets for the second and third experiments were formulated with the help of the computer to determine quantities of ingredients to provide various nutrients within given limits and specification. (Cassava meal was given a very low value so that maximum levels of 0, 20, 30 and 40% would be included in the diet. Two sets of four diets were formulated with or without 5% fish meal.)

During the first four weeks the weight gains of birds on the 5% fish meal diets peaked at 20% cassava meal while those on no fish meal showed a depression with 20% cassava meal. Generally those on 5% fish meal produced better weight gains than those on diets without fish meal. Surprisingly the birds on the latter diets outgained the former ones during the second four weeks. By the end of the eight week period even though birds on diets without fish meal were slightly heavier these differences were not large enough to be detected statistically. It may be concluded from the study that the broiler chick benefits from the readily available essential amino acids in the fish meal during the early stages of growth but later its benefit is not apparent.

Data on feed intake during the first four weeks show that as the level of cassava meal increased in the diets without fish meal the amount consumed decreased, but with diets that contained fish meal the feed intake increased with increase in the level of cassava meal. Similar quantities of the 0 and 5% fish meal diets were consumed during the second four weeks and the differences observed were deemed to be due to chance variation. This was also reflected in the feed intake to eight weeks.

On a practical basis, the poultry farmer is interested in the response of an animal when given a specified amount of feed and therefore predicted values were computed. The equation

$$Y = a+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5,$$ where

X_1 is the level of fish meal

X_2 is the level of cassava meal

X_3 is the level of cassava meal squared by fish meal

X_4 is the level of cassava meal squared and

X_5 is the amount of feed intake

was used to predict the response in weight gains.

The diets for the third experiment were pelleted and then crumbled and fed to broiler male chicks. It was observed that the differences in weight gains in response to the various levels of cassava meal in the diets were due to chance variation and it may therefore be concluded that cassava meal could be successfully included in broiler chick diets. However, one should ensure an adequate level of sulfur amino acids to help counter any hydrocyanic acid activity that may be present in the diets. Also the diets should be properly balanced.

ACKNOWLEDGEMENTS

The author wishes to acknowledge with grateful thanks the help, guidance and encouragement he received from his supervisor, Dr. J. D. Summers, and other members of his supervisory committee, Drs. E. T. Moran, Jr., W. D. Morrison, J. C. M. Shute and S. J. Slinger during the course of his work at the University of Guelph.

He is also appreciative of the technical and other assistance he received from Miss Patricia Manolis, Mrs. Marlene Mast, Messrs. J. Bishop, C. Dearing, L. J. Osburn and W. Stewart.

Very special thanks go to his fellow graduate students especially Mr. Ken MacKenzie for using the computer facilities of his company to formulate some of the experimental diets and Drs. Paul Flipot and W. Sandow Al-Hassan and Miss Laetitia Yiboe in taking time off their busy schedule to assist in the weekly weighing of the experimental birds.

His unreserved gratitude go to Dr. Gordon C. Ashton who gave of himself willingly and helped to bring order to the apparent chaotic mass of data and also to Mr. George C. Smith for his help in "communicating effectively" with the computer during the analysis of the data.

To his numerous friends who in one way or the other cheered his spirits up when the going was rough and heavy, the author wishes to express his sincere thanks.

To the Canadian International Development Agency through the Ghana-Guelph Project which provided for his sustenance and financial well being, the author is grateful.

Appreciative thanks are also expressed to Mrs. Beatrice O'Krafka for her patience in typing this thesis.

Finally, to his parents, Mr. and Mrs. J. G. Williams, and to his wife, Mrs. Nabilla Williams, without whom he would not have been where he is now, the author owes a debt of gratitude for their patience, encouragement and their prayers and to God, our Father, from whom he sought succour and strength when he had to "walk the lonesome valley" all by himself, he is forever thankful.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

INTRODUCTION

Cassava (Manihot esculanta Crantz) is a tropical root crop and depending on the region where it is grown, it is known either as cassava, mandioca, manioc, tapioca or yuca. It has been found to grow well within latitudes 30°N and S and from sea level to 6500 feet high. It tolerates temperatures ranging from 64°F (17.8°C) to well over 90°F (32.2°C) and soils which have a pH range of 5 to 9 (Rogers and Appan, 1972). Jones (1959) also indicated that it is tolerant of 20 to 200 inches of rainfall.

In 1972 the FAO reported that cassava production amounted to 57% of tropical root and tuber production but it utilized only 54% of the tropical root and tuber acreage.

In addition to the ecological adaptation of the crop, the principal attributes favouring cassava production in the less developed tropical nations and by the peasant farmers are listed below.

(a) It is easy to propagate. Stem cuttings are generally used therefore neither seeds nor part of the roots are required for planting; as a result, it makes it rather relatively more productive than grains and other root crops.

(b) It is relatively less expensive to produce than other crops. Even though it is not season bound as other crops, it is much better and less demanding to plant and harvest cassava when the soil is moist and soft. Because the plant has a dense leafy canopy, weeds do not grow profusely on cassava farms thus weeding is at a minimum.

(c) It is relatively high yielding - producing about 3.1 to 4.0 tons (long) per acre. Higher tonnage has been obtained on experimental farms (Enriquez and Ross, 1967 and Nestel, 1973).

(d) It is a reliable staple and an excellent producer of carbohydrate.

(e) It is a good risk-aversion crop (Philips, 1974).

It is apparently subject to minimal animal and pest attacks and will grow on soils which seem to be poor for other crops. It is also drought tolerant and could be left in the ground without harvesting for a long period of time (Nestel, 1973). However it tends to deteriorate rather quickly after harvesting unless it is processed.

Cassava is used as human food in the areas where it is grown and to a limited extent it is incorporated in animal diets. But in recent times it is assuming an increasing importance as an ingredient in animal feeds especially that of pigs and poultry, although only small quantities are incorporated in diets unless adequate supplementation with methionine or cystine is made.

Cassava, however, contains a cyanoglucoside which, on being hydrolyzed, produces cyanic acid which can be toxic. When small amounts are taken in, this may lead to chronic hydrocyanic acid toxicity. The cyanoglucoside factor is linamarin.

LITERATURE REVIEW

Cassava has been used in diets for feeding livestock and poultry for many years and prior to the Second World War it increased as a good source of energy in the diet but the quantity used has not been well defined (Anonymous, 1968). In some of the tropical countries where cassava is produced in large quantities, relatively small amounts are used for animal feed in relation to the production (Squibb and Wyld, 1951). Most of the cassava offered for international trade is imported from Thailand and its quality varies quite considerably.

Cassava meal is high in starch and low in crude fibre and very low in protein as compared with cereal grains. AGF (1962), as quoted by Vogt (1966) indicated that the cassava meal contained about 65% starch, three to five percent crude fibre and sometimes more than three percent sand. The meal is predominantly a polyglucose carbohydrate consisting of 20% amylose and 70% amylopectin (Johnson and Raymond, 1965). Cassava also contains a cyanogenic glucoside, linamarin, which, on being hydrolyzed, liberates hydrogen cyanide which is toxic and a growth depressor.

Cassava meal has been incorporated in swine diets for many years and since the 1900's a number of reports have appeared in the literature (Anton-Smith, 1968; Asico, 1941; Barbosa et al., 1957; Castillo et al., 1964; Maner et al., 1967, 1968; Modebe, 1963; Mondonedo, 1928; Oyenuga and

Opeke, 1957; Tracy, 1903; Velloso et al., 1967). The general observation from these studies is that cassava could be incorporated in swine diets and cassava silage could also be fed to swine. However it was observed that the carcasses graded lower than those from corn-fed groups because of the excessive fat that resulted from the cassava diets.

Dairy cattle and to a lesser extent beef cattle and sheep have also been fed feed containing cassava (Cardoso et al., 1968; Murillo, 1952; Shultz et al., 1972). Rats and guinea pigs have also been used to evaluate the effect of cassava as feed for animals and humans. The nutritive value of cassava meal and cassava leaf meal has been evaluated using the chicken (Olson et al., 1969; Ross and Enriquez, 1969).

For a period of 12 weeks Tabayoyong (1935) compared the growth rate of chicks fed cassava refuse meal, rice bran and a combination of rice bran and cassava meal. He reported poor growth in the group of chicks fed cassava refuse meal. Squibb and Wyld (1951) performed seven experiments with various levels of cassava meal included in chick diets to replace equal amounts of ground corn. Their findings indicated that there were only three experiments in which the chicks fed diets containing only corn signi ficantly ($P<0.01$) outgrew those birds fed diets with cassava meal. They noted, however, that even though they obtained their cassava meal from the same factory, the lots of cassava meal were different because they observed that some of the lots were "contaminated with root peelings and dirt". Thus they attributed the differences in growth rates of the chicks to this contamination.

In his review of the use of cassava meal in the diets for chicks, Vogt (1966) reported that Klein et al. (1954) raised the cassava meal content in chick diets to levels of 40% but only at the level of 10% were the chicks' growth comparable to those on the control diet.

Soares (1965) replaced ground corn with cassava meal in increments of 4.9% and the resulting eight diets varied from 0 to 34.3% in cassava meal content. Soybean meal was added in increasing amounts to keep the diets isonitrogenous. He observed significant differences in weight gains of the chicks on the higher cassava meal concentrations.

Vogt (1966) asserted, after his experiments, that broiler diets containing 30% cassava meal reduced weight gains at the end of eight weeks but that chicks on 10% cassava meal in the diet performed equally as well as those with no cassava meal in the diet in terms of weight gains. He attributed the depression in weight gains to the prussic acid or hydrocyanic acid content of the cassava meal. He also speculated that the depression in weight gains might have been caused by a phosphorylase inhibitor in the rind of the cassava tuber. Another possible reason for the reduction in feed consumption might be the fineness of the cassava meal. On the other hand, Enriquez and Ross (1967) reported satisfactory growth and feed conversion in three week old single comb White Leghorn (SCWL) chicks when the 50% cassava meal (replacing 50% of corn meal) was supplemented with 0.15% methionine and the diet was balanced with regard to protein.

Cassava meal and wheat middlings were used as carbohydrate substitutes for part of the ground corn in chick diets by Soares et al. (1968). These two ingredients replaced corn in increments of six percent of the diets and cassava meal and soybean meal were used in place of corn to equalize the crude protein content of the diets. On the whole, 42% of the corn was replaced. It was reported that there were no statistical differences in the rate of gain between treatments; however the chicks that were fed diets with 10% of the corn replaced by cassava meal had the greatest daily weight gain. Feed efficiency was best when the substitutions were between 0 and 30% of the diet.

Varied levels of cassava meal were used to replace corn in a 20% protein chick starter diet which was "known to give good growth" (Olson et al., 1969a). The findings from their work indicated that higher levels of cassava meal (37.5% and 45%) gave significantly ($P<0.05$) poorer gains than the corn basal diet. However in one experiment, with the addition of 0.10% methionine and 0.10% leucine to the diet containing 45% cassava meal the response was significant ($P<0.05$) and the results were not significantly different from the results on the corn basal diet. In another experiment, Olson et al. (1969b) supplemented the diets with methionine, leucine and a combination of the two. The chicks on the supplemented cassava diets were significantly lighter than similar chicks on corn basal diets with the same supplementation. Supplementing the cassava basal diets with both methionine and leucine, however, resulted in chicks that were significantly heavier than the unsupplemented basal cassava meal and the diet with only leucine supplementation. Cystine was also found to bring about comparable weight gains if added to cassava meal diets (Olson *et al.*, 1969b).

De Hernandez (1969) compared the nutritive value of cassava meal (*Manihot utilissima* Pohl) with that of a control diet consisting of corn starch, dehulled soybean meal, methionine, corn oil, minerals and vitamins. He reported that chicks fed the cassava meal diet grew as well as those on the control diet, but feed efficiency was better in the latter group. Mortality, he indicated, was essentially the same in both groups. He concluded therefore that cassava meal could be incorporated in diets for chicks. Gadelha *et al.* (1969), on the other hand, fed bran of cassava scraping at the following levels: 0, 15, 30 and 45% in diets in two experiments using 336 day-old straight-run Shaver Starbro chicks in order to study the nutritive and economic value of cassava meal as a source of energy in starting chick diets. The birds were fed for six weeks. All diets were supplemented with 0.2% D-L-methionine. They reported significant differences ($P<0.01$) between treatments and signifi cant linear effects in chick gains and feed efficiency in both experiments. They also observed that chicks gained at a slower rate and required more feed per kilogram of gain as the level of bran of cassava scrapings increased in the diet. However, the birds consumed less feed with increasing levels of the cassava product but the differences were not significant. In yet another experiment lasting six weeks, to measure the effect of feeding broilers 0, 15 and 30% cassava meal in diets, on body weight and feed efficiency, De J. Montilla et al. (1969) indicated that sun dried cassava root meal could be substituted for corn in broiler chick starter diets at levels up to 30% of the diet. Maust et al. (1972), however, reported that even though cassava flour had the highest metabolizable energy (ME) value of the test materials they investigated, the birds gained the least weight, they also had slight diarrhea and did not appear "as bright and alert as the other chicks on the experiment". They seemed to suggest that the failure of the chicks to gain weight was due to the growth depressing factors in crude cassava which were not completely eliminated from the sample of cassava meal used in the experiment.

Cassava meal has also been incorporated in layer diets by some workers. Pino (1962), in a personal communi cation from McWatt, reported the use of cassava in diets for layers, in the then British Guiana (now Guyana), constituting about 20.3% of the diet. Pillai et al. (1968) also used tapioca (cassava) spent pulp in poultry feed. They indicated that the composition of the tapioca spent pulp was:

Crude Protein	2.25%
Crude Fat	0.28%
Crude Fibre	14.39%
Nitrogen Free Extract	78.95%
Organic Matter	95.87%
Ash	4.13%
Calcium	0.29%
Phosphorus	0.05%

When the diet containing the tapioca spent pulp was fed to layers, they reported a highly significant increase of about 12% in the number of eggs laid by the birds. In another study evaluating the nutritive value of cassava root meal in grower and layer diets, Enriquez and Ross (1972) fed SCWL pullet chicks from six to 20 weeks of age isonitrogenous diets containing 0, 10, 25 and 50% cassava root meal. From 20 to 48 weeks of age all groups were fed the same standard layer diet. They found no significant difference in the pullets on the various dietary treatments with regard to the parameters measured egg production, feed conversion, egg weight, Haugh units, shell thickness, body weight gains and mortality. The same levels of cassava meal (as in the previous experiment) were fed to SCWL hens from 20 to 48 weeks in a second experiment. Again they reported no significant differences in the parameters used to evaluate the dietary treatments. They were of the opinion that for the 28 week period, 50% substitution did not have any adverse effect on the layers. Dun and Hearn (1973) also using Shaver 585's fed diets containing 60, 40, 20 and 0 percent cassava root meal from 28 to 52 weeks of age. Their results suggested that cassava meal could be incorporated in layer diets at levels up to 60% of the diet without any adverse effect on egg production, food consumption, shell quality and mortality.

Most of the workers who have been feeding cassava meal to chickens have just replaced part of the corn meal with the cassava meal to determine the nutritive value of the meal. The biological determination of the ME of the cassava meal has been reported only by Olson et al. (1969a) and Maust et al. (1972). Both of them used the procedure outlined by Hill et al. (1960). The test materials were manufactured differently because they were obtained from different sources. Maust et al. (1972) substituted their test material for glucose at 40% of the diet and Olson et al. (1969a) substituted theirs at both 40 and 50%. Maust et al. (1972) used male crossbred chicks (Vantress x White Plymouth Rock) and obtained an ME value of 4.31 Kcal per gram. Olson et al. (1969a) used straight run chicks (New Hampshire x SCWL). They reported an average ME value of 3.44 Kcal per gram on a dry matter basis. In another experiment, Olson et al. (1972) observed that the ambient temperature had no effect on the ME value of cassava meal.

Statement of the Problem

Poor growth of chickens has been associated with the feeding of diets containing higher levels of cassava meal as reported by a number of workers (Tabayoyong, 1935; Squibb and Wyld, 1951; Soares, 1965; Olson et al., 1969a,b; Maust et al., 1971) who have used various qualities of the meal in the diets for chickens. Some workers, however, were not able to obtain any statistical differences in response between inclusion of 10% cassava meal and the basal diet (Klein et al., 1954; Vogt, 1966; Soares et al., 1968; De Hernandez, 1969). But when the concentration was increased to over 20% cassava meal, the differences in weight gain responses were detected. When diets containing over 20% cassava meal were supplemented with methionine or cystine or both, the differences were no longer apparent (Olson et al., 1969b and Enriquez and Ross, 1967). It has been stated that cassava meal could be incorporated in chicken diets provided the cost of the meal was economically comparable to or better than the cost of cereal grains (Dun and Hearn, 1973). Most of these workers are in the developed marketing economies. In the developing marketing economies, like Ghana, however, where cassava could be grown in excess of human needs, it has not been incorporated to any extent in poultry feed. Since 1970, the yield of cassava in Ghana is more than eight times the yield of corn according to the FAO Production Yearbook for 1972. This yield could still be increased further if part of the cassava meal were needed for animal feed. The potential for increased acreage is there, since cassava at the moment is produced by the peasant farmer.

Cassava meal has been used as cereal grains have been utilized in feeds. But diets containing cassava meal have not been pelleted and fed to chickens. Vogt (1966) had inferred that probably one reason for poor growth rate of chickens fed diets containing cassava meal might be due to the fineness of the feed which in turn might have impeded the intake of enough feed to support proper growth rate. Ghana, like other tropical African countries, produces cereal grains like corn, guinea corn or sorghum and millet, but not enough of them to feed the human population and have some left for the animal population. Thus there is a competition between humans and livestock and poultry for cereal grains. If suitable substitutes for grain could be found to provide energy then the pressure on cereal grains would be reduced.

These studies were therefore undertaken to evaluate cassava meal (which can be obtained in Ghana) primarily for its energy value. It was necessary, therefore, to determine the ME value of the cassava meal to be used and also to find out how the birds would perform both on mash and pelleted (crumbled) diets containing various levels of cassava meal.

The first experiment performed was therefore one to determine the biological metabolizable energy (ME) using the whole diet and substituting part of this diet with the test material (cassava meal). The second and third experiments evaluated the performance in terms of weight gains and feed efficiency of broiler chicks on mash and pelleted (crumbled) diets, respectively.

MATERIALS AND METHODS

Cassava Meal

The cassava meal for these studies was obtained from Cali, Colombia, South America. (The processing procedure is included in the appendix p. 68.)

Experiment 1: Biological Metabolizable Energy (ME) Determination

Objective:

The object of this experiment was to determine the ME value of the cassava meal to be used in subsequent experiments.

Diets

A basal diet was formulated using about four percent corn meal, 85% soybean meal (49% Crude Protein) and other ingredients listed in Table 1. Grades I and II of the cassava meal were combined for this study. Table 1 also contains the seven dietary treatments that were imposed and the various proportions of the basal diet to the cassava meal.

Birds and Management

Three hundred and fifty Shaver broiler male chicks which formed 35 experimental units were used in this study.

Table 1. Compositions of Basal and Test Diets for Experiment 1.

Ingredients	Percent of Diet						
(a) Basal							
Corn	4.31						
Soybean Meal (49%)	85.00						
Stabilized Animal Tallow	3.00						
Calcium Carbonate	2.25						
Calcium Diphosphate	3.00						
Iodized Salt (0.015% KI)	0.50						
D-L-Methionine	0.40						
Choline Chloride	0.04						
Vitamin Mix[1]	1.00						
Mineral Mix[2]	0.50						
(b) Test Diets							
Basal	100	60	50	40	60	50	40
Cassava meal (Grades I & II)	-	40	50	60	-		
Cassava meal (Grade III)	-	-	-	-	40	50	60

[1] (Pure ingredients added per kilogram of diet) Vitamin A (10,000 IU/gm) 8000 IU; Vitamin D_3, 1600 IU; Vitamin E (Rovamix; 275 IU/g) 11.0 mg; Riboflavin (53 mg/gm) 9.0 mg; d Calcium pantothenate (70 mg/gm, 91.59% Panto) 11.0 mg; Vitamin B_{12} (132 mcg/gm) 13.0 mcg; Niacin 26.0 mg; Choline Chloride (50%)(74% Choline) 900 mg; Vitamin K (Hetrazeen, 35.27 mg/g) 1.5 mg; Folic Acid (13.23 mg/g) 1.5 mg; Biotin 0.25 mg; Santoquin (50%) 125.0 mg.

[2] (Pure ingredients added per kilogram of diet) Manganous oxide (56% Mn) 55 mg; Selenium oxide (71.16% Se) 0.1 mg; Zinc Oxide (80% Zn) 50.0 mg; Copper Sulphate (25% Cu) 5.0 mg; Ferrous oxide (69.94% Fe) 30.0 mg.

The birds were housed in electrically heated battery brooders. The fluorescent lamp in each pen was kept burning for 24 hours a day during the three week period of the experiment. A 20% protein commercial broiler chick starter was fed to all the birds for the first seven days. On the eighth day all the birds were weighed individually. They were then randomly allocated to pens in groups of ten. The birds were then randomly allotted to the dietary treatments. The trial lasted for 14 days with feed and water being supplied *ad libitum*.

The weights of the birds were taken as a group on day 1, 8 and 15. Feed consumption was recorded at the conclusion of the test.

Faeces

The total faeces was collected separately from each pen and weighed every other day. This was done to prevent excessive drying and thus loss of some of the nitrogen in the faeces, then samples were taken and stored in a freezer. Each succeeding sample was added to the previous sample in storage. The final sample was taken at the termination of the test. The pooled samples from each collection period were then freeze-dried to determine the moisture content and also to get them ready for other analytical determinations.

The following analyses were conducted:

(a) the gross energy of both the feed and faeces using a Parr Adiabatic Bomb Calorimeter;

(b) the nitrogen content of both the feed and the faeces using the Kjeldahl method outlined in the 11th Edition of A.O.A.C., Methods of Analysis, 1970.

Design

The experiment was conducted according to a randomized complete block design with five replicates (battery brooder tiers) of the seven dietary levels of the two different grades (Grades I and II combined and Grade III) of cassava. Confidence limits at 95% probability level were computed for the ascertained mean ME values by the relationship

$$CL = \bar{X} \pm \sqrt{\frac{S^2_{\bar{x}}}{n}} \times t0.05.$$

Results and Discussion

The gross energy and the percent nitrogen values obtained from the bomb calorimeter and nitrogen determination of each of the mixed diet and faeces for each pen were used to calculate the ME corrected for nitrogen retained from the equation

$$ME = \left(\frac{\text{Gross Energy Intake} \quad \text{Gross Energy Output}}{\text{Feed Intake}}\right)$$

$$\left(\frac{\text{Nitrogen Intake} - \text{Nitrogen Output}}{\text{Feed Intake}} \times 8.73\right)$$

Each of these individual pen ME's then became the value for d in the equation,

$$x = \frac{d-ab}{c} \text{ from } ab+cx = d,$$

where

x is the ME for the cassava test material;

d is the individual pen ME after correcting for nitrogen retained;

a is the proportion of the basal diet in the mixed diet;

b is the ME value obtained for the basal diet; and

c is the proportion of the cassava test material in the mixed diet,

to derive the ME for the cassava meal.

The fifteen ME values thus obtained for each of Grades I and II and for Grade III were averaged to yield 3.59 Kcal/g ± 0.03 and 3.20 Kcal/g ± 0.04, respectively. The 95% confidence limits (lower and upper) were computed yielding (3.52 and 3.65), and (3.11 and 3.29) for Grades I and II and for Grade III, respectively. Olson *et al.* (1969a) reported an average determined ME, on a dry matter basis, to be 3.44 Kcal/g with a standard deviation of ± 0.095. The computed lower and upper 95% confidence limits were 3.37 and 3.51 Kcal/g, respectively. Maust *et al.* (1972) using a meal which was "fit for human consumption" obtained a value of 4.31 Kcal/g with the chick. Based on acid detergent fibre procedure, they determined the fibre content of their meal to be nil. Thus their meal can be considered predominantly starch. Hill (1962) found that the ME content of starch was 4.08 Kg/g. The fibre content of Grades I and II was 2.33% and that for Grade III 7.22%.

Mortality

The mortality was negligible. Only two birds died during the period and both were from different pens on the basal diet. No birds died from the groups that were fed diets containing cassava meal.

Experiment 2: Broiler Performance on Diets with Four Levels of Cassava Meal in the Presence and Absence of Fish Meal

Objectives:

(a) To compare the performance of broiler males fed four levels of cassava meal in diets with or without fish meal.

(b) To ascertain if weight gains depend on levels of cassava and fish meals and the amount consumed and, if they do, to get a measure of the relationship. (Predict weight gains from levels of cassava and fish meals and the quantity of feed intake.)

Diets

All diets were formulated using the facilities of the computer (linear programming and least cost formulation) to determine quantities of ingredients to provide various nutrients within given limits and specifications. (Cassava meal was given a low value in order to have it included in the diets at the specified levels) (Tables 2 and 3). Two sets of diets were mixed. Both sets had 0, 20, 30 and 40% cassava meal but one set was without fish meal while the other set had 5% fish meal in both the starter and finisher diets. The fish meal had a protein level of 72%.

The starter and finisher diets were programmed to provide a crude protein content of 23% and 18% respectively and ME values of 3.01 Kcal/g and 3.11 Kcal/g respectively. Calculated values using factors obtained from Scott et al. (1969), of the starter and finisher diets, were 22.76% crude protein and from 3.01 to 3.08 Kcal/g and 17.76% crude protein and from 3.11 to 3.18 Kcal/g, respectively.

The cassava meal was included in the diet solely for its energy value and no account was taken of other nutrients. The fish meal was included as a source of animal protein. D-L-methionine was added to each diet except the finisher diets with fish meal, so that the methionine + cystine content of the diets was about 0.77% of the diet or 3.38% of the protein for the starter diets and 0.57% of the finisher diets or 3.21% of the protein. These values are slightly lower than the requirements for methionine and cystine recommended by the National Academy of Sciences (1971). Their requirement is set at 0.86% at 3.20 Kcal/g ME and .75% at 3.20 Kcal/g for the finisher diet. Scott (1974) also

Table 2. Composition of the Computer Formulated Diets for Experiments 2 and 3.[a]

Ingredients	Starter Diets %							
Cassava Meal	0	0	20	20	30	30	40	40
Fish Meal (72% Protein)	0	5	0	5	0	5	0	5
Corn Meal	56.03	60.53	30.20	34.55	17.06	21.56	4.07	8.57
Soybean Meal (49%)	36.59	29.65	41.13	34.21	43.43	36.89	45.71	38.77
Stabilized Animal Tallow	3.51	2.24	5.00	3.73	5.76	4.48	6.50	5.22
Calcium Carbonate	1.39	0.96	1.27	0.83	1.21	0.77	1.14	0.71
Calcium Diphosphate	1.58	0.79	1.61	0.81	1.62	0.82	1.63	0.83
Iodized Salt (0.015% KI)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
D-L-Methionine	0.06	0.01	0.08	0.03	0.09	0.04	0.10	0.05
Choline Chloride	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.05
Vitamin Mix[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

[1] (See [1] under Table 1).

[a] Starter diets for broiler chicks.

Table 3. Composition of the Computer Formulated Diets for Experiments 2 and 3.[a]

Ingredients	Finishing Diets %							
Cassava Meal	0	0	20	20	30	30	40	40
Fish Meal (72% Protein)	0	5	0	5	0	5	0	5
Corn Meal	69.59	73.60	43.61	48.07	30.59	35.08	17.63	22.11
Soybean Meal (49%)	24.01	17.35	28.57	21.65	30.86	23.92	33.13	26.19
Stabilized Animal Tallow	3.10	2.00	4.60	3.34	5.35	4.08	6.09	2.82
Calcium Carbonate	1.26	1.00	1.13	0.70	1.07	0.64	1.01	0.58
Calcium Diphosphate	1.18	0.38	1.12	0.41	1.21	0.42	1.22	0.43
Iodized Salt (0.015% KI)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
D-L-Methionine	0.003	0	0.02	0	0.03	0	0.04	0
Choline Chloride	0.06	0.06	0.07	0.07	0.08	0.07	0.07	0.08
Vitamin Mix[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

[1] (See [1] under Table 1).

[a] Finisher diets for broiler chicks.

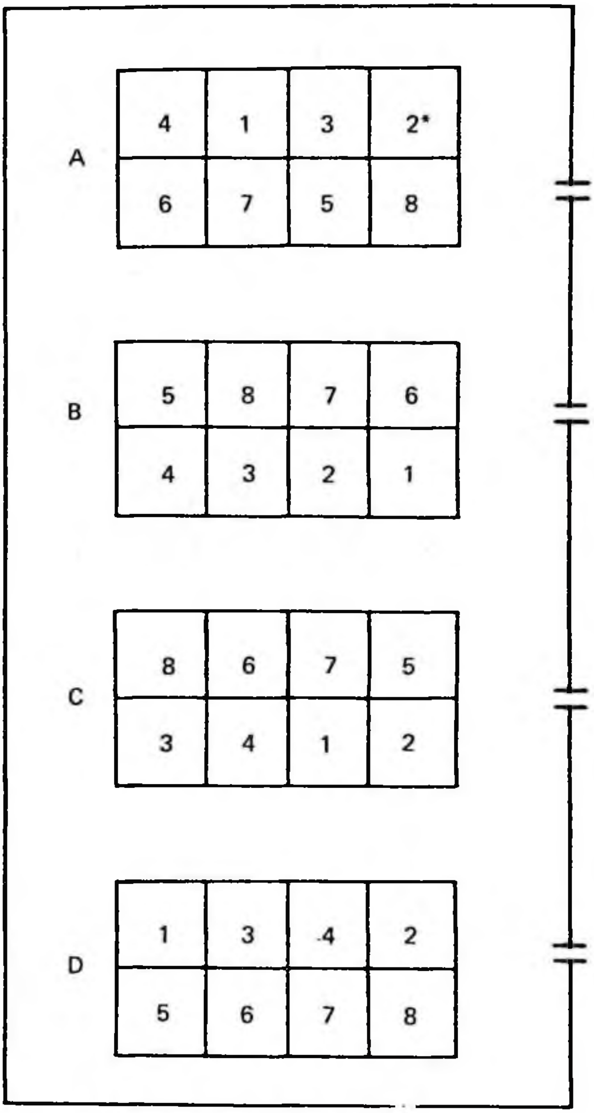
indicated in Feedstuffs Yearbook for 1974 that the methionine + cystine level may be 3.5% of the dietary protein. This value is slightly higher than the calculated value obtained for the methionine + cystine content of the diets used.

The cassava meal is very floury and starchy. When it is mixed with the other ingredients, however, the diet is not quite as floury as reported by Vogt (1966). The colour changes from yellow to grayish white depending on the amount of yellow corn in the diet. This may tend to affect the colour of the skin of the bird fed increasing levels of cassava meal and decreasing levels of corn in the diet. In Ghana, there is no consumer preference for either white or yellow skinned bird. However, in some countries that have developed marketing economies the housewife's acceptance of the broiler depends, to some extent, on the colour of the skin of the bird. Thus birds fed higher levels of cassava meal with decreasing levels of yellow corn may be accepted in one country and rejected in another.

Birds and Management

Three hundred and twenty commercial male broiler chicks were obtained and these formed 32 experimental units for this study (Figure 1). They were kept in their transit boxes from the hatchery for two days after hatching (without feed in order that they may utilize most of the yolk) and then they were weighed individually and randomly

Figure 1. A Diagram of the Floor Plan and Allocation of Dietary Treatments for Birds in Experiment 2



*Diets 1-4 do not contain any fishmeal

Diets 5-8 contain 5% fishmeal

assigned to cages in groups of ten having essentially the same average weight. The cages were in a windowless house. A few heating infrared lamps were provided to augment the heat units in the room. These were of little avail during a particularly cold weekend when the temperature in the room dropped drastically because of low outside temperature. The outside maximum and minimum temperatures for Friday, Saturday and Sunday (February 22, 23 and 24) were 41°F (5°C), 31°F (-0.6°C); 16°F (-8.9°C), 13°F (-10.6°C) and 16°F (-8.9°C), 0°F (-17.8°C). (Thirty-three birds were lost as a result of the drop in environmental temperature.)

The feed was provided in a long trough which had been divided into sections to provide four separate feeding spaces for the birds in each of the four cages. The trough was outside the cages. Water was provided in small plastic cups with shut off valves. These were located inside each cage. The birds were also provided with incandescent lamps throughout the experimental period.

Weekly weights were taken both of the birds and feed. For the first four weeks, the birds were weighed without fasting, but during the last four weeks they were fasted for at least four hours before their weights were ascertained. This was done to eliminate any advantage in weight gain due to the fill in the alimentary tract at the time of weighing. Even though individual weights of each bird were taken, since they all ate from the same trough, for statistical analysis, the average weight gain for the group was used. The final weights were taken on the 54th day and feed was withdrawn for the night in preparation for slaughter the following day.

On the 55th day, two randomly chosen birds from each pen were sacrificed with chloroform and stored immediately in a freezer and left until they were taken out and prepared for chemical analysis. These birds were ground, feathers and all, and samples were taken and freeze-dried for the following determinations: % nitrogen, and therefore, % crude protein, % ash, % moisture and % ether-extract.

The birds remaining in each group were slaughtered on the 55th day, eviscerated and chilled overnight. They were visually appraised for conformation, fleshing, breast fat, back fat, leg condition and condition of the keel. Any cysts were also noted. Unfortunately the numbers in some of the pens were so small that no meaningful statements could be made about the results. Because of this, these are left out of this thesis.

Design

This trial was conducted according to a randomized complete block design with four replicates (blocks). The treatments consisted of all combinations of two levels of fish meal and four levels of cassava meal in the diets. The experimental unit was a cage of 10 birds.

Mortality

Thirty-three chicks were lost over the cold weekend in February, 1974. Eight others were destroyed because they had leg problems which prevented them from getting to the feeders to feed. Another eight chicks died but their deaths cannot be imputed to the dietary treatments imposed since mortality occurred randomly in the groups (Table 4).

Data Analysis

The data on the live weights, feed intake and body composition (Appendix Tables 11 and 12) were subjected to covariance and regression analyses. The covariance analysis was used to adjust the weight gains for the periods 1 to 4, 5 to 8 and 1 to 8 weeks and the body composition to the average feed intake also for the experiment for the periods 1 to 4, 5 to 8 and 1 to 8 weeks. Polynomial coefficients (Ci) were generated using the computer in order to have orthogonal single degree of freedom regression comparisons in the presence of the unequal spacing of the cassava meal levels. These Ci values are given in Appendix Table 1b. The upper and lower 95% confidence limits were computed for mean differences where appropriate. Any mean differences whose limits do not encompass zero are declared real differences rather than being taken as the result of chance variation.

All tests of significance were based on a probability level of 5 percent.

Table 4. Mortality - Dead and Destroyed Chickens during the Period of Experiment 2.

Fish Meal %	Cassava Meal %	Lost[1] (Smothered)	Destroyed	Died	Total
0	0	4	2	0	6
0	20	2	1	1	4
0	30	3	2	0	5
0	40	10	0	2	12
5	0	2	0	1	3
5	20	4	1	0	5
5	30	3	2	4	9
5	40	5	0	0	5
Total		33	8	8	49

[1] On the fourth weekend in February, 1974, the temperature dipped very low and 33 of the birds were found dead. The maximum and minimum temperatures for Friday, Saturday and Sunday, February 22, 23 and 24 were 41°F (5°C), 31°F (-0.6°C); 16°F (-8.9°C), 13°F (-10.6°C); and 16°F (-8.9°C), 0°F (17.8°C).

Results and Discussion

First Four Weeks

The results tabulated in Table 5 for this period and the graph in Figure 2 show that the mean weight gains of birds on the 5% fish meal peaked at 20% cassava meal while those on no fish meal dipped at 20% cassava meal. The birds on diets containing 20% and 30% cassava meal and 5% fish meal gained more weight relative to 0 and 40% cassava meal than those on similar diets without the fish meal. The analysis of variance of both the unadjusted and adjusted means indicate a significant interaction between fish and cassava meals (quadratic regression) (Appendix Table 1a).

Since these weight gains (Table 5) were adjusted to the average feed intake, these figures indicate also the efficiency with which the ingredient combination of fish and cassava meals was utilized. One might infer from this that since fish meal, when properly manufactured, contains adequate quantities of all essential amino acids required by the chick, and also it is an especially good source of lysine and methionine (Scott et al., 1969), the growing chick might have benefited very well from its inclusion in the diets.

Second Four Weeks

The analysis of covariance on the data for the period 5 to 8 weeks (Table 5, Figure 3 and Appendix Table 3),

Table 5. Means of Weight Gains Unadjusted and Adjusted to the Average Feed Intake According to Diet Combination and Period of Feeding, Experiment 2.

Period weeks	Fish Meal %	Cassava Meal %			
		0	20	30	40
		g			
First Four Weeks					
Unadjusted	0	610	554	565	564
	5	588	628	592	572
Adjusted	0	596	557	566	570
	5	597	632	588	568
Second Four Weeks					
Unadjusted	0	963	916	861	949
	5	865	836	842	834
Adjusted	0	939	911	878	930
	5	884	828	853	842
Eight Week Period					
Unadjusted	0	1572	1470	1427	1513
	5	1452	1464	1434	1405
Adjusted	0	1513	1469	1448	1504
	5	1496	1462	1440	1406

Figure 2. Means of Weight Gains During the First Four Weeks Adjusted to the Average Feed Intake According to the Cassava Level and Fish Meal Level of the Diet in Experiment 2.

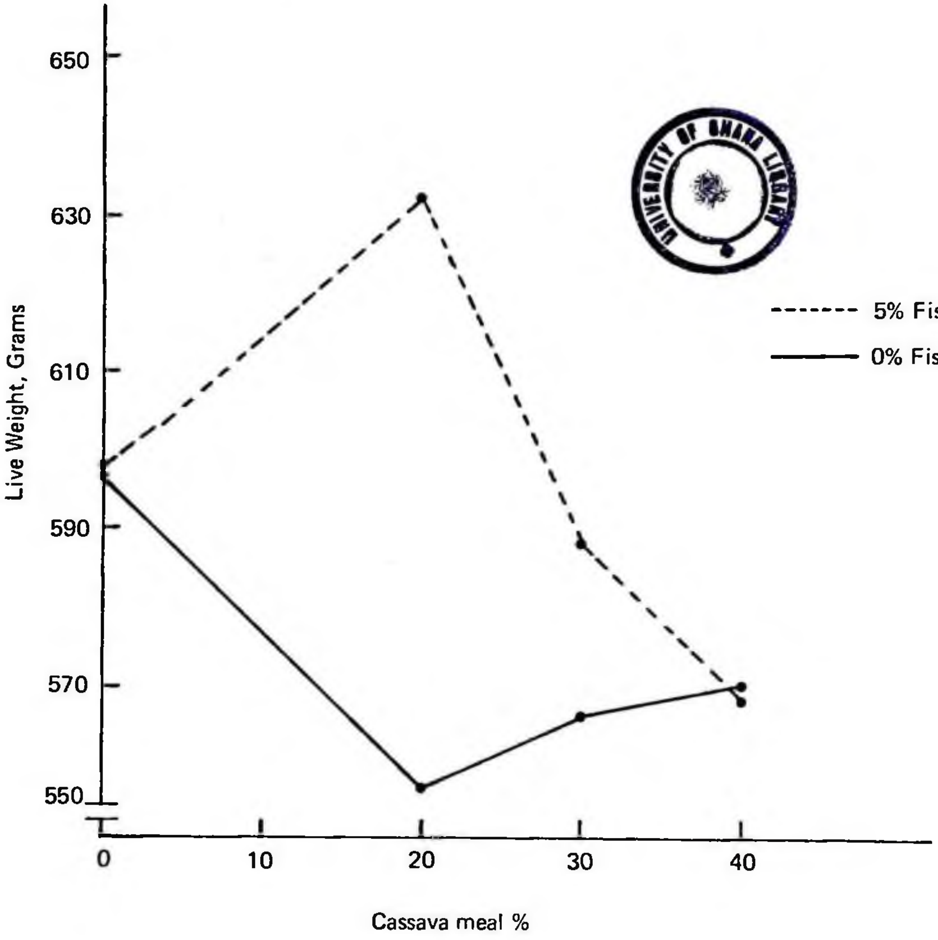
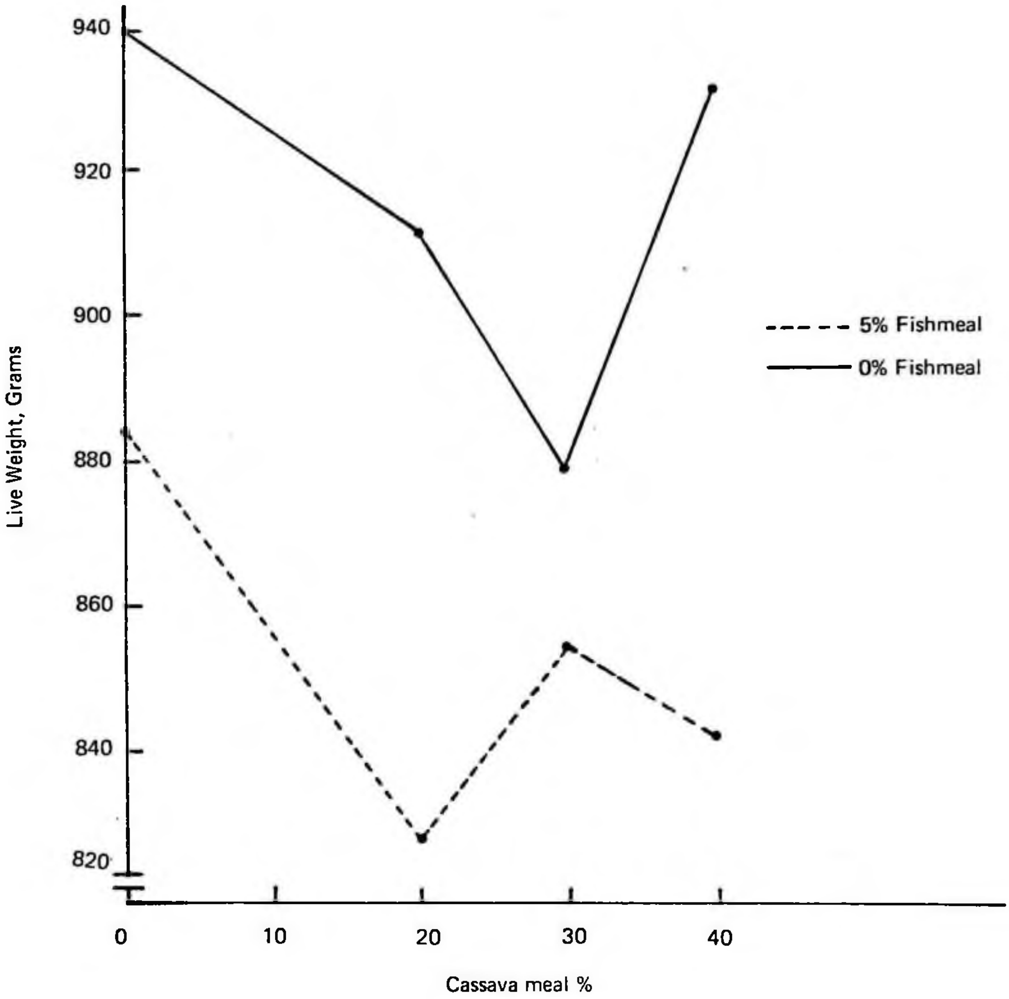


Figure 3. Means of Weight Gains During the Second Four Weeks Adjusted to the Average Feed Intake According to the Cassava Level and Fish Meal Level of the Diet in Experiment 2.



showed only one significant treatment effect which was that between levels of fish meal (Table 6). Since levels of cassava and fish meals appear to operate independently here, it is appropriate to test the main effects of the diet.

Surprisingly, the weight gains obtained on the diets without fish meal (914 g) were higher than those which included fish meal (852 g). One would have thought that since the birds gained well on diets with fish meal during the first four week period, they would continue to gain as much or maintain their gain during the second four week period. But those on diets which did not include fish meal outgained the other group. It is obvious that during this period the broiler was capable of meeting its essential amino acid requirement for growth with the all vegetable diet. Also, those fed the diet with no fish meal may have compensated for the retardation in weight gains during the first four weeks.

In terms of efficiency (since these weight gains have been adjusted to the average feed intake) it appears from Table 5 that the most efficient diet was the one without fish meal and cassava meal. The next most efficient diet was that with 40% cassava meal without fish meal and the diet that produced the lowest weight gains in that set of diets was that containing 30% cassava meal. With regard to the diets with 5% fish meal, the most efficient diet was again the 0% cassava meal and the least efficient was the 20% cassava meal.

Table 6. Confidence Limits for Mean Differences in Weight Gains of Birds in Experiment 2.

Period weeks	Fish Meal %	Mean	Mean Difference	95% Confidence limits for mean difference Lower	Upper
Second Four Weeks	0	914			
	5	852	62	13	112
Eight Week Period	0	1484			
	5	1451	33	-11	76

Eight Week Period

When the covariance analysis is scanned for the 1-8 weeks (Table 5 and Appendix Table 5), it is noted that there were no significant treatment effects over the whole eight week period. With adjustment for feed intake, it seems that the beneficial effect of the fish meal during the first four weeks did not carry over during the second four weeks. Although the data adjusted weight gains (Table 5) show that the diets without fish meal in every case gave the greater gain, the statistical analysis did not disprove the null hypothesis of only chance variation in weight gains for this comparison. The 95% confidence limits for the mean difference between 0 and 5% fish meal encompassed zero (Table 6).

Feed Intake

The data in Table 7 and the analysis of variance in Appendix Tables 2, 4 and 6 show that except for the first four weeks the mean differences observed among the diet combinations were due to chance variation. During the first four weeks, however, the birds on diets with no fish meal took in less feed as the level of cassava increased but those birds on 5% fish meal increased their feed intake as the level of cassava meal increased in the diet.

Dietary Methionine and Cystine (Sulfur Amino Acids)

Where the methionine level was inadequate (Table 3)

Table 7a. The Feed Intake of Birds on the Different Diet Combinations for the Periods 1-4, 5-8 and 1-8 Weeks in Experiment 2.

Period weeks	Fish Meal %	Cassava Meal % 0	20	30	40
			g		
First Four Weeks	0	1248	1139	1152	1110
	5	1093	1131	1182	1185
Second Four Weeks	0	2721	2652	2569	2702
	5	2560	2662	2587	2600
Eight Week Period	0	3969	3791	3721	3812
	5	3654	3793	3769	3785

Table 7b. Confidence Limits for Mean Differences in Feed Intake of Birds for the Fish Meal Comparisons in Experiment 2.

Period weeks	Fish Meal %	Mean	Mean Difference	95% Confidence limits for mean difference Lower	Upper
Second Four Weeks	0	2661			
	5	2602	59	-42	160
Eight Week Period	0	3823			
	5	3750	73	-54	200

the diets were supplemented with methionine to bring their levels to about 3% of the total protein or about 0.77% of the total diet.

Enriquez and Ross (1967) indicated that methionine be added to the diets which contain 50% cassava meal because both 0.15% and 0.20% methionine in the diet consistently improved the efficiency of feed utilization and also improved weight gains. They did not indicate, however, what the calculated level of methionine was in the diet before supplementation. Olson et al. (1969a) also observed that the supplementation of 45% cassava meal with 0.10% methionine, when the calculated methionine level in the diet was about 40%, gave a substantial response but the results were not significantly different from the results obtained with the corn basal diet. In another experiment (1969b) they also observed that 0.20% supplemental methionine which resulted in 0.60% methionine and 0.28% cystine produced optimum results. They also noted that with the addition of 0.40 or 0.80% cystine to the diet, equal performance was achieved. It could be assumed that the beneficial response from methionine and/or cystine supplementation might be due to the indirect donation of sulfur which in turn reacted with the hydrocyanic acid and therefore transformed a potentially toxic material to a non toxic thiocyanate (Oke, 1973). This statement is supported by an inference from Voegthin et al. (1926) that a dose of cystine injected immediately before ingestion of cyanide protected animals from a minimum lethal dose.

In view of the considerable evidence that with adequate supplementation of methionine in the diet, the growth depressing factor in cassava meal may be overcome (Enriquez and Ross, 1967; Olson et al., 1969), one is tempted to postulate that in countries with developed marketing economies where livestock and poultry do not compete with humans for cereal grains (corn in particular) and D-L-methionine is relatively easy to obtain, cassava meal could be included in the diets for broilers up to about 40% without additional supplementation of methionine provided that this sulfur amino acid is over 0.70% of the diet for the starter diets and over 0.50% of the diet for the finisher diets. Its use may depend, however, on the cost of the meal in relation to the cost of cereal grains and D-L-methionine (Dun and Hearn, 1973). But in the tropics (in the developing marketing economies) where cassava can be grown and yields obtained far in excess of human requirement, the excess roots could be processed into cassava meal and used for poultry and livestock feed. On the other hand, since it may be difficult to obtain synthetic D-L-methionine cheaply, other nitrogenous or leguminous (peanut and coconut meals) or animal sources with high sulfur amino acid content could be used to supplement the cassava meal diets thus sparing the cereal grains (especially corn) for human consumption.

Effect of the Diets on Body Composition

With regard to body composition (percent moisture, protein, fat and ash), none of the imposed treatments nor their interactions were statistically significant and the differences observed may be due to chance variation (Table 8 and Figures 4a, b, c and d). The results seem to suggest that none of the dietary treatments had any advantageous influence over the others in bringing about differences in the components measured (Appendix Tables 7 to 10).

Regression Analysis

Ghana imports concentrates separately and also in ready mixed diets for poultry. Both the concentrates and the mixed diets usually contain fish meal as one of the main sources of protein. Soybean meal is seldom used probably because of its cost. It is for this reason that fish meal was incorporated in the diets formulated for the broilers.

Simple tests of significance between two means and the shape of the best fitting lines are of little or no help to the animal feeder. What could be of use would be an estimate of the expected response of an animal when it is given a specified amount of feed. Such estimates could be derived from a regression analysis. After a study of several regression equations, the one selected was of the form:

$Y = a+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5$, where

Y is the predicted weight gains in grams;

Table 8. Percentage Body Composition Unadjusted and Adjusted to the Average Feed Intake According to Diet Combination in Experiment 2.

	Fish Meal %	Cassava Meal %			
		0	20	30	40
Moisture					
Unadjusted	0	65	66	66	66
	5	65	66	65	66
Adjusted	0	65	66	66	66
	5	65	66	65	66
Protein (Moisture Free Basis)					
Unadjusted	0	62	63	62	63
	5	64	64	62	66
Adjusted	0	63	63	61	63
	5	63	64	62	66
Fat (Moisture Free Basis)					
Unadjusted	0	31	30	33	32
	5	29	29	32	27
Adjusted	0	29	30	33	31
	5	30	29	32	27
Ash (Moisture Free Basis)					
Unadjusted	0	9	9	8	8
	5	9	9	8	9
Adjusted	0	9	9	8	8
	5	9	9	8	9

Figure 4a & b. Percentage Body Composition (Protein & Moisture) Adjusted to the Average Feed Intake According to the Cassava Level and the Fish Meal Level in the Diet of Experiment 2.

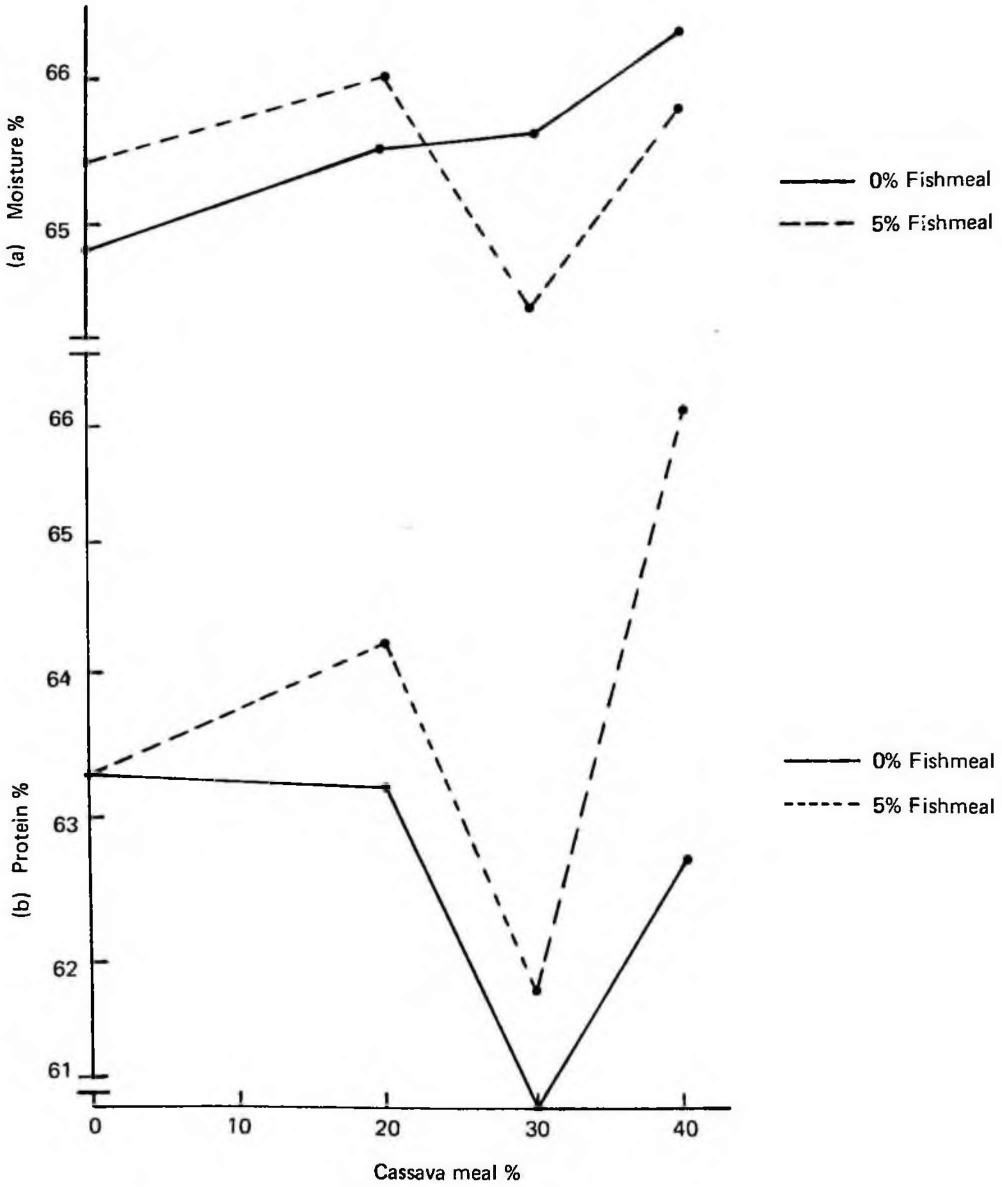
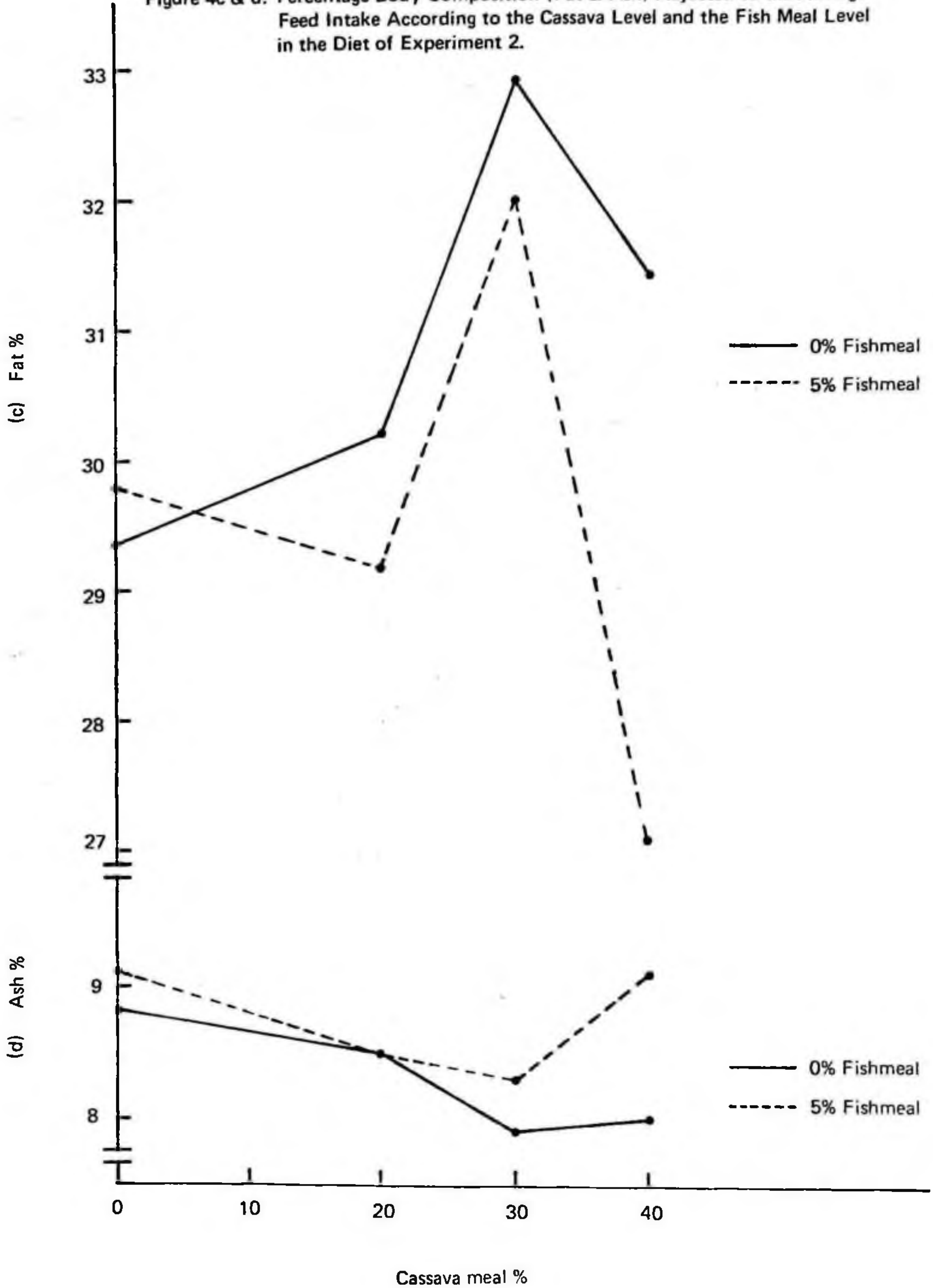


Figure 4c & d. Percentage Body Composition (Fat & Ash) Adjusted to the Average Feed Intake According to the Cassava Level and the Fish Meal Level in the Diet of Experiment 2.



X_1 is the level of fish meal in the diet;

X_2 is the level of cassava meal in the diet;

X_3 is the level of fish meal by the level of cassava meal squared;

X_4 is the level of cassava meal squared;

X_5 is the feed intake in grams.

The regression coefficients in Table 9a were generated and used to predict the expected weight gains for the different production periods. The lower and upper expected 95% confidence limits values are given in Table 9b.

Weight Gains

Maust et al. (1972) reported poorer weight gains in birds fed 40% cassava meal as compared to the other test materials such as rice bran, cowpeas fed raw, germinated and autoclaved, and indicated that even though the cassava meal had the highest ME value over all the other test materials, the chicks gained the least amount of weight. But birds in this study on 40% cassava meal, with or without fish meal, gained over 560 grams during a four week period which is about twice as much as the weight gains reported by Maust et al. Their birds were on cassava meal diet for only two weeks but they were four weeks old whereas the birds in the present study were fed cassava from the day they were put in the cages at the beginning of the study to the end of the experimental period. This was done because it was assumed that if poultry farmers are going to feed

Table 9a. Regression Coefficients for the Prediction Equation Experiment 2.

Dependent variable	Intercept (a)	Fish Meal (F)	Cassava Meal (C)	F x C^2	C^2	Feed Intake
Gain 1-4	370.4	7.905	0.199	-0.004	-0.013	0.179
Gain 5-8	131.4	10.545	-3.676	-0.002	0.081	0.306
Gain 1-8	52.23	2.865	-2.998	-0.012	0.072	0.381
Protein	85.27	0.052	-0.083	0.0003	0.001	-0.006
Moisture	64.39	0.128	0.021	-0.0001	0.0003	0.0001
Fat	7.053	0.054	0.142	-0.0005	-0.002	0.006
Ash	11.145	-0.002	-0.053	0.0001	0.0007	-0.0006

Table 9b. Lower and Upper 95% Confidence Limits for 1-8 Weeks' Gains at Specified Levels of Cassava Meal, Fish Meal and Feed Intake, g Experiment 2.

Feed g	Fish Meal %	Cassava Meal %				
		0	10	20	30	40
				g		
3428	0	1378-1525	1346-1478	1330-1456	1339-1448	1346-1485
	2.5	1378-1496	1343-1448	1316-1426	1314-1412	1312-1430
	5.0	1356-1490	1320-1440	1290-1409	1276-1388	1250-1403
3590	0	1420-1551	1389-1503	1373-1481	1383-1473	1385-1514
	2.5	1420-1523	1427-1502	1360-1451	1359-1435	1355-1456
	5.0	1395-1520	1361-1467	1332-1435	1320-1412	1292-1430
3752	0	1458-1581	1429-1532	1412-1510	1422-1503	1421-1546
	2.5	1458-1553	1427-1502	1400-1479	1400-1463	1393-1486
	5.0	1431-1552	1398-1499	1370-1466	1360-1441	1331-1459
3914	0	1493-1615	1464-1565	1447-1544	1456-1538	1454-1583
	2.5	1491-1589	1461-1537	1434-1514	1433-1498	1427-1521
	5.0	1462-1589	1430-1535	1403-1501	1394-1475	1367-1492
4076	0	1524-1653	1494-1603	1477-1582	1484-1578	1482-1623
	2.5	1519-1629	1488-1577	1462-1554	1461-1539	1456-1560
	5.0	1491-1629	1458-1576	1431-1541	1423-1515	1399-1529
4238	0	1551-1694	1521-1645	1504-1624	1508-1622	1508-1665
	2.5	1544-1672	1512-1622	1486-1598	1484-1584	1481-1604
	5.0	1516-1672	1483-1619	1457-1585	1448-1558	1427-1569
4400	0	1577-1737	1545-1689	1527-1669	1530-1668	1532-1710
	2.5	1567-1718	1534-1669	1509-1644	1505-1632	1504-1649
	5.0	1540-1717	1506-1665	1480-1630	1470-1604	1453-1612

diets with cassava meal they are going to start feeding them immediately the birds arrive on the farm. Another reason was that if the cassava meal is detrimental, it is likely to be noticed at this earlier age.

Moran (1973) reported weight gains of floor reared broiler males in excess of 2000 grams over an eight week period. Birds in this study, on the other hand, were reared in cages in a poorly insulated house (as evidenced by the mortality recorded over the weekend in February, 1974). For the whole of the 54 days that they were on the diets containing various levels of cassava and fish meals, the birds did not attain more than 1750 g in weight gains even including birds on the corn-soybean meal diets (Appendix Table 11).

There was some spillage of feed which could not be collected and weighed because it became mixed with the faeces under the cages (Appendix Table 12). This spillage did not occur with any particular group of birds thus suggesting that acceptability of the feed was not a problem. Therefore feed spillage appeared to be more of a management problem. As a result of the above, the values for feed intake may have a higher than usual error associated with them. It should also be noted that the birds were kept for 54 days instead of 56 days.

The predicted responses to specified levels of cassava meal, fish meal and feed intake are given in Table 9b. It will be observed that as the feed intake increases, the weight gains also tend to increase. As regards levels of both cassava meal and fish meal, however, the opposite effect is observed - as the levels increase the weight gains generally tend to increase slightly. In the developed marketing economies of the world, this may not be an impressive response, but in some countries with developing economies, however, where sometimes animal feed is difficult to obtain and expensive but where cassava meal may be processed without too much capital investment, feed manufacturers should be considering the use of cassava meal as an ingredient in formulating diets for broilers. A word of caution must be sounded here that, processors must make sure that the amino acids required by the chicks are adequate and the sulfur amino acids are not deficient. This is because the level of protein in the cassava meal is very low, about 2 or 3%, and therefore it cannot replace cereal grains in the diets pound for pound without adequate protein supplementation. They should also ensure that the whole diet is properly balanced.

Vogt (1966) attributed the poor weight gains of chicks fed cassava meal (among other things) to the fineness of the diets. But even though the diets used in the previous experiments were not quite floury fine, they were pelleted and then crumbled in order to observe how the birds perform on crumbled cassava meal diets. Thus a third experiment was carried out.

Experiment 3: The performance of broiler male chicks on pelleted and crumbled diets containing 0, 20, 30 and 40% cassava meal with or without fish meal.

Objective:

To compare the performance of broilers on different levels of cassava meal and fish meal in a computer formulated broiler diets which were offered in crumbled form in terms of:

(a) weight gains and

(b) feed utilization.

Diets

The same diets that were mixed for the previous experiment were pelleted and then crumbled. The temperature at which the diets were pelleted was attained by trial and error. The operator of the pelleting machine observed that a temperature approximately 160°F (71°C) was suitable for the pelleting of the cassava meal diets because the pellets produced were neither shiny nor mushy and the ampmeter was reading between 5 and 6 which is the normal range at which other diets have been pelleted. The mash was extruded through a seven-thirty seconds die. The pellets were later passed through the crumbler to make crumbles for the young chicks.

Birds and Management

Four hundred Shaver strain male broiler chicks were acquired forming 40 experimental units for this study. The birds were left in their transit boxes overnight without feed and water. On the following day, they were weighed and randomly assigned in groups of ten to separate pens in electrically heated battery brooders. The average weight was similar in each pen. The diets were also randomly allocated to the pens in tiers so that each tier was a block. (The birds were placed in the top five tiers.) Feed and water were provided *ad libitum*. The birds were kept in the brooders which were located in the same room as in experiment 1. The trial lasted two weeks.

The birds were weighed on the first, eighth, and fifteenth days of the experimental period. The weight of the feed was taken at the beginning and termination of the experiment.

Design

The experimental design, like the design for the second experiment, was a randomized complete block with five replicates (blocks). The treatments also consisted of the same combinations of two levels of fish meal and four levels of cassava meal in the diets. The experimental unit was a pen of ten chicks.

Mortality

Only one bird died during the experimental period.

Data Analysis

The data were subjected to analyses of covariance and regression (Table 10, Figure 5 and Appendix Tables 13 and 14). The upper and lower 95% confidence limits were computed for mean differences where appropriate. Any mean differences whose limits encompass zero are declared the result of chance variation and not real differences.

All tests of significance were based on a probability level of 5 percent.

Results and Discussion

Technically, the results of this experiment cannot be compared with the results of the previous experiment where mash-type feed was offered the birds and also a different type of bird was used. Secondly, in the previous experiment the birds were kept in grower cages in a windowless, poorly insulated, steam heated house whereas in the present one the birds were in electrically heated battery brooders in a room with a thermostatically controlled exhaust fan. It is also steam heated. Thirdly, all the treatment combinations were not available at the same time in the same experiment and therefore the second experiment cannot be considered a replication of the previous experiment. Thus any reference would not be in terms of comparison

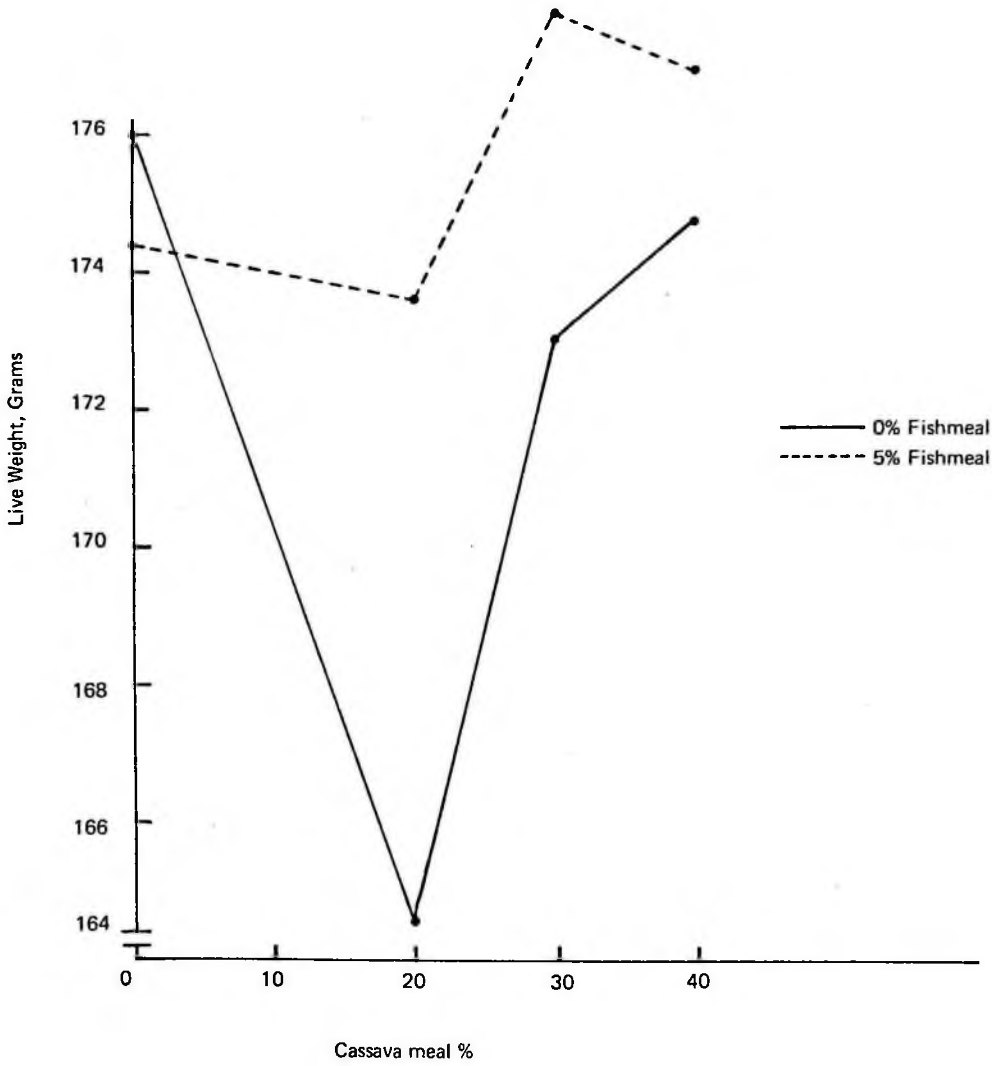
Table 10a. Confidence Limits for Mean Differences in Weight Gains in Birds on Crumbled Diets Experiment 3.

Fish Meal %	Mean	Mean Difference	95% Confidence limits for mean difference Lower	Upper
0	172			
5	176	-4	-11	4

Table 10b. Means of Weight Gains Adjusted to the Average Feed Intake on Crumbled Diets According to Diet Combination Experiment 3.

Fish Meal %	Cassava Meal % 0	20	30	40
		g		
0	176	165	173	175
5	174	174	178	177

Figure 5. Means of Weight Gains Adjusted to the Average Feed Intake According to the Cassava Level and the Fish Meal Level of the Diet of Experiment 3.



but in terms of confirmation or contradiction of what has previously been observed. In the analysis of covariance of the weight gains with covariate feed intake (Appendix Table 13) neither the main effects nor the interactions were statistically significant. This suggests that the differences observed were due to chance and the four levels of cassava meal were equally as good as were the two levels of fish meal. It may be observed, however, that like the mash-type feed experiment, the diet without fish meal but containing 20% cassava meal produced a mean weight gain which was slightly lower than any other diet; but it was not low enough to be detected as being statistically different from the other diets (Table 10a and Figure 5).

As regards efficiency of utilization of feed, it seems that the diet made up of 30% cassava and 5% fish meal (among other ingredients) produced slightly more weight gain than any other combination. Here again the response was not large enough to be statistically significantly different from the other combinations. These are supported by the 95% confidence limits for mean difference (Table 10a).

The observed weight gains and feed intakes are recorded in Appendix Tables 14a and b.

Looking at Appendix Table 15 the pelleted and then crumbled diets produced ratios of weight gains to a unit of feed intake in the order of over 0.60 on the average. The mash-type diets produced ratios in the order of 0.50. This apparent discrepancy may be due in part to the amount of feed wasted under the cages which was charged to the chicks in the second experiment since with the crumbled feed there was little or no spillage and thus the ratios were very good. However, part of the improvement in feed utilization is due to the physical form of the diet.

In connection with the regression analysis the following regression coefficients were obtained

$$140.7828+0.5598X_1-0.4179X_2+0.0002X_3+0.0115X_4 +0.1258X_5.$$

These coefficients were then incorporated into the equation for predicting weight gains. The confidence limits associated with the predicted values are in Appendix Table 16.

The mathematical model is the same as in experiment 2.

$$Y = a+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5$$

Y is the predicted weight gain

X_1 is the level of fish meal in the diet

X_2 is the level of cassava meal in the diet

X_3 is the level of cassava meal squared by fish meal

X_4 is the level of cassava meal squared

X_5 is the amount of feed consumed

The lower and upper 95% confidence limits and the means are provided in Table 11.

Table 11. Lower and Upper 95% Confidence Limits and the Mean of Weight Gains for Birds on Crumbled Diets Experiment 3.

Fish Meal %		Cassava Meal %			
		0	20	30	40
			g		
0		165-184	161-176	160-175	165-184
	Mean	175	168	168	175
5		167-183	171-181	171-183	168-182
	Mean	176	173	176	177

SUMMARY AND CONCLUSIONS

Cassava, a tropical root crop, was evaluated as the main source of energy in the diet using male broiler birds. Fish meal was also evaluated along with the cassava meal since Ghana poultry farmers use feed that has fish meal as the main source of protein.

Biological ME was determined by substituting part of the basal diet with levels of cassava meal as the test material. The basal diet consisted of corn, soybean meal, vitamin and mineral mixes in such a way that when the basal diet was diluted with the various levels of the test material, the crude protein level of the ration would not be less than 22%. The gross energy intake and output and the nitrogen intake and output were determined. The ME was corrected for the nitrogen retained. On a dry matter basis, the value of 3.59 ± 0.03 Kcal/gram was obtained for the Grades I and II combined and 3.20 ± 0.04 Kcal/gram for the Grade III material. (On "as is" basis, the values were 3.13 Kcal/gram for the former grades and 2.79 Kcal/gram for the latter grade.)

In a second experiment, a two by four factorial study was conducted to appraise primarily the feeding value of cassava meal for broilers. The factors were two levels of fish meal and four levels of cassava meal. The diets were formulated with the help of the computer. Eight diets were mixed: 0, 20, 30, 40% cassava meal with and without

5% fish meal included in the diets. The starter diets were formulated to contain about 23% crude protein and at least 3.011 Kcal/gram ME. For the finisher diets, the crude protein level was about 18% and at least 3.110 Kcal/gram ME.

The cassava meal was included in the diet strictly for its energy value. The other nutrients that the meal may contain were utilized as margins of safety. In order to provide adequate sulfur amino acids in the diets, methionine was used to supplement the diets.

Two birds from each group were sacrificed and stored in a freezer until chemical analyses were performed. Moisture, crude protein, crude fat and ash content were determined.

During the first four weeks, the birds on 5% fish meal outgained those on diets without fish meal and the most efficient diet was the diet containing 20% cassava and 5% fish meals. The means of the weight gains achieved on 0, 20, 30% cassava meal diets were not different from each other statistically, but the means of the weight gains achieved on the 0 and 40% cassava meal diets were statistically different. However the mean differences observed on the weight gains of birds on 20, 30 and 40% cassava meal diets were due to random variation.

During the second four week period, the group on no fish meal outgained those on 5% fish meal and the mean difference was statistically different. However, with regard to the levels of cassava meal the mean differences were not large enough to be detected as being statistically different. When both periods were combined for the eight week period, the upper and lower limits of the 95% confidence limits for the mean difference for the level of fish meal did not encompass zero thus it was concluded that the mean difference observed with the diets containing fish meal and those without fish meal was statistically different. However, the upper and lower limits of the mean differences for the four levels of cassava meal encompassed zero therefore it was inferred that the differences were due to chance variation.

Regression analyses were computed in order to obtain regression coefficients for a linear model to predict weight gains when given levels of cassava and fish meals and the amount of feed consumed. The mathematical model for the equation is

$Y = a+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5$, where

Y is the predicted weight gain in grams

X_1 is the level of fish meal for 0 to 5%

X_2 is the level of cassava meal for 0 to 40%

X_3 is the level of cassava meal squared by level of fish meal

X_4 is the level of cassava meal squared and

X_5 is the amount of feed intake or consumed in grams.

In order to cut down on the fineness of the diets containing cassava meal, the same feed was pelleted and then crumbled and fed to another set of broiler male chicks. Little spillage of feed occurred during the two week period and the mortality was very low. The mean differences observed for both the levels of cassava meals and the levels of fish meal were not large enough to be detected by the 95% confidence limits for the mean differences and that these observed mean differences were due to chance or random variation.

It may therefore be concluded from these studies that

(a) the ME value for cassava meal which does not contain much of the rind and outer covering was 3.587 ± 0.0817 Kcal per gram and the meal which has more of the rind and the outer covering than the starchy part had a value of 3.198 ± 0.1161 Kcal per gram on a dry matter basis;

(b) the fish meal was beneficial at the growing period of the broiler chick during the first four weeks of the life of the chick but this advantage was not observed during the second four week period;

(c) during the whole production period (weeks one to eight) the birds on no fish meal diets outgained those on 5% fish meal diets;

(d) the weight gains achieved on the levels of cassava meal diets studied (that is 0, 20, 30, 40%) were essentially the same;

(e) a growth depressing factor in cassava meal was not obvious from these studies. The sulfur amino acid content of the diets seemed to be adequate to support growth and counteract any effect of hydrocyanic acid in the diet;

(f) the crumbling of the pellets reduced the fineness of the diets containing cassava meal and the amount of feed left in the water troughs was also reduced.

It would appear from this study that there is a potential for incorporating cassava meal in poultry feed. Ghana, which has the possibility to increase her production of cassava, can benefit from inclusion of cassava meal in diets for poultry provided the diets are properly balanced and there is enough sulfur amino acids to counteract any hydrocyanic acid that may be present.

BIBLIOGRAPHY

AGF. 1962. Tapiokamehl schwankt im Futterwert und Preis. Deutsche Geflügelwirtschaft. 14:649.

Anonymous. 1968. The markets for manioc as a raw material for the manufacture of compound animal feeding stuffs in the Federal Republic of Germany, the Netherlands and Belgium. Int. Trade Centre. UNCTAD-GATT. FS21.

Anton-Smith, J. 1968. Observations on methods of feeding cassava to pigs. Mt. Makula Res. Sta. Chilanga, Zambia.

Asico, P.M. 1941. A comparative study of gaplek meal (cassava) and corn as basal feed for growing and fattening pigs. Philip. Agric. 29:706-711.

Association of Official Agricultural Chemists. Methods of Analysis. 11th Ed. Washington, D.C. 1970.

Barbosa, A.S., J.A. Carneiro-Vianna, H.A. Moreira and C.M.F. Carvallo. 1957. Cassava roots (dried) as a substi tute of wheat byproducts for growing swine. ARQ, ESC. Veterinaria Univ. Minas Gerais (Belo Horizonte). 10:15-24.

Cardoso, R.M., J. Campos, D.L. Hill and J.F. Coelho de Silva. 1968. The effect of the gradual substitution of maize by cassava meal on milk production. Rev. Ceres. 14:82.

Castillo, L.S., F.B. Aglibut, T.A. Javier, A.L. Gerpacio, G.V. Garcia, R.B. Puyaoan and B.B. Ramin. 1964.

Camote and cassava tuber silage as replacement for corn in swine growing and fattening rations. Philip. Agric. 47(9/10):460-474.

De Hernandez, I.T. 1969. Investigaciones acerca del valor nutritivo de la yuca para el pollito. Tec. Peevar Mex. 12/13:5-11.

De J. Montilla, J., S. Carmen Rosa Mendez and H. Widenhoffer. 1969. Utilizacion de la havina de tuberculo de yuca (Manihot esculanta) en raciones inicadoras para pollos de engorde. Arch. Latinamer Nutr. 19(4):381-389.

Dun, P. and J.P. Hearn. 1973. Cassava root meal in layer rations. Personal communication.

Enriquez, F.Q. and E. Ross. 1967. The value of cassava root meal for chicks. Poultry Sci. 46(3):622-626.

Enriquez, F.Q. and E. Ross. 1972. Cassava root meal in grower and layer diets. Poultry Sci. 51(1):228-232.

FAO. Production Yearbooks. 1971 and 1972.

Gadelha, J.A., J. Campos and V. Mayrose. 1969. Farelo de raspa de mandioca na alimentacao de Pintos. Experientiae. 9(4):111-132.

Hill, F.W., D.L. Anderson, R. Renner and L.B. Carew, Jr. 1960. Studies of the metabolizable energy of grain and grain products for chickens. Poultry Sci. 39: 573-583.

Hill, F.W. 1962. Cited by Bolton, W. (1962), XIIth World Poultry Congress, Proceedings of Symposia, Sydney, Australia. 38-42.

Johnson, R.M. and W.D. Raymond. 1965. The chemical composition of some tropical food plants. IV. Manioc. Tropical Sci. 7(3):109-115.

Jones, W.O. 1959. Manioc in Africa. Stanford University Press. Stanford, California.

Klein, F.W. and G.V. Barlowen. 1954. Tapiokamehl im Aufzuchtfutter. Arch. f. Geflugelk. 18:415.

Maner, J.H., J. Buitrago and I. Jimenez. 1967. Utilization of yuca in swine feeding. Proc. Int. Symp. on Trop. Root Crops, Univ. of W.I., St. Augustine, Trinidad. 2(6):62-71.

Maner, J.H., J. Buitrago and I. Jimenez. 1968. Utilization of yuca in swine feeding. Instituo Colombiano Agropecuario and Rockefeller Foundation, Cali, Colombia, S.A.

Maust, L.E., M.L. Scott and W.G. Pond. 1972. The metabolizable energy of rice bran, cassava flour, and black-eye cowpeas for growing chickens. Poultry Sci. 51 (4):1397-1401.

Modebe, A.N.A. 1963. Preliminary trial on the value of dried cassava (*Manihot utilissima* Pohl) for pig feeding. J. West African Sci. Assoc. 7(2):127-133.

Mondonedo, M. 1928. A comparative study of corn and cassava as feeds for hogs. II. Ground corn versus raw chopped cassava. Phil. Agr. 17:105-107.

Moran, E.T., Jr. 1973. Protein needs of the male and female broiler chicken. Proceedings 1973 Maryland Nutrition

Conference for feed manufacturers. pp. 19-24.

Murillo, O.E. 1952. Valor de la harina de hojas y tallos deshidratados de yuca eu la production de leche. Turrialba. 2(4):166-169.

National Academy of Sciences. National Research Council. 1971. Washington, D.C.

Nestel, B. 1973. Current utilization and future potential for cassava in Chronic Cassava Toxicity. Proc. of an Interdisciplinary Workshop. London, England. Editors: B. Nestel and R. MacIntyre. lDRC-010e.

Oke, O.L. 1973. The mode of cyanide detoxication in Chronic Cassava Toxicity. Proc. of an Interdisciplinary Workshop. London, England. Editors: B. Nestel and R. MacIntyre. lDRC-010e.

Olson, D.W., M.L. Sunde and H.R. Bird. 1969a. The metabolizable energy content and feeding value of mandioca meal in diets for chicks. Poultry Sci. 48 (4):1445-1452.

Olson, D.W., M.L. Sunde and H.R. Bird. 1969b. Amino acid supplementation of mandioca meal chick diets. Poultry Sci. 48(6):1950-1953.

Olson, D.W., M.L. Sunde and H.R. Bird. 1972. The effect of temperature on metabolizable energy determination and utilization by the growing chick. Poultry Sci. 51 (6):1915-1922.

Oyenuga, V.A. and L.K. Opeke. 1957. The value of cassava rations for pork and bacon production. W.A. J.

Biol. Chem. 1(1):3-14.

Philips, T.P. 1974. Cassava Utilization and Potential Markets. 1DRC-020e.

Pillai, S.C., E.G. Srinath, M.L. Mathur, P.M.N. Naidu and P.G. Muthanna. 1968. Tapioca spent pulp as an ingredient in poultry feed. Curr. Sci. 37(21):603-5

Pino, J.A. 1962. Sources of energy for poultry in the Pacific area. World's Poultry Sci. J. 18:406.

Rogers, D.J. and S.B. Appan. 1972. Cassava (Manihot esculanta Crantz), the plant, World Production and its importance in world food supply. In C.H. Hendershott et al. A Literature Review and Researc Recommendations on Cassava. Univ. of Georgia, Athe Ga.

Ross, E. and F.Q. Enriquez. 1969. The nutritive value of cassava leaf meal. Poultry Sci. 48(3):846-853.

Scott, M.L. 1974. Nutrient requirements of chickens, tur keys. Feedstuffs Yearbook Issue: Vol. 46(38), 63-6

Scott, M.L., M.C. Nesheim and R.J. Young. 1969. Nutritio of the Chicken. M.L. Scott and Associates, Ithaca, N.Y.

Shultz, T.A., E. Shultz and C.F. Chicco. 1972. Pressure cooked urea-cassava meal for lambs consuming low quality hay. J. of Animal Science. 35(4):865-870.

Soares, P.R. 1965. Whole mandioca meal and wheat mill feed in the feeding of chicks. Master's Thesis. Universidade Rural Do Estado De Minas Gerais, Vicosa, Brazil.

Soares, P.R., J. Campos and J.H. Conrad. 1968. Farelo integral de raspa de mandioca e farelinho de trigo na alimentacao de pintos. Experientiae. 8(4): 109-141.

Squibb, R.L. and M.K. Wyld. 1951. Effect of yuca meal in baby chick rations. Turrialba. 1(6):298-299.

Tabayoyong, T.T. 1935. The value of cassava refuse meal in the ration for growing chicks. Philip. Agric. 24:509-518.

Tracy, S.M. 1903. Cassava. USDA Farmers Bull. 167. Washington, D.C.

Velloso, L., J. Silveira, A.J. Rodrigues and N.W. Robinson. 1967. Estudo do valor de alguns fenos de plantas tropicais comparados a alfalfa em racoes de suinos. Boeltim de Industria Animal. 24:53-57.

Voegthin, O., J.M. Johnson and H.A. Dyer. 1926. Glutha-thione content of turnover animals. J. Pharmacol. Exp. Ther. 27:467-473.

Vogt, H. 1966. The use of tapioca meal in poultry rations. World Poultry Sci. J. 22(2):113-125.

APPENDICES

APPENDIX

Cassava Meal Used for the Experiments

The cassava meal used in these experiments was obtained from Cali, Colombia, South America. The fresh cassava from which the chips were made was obtained from two different farms but it was all of the same variety and approximately of the same age (9 months).

Processing: The tubers were washed and according to a note accompanying the shipment the cassava "was chipped with a simple chipper we have been working with here. It consists of the end of a barrel which has been punched and mounted on a shaft to form a rotating grater. This chipper does a good uniform job and has a satisfactory capacity. There is a problem, however, in that it also partially separates the outer cork layer (bark) of the peeling from the centre or cortex of the root.

"This material could have been mixed back with the rest of the root, however, this was not done and in fact another separation was made so there is a three way classification of material:

"First Grade. The best quality clean material with only relatively small amounts of the outer peel present.

"Second Grade. This has a medium amount of peel and would be perhaps a normal mixture of peel and root cortex.

"Third Grade. Practically all outer peel with only a few pieces of the central part of the root."

The dried cassava chips had a moisture content of about 10%. On arrival here in Guelph the chips were ground with a hammer mill in their separate grades and they were stored in a walk-in cooler until the meal was needed for the formulation of treatment diets.

Appendix Table la. Analysis of covariance (G1-4) with covariate 1-4 feed intake in Experiment 2.

Sources	df	Mean Square	F
Replication	3	1183.25	1.89
Cassava L_1 (CL)	1	3471.96	5.54*
L_2	1	482.73	0.77
L_3	1	232.14	0.37
Fish (F)	1	4450.32	7.10*
F x CL_1	1	8.79	0.01
CL_2	1	6494.85	10.36*
CL_3	1	1250.05	1.99
Error	19	717.31	
Feed (1-4)	1	2344.44	3.78
Error[1]	18	626.92	

* Significant at P=0.05 based on 18 df

Appendix Table 1b. Polynomial coefficients (Ci) in the presence of unequal spacing of the cassava meal levels.

	Cassava Meal %			
Contrast	0	20	30	40
Linear Regression	-0.7606	-0.0845	0.2535	0.5916
Quadratic Regression	0.4029	-0.6446	-0.3223	0.5640
Cubic Regression	-0.0953	0.5720	-0.7627	0.2860

Appendix Table 2. Analysis of variance for observed feed intake for the period 1-4 weeks in Experiment 2.

Source	df	Mean Square	F
Replication	3	1638.57	0.30
Cassava L_1 (CL)	1	1074.57	0.19
L_2	1	984.10	0.18
L_3	1	4696.46	0.85
Fish (F)	1	1696.53	0.31
F x CL_1	1	58074.81	10.51*
CL_2	1	1175.26	0.21
CL_3	1	142.99	0.03
Error	21	5524.57	

* Significant at P=0.05 based on 21 df

Appendix Table 3. Analysis of covariance (G5-8) with covariate 5-8 feed intake in Experiment 2.

Source	df	Mean Square	F
Replication	3	2538.38	0.57
Cassava L_1 (CL)	1	4173.56	0.94
L_2	1	5997.81	1.35
L_3	1	95.81	0.02
Fish (F)	1	29296.19	6.57*
F x CL_1	1	150.50	0.03
CL_2	1	203.44	0.04
CL_3	1	4728.00	1.06
Error	19	5694.97	
Feed (5-8)	1	1141.65	0.26
Error[1]	18	4456.61	

* Significant at P=0.05 based on 18 df

Appendix Table 4. Analysis of variance for observed feed intake for the period 5-8 weeks in Experiment 2.

Source	df	Mean Square	F
Replication	3	41795.14	2.22
Cassava L_1 (CL)	1	982.08	0.05
L_2	1	1927.23	0.10
L_3	1	28740.14	1.53
Fish (F)	1	27671.26	1.47
F x CL_1	1	8452.13	0.45
CL_2	1	36383.20	1.93
CL_3	1	977.00	0.05
Error	21	18815.00	

Appendix Table 5. Analysis of covariance (G1-8) with covariate 1-8 feed intake in Experiment 2.

Source	df	Mean Square	F
Replication	3	4072.02	1.18
Cassava L_1 (CL)	1	13371.69	3.88
L_2	1	2209.63	0.64
L_3	1	781.88	0.23
Fish (F)	1	7997.50	2.23
F x CL_1	1	3661.56	1.06
CL_2	1	5674.88	1.65
CL_3	1	1142.19	0.33
Error	19	33003.10	
Feed (1-8)	1	565010.40	163.91
Error[1]	18	3447.14	

Appendix Table 6. Analysis of variance for observed feed intake for the period 1-8 weeks in Experiment 2.

Source	df	Mean Square	F
Replication	3	38619.04	1.29
Cassava L_1 (CL)	1	4111.21	0.14
L_2	1	5665.67	0.19
L_3	1	10200.69	0.34
Fish (F)	1	43071.10	1.44
F x CL_1	1	110837.44	3.71
CL_2	1	50636.64	1.70
CL_3	1	372.45	0.01
Error	21	29859.95	

Appendix Table 7a. Analysis of covariance for moisture with covariate 1-8 feed intake in Experiment 2.

Source	df	Mean Square	F
Replication	3	0.99	1.22
Cassava L_1 (CL)	1	2.49	3.06
L_2	1	0.002	0.002
L_3	1	0.94	1.16
Fish (F)	1	0.06	0.07
F x CL_1	1	1.10	1.35
CL_2	1	0.17	0.22
CL_3	1	0.09	0.10
Error	21	0.78	
Feed	1	0.001	<1
Error[1]	20	0.81	

Appendix Table 7b. Confidence limits for mean differences in moisture of birds in Experiment 2.

Fish Meal %	Mean	Mean Difference	95% Confidence limits for mean difference Lower	Upper
Eight Week Period				
0	66			
5	66	0	1	1

Appendix Table 8a. Analysis of covariance (protein) with covariate 1-8 feed intake in Experiment 2.

Source	df	Mean Square	F
Replication	3	17.89	2.07
Cassava L_1 (CL)	1	0.02	0.003
L_2	1	5.65	0.65
L_3	1	29.84	3.45
Fish (F)	1	11.23	1.30
F x CL_1	1	6.59	0.76
CL_2	1	1.45	0.17
CL_3	1	1.22	0.14
Error	21	9.98	
Feed (1-8)	1	36.82	4.26
Error[1]	20	8.64	

Appendix Table 8b. Confidence limits for mean differences in percent protein of birds in Experiment 2.

Fish Meal %	Mean	Mean Difference	95% Confidence limits for mean difference Lower	Upper
Eight Week Period				
0	63			
5	64	-1	-3	1

Appendix Table 9a. Analysis of covariance for fat with covariate 1-8 feed intake in Experiment 2.

Source	df	Mean Square	F
Replication	3	33.11	2.96
Cassava L_1 (CL)	1	1.90	0.17
L_2	1	11.59	1.04
L_3	1	39.81	3.56
Fish (F)	1	15.27	1.36
F x CL_1	1	15.71	1.40
CL_2	1	3.29	0.29
CL_3	1	2.38	0.21
Error	21	12.36	
Feed 1-8	1	35.63	3.18
Error[1]	20	11.19	

Appendix Table 9b. Confidence limits for mean difference in fat of birds in Experiment 2.

Fish Meal %	Mean	Mean Difference	95% Confidence limits for mean difference Lower	Upper
Eight Week Period				
0	31			
5	30	1	1	4

Appendix Table 10a. Analysis of covariance for ash with covariate 1-8 feed intake in Experiment 2.

Source	df	Mean Square	F
Replication	3	0.30	0.54
Cassava L_1 (CL)	1	1.31	2.39
L_2	1	1.01	1.83
L_3	1	0.42	0.76
Fish (F)	1	1.46	2.67
F x CL_1	1	0.50	0.91
CL_2	1	0.59	1.07
CL_3	1	0.01	0.01
Error	21	0.53	
Feed	1	0.08	0.15
Error¹	20	0.55	

Appendix Table 10b. Confidence limits for mean difference in ash for birds in Experiment 2.

Fish Meal %	Mean	Mean Difference	95% Confidence limits for mean difference Lower	Upper
Eight Week Period				
0	8			
5	9	1	-1	0

Appendix Table 11. Observed weight gains for birds for the periods 1-4, 5-8 and 1-8 weeks, grams in Experiment 2.

Period weeks	Rep	Fish Meal %	Cassava Meal % 0	20	30	40
1-4	1	0	658	546	582	564
		5	606	663	615	572
	2	0	604	507	572	559
		5	593	611	595	579
	3	0	617	567	521	546
		5	585	615	589	576
	4	0	559	597	587	587
		5	567	624	570	560
5-8	1	0	1082	1042	889	973
		5	905	761	900	833
	2	0	962	831	817	798
		5	882	877	707	913
	3	0	918	883	980	1019
		5	887	894	877	800
	4	0	889	909	849	1003
		5	786	812	883	789
1-8	1	0	1740	1588	1471	1537
		5	1511	1424	1515	1405
	2	0	1566	1338	1389	1359
		5	1473	1488	1302	1492
	3	0	1535	1450	1411	1565
		5	1472	1509	1466	1376
	4	0	1448	1506	1436	1592
		5	1353	1436	1453	1349

Appendix Table 12. Observed feed intake by birds for the periods 1-4, 5-8, 1-8 weeks, grams in Experiment 2.

Period weeks	Rep	Fish Meal %	Cassava Meal % 0	20	30	40
1-4	1	0	1410	1093	1173	1050
		5	1116	1057	1162	1133
	2	0	1275	1165	1107	1062
		5	1175	1158	1102	1231
	3	0	1204	1163	1157	1135
		5	1040	1155	1315	1211
	4	0	1103	1136	1171	1193
		5	1042	1153	1149	1165
5-8	1	0	2991	2807	2563	2961
		5	2546	2691	2687	2415
	2	0	2560	2475	2452	2366
		5	2510	2626	2563	2715
	3	0	2615	2570	2683	2643
		5	2649	2671	2537	2760
	4	0	2717	2755	2578	2839
		5	2536	2659	2561	2508
1-8	1	0	4401	3900	3736	4011
		5	3662	3748	3849	3548
	2	0	3835	3640	3559	3420
		5	3685	3784	3665	3446
	3	0	3819	3733	3840	3778
		5	3689	3826	3852	3971
	4	0	3820	3891	3749	4032
		5	3578	3812	3710	3673

Appendix Table 13. Analysis of covariance (crumbled feed) with covariate 1-2 feed intake in Experiment 3.

Source	df	Mean Square	F
Replication	4	58.82	0.42
Cassava L_1 (CL)	1	5.76	0.04
L_2	1	175.67	1.24
L_3	1	119.16	0.84
Fish (F)	1	126.50	0.89
F x CL_1	1	23.44	0.17
CL_2	1	108.97	0.77
CL_3	1	13.38	0.09
Error	28	138.70	
Feed	1	64.40	0.46
Error[1]	27	141.45	

Appendix Table 14a. Observed weight gains on crumbled diets for birds in Experiment 3.

Period weeks	Rep	Fish Meal %	Cassava Meal %			
			0	20	30	40
			g			
1-2	1	0	184	176	163	188
		5	182	170	171	172
	2	0	184	152	187	185
		5	179	170	176	176
	3	0	186	157	156	148
		5	163	177	179	185
	4	0	179	171	191	171
		5	172	185	168	177
	5	0	150	169	165	178
		5	181	167	193	172

Appendix Table 14b. Observed feed intake of crumbled feed for birds in Experiment 3.

			g			
1-2	1	0	270	250	230	255
		5	260	260	270	245
	2	0	250	310	270	272
		5	250	270	270	255
	3	0	270	240	230	225
		5	250	260	250	245
	4	0	260	260	270	255
		5	320	240	240	255
	5	0	260	240	240	245
		5	260	260	280	255

Appendix Table 15. Ratios of gain weight to feed intake of birds in Experiments 2 and 3 for the first 2 weeks.

Exp.	Rep	Fish Meal %	Cassava Meal %			
			0	20	30	40
2	1	0	0.37	0.57	0.56	0.40
		5	0.60	0.67	0.82	0.50
	2	0	0.52	0.40	0.47	0.56
		5	0.52	0.61	0.48	0.45
	3	0	0.56	0.50	0.44	0.48
		5	0.71	0.60	0.85	0.46
	4	0	0.54	0.60	0.44	0.52
		5	0.57	0.59	0.51	0.52
3	1	0	0.68	0.70	0.71	0.74
		5	0.70	0.66	0.64	0.70
	2	0	0.73	0.49	0.69	0.68
		5	0.72	0.63	0.66	0.69
	3	0	0.69	0.65	0.68	0.66
		5	0.65	0.68	0.72	0.75
	4	0	0.69	0.66	0.71	0.67
		5	0.54	0.77	0.70	0.69
	5	0	0.58	0.71	0.69	0.73
		5	0.70	0.64	0.69	0.67

Appendix Table 16. 95% confidence limits for weight gains using predicted values for independent variables (Experiment 3).

Feed grams	Fish Meal %	Cassava Meal %				
		0	10	20	30	40
				g		
225	0	157-181	156-177	156-175	159-175	160-181
	2.5	159-181	158-177	158-176	161-177	164-182
	5.0	159-185	158-180	158-179	161-180	164-186
244	0	162-181	160-177	160-175	163-176	164-183
	2.5	164-181	163-177	163-176	166-176	168-182
	5.0	164-185	163-180	163-179	166-179	168-187
263	0	165-183	163-179	163-177	165-178	166-186
	2.5	168-183	168-178	166-178	169-178	170-185
	5.0	167-186	166-181	166-181	169-181	170-189
282	0	166-186	164-182	164-182	166-183	166-190
	2.5	170-186	168-182	166-182	169-183	171-190
	5.0	169-189	168-185	167-184	170-186	171-193
301	0	166-191	164-187	163-187	165-188	166-195
	2.5	170-190	167-187	166-187	168-189	170-195
	5.0	170-193	168-189	167-189	169-191	171-198