c.1

BIOLOGICAL AVAILABILITY OF MINERALS FROM ORGANIC AND INORGANIC SOURCES FOR THE CHICK

by

© Lai Mon Aw-Yong

B.Sc. (Hons.), McGill University, 1972
M.Sc., University of British Columbia, 1974

A THESIS SUBMITTED IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF
DOCTOR OF PHILOSOPHY

in

THE DEPARTMENT OF POULTRY SCIENCE

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Poultry Science

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date Sept. 8, 1980

ABSTRACT

Availability of six minerals (Ca, P, Mg, Mn, Zn, and Cu) in commercial wheat, triticale, corn and barley samples was estimated with three-week old growing chicks. Effects of soybean meal and wheat fed at different dietary concentration on availability of these minerals were studied. The availability of minerals from specific inorganic sources were also evaluated. Availability value was determined by a balance procedure corrected for endogenous minerals.

Results indicated that the availability of calcium, phosphorus, magnesium, manganese, zinc, and copper was 71.0, 67.4, 53.5, 48.4, 49.6 and 78.5%, respectively for the wheat and triticale samples. Copper availability was the highest in corn (87.2%), followed by calcium (70.0%), phosphorus (60.9%), manganese (60.0%), zinc (57.5%) and magnesium (51.0%). The availability of Ca, P, Mg, Mn, Zn and Cu in barley was 68.9, 68.8, 54.9, 54.9, 49.1 and 77.5%, respectively. Significant variation ($P \leq 0.05$) exists among the cereal grains tested. Results indicate that mineral availability is influenced by the origin of the samples obtained. Availability of minerals is affected by the concentration of ingredients in the test diet. Significant differences ($P \leq 0.05$) were observed in availability for all the minerals tested when soybean meal and wheat were supplied in the test mixture at five levels.

Calcium and phosphorus from calcium phosphate were highly available to growing chicks. However, the availability decreased rapidly when the mineral level was in excess of the dietary requirement. Six levels of magnesium (150, 300, 450, 600, 750, and 900 ppm) from magnesium carbonate were evaluated. Results showed that magnesium was highly available to growing chicks. The values ranged from 82.3 to 61.9%. Excess amounts of magnesium in the diet tended to reduce the availability value. Various levels (25, 50, 75, 100 and 125 ppm) of manganese from manganese sulfate were tested. Manganese appeared to be poorly available for the levels tested. Zinc availability from zinc oxide was highly available for the chick. The availability values ranged from 84.4 to 93% for all the diets containing 25 to 125 ppm of zinc. The availability of copper from copper sulfate was moderate to high (72.1-80.2%) for the low dietary copper concentrations (2-32 ppm). However, the copper availability values (61.8-63.6%) tended to decrease at higher dietary concentration (50-250 ppm).

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF APPENDIX TABLES

ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to his research supervisor, Dr. D. B. Bragg, Professor and Head of the Poultry Science Department, for his invaluable guidance, constant encouragement and constructive critisicm throughout the course of this study and the preparation of the manuscript.

Sincere appreciation is also extended to the members of my thesis committee: Professor B. E. March, Department of Poultry Science; Dr. Fitzsimmons, Associate Professor, Department of Poultry Science; and Dr. R. M. Beames, Associate Professor, Department of Animal Science for their advice and encouragement during the preparation and writing of this thesis.

The technical assistance given by Mr. R. Soong, Mr. M. Hudson and other laboratory and farm personnel was greatly appreciated.

The financial support by National Research Council, Canada for this study is also gratefully acknowledged.

It is the author's wish to dedicate this thesis to his wife, Boh-Sing and his parents, Mr. and Mrs. Y. Aw-Yong.

INTRODUCTION

The concept of nutrient availability of feedstuff has become very important for the modern livestock and feed industries. It is a current practice to formulate feed for livestock based on the content of various nutrients in the feed ingredients. The nutritive value of a feedstuff is determined by the content of the available nutrients in the feed. In the study of nutrient metabolism, it is generally recognized that the total content of a nutrient in a particular feedstuff used in a complete diet has little significance unless it is qualified by a factor indicating the biological availability of the nutrients to animals. For an example, amino acid or mineral content in the feedstuff does not indicate the degree in which the nutrient is utilized when consumed by an animal. No element is completely absorbed and utilized. At the best, part of the element is lost in normal digestive and metabolic processes. Recent research has indicated that there is a significant difference between total content of nutrients and quantities available.

Publications by the Nutrition Committee of the National Research Council on Nutrient Requirements for Livestock have been determined with the diet formulated by total nutrient content on the assumption that the nutrient in feedstuff is highly available. More precise recommendations have not been possible due to the shortage of nutrient availability information for most feed ingredients. Precise availability measurements for feed ingredients become increasingly urgent for economical dietary formulation due to soaring feed costs at present and in the foreseeable future. It is therefore necessary to evaluate how much of the total nutrient content is actually available to animals relative to meeting requirements for maintenance and productive function (growth and reproduction).

Cereal grains (wheat, corn and barley) are the most common feed grains utilized in the livestock industry. These cereals are used mainly as energy and protein sources for animal production. However, the mineral contribution of these cereals has always been overlooked during feed formulation. Many minerals in cereal grains are present in low concentrations. Thus, there has been little interest in studies on mineral availability of these feedstuffs. Although several studies have reported low availability of phosphorus in vegetables to monogastric animals, conflicting findings have been reported in the literature. The discrepancy may be due to the various methods used for availability estimation in different laboratories as well as variability among samples. Most studies on mineral availability were determined on relative bioavailability assuming 100% mineral available in an inorganic salt instead of true availability measurements. The breakthrough of the true availability estimation method by Nwokolo *et al.* (1976) has stimulated enthusiasm for studying other feedstuffs. In addition, increasing feed costs have also encouraged mineral nutrition and availability studies in general feedstuffs.

The objectives of this study were to evaluate the availability of minerals (calcium, phosphorus, magnesium, manganese, zinc and copper) from cereal grains (wheat, corn, barley and triticale) and inorganic mineral salts. Comparison was also made on variation in availability in different shipments of grains from commercial sources. The effect of different levels of feedstuff in the test mixture on availability was also studied.

It has been assumed in most cases that inorganic minerals are totally available to the animal when conducting the relative availability study of the feedstuffs. Very limited information is available to demonstrate the true availability of inorganic mineral sources to animals. Therefore, the final phase of this study was focused on the true availability of minerals from inorganic sources and the effect of inorganic mineral levels (Ca, P, Mg, Mn, Zn and Cu) on availability from various mineral salts.

LITERATURE REVIEW

I. *Methods and Techniques for Estimating Mineral Availability*

Methods commonly employed to study the availability or utilization of mineral for various species of animals, may be divided into three categories: (1) Chemical Balance Method; (2) Biological Assay Procedures; and (3) *In-vitro* Assay Procedures.

(1) *Chemical Balance Method*

(a) *Apparent digestibility*

According to Mitchell (1964), apparent digestibility is one of the most common methods used in determining availability. This method is simple, requires only a knowledge of the intake and total fecal excretion of the test minerals. However, this is an unsatisfactory method because it does not take metabolic fecal and endogenous urinary losses into account. As a consequence, there is a tendency to underestimate utilization of test minerals. Ammerman *et al.* (1957) employed the procedure to study the bio-availability of various inorganic phosphate sources for sheep. Rock and Campling (1962) pointed out that most information on utilization in ruminants is calculated on this basis. Calcium utilization is also commonly estimated by this method. It is obvious that the balance technique using only apparent digestibility results are not indicative of the availability of minerals to livestock. Modification of the method is needed to obtain the true digestibility or availability of mineral for animals.

(b) True digestibility

The availability of mineral estimated by true digestibility account for the metabolic fecal and endogenous mineral loss which is not of feed origin present in the fecal and urinary excretion. Although the estimate of availability for mineral by this method is far more accurate, the procedure employed to estimate the endogenous loss of fecal and urinary mineral is usually tedious and laborous. Nwokolo *et al.* (1976), recently developed a method to estimate endogenous mineral excretion in the chick. The procedure involves the use of purified mineral free diets which are formulated so as to exclude minerals being tested. The endogenous mineral excretion is determined with chicks fed the purified diet. The advantage of this procedure is the short period of time required for the whole experiment, so that the delicate mineral equilibrium of the animals is not disturbed substantially. As a result, a more realistic estimate of mineral availability is obtained.

(c) Carcass analysis technique

Fincke and Sherman (1935) were the first to determine calcium retention of the animal by carcass analysis. The technique involves the use of litter mates, some of which are slaughtered at the beginning of the experiment to determine the content of the test mineral. The other members of the litter are fed a controlled diet in which the test ingredient is the only source of the mineral under study. Amount of feed intake is recorded during the experimental period so that the total mineral intake can be calculated. The test animals are slaughtered when the experiment is terminated. The animals are ashed and mineral content is determined. The availability can be estimated from the mineral retained expressed as a fraction of mineral intake. The carcass analysis method apparently gives reasonable estimates on availability. Armstrong and Thomas (1952) observed no significant differences between calcium availability results obtained by other methods compared to the carcass analysis method. The limitation of the method is that it is laborious particularly when dealing with large animals. Homogenous carcass samples must be taken for the analysis.

(d) Radioisotope technique

Radioisotopes have been employed to estimate mineral availability for a number of years. Two techniques have commonly been used, isotope dilution technique and comparative balance technique with radioisotope. Isotope dilution technique involves a single injection intravenously (Hansard *et al.*, 1952; 1954), intramuscularly (Evans *et al.*, 1979), or multiple doses of radioisotope of the test element (Visek *et al.*, 1953). If there is no endogenous excretion of mineral, the specific activities of the isotopes in the feces and plasma should be identical at equilibrium. Therefore, the dilution of the total element in the feces by endogenous excretion can be measured by difference in the plasma and fecal specific activities.

The comparative balance technique involves pairs of animals. One animal is dosed orally while the other is injected intravenously with a radioisotope of the test element. It is assumed that the element from dietary sources becomes completely labelled by the orally administered radioisotope element. Endogenous excretion is estimated from an intravenously injected animal. This procedure was modified by Aubert *et al.* (1963) who proposed the use of two different isotopes with the same animal. This eliminates the use of paired animals. The main assumption in the comparative balance procedure is based on the dietary source becoming fully labelled by the oral dose of radioisotope. This assumption was questioned by several researchers (Tillman and Brethone, 1958; Field, 1961). The above assumption is eliminated when the dietary source is pre-labelled as carried out by Ammerman *et al.* (1963), in which the uniformity of labelling was confirmed.

Guenter and Sell (1974) have proposed a method to determine the "true" availability of mineral with a radioisotope. The procedure involves combining the comparative balance and isotope dilution technique for segregating the mineral in ingesta or feces according to dietary or endogenous origin.

Most recently, Evans and Johnson (1977) have established the use of the extrinsic label technique to determine zinc availability in food. These workers were able to demonstrate that endogenous zinc and exogenous ^{65}Zn enter a common pool prior to being absorbed from the intestine. Since extrinsic ^{65}Zn enters a common pool with intrinsic zinc, whole body absorption of extrinsic ^{65}Zn was used to obtain an accurate estimate of availability of zinc in food. The formula employed for the calculation is percent ^{65}Zn absorbed

$$= \frac{\text{cpm in carcass, blood, urine}}{\text{cpm in carcass, blood, gastrointestine tract x feces}} \times 100$$

(2) *Biological Assay Techniques*

(a) *Bone ash method*

The balance studies in general are more tedious and laborious. It has led many workers to consider methods which give at least a comparative measure of the degree of utilization of minerals in dietary sources. The most simple way to evaluate biological availability of mineral is to compare growth rate and bone ash content of chicks fed test material to those fed the standard inorganic source. Baruah *et al.* (1960) and Hijikuro *et al.* (1967) showed the relative response of chicks on the test material by an index taking the resonse of the chicks on the standard as 100.

Gillis *et al.* (1954) were the first to attempt the determination quantitatively of phosphorus availability by measuring bone ash content of test animals. The assay involved the establishment of a standard response curve using a semi-purified basal diet and graded levels of an inorganic phosphate source in which availability was assumed or known to be 100% at low dietary level. The test ingredient was substituted for a small fraction of the basal diet. A straight line curve was obtained by plotting the percentage of bone ash of solvent extracted left chick tibia against the logarithm of the percentage dietary mineral. Biological availability was defined as the ratio, expressed as a percentage of the amount of the inorganic salt to the amount of test ingredient which produced the same bone ash when each was added to the basal diet. Percentage bone ash is the most commonly used test for estimating mineral availability in feed. Nelson (1967) noted that bone ash content is one of the most sensitive, practical criteria for evaluating the availability of dietary phosphorus. It is more accurate than body weight (Nelson and Walker, 1964; Dilworth and Day, 1964), and is little affected by other dietary variables. Calcium and phosphate retention has frequently been assessed by measuring the incremental retention in a selected bone caused by a known amount of dietary element (Ammerman *et al.*, 1960). This technique, however, can only be used with young growing animals. Lengemann (1959) and Patrick and Bacon (1957) have used the ^{45}Ca content of rat tibia or femurs to assess utilization of dietary sources labelled by an oral dose of radioisotope.

(b) *Toe ash method*

Yoshida and Hoshii (1977) have developed a toe-ash method to estimate phosphorus availability for the growing chick. It was observed that there was a linear relationship between dietary phosphorus and toe ash content within the range of added phosphorus from 0 to 0.3%. The availability of phosphorus can therefore be determined by a slope ratio assay of the linear regression lines between added phosphorus and toe ash content.

A ten day feeding period is required for this assay. The authors indicated that the toe ash content method was more superior than tibia ash content method in measuring availability. The result obtained by toe ash content was in agreement with the carcass analysis method (Hoshii and Yoshida, 1978b).

(c) Body weight method

Long *et al.* (1956) used body weight as a criterion to assess phosphorus supplement for cattle by adding it to a low phosphorus diet. O'Dell *et al.* (1972) used body weight in estimating mineral availability to chick. The technique involves establishing standard curves by supplementing basal diets with graded levels of the test element of an inorganic form which is assumed to be 100% available. A linear response can be obtained by plotting weight or weight gain versus the logarithm of the supplement at lower levels of supplementation. The test ingredients are subsequently substituted for carbohydrate in the basal diet at low level. The quantity of biologically available mineral is estimated from the standard curve and divided by the content of test mineral in the ingredient. This method was, however, criticized by Nelson (1967), to be inaccurate in measuring available phosphorus and yielding misleading conclusions.

(d) *Other miscellaneous methods*

Other biological assay techniques are being employed in estimating mineral availability. Wilder *et al.* (1933) studied the availability of various forms of iodine (dried kelp, iodized linseed meal and potassium iodide) to the laying hen by observing their effects upon the iodine content of the egg. Mittler and Banhan (1954) used the enlargement of the thyroid gland as a criterion to study the nutritional availability of several iodide compounds to albino rat. Very extensive studies have been made on the blood as a measure of mineral availability, particularly of iron and magnesium.

Thompson and Raven (1959) measured the utilization of iron from a number of herbage species by means of relative rates of haemoglobin regeneration in rats rendered anaemic by prior feeding on an iron deficient diet. The haemoglobin repletion method was also employed by Pla and Fritz (1971) studying availability of supplemental iron from several sources to chicks and rats. The results have been satisfactory and the method was proposed to be adopted by A.O.A.C.

(3) *In Vitro Assay Procedure*

Anderson *et al.* (1956) have devised a rapid *in vitro* method of evaluating phosphorus supplements for ruminants by measuring the decomposition of cellulose in an artifical rumen when the supplement was the sole source of phosphate for the microorganism. Values obtained were in reasonable agreement with those found by animal experiment.

II. *Availability of Mineral in Feed Ingredients from Vegetable Sources*

Relatively little information has been developed on the biological availability of minerals from different plant sources for livestock, especially for non-ruminant. Most of the work on mineral studies has been devoted to calcium and phosphorus, particularly phytate phosphate. A significant portion of the total phosphate of plant origin is present in this form.

Armstrong and Thomas (1952) reported that calcium availability of lucerne, red clover and wild white clover were 84.89, 83.11 and 79.95%, respectively for rats. In the following year the availability of calcium in three herbs of grassland (burnet, chicory and narrow leaved plantain) were estimated to be 80.38, 87.73 and 95.28%, respectively (Armstrong *et al.*, 1953). Another report by Armstrong *et al.* (1957) showed that the calcium availability of three grasses, timothy, perennial rye grasses and cocksfoot were 78.99, 76.53 and 69.02%, respectively. The availability of calcium in amaranthus, sesbania grandiflora and moringa oleifera were estimated by Devadatta and Appana (1954), to be 74-78, 85 and 69%, respectively. As early as 1939, Common reported that the phosphorus in plants passed through the hen unhydrolyzed. Gillis *et al.* (1953) later observed that phosphorus from isolated calcium phytate was less than 50% as biologically available as that from dicalcium or deflourinated phosphate and 10% phosphorus availability was reported from phytate phosphate. Ashton *et al.* (1960) showed that approximately 20% of the phytate phosphorus was retained by four-week old chicks while six-week old chicks retained 36 to 49% of phytate phosphorus. However, Temperton and Cassidy (1964) observed that chicks utilized approximately 60.7% non-phytate phosphorus. Salman and McGinnis (1968), using laying hens, reported that phosphorus utilization in rations containing 0.3% plant phosphorus was insignificantly different from its utilization in ration containing either 0.6% plant phosphorus or 0.3% plant phosphorus plus 0.3% inorganic phosphorus.

Nwokolo *et al.* (1976) observed that the availability of phosphorus from soybean meal, rapeseed meal, cottonseed and palm kernel meal to four-week old chicks was 89.3, 74.8, 76.9 and 70.8%, respectively. Availability of the mineral was estimated by the percentage of the mineral retained in the chick using a correction for endogenous fecal mineral excreted. Most recently Hoshii and Yoshida (1978a), using toe ash content technique reported that phosphorus in wheat, wheat bran and barley has availability higher than 60%. A significant strain difference in phosphorus availability was observed between two strains of wheat. The authors also observed that the phosphorus in feed ingredients of animal origin (e.g. fish meals and meat and bone meals) was highly available while availability of phosphorus in plant sources (e.g. plant oil cake, yellow corn and milo) was very low.

Woodman and Evans (1948) showed that 30 to 40% of the phosphorus in barley-wheat bran with no added inorganic source was absorbed by pigs raised from 50 to 90 kg of weight. Besecker *et al.* (1967) obtained an apparent phosphorus digestibility value in barley of 17.7% when it was fed to 45 kg pigs in a diet containing a 0.3% total phosphorus. Tonroy *et al.* (1973) reported apparent phosphorus digestibility values of 4.5 and 63.7% for sorghum grain and dicalcium phosphate, respectively. Bayley and Thomson (1969) stated that 27 kg pigs were able to absorb 19% of the phosphorus contained in a corn-soybean meal diet containing 0.9% Ca and 0.35% total phosphorus when fed in meal form, whereas 3% phosphate absorbability value was reported by Bayley *et al.* (1975) for a corn-soybean meal diet to 25 kg pigs. Most recently, Miracle *et al.* (1977) observed that the phosphorus availability in corn, wheat and soybean for pigs is 16, 51 and 18%, respectively. Pierce *et al.* (1977) also showed that the apparent digestibility of phosphorus in wheat was no better than in corn and that the phytate from calcium phytate was essentially unavailable for growing pigs (11-45 kg).

The literature indicates that there are tremendous differences regarding phosphorus availability from various sources. The differences may be due to the source of materials tested, methods used, species and age differences. The National Research Council (NRC, 1969) suggested that approximately 20 to 50% of phosphorus in plant materials may be utilized by non-ruminants.

Peer (1972) in a review of the literature indicated that the availability of magnesium in forages ranges from 10 to 25% with a mean of approximately 20%. Availability from grains and concentrations ranges from 30 to 40% for ruminants.

Very limited information on magnesium, zinc, manganese and copper availability has been published for poultry. Guenter and Sell (1974), using intramuscular injection of radioactive Mg-28, reported that the availability of magnesium for wheat, corn, barley, oat, rice and soybean meal was 48.1, 47.5, 54.2, 82.9, 42.2 and 60.4%, respectively, for the mature male chicken. Recently Nwokolo *et al.* (1976) reported that availability of magnesium in soybean, rapeseed, cottonseed and palm kernel meal was 77.4, 61.1, 74.6 and 56.4%, respectively.

O'Dell *et al.* (1972) using growth response of chicks observed that the availability of zinc in sesame meal, soybean meal and fish meal was 57, 67 and 75%, respectively. Zinc availability of raw corn endosperm flour was reported to be 51% for rats (Evans and Johnson, 1977). Nwokolo *et al.* (1976) evaluated availability of several minerals in plant protein sources and reported that zinc availability in soybean, rapeseed, cottonseed and palm kernel meals were 66.5, 44.0, 38.0 and 13.5%, respectively. The manganese availability was 76.1, 56.7, 76.3 and 45.7%, respectively. The copper availability was 51.0, 62.2, 42.3 and 44.7%, respectively for four-week old broiler chicks.

III. *Availability of Minerals in Inorganic Sources for Livestock*

Minerals of plant origin are not adequate to meet the mineral requirement for livestock production. Therefore, practical feed formulation utilizes inorganic mineral supplements to obtain the optimum dietary concentration. Hence the bioavailability of inorganic minerals have been of interest to many research workers.

(1) Calcium

Relatively little information has been developed on comparative biological availability of calcium from different feed sources for animals. There is considerably more research on the comparative value of calcium source reported for poultry than for other species. According to the results of some studies on various calcium sources including calcium carbonate, calcium sulfate, oyster shell, limestone, various calcium phosphates, calcium gluconate and fish meal (Bethke *et al.*, 1929; Deobald *et al.*, 1936; Waldroup *et al.*, 1964; Sandorf and Mullar, 1965; Hurwitz and Rand, 1965), there are no differences in biological availability among different calcium sources using bone ash and weight gain in chicks as the criteria of response. In contrast to these reports, however, a number of researchers have reported differences in biological availability between various calcium carriers for young chicks. Motzok *et al.* (1965) observed that the calcium in soft phosphate was 70% as available as that in calcium carbonate (100%) and dicalcium phosphate (100%). In these studies, the effectiveness of calcium was found to be sensitive to the Ca:P ratio. Hurwitz and Rand (1965) reported that the calcium in gypsum was 90% as available as limestone when feed intake was equilized. Calcium availability of several feed grade calcium phosphates has been measured using bone ash as the criterion of response. Dilworth *et al.* (1964) observed that the relative calcium availability in the sources ranged from 68 to 95% as compared to calcium carbonate. Blair *et al.* (1965) reported significant differences in the availability of calcium carbonate and various phosphate salts. The calcium in dolomitic limestone was from 64 to 68% as available as that in pure calcium carbonate in which average availability was 66% (Stillmak and Sunde, 1971). A recent study by Reid and Weber (1976) on calcium availability of five ground limestone samples with laying hens showed that the ground limestone samples varied from 82.4 to 98.4% calcium availability when apparent calcium retention and egg shell thickness were employed as the test criteria. In other reports, differences in calcium availability were observed when hydrated and anhydrous dicalcium phosphate were compared (Rucker *et al.*, 1968).

Buckner *et al.* (1929) showed that calcium carbonate was superior to a number of calcium salts for egg production as judged by eggs shell weight. Balloun and Marion (1962) demonstrated the differences in relative efficiency of calcium lactate and calcium carbonate in the production of egg shell. However, most laboratories have been unable to demonstrate significant differences in the bioavailability of a number of calcium sources using egg production, egg shell quality and bone ash values as criteria (Hurwitz and Rand, 1965; Heywang and Lowe, 1962).

(2) Phosphate

A large number of studies have been conducted to determine the relative biological value of the various inorganic phosphate sources for the chick. Gillis *et al.* (1954), were the first to quantitate the availability in various phosphate compounds for the chick. Assuming beta-tricalcium phosphate to be 100% available, the relative values for monocalcium phosphate, dicalcium phosphate, defluorinated phosphate and low fluorinated phosphate were 113, 98, 98 and 87%, respectively. Similar results were obtained by Nelson and Walker (1964), but with a lower value in low fluoride rock (68%). Peeler (1972) made the comparison of bioavailability of various phosphorus sources noting that the results obtained from different laboratories (Gillis *et al.*, 1954; Nelson and Peeler, 1961; Nelson and Walker, 1964; Dilworth and Day, 1964), were apparently in good agreement. Numerous studies have demonstrated that the level of calcium in the diet has a considerable influence on the response of chicks to certain phosphate sources.

A series of studies on the comparative availability of inorganic phosphate for laying hen was reported by Singsen *et al.* (1969a). On the basis of all performance characteristics observed, the soft phosphate availability has a slightly higher availability value than low fluorine rock phosphate and essentially equal availability to defluorinated and dicalcium phosphate. A further experiment by Singsen *et al.* (1969b) indicated that the biological availability of low fluorine rock phosphate was 25% for the laying hen.

In studies with inorganic sources, Wilcox and Associates (1954, 1955) found wide differences in the availability of young turkeys to utilize various phosphates. Availability values ranged from low to very high, based on growth rate and bone ash observations.

Gillis *et al.* (1962) and Scott *et al.* (1962) reported that for the turkey poult the primary calcium phosphate salt is most biologically available followed by the secondary salt with the tertiary salt or tricalcium phosphate having the least biological availability of the three. Therefore it is noted that hydrated dicalcium phosphate ($CaHPO_4 \cdot H_2O$) is an excellent source of phosphate, whereas the anhydrous form of dicalcium phosphate ($CaHPO_4$) is very poorly utilized by turkey (Gillis *et al.*, 1962; Scott *et al.*, 1962; Rucker *et al.*, 1968). Sullivan (1966) reported that relative availability of dicalcium phosphate, defluorinated phosphate and low fluorinated rock phosphate for the turkey was 98.4, 82.6 and 91.2%, respectively in which monocalcium phosphate was assumed to be 100% availability.

(3) Magnesium

Ammerman and Associates (1972) compared the availability of several magnesium salts for sheep and reported that biological availability values for $MgCO_3$, MgO and $MgSO_4$ were 43.77, 50.87 and 57.63%, respectively. When reagent grade magnesium oxide was assigned a value of 100, the relative value of $MgSO_4$ was 113% and reagent grade $MgCO_3$ was 86%. Cook (1973) used balance studies to evaluate various inorganic magnesium salts and reported that magnesium carbonate was the most available form. Magnesium chloride was as available as carbonate form. The oxide, phosphate, sulfate and silicate salts were slightly lower compared to magnesium carbonate.

Limited information has been reported for availability of inorganic magnesium source to poultry. Guenter and Sell (1974) using radioisotope technique showed that the availability of magnesium from $MgSO_4 \cdot 7H_2O$ was 57.4%.

(4) *Manganese, Zinc and Copper*

Little work has been conducted on the bioavailability of inorganic sources of manganese, zinc and copper. Most of the data reported were qualitative rather than quantitative. Schaible and Bandemer (1942) reported that manganese oxide, manganese carbonate, manganese sulfate, manganese chloride (with widely varying solubility) are equally valuable as sources of manganese in poultry rations and presumable, therefore, are equally well absorbed. However, Henning *et al.* (1967) observed that radioactivity as $^{54}MnCl_2$ was incorporated into the body of chicks to a greater extent than that supplied as $^{54}MnSO_4$ or $^{54}MnO_2$. Recent research indicated that differences in the availability of manganese from different sources exist (Watson *et al.*, 1970). Using biological assay, Watson *et al.* (1971) showed that the availability was different between the carbonate and oxide forms of manganese. However, no quantitative data were reported.

Edwards (1959) observed that zinc in the forms of zinc sulfate, willemite, zinc carbonate, zinc metal, zinc oxide (technical grade) and zinc oxide (A.R. grade) is relatively available to the young growing chicken whereas, zinc in sphalerite (mostly zinc sulfide) and in franklinite (oxides of Zn, Fe and Mn) is laregly unavailable. Kratzer and Vohra (1966) also showed that zinc is less available from zinc orthophosphate, zinc tripolyphosphate, zinc hexametaphosphate, zinc pyrophosphate and zinc phytate than from oxide.

Anemic rats were shown to be unable to use the copper of copper sulfide or copper porphyrin, whereas the oxide, hydroxide and pyrophosphate were readily utilized (Schultze *et al.*, 1936). Pigs also absorb the copper of cupric sulfide much less efficiently than that of cupric sulfate (Bowland *et al.*, 1961).

IV. Factors Affecting Mineral Availability

Several factors influence the bioavailability of mineral elements. One of the most significant factors is the phytic acid (inositol hexaphosphoric acid) which chelates mineral elements reducing the availability to the animals (Nelson *et al.*, 1968; Davies and Nightingale, 1975). These workers suggest that phytate probably chelates part of all the cation required by animals. Phytate has also been shown to form stable complexes *in vitro* with Cu, Zn, Co, Mn, Fe and Ca (Oberleas, 1973). Some other recognized factors affecting mineral availability are crude fibre, oxalate, ethylenediaminetetraacetate (EDTA), protein and amino acids, vitamins, antibiotics and interaction between mineral elements.

(1) Phytic Acid

An earlier report by Bruce and Callow (1934) suggested that phytic acid would render calcium unavailable for absorption by the formation of insoluble calcium phytate. They also showed that phosphorus from cereal sources was less effective than inorganic phytate phosphorus in healing rickets and suggested that phosphorus as phytate was poorly absorbed from the intestinal tract.

The poor utilization of phytate phosphorus by various poultry species has been reported by many researchers (e.g. Lower *et al.*, 1939; Gillis *et al.*, 1957) and in a review of Nelson (1967). In contrast to this, the addition of phytate as bran (Roberts and Yudkin, 1961) or as a mixture of pentacalcium phytate and sodium phytate (Hoff-Jorgensen, 1946) was reported to increase availability of phosphorus on cereal-based diets. It is apparent that observed values for the ability of chickens to utilize phytate phosphorus may be different due to criteria and material used in the assay. Methods to improve phosphorus availability have been indicated by several workers (Anderson, 1915; Singsen, 1948; Summer *et al.*, 1967). Phytic acid also reduces availability of iron (McCance *et al.*, 1943; Davies and Nightingale, 1975), magnesium (Roberts and Yudkin, 1961; Likuski and Forbes, 1965), zinc (O'Dell and Savage, 1960; Oberleas *et al.*, 1960, Davies and Nightingale, 1975; Davies and Reid, 1979), manganese and copper (Davies and Nightingale, 1975). Byrd and Matrone (1965) and Oberleas *et al.* (1966) have suggested that the interference in zinc absorption by phytic acid was due to zinc combining with phytate and calcium to form an insoluble Zn-Ca-phytate complex. This was confirmed by Oberleas (1973), Davies and Nightingale (1975) and Davies and Reid (1979). Nwokolo and Bragg (1977) reported that phytic acid content of soybean, rapeseed, cotton seed and palm kernel meals significantly affected availability of phosphorus, calcium, zinc and magnesium but not manganese and copper. It is evident that phytic acid is a factor influencing the availability of minerals.

(2) *Fiber*

Armstrong *et al.* (1953), in the study on the availability of calcium in three herbs of grassland, reported an inverse relationship between calcium availability and crude fiber content. Smith (1961) demonstrated that net absorption of calcium and magnesium decreased in milk fed calves ingesting a high level of fiber as wood shavings. Reinhold (1975) reported that crude fiber caused the decreased availability of zinc for intestinal absorption. Nwokolo and Bragg (1977) reported that crude fiber content of soybean, rapeseed, cottonseed and palm kernel meals significantly depressed availability of calcium, phosphorus, magnesium, manganese, zinc and copper in growing chicks. Reinhold *et al.* (1975, 1976) also observed that fiber was a determinant of availability of calcium, zinc and iron in breadstuff for man. Eastwood (1973) suggested that vegetable fibre consists of a heterogeneous complex of polysaccharides and lignin capable of sequestering water, cation or anion depending on the chemistry of the constituent macromolecules. Oberleas and Hardland (1977) indicated that fiber may affect mineral availability by any or all of the following mechanisms: acting as a cation exchanger, diluting the intestinal contents, altering transit time or changing the oxidation-reduction potential of the gastrointestinal tract. McConnell *et al.* (1974) suggested that the -COOH groups of fiber polysaccharides are responsible for the apparent cation exchange capacity. However, -OH,-PO$(OH)_2$ and -SO_3 are also able to reversably exchange organic radicals for cations in the surrounding environment (Oberleas and Hardland, 1977). It appears that fiber is implicated as a causative agent in reduction of mineral bioavailability.

(3) *Oxalic Acid*

High concentration of oxalic acid in food can impair the availability of minerals by forming a poorly absorbable mineral oxalate (Mitchell, 1939; 1942). Skorkowska-Zieleniewska *et al.* (1974) showed that diets containing oxalic acid reduced calcium, magnesium and iron absorption. Similar results were observed for calcium (Murillo *et al.* (1973) and phosphorus (Compere, 1966). However, Brune and Bredehorn (1962) demonstrated that pigs apparently utilized calcium oxalate as effectively as other calcium sources. Patel *et al.* (1967) reported that most concentrates and vegetable leaves had practically no oxalates. Fasett (1966) who critically evaluated the literature pertaining to possible oxalate interference with calcium metabolism concluded that there was very little danger associated with ingesting oxalate containing plants.

(4) *Ethylene-Diamine-Tetraaccate (EDTA)*

The role of mineral ion chelation has been discussed by Scott *et al.* (1969). They point out that organic chelates may be the most important factor governing the absorption of mineral elements, e.g. ascorbic acid and amino acids. There are some chelates which can decrease the availability of one or more mineral elements and simultaneously improve the availability of other minerals. Kratzer *et al.* (1959) observed that the availability of zinc for chicks on a purified diet containing soybean protein was greatly enhanced by the addition of EDTA. Similar results were reported on chicks fed purified diets and EDTA by other workers (Davis *et al.*, 1962; Likuskin and Forbes, 1964; O'Dell *et al.*, 1964). Kratzer and Starcher (1963) indicated that EDTA not only improved the availability of zinc already present in the diet but also made added zinc more effective for use by poults. Similar evidence was reported in rats (Oberleas *et al.*, 1966). EDTA improved utilizaton of manganese and copper in chickens receiving a diet containing isolated soybean protein (Scott *et al.*, 1969). EDTA decreased iron availability to rats (Larsen *et al.*, 1960) and chicks (Fritz *et al.*, 1971). A study was reported by Suso and Edwards (1960) concerning the influence of various chelating agents on absorption of ^{60}Co, ^{59}Fe, ^{54}Mn and ^{65}Zn in the chicken. Results showed a significant increase in ^{65}Zn absorption but a non-significant increase in ^{54}Mn absorption with increasing levels of EDTA. Dietary of EDTA decreased absorption of ^{59}Fe and ^{60}Co (Fritz *et al.*, 1971) for chicks. These results demonstrated that EDTA bound iron and manganese very tightly making these elements less available for utilization. The free acid form of EDTA was more detrimental than was calcium disodium EDTA or disodium EDTA. Addition at critical levels of any form of EDTA to the diet reduced the hemoglobin levels in the chicks indicating the EDTA interference with iron utilizaton. Also the incidence of perosis increased indicating that EDTA interfered with manganese utilization.

(5) Protein and Amino Acids

Various protein sources have been reported to interfere with the availability of minerals in the diets. These include peas (Kienholz *et al.*, 1959; Kienholz *et al.*, 1962) isolated soybean protein (O'Dell and Savage, 1960), sesame meal (Lease *et al.*, 1960), safflower, cottonseed, soybean meals (Lease and Williams, 1976a,b), free amino acid and casein diets (Likuski and Fores, 1964). Isolated soybean protein reduced the availability of molybdenum (Reid *et al.*, 1956), zinc (O'Dell and Savage, 1960) and manganese and copper (Davis *et al.*, 1962). Copper can form insoluble complexes with protein which are unavailable for absorption (Underwood, 1977). The same mechanism would likely apply to other minerals listed above.

Wasserman *et al.* (1956) reported that several amino acids promoted calcium absorption and that lysine and arginine were the most effective. Amino acids, especially cysteine and histidine, are also effective metal binding agents. Van Campen and Gross (1969) reported that histidine increased ^{59}Fe uptake from isolated segments of rat duodenum. Van Campen (1973) also observed enhancement of iron absorption from a ligated segment of rats intestine by histidine, cystine and lysine. Cysteine and histidine were shown to have a beneficial effect on the zinc deficiency syndrome (Nielsen *et al.*, 1966a; 1966b). Zinc deficient chicks fed isolated soybean protein and a supplement of 1.0 and 2.0% histidine showed alleviation of leg disorders (Nielsen, 1966a). A supplement of 0.5% cysteine alleviated all signs of zinc deficiency (Nielsen *et al.*, 1966a). It was noted that supplementation of cysteine improved the body weight gain, feathering and tibia zinc concentration, possibly due to improved zinc availability in the diet. However, supplementation of histidine did not give the same response. Coleman *et al.* (1969) showed that a supplementation of 2.0% arginine hydrochloride in a zinc deficient diet of chicks aggravated both the leg abnormality and feather defects and tended to depress growth. It seems, therefore, that cysteine, histidine and arginine are possible antagonists of zinc in some aspects of the chick metabolism. Miski and Kratzer (1977) observed that protein deficiency lowers the efficiency of iron utilization while glycine and tryptophan supplementation enhance iron absorption.

(6) *Lactose*

Lactose has been reported to promote calcium absorption by many workers (Wasserman *et al.*, 1956; Langemann *et al.*, 1959). Wasserman and Comar (1959) stated that some other carbohydrates having an action similar to that of lactose, stayed for some time in the intestinal lumen (cellobiose, sorbose, ribose and xylose), but that carbohydrates that were rapidly absorbed had little or no effect. Bile acids were reported to increase calcium absorption by improving the solubility of calcium in lipid solvents (Webling and Holdsworth, 1966).

(7) Vitamins

Vitamin D has been reported by a number of investigators to influence the absorption of various cations. Sobel and Burger (1955) reported that Vitamin D increased the levels of lead in blood while Greenberg (1945) showed an increase in strontium absorption due to vitamin D administration. Meintzer and Steenbock (1955) reported that diets low in vitamin D fed to rats depressed magnesium absorption. Workers and Migicovsky (1961a,b) observed that vitamin D increased absorption of calcium, strontium, beryllium, magnesium, barium, zinc and cadmium. Cobalt and cesium were also observed to be in the list but not sodium, potassium, copper, iron and zinc (Wasserman, 1962). Vitamin D has also been demonstrated to enhance absorption of iron and cobalt (Musahara and Migicovsky, 1963) and zinc (Kienholz *et al.*, 1964). The relationship between vitamin D and calcium absorption has been studied most extensively in the last two decades. Present evidence suggests that intestinal calcium binding protein (CaBP) is controlled by the concentration of 1,25-dihydroxycholecalciferol (vitamin D derivative) in the cells of this organ (Edelstein *et al.*, 1975). The synthesis is mediated by a specific mRNA resulting from events following the binding of 1,25-dihydroxycholecalciferol to a chromatin receptor (Emtage *et al.*, 1974). The vitamin D, therefore, enhances the production of CaBP in the intestine such that the absorption of calcium is increased.

Large amounts of vitamin C (ascorbic acid) will depress the intestinal absorption of copper apparently by formation of mercaptides with metallothionein (Evans *et al.*, 1973). High dietary ascorbic acid has been demonstrated in increasing the severity of copper deficiency in chicks (Hill and Starcher, 1965) and rabbits (Hunt and Carlton, 1965).

(8) Antibiotics

Antibiotics have been reported to improve the mineral availability in swine rations (Kirchgessner *et al.*, 1961; Kirchgessner, 1965). In balance experiments using pigs and poultry, the daily retention of cobalt and zinc was more than doubled and copper retention tripled as the diet was supplemented with antibiotics. Increments of manganese and iron retention in animals receiving antibiotics have also been reported. In addition, Kirchgessner *et al.* (1961) using balance methods, observed that retention of phosphorus, magnesium, manganese, copper, iron, cobalt and silicon was increased by antiobiotics in the young but not in mature pigs.

(9) Species Difference

Species difference in the utilization of trace minerals were also recognized. Hay fiber is not a good source of iron for chick diets even though such hay contains 100 to 200 ppm of iron (NRC, 1969). Most of the nutrients that are present would not become available to non-ruminant animals because they do not digest such materials effectively. In animal studies, little difference was observed in the response of chicks and rats when ascorbic acid was added to the test diet with known addition of iron (Fritz *et al.*, 1970; Fritz and Pla, 1972). However, ascorbic acid increases the iron absorption in man (Pla and Fritz, 1972). Elwood (1965) also reported that ferric and ferrous salts were equally available to the rats but not man.

(10) Mineral Interaction

Early observations on mineral interrelationships indicates that low calcium rations disturb phosphorus balance. Later investigators revealed fundamental interdependencies between calcium and manganese, zinc and calcium, phosphorus and magnesium, cadmium and zinc (Hill *et al.*, 1963; Forbes, 1963), iron and manganese (Thomson, *et al.*, 1971). The influence of availability of minerals to a considerable degree is related to competition for binding sites in or on mucosal cells and for carrier molecules.

High calcium and high inorganic phosphorus aggravate zinc deficiency in rats (Cabell and Earle, 1965). Conversely, low calcium intakes can alleviate the effects of zinc deficiency. Less copper was absorbed by mice from a high calcium than from a low calcium diet due to an increase in intestinal pH (Tompsett, 1940) and diets high in calcium enhance copper toxicity in pigs, persumably due to a lowering of zinc availability (Suttle and Mills, 1966). Nugara and Edwards (1962) noted that high dietary phosphorus reduced magnesium retention at the absorption site in chicks. It was also shown by O'Dell *et al.* (1960) using guinea pigs in balance studies that a high dietary phosphorus level decreased magnesium absorption. Forbes (1963) observed that calcium and phosphorus depressed magnesium absorption and high calcium levels drastically affected phosphorus absorption irrespective of magnesium levels in the diet. The biological antagonism between copper and zinc was demonstrated by Smith and Larson (1946). Van Reen (1953) observed that copper supplementation alleviated the effects of zinc toxicity while the reverse reaction was reported by Ritchie *et al.* (1963). Van Campen (1969) showed that copper-induced depression in ^{65}Zn absorption was mediated at the intestinal level, possibly due to direct competition between zinc and copper for a common carrier. Kirchgessner and Grassmann (1969) reported that high levels of copper sulfate supplementation in pig rations produced higher retention of iron, zinc, manganese and cobalt.

High dietary levels of cadmium depress copper uptake and even a relatively small increase in cadmium intake can adversely affect copper metabolism when copper intakes are marginal (Underwood, 1977). Molybdenum and sulfate can either increase or decrease the copper status of an animal, depending on their intake relative to that of copper (Underwood, 1977). Huisingh *et al.* (1973) proposed that copper can interact with molybdenum to form a biological unavailable Cu-Mo-complex (cupric molybdate). Suttle (1975) proposed the three way Cu-Mo-S interaction thereby eliminating the utilization of dietary copper to animal.

Lassiter *et al.* (1969) reported that increased dietary calcium enhanced manganese absorption in rats. Conversely, increased manganese in the diet enhanced calcium absorption (Alcock and MacIntyre, 1960). Manganese availability is affected by high dietary levels of calcium and is believed to be due to a reduction in soluble manganese through absorption by solid mineral (Schaible and Bandemer, 1942). Thomason *et al.* (1971) observed that manganese competes with iron and cobalt for common binding sites when transporting these minerals from the lumen to mucosal cells then to other parts of the body. This showed that the addition of iron competitively inhibited manganese absorption in iron deficient rats. Conversely, high manganese intakes reduced iron absorption.

(11) Feed Processing

Processing may affect both the total quantity of the mineral element and its bio-availability. Grinding is likely to make any feed ingredient more digestible and thereby increase the nutritional value of essential nutrients. When whole grains are compared with ground grains, the total digestible nutrient content is higher in the ground material (Titus and Fritz, 1971), but the effect on specific minerals is not known. Grinding may also add elements to the feed. Ammerman *et al.* (1970) showed that grinding citrus pulp in a Wiley mill significantly increased the quantities of iron, copper, manganese and sodium.

Processing may affect bio-availability as well as the total quantity of iron. Theuer *et al.* (1971) reported that iron added to liquid infant formulas in the form of poorly utilized salts became much more available after routine processing. Singsen (1948) demonstrated that autoclaving wheat bran made more of its phosphorus available to the growing chicken for bone development. Marked increase in the inorganic phosphorus content by autoclaving was observed with isolated soybean meal (O'Dell, 1962), sesame meal (Lease, 1966). Summers *et al.* (1967) showed that a significant proportion of the phytin phosphorus of wheat bran can be made available to the chick for growth by steam pelleting. However, pelleting and crumbling the pellets do not affect the trace minerals contribution of the feed. Crumbled pellets had about the same mineral content and iron bio-availability as did the mash from which they were made (Fritz, 1973).

(12) Endocrine Influence

Hormones were reported to affect mineral availability (Hanna and MacIntyre, 1960). Administration of aldosterone to both normal and adrenalectomized rats resulted in decreases in the apparent availability of the dietary magnesium. These results were confirmed by Care and Rose (1963) in the intact sheep using deoxy-corticosterone acetate instead of aldosterone.

(13) Miscellaneous Factors

There are miscellaneous factors linked to mineral availability. Kienholz (1962) reported a factor (not phytate) in peas which interfered with availability of zinc for chick growth. Autoclaving the peas appeared to improve the situation. It was postulated that a heat labile protein likely interfered with zinc availability. It has also been reported by Davis *et al.* (1962) that a component which can bind zinc, manganese and copper in isolated soybean protein causes chicks to develop the respective deficiency symptom because of unavailability of this mineral. However, addition of EDTA can improve the situation, i.e. reduce the requirement of mineral supplementation.

MATERIALS AND METHODS

Eleven wheat, ten corn and one soybean meal samples were collected from a local commercial feed company between January and August, 1977. In addition, three barley samples were obtained from three different sources, a local feed company, a Chilliwack producer (B.C.) and Alaska. A triticale sample was obtained from Regina, Saskatcehwan. Wheat, corn and soybean samples were collected randomly from different shipments of grains to the Poultry Nutrition Unit at the University of British Columbia. All feed grains arrived in ground form except the barley and triticale samples. All feed grains were re-ground with a Wiley Mill equipped with a one mm screen in the Poultry Science Laboratory before being utilized in the experiment.

Proximate analysis was carried out for all feed samples for dry matter, crude protein (N x 6.25), ether extract and ash content with standardized methods described in A.O.A.C. (1965). The crude fiber (acid detergent fiber) content of the feed ingredient was analysed by the method developed by Wäldern (1971). The mineral content of the grains was determined by a dry ashing method followed by atomic absorption procedure (Heckman, 1967) except phosphorus where determinations were by spectrophotometer (Ministry of Agriculture, Fisheries and Food, U.K., 1973).

All analytical results were expressed on a dry matter basis. Mineral (calcium, phosphorus, magnesium, manganese, zinc and copper) availability studies were conducted on ingredients using three week old growing broiler chicks. In addition, the availability of inorganic mineral calcium, phosphorus, magnesium, manganese, zinc and copper from various sources were studied in the series of experimental trials. The broiler chicks utilized in these experimental trials were purchased at one-day of age from a hatchery in the Fraser Valley area of B.C. The chicks were raised in stainless steel thermostatic control brooder cages to three weeks of age before commencing the experiments. Broiler chicks were fed a 20% crude protein commercial started diet from day of age to three weeks. Feed and water were supplied *ad libitum.*

A completely randomized block design was employed in all availability trials. Chicks were weighed at three weeks of age and distributed to stainless steel metabolism cages. The same starter diet was offered during the acclimatization period and water was fed free of choice. Test diets were offered at about 25 days of age. The detailed procedure will be discussed later. Test diet consumption was recorded for each cage and fecal collection was carried out at the end of each testing period.

Data obtained were subjected to analysis of variance (Snedecor, 1956) and a statistical comparison of means was by the multiple range test (Tukey, 1963).

Trial 1: Mineral Availability from Wheat and Triticale

The trial was conducted to estimate availability of calcium, phosphorus, magnesium, manganese, zinc and copper from eleven wheat samples and one triticale sample. Two hundred and eighty uniform size three week old birds were employed. All birds were weighed and transferred randomly to the stainless steel metabolism cages with four birds per cage. The test birds remained on starter diet until twenty-four days of age to acclimatize to the new environment. On the twenty-fourth day, all birds were supplied with a starter diet containing 0.3% ferric oxide marker for four hours, then fasted for sixteen hours. Following the fast period birds were fed a synthetic diet (Table 1) for four hours. Birds were then fasted for another hour before returning to the marker diet.

Feces derived from the synthetic diet were collected (i.e. the feces obtained from the end of first batch of marked excreta and the reappearing of the marked excreta). On the twenty-fifth day, the same procedure was repeated except the wheat and triticale samples replaced the synthetic diet. There were four replicates for each tested ingredient.

Feed including synthetic, test diets and water were offered *ad libitum* during testing period. Limited water was given during the sixteen hours fasting period. Feed consumption of both synthetic diet and test diets were recorded at the end of each period. Total marker-free feces were collected from each individual cage. The feces from each cage was oven dried after collection at 85^{o}C for 48 hours. The dry feces were weighed and ground into the fine powder form with the microgrinder (Kurzzertbetrieb) and collected for later mineral analysis.

TABLE 1: Composition of Synthetic Diet used throughout the Experimental Trials

Ingredient	Percent
Starch	40.6
Sucrose	40.6
Alpha-cellulose	13.8
Corn oil	5.0
	100.0

The mineral content of wheat, triticale samples and feces from both synthetic and diets were determined by an atomic absorption spectrophotometer following a low temperature dry ashing at 450^{o}C in the muffle furnace for 36 hours. The phosphorus as well as other minerals can therefore be determined from the ash sample. The analytical method was described in "The Analysis of Agricultural Materials" (Ministry of Agriculture, Fisheries and Food, U.K., 1973). Calcium, magnesium, manganese, zinc and copper were determined by a Jarrel Ash atomic absorption spectrophotometry. Lathanium oxide (0.5% v/w) was required in the test solution to reduce the interference from phosphorus when calcium and magensium was analyzed. Phosphorus was determined by a Unican SP1800 Ultraviolet Spectrophotometer following color development with ammonium molybdate.

The proximate analysis of wheat and triticale samples is shown in Table 2. Content of minerals in samples determined and expressed on a dry matter basis are shown in Table 3.

The formula used to calculate the percentage availability of minerals after analysis of ingredients and excreta was developed by Nwokolo *et al.* (1976) as follows:

$$\text{Percent mineral availability} = \frac{\text{TMI} - (\text{TFME} - \text{EFME})}{\text{TMI}} \times 100$$

where TMI Total mineral intake from feed ingredient

TFME Total fecal mineral excreted

EFME Endogenous fecal mineral excreted

TABLE 2: Chemical Analysis of the Eleven Wheat and One Triticale Samples (dry matter basis)

Sample	Dry matter	Crude protein	Ether extract	Crude fiber[1]	Ash
			%		
Wheat #1	87.9	13.1	2.1	4.2	2.1
Wheat #2	92.2	14.3	2.4	4.6	2.0
Wheat #3	86.4	15.1	2.3	4.0	2.0
Wheat #4	89.7	15.6	1.9	4.0	1.9
Wheat #5	90.0	15.3	2.1	3.4	2.1
Wheat #6	90.0	15.7	2.1	2.3	1.5
Wheat #7	88.1	14.7	2.1	2.9	1.5
Wheat #8	89.7	16.7	2.1	2.8	1.6
Wheat #9	90.0	16.2	2.0	2.6	1.7
Wheat #10	89.6	16.7	2.1	2.7	1.9
Wheat #11	88.9	17.7	1.6	3.7	1.6
Triticale	92.7	12.7	1.6	3.7	1.6
Average	89.6	15.3	2.0	3.4	1.8

[1]Acid detergent fiber

TABLE 3: Mineral Content of Eleven Wheat and a Triticale Samples (dry matter basis)

Sample	Ca	P	Mg	Mn	Zn	Cu
	ppm					
Wheat #1	500	4300	1500	44	38	23
Wheat #2	500	3900	1500	52	40	20
Wheat #3	600	4000	1500	58	52	19
Wheat #4	1000	4000	1500	29	37	11
Wheat #5	600	3200	1500	48	33	11
Wheat #6	500	3300	1300	41	31	15
Wheat #7	800	3700	1300	29	45	18
Wheat #8	500	4400	1400	44	41	16
Wheat #9	600	4200	1500	45	35	19
Wheat #10	900	4400	1400	46	38	19
Wheat #11	600	4200	1500	39	38	16
Triticale	600	3900	1500	43	26	22
Average	641±168[1]	3967±400	1450±80	43±8	38±7	17±4

[1]Standard deviation of sample mean

The availability data was subjected to analysis of variance and the statistical comparison of mean was the multiple range test (Tukey, 1953).

Trial 2: Mineral Availability from Corn

Corn samples were analysed for dry matter, crude protein, ether extract, crude fiber and ash as shown in Table 4. The concentrations of calcium, phosphorus, magnesium, manganese, zinc and copper in the samples are shown in Table 5. The procedure employed was the same as the procedure outlined in Trial 1.

Trial 3: Mineral Availability from Barley

The composition of the barley is shown in Table 6. The content of minerals is presented in Table 7. The purpose of the trial was not only to study the calcium, phosphorus, magnesium, manganese, zinc and copper availability in barley but also the effects of location and source of the grain on mineral availability. The Chilliwack and Alaska barley were obtained in whole grain form while the barley samples purchased from a local feed company was in ground form. However, all barley samples were ground through a 1-mm sieve by a Wiley mill before the experiment.

The experimental procedure was the same as outlined in Trial 1.

TABLE 4: Chemical Analysis of the Ten Corn Samples (dry matter basis)

Sample	Dry matter	Crude protein	Ether extract	Crude fiber[1]	Ash
	%				
Corn #1	90.2	10.9	4.2	4.2	1.9
Corn #2	86.8	10.3	4.2	3.8	1.6
Corn #3	86.8	11.1	3.8	4.3	1.9
Corn #4	90.0	10.9	4.2	2.9	1.4
Corn #5	90.4	10.0	4.2	2.7	1.4
Corn #6	88.1	11.5	4.2	2.5	1.3
Corn #7	88.0	11.5	4.3	2.4	1.2
Corn #8	89.9	11.2	4.2	4.0	1.6
Corn #9	89.6	10.3	3.6	2.0	1.2
Corn #10	88.1	9.0	4.0	2.2	1.4
Average	88.8	10.7	4.1	3.1	1.5

[1]Acid detergent fiber

TABLE 5: Mineral Content of Ten Corn Samples (dry matter basis)

Sample	Ca	P	Mg	Mn	Zn	Cu
	ppm					
Corn #1	600	3400	1300	35	40	20
Corn #2	500	3000	1100	35	35	21
Corn #3	500	2700	1000	26	23	18
Corn #4	400	3000	1200	13	31	16
Corn #5	700	2900	1300	14	20	16
Corn #6	200	2800	1200	8	29	18
Corn #7	200	2700	1200	9	21	21
Corn #8	500	3100	1200	11	19	16
Corn #9	200	3300	1100	11	22	16
Corn #10	500	3300	1100	11	21	16
Average	430±178[1]	3020±252	1170±95	17±11	26±7	18±2

[1]Standard deviation of sample mean

TABLE 6: Chemical Analysis of Three Barley Samples from Different Sources (dry matter basis)

Sample	Dry matter	Crude protein	Ether extract	Crude fiber[1]	Ash
			%		
Barley #1 (Commercial)	87.4	12.0	2.2	6.5	3.2
Barley #2 (Chilliwack)	87.0	12.5	2.0	7.6	2.3
Barley #3 (Alaska)	93.3	15.8	2.4	7.3	1.5
Average	89.2	13.4	2.2	7.1	2.2

[1]Acid detergent fiber

TABLE 7: The Mineral Content of Three Barley Samples from Different Sources (dry matter basis)

Sample	Ca	P	Mg	Mn	Zn	Cu
	ppm					
Barley #1 (Commercial)	900	4600	1500	35	38	19
Barley #2 (Chilliwack)	500	3400	1300	26	27	19
Barley #3 (Alaska)	700	2800	1400	26	38	22
Average	700±200[1]	3600±917	1400±100	29±5	34±6	20±2

[1]Standard deviation of sample mean

Trial 4: Availability of Mineral in Diet Containing Different Levels of Soybean Meal

The objective was to study the effect on mineral availability on the levels of soybean meal (i.e. protein concentration) in the feed. Soybean meal was purchased from a local feed company. The composition of the soybean meal and dietary treatments were analysed and presented in Table 8. The mineral content of the soybean meal was shown in Table 9. The nitrogen and mineral-free synthetic diet used in this trial was the same as was used in Trial 1. Five levels of soybean were mixed with the appropriate amount of synthetic diet in a Hobart mixer (Model D-300).

The experimental arrangement was a completely randomized design. There were four replicates for each dietary treatment, each replicate included four birds (three weeks of age). The procedure was basically the same as outlined in Trial 1.

Trial 5: Availability of Mineral in Diet Containing Different Levels of Wheat

The experimental arrangement was the same as Trial 4 except wheat was employed as a testing material. The objective of the experiment was to study the influence of mineral availability of different levels of wheat. The proximate analysis of wheat is shown in Table 10. The mineral contents of dietary treatments are shown in Table 11. Experimental design and procedure were outlined in Trials 1 and 4.

TABLE 8: Proximate Analysis of Diets in Trial 4 (dry matter basis).

Treatment	Protein	Ether extract	Crude fiber[1]	Ash
	%			
1. Soybean meal (SBM)	52.0	1.94	6.73	6.27
2. S.D.[2] (S.D.) + 75% SBM	39.0	1.46	5.05	4.70
3. S.D. + 50% SBM	26.0	0.97	3.37	3.14
4. S.D. + 25% SBM	13.0	0.49	1.68	1.57
5. S.D. + 12.5% SBM	6.5	0.24	0.84	0.78

[1]Acid detergent fiber

[2]Synthetic diet as indicated in Table 1

TABLE 9: Mineral Content of Diets in Trial 4 (dry matter basis)

Treatment	Ca	P	Mg	Mn	Zn	Cu
	ppm					
1. SBM[1] (100%)	3280	6500	3030	41	52	16
2. S.D.[2]+75% SBM	2460	5000	2270	31	39	12
3. S.D.+50% SBM	1640	3100	1520	21	26	6
4. S.D.+25% SBM	820	1600	760	10	13	3
5. S.D.+12.5 SBM	410	800	380	5	7	2

[1]Soybean meal

[2]Synthetic diet as indicated in Table 1

TABLE 10: Proximate Analysis of Diets in Trial 5 (dry matter basis)

Treatment	Protein	Ether extract	Crude fiber[1]	Ash
	%			
1. Wheat (100%)	17.7	1.60	3.70	1.60
2. S.D.[2] + 75% wheat	13.3	1.20	2.78	1.20
3. S.D. + 50% wheat	8.9	0.80	1.85	0.80
4. S.D. + 25% wheat	4.4	0.40	0.93	0.40
5. S.D. + 12.5% wheat	2.2	0.20	0.46	0.20

[1]Acid detergent fiber

[2]Synthetic diet as indicated in Table 1

TABLE 11: Mineral Content of Diets in Trial 5 (dry matter basis)

Treatment	Ca	P	Mg	Mn	Zn	Cu
	ppm					
1. Wheat (100%)	580	3900	1530	39	38	16
2. S.D.[1]+75% wheat	435	2925	1148	29	29	12
3. S.D.+50% wheat	290	1950	765	20	19	6
4. S.D.+25% wheat	145	975	383	10	10	3
5. S.D.+12.5% wheat	73	488	192	5	5	2

[1]Synthetic diet as indicated in Table 1

Trial 6: Availability of Calcium and Phosphorus from Calcium Phosphate (Dibasic)

The calcium and phosphorus in calcium phosphate has been regarded as highly available to livestock. Calcium and phosphorus content of most common feedstuff of plant origin do not adequately support the normal functions of animals, including maintenance, growth and reproduction. Calcium and phosphorus from inorganic sources are usually incorporated into predominantly plant type diets to meet the biological requirements. The availability of calcium in various calcium sources for chicks have been reported by many workers (Bethke *et al.*, 1929; Waldroup *et al.*, 1964; Spandrorf and Leong, 1965). The criteria used were usually growth and tibia ash and the most available source was used as an index for other mineral sources. No true availability data of calcium phosphate have been reported by using the biological assay method developed by Nwokolo *et al.* (1976) or a similar procedure.

The objective of this trial was to study the availability of calcium phosphate to three-week old broiler chicks as well as the effect of levels of calcium and phosphorus in the test diet on availability of these minerals to the chicks. Nine levels of calcium and phosphorus were studied in this trial. Calcium phosphate was incorporated into the synthetic diet which was essentially mineral-free. The nine dietary treatments are shown in Table 12. The composition of the synthetic diet was shown in Table 1 of Trial 1. The experimental design and procedure was as outlined in Trial 1. Data collected was subjected to analysis of variance and a statistical comparison of means was by the multiple range test (Tukey, 1953).

TABLE 12: Outline of Dietary Treatments in Trial 6

Treatment		Ca (%)[1]		P (%)[1]
1. S.D.[2]	+	0.0125	+	0.0097
2. S.D.	+	0.025	+	0.0194
3. S.D.	+	0.050	+	0.0388
4. S.D.	+	0.100	+	0.0766
5. S.D.	+	0.200	+	0.1553
6. S.D.	+	0.400	+	0.3105
7. S.D.	+	0.800	+	0.6210
8. S.D.	+	1.200	+	0.9315
9. S.D.	+	1.600	+	1.2420

[1] Calcium phosphate source (dibasic)
[2] Synthetic diet as indicated in Table 1

Trial 7: Availability of Magnesium from Magnesium Carbonate

Magnesium has been recognized as an important essential dietary mineral for many years and under a number of feeding situations supplemental magnesium is required for optimum performance. Most work in magnesium availability was carried out with ruminant animals because of the high incidence of deficiency found in this species. Data reported indicates the relative availability rather than true availability. Cereal grains are the major feed ingredients for monogastric animals. Cereals generally supply adequate magnesium to meet monogastric animal needs. Therefore, no inorganic magnesium is usually supplemented to the balanced diet.

Little information on inorganic magnesium availability has been reported in the literature for poultry. The present trial was designed to estimate the true availability of magnesium from magnesium carbonate using growing broiler chicks. Diets containing six levels of magnesium were formulated as shown in Table 13. Levels range from below to an excess of the magnesium requirement according to NRC-- Nutrient Requirements of Poultry (1977).

The procedure used for the experiment is the same as outlined in Trial 1. Data obtained were subjected to analysis of variance and the different means were tested for multiple range analysis (Tukey, 1953).

TABLE 13: Outline of Dietary Treatments in Trial 7

Treatment		Mg[1] level (ppm)
1. S.D.[2]	+	150
2. S.D.	+	300
3. S.D.	+	450
4. S.D.	+	600
5. S.D.	+	750
6. S.D.	+	900

[1]Magnesium carbonate source

[2]Synthetic diet as indicated in Table 1

Trial 8: Availability of Manganese from Manganese Sulfate

Manganese content of the conventional feed ingredients is generally low. Inorganic manganese from various sources is always included in the diet to prevent manganese deficiency. Very limited information is available concerning the bioavailability of manganese in various inorganic sources. An early study by Schaible and Bandemer (1942) reported that manganese in the forms of oxide, carbonate, sulfate and chloride is equally available to poultry. However, later investigation indicated that differences existed in manganese availability from various inorganic sources (Henning *et al.*, 1967; Watson *et al.*, 1970; 1971). Most of the work was done qualitatively instead of quantitatively. Therefore, no true availability value has been reported for biological availability from inorganic sources.

The present study was designed to evaluate the bioavailability of manganese in manganese sulfate as well as the effect of dietary levels of the manganese supplement on the availability of manganese for growing chicks. The dietary treatments of this trial are shown in Table 14. The procedure used for the trial was similar to that outlined in Trial 1.

Trial 9: Availability of Zinc from Zinc Oxide

Little information is available in the literature regarding the inorganic zinc availability to animals. Edwards (1959) reported that zinc in the form of zinc sulfate, willenite, zinc carbonate and zinc oxide (A.R. grade) is relatively available to the young growing

TABLE 14: Outline of Dietary Treatments in Trial 8

Treatment		Mn[1] level (ppm)
1. S.D.[2]	+	25
2. S.D.	+	50
3. S.D.	+	75
4. S.D.	+	100
5. S.D.	+	125

[1] Manganese sulfate source

[2] Synthetic diet as indicated in Table 1

chicks, whereas zinc in sphalerite (mostly zinc sulfide) and in franklinite (oxide of zinc, iron, manganese) is largely unavailable. There are no true availability values reported in the literature. The present experiment was conducted to study the availability of zinc from zinc oxide and the influence of levels of zinc oxide on availability of Zn to growing chicks. Five dietary treatment levels were utilized as shown in Table 15. The experimental procedure was the same as outlined in Trial 1.

Trials 10 and 11: Availability of Copper from Copper Sulfate

Similar to most other trace minerals, the availability value of copper from various inorganic sources is not available. An early study by Schultze *et al.* (1936) indicated that copper of copper sulfide or copper prophyrin was not utilized by rats whereas copper in oxide, hydroxide and pyrophosphate forms was readily utilized. The objective of the present study was to estimate the availability of copper in copper sulfate to the growing broiler chicks and the influence of copper levels in the diet on copper availability. The dietary treatments in Trials 10 and 11 are presented in Tables 16 and 17. Trial 10 was arranged to study the lower levels of dietary copper, whereas, Trial 11 was carried out in the higher range of dietary treatments. Eighty birds were employed in these trials. The experimental procedure was the same as outlined in Trial 1.

TABLE 15: Outline of Dietary Treatments in Trial 9

Treatment		Zn[1] level (ppm)
1. S.D.[2]	+	25
2. S.D.	+	50
3. S.D.	+	75
4. S.D.	+	100
5. S.D.	+	125

[1]Zinc oxide source

[2]Synthetic diet as indicated in Table 1

TABLE 16: Outline of Dietary Treatments in Trial 10

Treatment		Cu[1] level (ppm)
1. S.D.[2]	+	2
2. S.D.	+	4
3. S.D.	+	8
4. S.D.	+	16
5. S.D.	+	32

[1]Copper sulfate source

[2]Synthetic diet as indicated in Table 1

TABLE 17: Outline of Dietary Treatments in Trial 11

Treatment		Cu[1] level (ppm)
1. S.D.[2]	+	50
2. S.D.	+	100
3. S.D.	+	150
4. S.D.	+	200
5. S.D.	+	250

[1]Copper sulfate source

[2]Synthetic diet as indicated in Table 1

RESULTS AND DISCUSSION

Trial 1

The mineral content of the wheat samples is shown in Table 3. Wheat is high in phosphorus (average 3,967 ppm) and magnesium (1,450 ppm), but low in calcium (641 ppm), manganese (43 ppm), zinc (38 ppm) and copper (17 ppm). There were considerable variations in mineral content within the samples tested, especially with respect to calcium, manganese, zinc and copper. The variations may be due to different soil type, genetic difference of wheat samples and influence of season and state of maturity (Underwood, 1977). Mineral content in wheat does not satisfy the minimum nutritional requirement of livestock. The low mineral content and lack of availability data contribute to neglect in utilizing these minerals to advantage in a formulation. The high cost of feed ingredients, including inorganic mineral salts, in the future will certainly demonstrate the need to re-evaluate the mineral contribution of wheat and other cereal grains.

The percent availability of minerals in wheat samples is shown in Table 18. The average results of all the minerals tested indicate that copper has the highest availability (78.6%) in these grains. It was followed by calcium (71%), phosphorus (67.4%), magnesium (53.5%), zinc (49.6%) and manganese (48.4%). Significant variation was observed among the grain samples tested in respect to all minerals studied.

TABLE 18: Percent Availability of Minerals from Wheat and Triticale Samples

Samples	Availability (%)[1]					
	Ca	P	Mg	Mn	Zn	Cu
Wheat #1	70.4^{b}	69.3^{c}	52.3^{bc}	64.3^{e}	50.6^{de}	92.9^{i}
Wheat #2	65.4^{a}	63.0^{bc}	56.3^{c}	56.0^{cd}	36.6^{a}	88.2^{hi}
Wheat #3	65.5^{a}	56.3^{a}	48.8^{ab}	59.3^{de}	44.0^{b}	76.7^{ef}
Wheat #4	65.5^{a}	62.2^{b}	46.6^{ab}	42.8^{b}	44.5^{bc}	66.7^{bc}
Wheat #5	82.9^{d}	76.0^{d}	56.1^{c}	51.4^{c}	42.0^{b}	84.5^{gh}
Wheat #6	70.5^{b}	77.8^{d}	70.5^{d}	52.2^{c}	46.0^{bcd}	64.3^{ab}
Wheat #7	67.8^{ab}	79.0^{d}	67.8^{d}	41.4^{b}	65.1^{g}	91.9^{i}
Wheat #8	64.7^{a}	61.0^{ab}	44.2^{a}	43.3^{b}	48.9^{cde}	74.6^{de}
Wheat #9	77.2^{c}	66.2^{bc}	48.0^{ab}	41.8^{b}	51.7^{3}	81.0^{fg}
Wheat #10	68.7^{ab}	66.3^{bc}	45.2^{a}	39.0^{ab}	46.1^{bcd}	70.8^{cd}
Wheat #11	66.0^{ab}	65.4^{b}	48.4^{ab}	34.9^{a}	62.3^{g}	60.6^{a}
Triticale	87.5^{d}	66.9^{bc}	58.1^{c}	54.2^{cd}	57.1^{f}	90.0^{hi}
Average	71.0±7.5[2]	67.5±7.0	53.5±8.6	48.4±9.1	49.6±8.4	78.5±11.3

[1]Means with different superscripts within a column are significantly different ($P \leq 0.05$).

[2]Standard deviation of sample mean

(a) Calcium

Results indicate a significant difference among samples of wheat and the multiple range comparison (Tukey test) showed no significant difference among wheat sample numbers 2, 3, 4, 7, 8, 10 and 11. However, differences were observed when compared to sample numbers 1, 5, 6, 9 and triticale. Wheat #5 is significantly higher than any other wheat sample with the exception that it did not differ from triticale.

In the review of literature, no availability data for minerals in wheat were reported. This was probably because the low calcium content in wheat did not stimulate investigation, and there was no simple and rapid procedure to study the mineral availability before 1976. The inexpensive calcium source from limestone has also discouraged calcium availability study. However, the results in this experiment showed that the average calcium availability of wheat was 71.0%, which was in agreement with dietary calcium retention studies of complete diets employing radioactive isotopes by Driggers and Comar (1949), and more recently by Bragg *et al.* (1971). These investigators reported that approximately 70% of the dietary calcium was retained by laying hens. Nwokolo *et al.* (1976), using three-week old broiler chicks reported similar availability values (72.6%) for soybean, rapeseed, cottonseed, and palm kernel meal. Results from this study were also in agreement with the data published by Armstrong and Thomas (1952), Armstrong *et al.* (1953), and Armstrong (1957), using various herbs of grassland as well as Devadatta and Appana (1954), in studies of various vegetables. It appears that calcium availability to animals is similar from various plant sources.

(b) Phosphorus

The phosphorus availability varied from sample to sample as shown in Table 18. The values ranged from 56.3 to 79% for eleven wheat and one triticale samples. The average phosphorus availability of eleven samples of wheat and triticale was 67.4%. Significant differences were observed in phosphorus availability among these grain samples. Phosphorus availability from wheat sample numbers 5, 6 and 7 were not significantly different from one another but were significantly higher than any other sample. Wheat numbers 1, 2, 9 and 10 and triticale were significantly higher than wheat number 3. There was no difference among wheat numbers 2, 4, 8, 9, 10, 11 and triticale. Wheat number 2 was significantly higher than wheat number 11. Hoshii and Hoshida (1978a) reported that variation existed for phosphorus availability in wheat. They demonstrated a significant difference between two strains of wheat (Glenlea and Pitic 62). The wheat samples obtained for the present experiment arrived from the commercial wheat pool. Therefore wheat samples may have originated at a number of locations with the different date of shipments. Variety differences are also possible.

It has been generally considered that phosphorus of plant origin is poorly available due to the influence of phytates (Taylor, 1965). However, there is wide disagreement among investigators on the ability of chicks to utilize phytate phosphorus. Ashton *et al.* (1960) observed that four-week old chicks retained approximately 20% of phytate phosphorus while six-week old chicks retained 36% to 49% of this phosphorus. Nelson *et al.* (1968) showed that phytate phosphorus of commercial soybean meal was completely unavailable. Temperton and Cassidy (1964) reported that chicks utilized approximately 60% of the non-phytate phosphate. Salman and McGinnis (1968) showed that utilization of phosphorus from plant origin in laying hens was quite high. Recently, Nwokolo *et al.* (1976) reported that availability of phosphorus from protein supplements, soybean; rapeseed; cottonseed and palm kernel meal, to four-week old broiler chicks were 89.3, 74.8, 76.9 and 70.8%, respectively. Most recently Hoshii and Yoshida (1978a) showed that the phosphorus in wheat and wheat bran were over 60% available. However, the nutritional committee for NRC (1969) suggested that the available phosphorus from plant origin was approximately 20-50% for chicks or swine.

Results in the this study showed that the availability of phosphorus in wheat was 67.4%. This agreed well with the results reported by Hoshii and Yoshida (1978b), using toe ash and carcass phosphorus content as criteria in the determination. The existing work in pigs for phosphorus availability shows lower values in most cases for feed of plant origin (Besecker *et al.*, 1967; Bayley and Thomson, 1969; Tonroy *et al.*, 1973). Most of these studies utilized apparent digestibility as the criterion of measurement. The apparent availability values underestimate the true availability because endogenous phosphorus excretion has not been considered.

(c) *Magnesium*

Significant variation was observed for the magnesium availability in all the wheat samples. Percent availability ranged from 44.2 to 70.5% and the mean of samples including triticale was 53.5%. Wheat numbers 6 and 7 were significantly higher than any other wheat sample. Wheat numbers 2, 5 and triticale were significantly higher than wheat numbers 3, 4, 8, 9, 10 and 11. The former and the later groups did not differ from each other. The average value in this study was slightly higher than the value (48.1%) reported by Guenter and Sell (1974), using intramuscular injection of radioactive ^{28}Mg. However, most of the values in wheat ranged between 44.2 to 58.1%. Recently, Nwokolo *et al.* (1976) reported that the availability of magnesium in soybean, rapeseed, cottonseed and palm kernel meals was 77.4, 61.1, 74.6 and 56.4%, respectively. These values were higher than wheat in the present study. In ruminants, Peer (1972) indicated that magnesium availability in forage ranged from 10 to 25% with a mean of approximately 20%. Grains and protein concentrates ranged from 30 to 40%.

On the basis of information reported it appears that availability of magnesium is lower in wheat than was observed in plant protein concentrates. In general, no magnesium supplementation is required in poultry diets because the feed ingredients supply an adequate amount of available magnesium.

(d) *Manganese*

Results indicated that there were significant differences among the wheat and triticale samples tested. Availability of manganese ranged from 34.9 (wheat 11) to 64.3% (wheat 1) with the mean of 48.4% for eleven samples and triticale. Wheat number 1 did not differ from wheat number 3, but was significantly higher than other wheat samples. Wheat numbers 2, 3 and triticale were significantly higher than wheat numbers 7, 8, 9, 10 and 11, while wheat numbers 2, 5, 6 and triticale were not significantly different. Little information has been reported on manganese availability for wheat in the literature.

The relatively poor content as well as poor availability of manganese in wheat can cause the manganese deficiency problem in chicks without dietary manganese supplementation. An inorganic manganese salt is usually employed as the supplement for poultry diets. Nwokolo (1977) showed that manganese in palm kernel meal was poorly available (45.1%) whereas fairly high availability was observed in soybean (76.1%) and cottonseed (76.3%) and a lower value for rapeseed meal (56.7%).

(e) *Zinc*

The average zinc content of wheat samples and triticale was 37 ppm. Slight variation in zinc content was observed except in wheat number 3 which showed the highest value, 52 ppm. Results (Table 18) showed that zinc availability of wheat and triticale ranged from 36.6% (wheat number 3) to 65.1% (wheat number 7) with a mean of 49.6%. Zinc availability of wheat was higher in wheat number 7 and 11 and lowest in wheat number 2. Wheat numbers 3, 4, 5, 6 and 10 were not significantly different, whereas triticale was higher than any other wheat sample except wheat numbers 7 and 11. The results indicated considerable variation among the wheat samples. The average value of wheat was lower than soybean meal (66.5%) and rapeseed meal (57.6%) but higher than cottonseed meal (38.0%) and palm kernel meal (13.9%), reported by Nwokolo *et al.* (1976). O'Dell *et al.* (1972) reported that the availability of zinc in sesame meal, soybean meal and fish meal were 57.0, 67.0 and 75.0%, respectively for chicks. Evans and Johnson (1977) also reported that zinc availability in raw corn endosperm was 51.0% for rats. The zinc requirement for the growing broiler chick is 40 ppm (NRC, 1977). The low content and low zinc availability in wheat suggests that zinc supplementation is needed if wheat is used predominantly as the energy source of the diet.

(f) *Copper*

The results showed that copper in wheat and triticale samples were highly available. The copper availability for wheat samples ranged from 60.6 (wheat number 11) to 92.6% (wheat number 1) with a mean of 78.5%. This value was higher than that of any other mineral tested. Wheat numbers 1, 2, 7 and triticale showed the highest available copper for chicks. These wheat and triticale samples were not significantly different from each other, but were significantly higher than wheat numbers 3, 4, 6, 8, 9, 10 and 11. Wheat number 11 was significantly lower than oher samples tested.

Nwokolo *et al.* (1976) reported that the copper availability values from soybean, rapeseed, cottonseed and palm kernel meals were 51, 62.2, 42.3 and 44.7%, respectively. These protein supplements had lower copper availability than wheat in this study. The difference may be due to the higher protein content of the protein concentrates since copper can form an insoluble complex with protein and reduce the absorption of copper (Underwood, 1977).

Trial 2

The chemical composition of corn samples utilized in this study is presented in Table 4. The average crude protein, ether extract, crude fiber and ash were 10.7, 4.1, 3.1 and 1.5% (D.M.), respectively. The mineral content of corn samples was shown in Table 5. Similar to wheat, corn was high in phosphorus (3020 ppm) and magnesium (1170 ppm) but low in calcium (430 ppm), manganese (17 ppm), zinc (26 ppm) and copper (18 ppm). All values were reported on dry matter basis.

The results of mineral (Ca, P, Mg, Mn, Zn and Cu) availability for corn samples to three-week old broiler chicks were shown in Table 19.

TABLE 19: Availability of Minerals from Ten Corn Samples

Sample	Availability (%)[1]					
	Ca	P	Mg	Mn	Zn	Cu
Corn #1	71.7^{de}	72.2^{e}	56.6^{d}	70.1^{e}	65.5^{d}	86.6^{bc}
Corn #2	65.2^{b}	52.9^{ab}	55.7^{cd}	77.3^{f}	72.5^{e}	92.7^{e}
Corn #3	59.9^{a}	49.0^{a}	52.7^{bcd}	63.1^{d}	46.3^{b}	86.1^{bc}
Corn #4	70.9^{cd}	65.9^{d}	55.7^{cd}	55.8^{bc}	77.1^{e}	91.7^{de}
Corn #5	75.8^{f}	59.1^{c}	51.9^{bcd}	64.1^{de}	44.2^{ab}	94.5^{e}
Corn #6	76.6^{f}	68.5^{de}	50.7^{bc}	61.7^{cd}	62.8^{d}	87.7^{cd}
Corn #7	68.3^{bcd}	69.0^{de}	47.3^{ab}	56.2^{bc}	41.2^{a}	86.0^{bc}
Corn #8	68.0^{bcd}	58.3^{bc}	47.1^{ab}	50.4^{b}	53.4^{c}	82.9^{ab}
Corn #9	75.6^{ef}	59.3^{c}	48.3^{ab}	56.3^{c}	65.0^{d}	81.5^{a}
Corn #10	67.7^{bc}	54.4^{bc}	44.1^{a}	44.6^{a}	47.5^{b}	82.5^{ab}
Average	70.0±5.3[2]	60.9±7.7	51.0±4.3	60.0±9.5	57.6±12.7	87.2±4.5

[1]Means with different superscripts within a column are significantly different ($P \leq 0.05$)

[2]Standard deviation of sample mean

Corn has been used extensively in poultry feeding and the mineral availability data will be valuable to formulate least cost diets. The availability results showed that significant variation ($p \leq 0.05$) existed in corn samples for all the minerals tested. This variation may be a combination of influences such as variety, soil-type and environmental factors. Although corn has long been used for animal feed, little is known of its mineral availability. The following discussion will deal with the availability of individual minerals to the growing broiler.

(a) *Calcium*

The calcium content of the ten corn samples varied from 200 to 700 ppm, with an average of 400 ppm. This was slightly higher than values currently reported (NRC, 1977). The calcium availability in ten corn samples ranged from 59.9 to 76.6% with the mean of 70.0%. Variations between samples were highly significant ($p \leq 0.05$). Corn numbers 5 and 6 were significantly higher than other corn samples except corn number 9. Corn number 3 had a significantly lower availability value than other samples. Corn numbers 2, 7, 8 and 10 did not differ significantly from each other. A similar situation was observed in corn numbers 1, 4, 7 and 8. The availability value of calcium in corn is moderately high and similar to values obtained for wheat in Trial 1.

Published information is lacking with regard to calcium availability in corn. Phytic acid has been reported to affect mineral availability including calcium (Bruce and Callow, 1934), phosphorus (Gillis *et al.*, 1957; Nelson, 1967), magnesium (Robert and Yudkin, 1961; Lukuski and Forbes, 1956), and zinc (O'Dell and Salvage, 1960; Davies and Nightingale, 1975), manganese and copper (Davies and Nightingale, 1975). The phytic content reported for corn and wheat was 0.6 and 0.7%, respectively (Nelson *et al.*, 1968). This may explain, partly, the similarity of calcium availability for these two grains.

(b) *Phosphorus*

Results showed that phosphorus availability in corn ranged from 49 to 72.2% with a mean of 60.9%. Corn numbers 1, 6 and 7 were significantly higher than corn numbers 2, 3, 5, 8, 9 and 10, whereas 5, 8, 9 and 10 were not significantly different from each other as well as corn number 2, 8, and 10. The National Research Council (1969) suggested that phosphorus availability from plant origin was about 20-50% due to the high phytate content of the grains' source. Although the total phosphate in corn and wheat is 66 and 67% of phytate phosphorus, respectively (Nelson *et al.*, 1968), results for available phosphorus in corn is somewhat lower than the value observed for wheat in Trial 1. The higher value in wheat may be explained by the higher phytase activity of wheat (McCance and Widdowson, 1944) which can catalyze the phytate phosphate digestion in the gut.

There has always been a controversy regarding the availability of phosphate from ingredients of plant origin for swine and poultry. The low phosphate availability from plant sources has been reported to be 30-40% in barley-wheat diets (Woodman and Evans, 1948), 17.7% in barley (Besecker *et al.*, 1967), 19% in corn-soy diets (Bayley and Thomson, 1969), 4.5% in sorghum (Tonroy, 1973), 16, 51 and 18% in corn, wheat and soybean meal, respectively for pigs (Miracle *et al.*, 1977). In most cases, studies were conducted using apparent digestibility as a determination criterion. No endogenous excretion was corrected from the feces. This may explain why the value of availability was generally lower. It is well known that many other factors may also play a role in rendering the phosphorus available in grains as reported in the literature review. However, it is reasonable to believe that the phosphorus from plants is currently underestimated. The higher phosphorus availability from plants for poultry has been supported by Salman and McGinnis (1968), and Nwokolo *et al.* (1976). The latter authors used the endogenous correction for the phosphorus available determination. The result of present studies also indicated the higher phosphorus availability from corn for the growing broiler chicks.

(c) *Magnesium*

The availability of magnesium in corn samples ranged from 44.1 (corn number 10) to 56.6% (corn number 1), with a mean of 51.0%. Magnesium availability was comparatively lower than the availability of other minerals tested on an average basis. Corn number 1 was significantly higher than corn numbers 6, 7, 8, 9 and 10 but similar to corn numbers 2, 3, 4, and 5. Corn numbers 5, 6, 7, 8 and 9 did not differ significantly from each other. Corn number 10 was significantly lower than corn numbers 1, 2, 3, 4, 5 and 6, but not significantly different from corn numbers 7, 8, 9 and 10. This indicates the variation among samples taken from commercial supplies of different time periods. The average value of magnesium availability in this study was slightly higher than the value (47.5%) published by Guenter and Sell (1974), using intramuscular injection of radioactive ^{28}Mg in roasters. Also, a similar value (53.5%) was obtained for wheat (Trial 1). However, these values were lower than that for soybean (77.4%), rapeseed (61.1%), cottonseed (74.6%) and palm kernel (56.4%) meals reported by Nwokolo *et al.* (1976). It appears that plant protein concentrates supply magnesium in a more available form than do the grains.

(d) *Manganese*

Results showed that the manganese availability of corn ranged from 44.6% (corn number 10) to 77.3% (corn number 2) with an average of 60% for growing broiler chicks. Corn number 2 was significantly higher than any other corn samples; conversely, corn number 10 gave the lowest value. Corn numbers 3, 5 and 6 were similar but were significantly higher than corn numbers 8 and 10. Corn numbers 4, 6, 7 and 9 did not significantly differ from each other. Similar to other minerals, there was a wide variation among the corn samples regarding manganese availability. Since the trace mineral content in corn was quite low, the variation may be attributed to soil mineral and fertilizer application on the field. Although inorganic magnanese salts are currently used in preventing the manganese deficiency, little information is available relative to manganese availability from either plants or inorganic salts. The only studies on plants were reported by Nwokolo *et al.* (1976) on protein concentrates. These authors reported that the manganese availability of soybean, rapeseed, cotton seed and palm kernel meals were 76.1, 56.7, 76.3 and 75.7%, respectively to growing broiler chicks.

(e) *Zinc*

The availability of zinc ranged from 41.2% (corn number 7) to 77.1% (corn number 4), with a mean of 57.5%. Corn numbers 4 and 2 were higher than any other corn samples. Corn numbers 1 and 6 were significantly higher than corn numbers 3, 5, 7, 8 and 10. Corn number 7 was lowest compared to other corn samples. Corn numbers 3, 5 and 10 were not significantly different to each other. The results also indicate the variability of corn availability in different samples. Evans and Johnson (1979) showed that zinc availability in raw corn endosperm flour was 51% in rat experiments. O'Dell *et al.* (1972), using growth response of chicks as criteria, reported that the availability of zinc in sesame, soybean and fish meals were 57, 67 and 75%, respectively. Zinc availability in soybean, rapeseed, cottonseed and palm kernel meals was also reported by Nwokolo *et al.* (1976).

(f) Copper

Copper availability was highest among all the minerals tested in corn. The copper availability ranged from 81.5% (corn number 9) to 94.5% (corn number 5) with an average of 87.2%. Corn numbers 2, 4 and 5 were significantly higher than corn numbers 1, 3, 7, 8, 9 and 10 while corn numbers 1, 3, 7, 8 and 10 were not significantly different from each other. Corn number 9 (81.5%) had the lowest copper availability value. The results indicate that copper is highly available in corn. However, the availability varied significantly among samples. The content of copper in corn of the present studies was higher than currently reported (NRC, 1960). The total amount of copper in grain is small and the difference of copper content may be attributed to variation of soil or fertilizer application in the field.

Trial 3

The mineral content of three barley samples is shown in Table 7. The average concentration of calcium, phosphorus, magnesium, manganese, zinc and copper were 600, 3600, 1400, 29, 34 and 20 ppm, respectively. Similar to wheat and corn, barley samples contained a high level of phosphorus and magnesium but were low in calcium and trace minerals. The trace mineral content in barley samples was higher than expected. The average mineral availability of commercial barley (barley number 1), Chilliwack barley (barley number 2) and Alaska barley (barley number 3) for calcium, phosphorus, magnesium, zinc and copper were 68.9, 68.8, 54.9, 54.9, 49.1 and 77.5%, respectively (Table 20).

TABLE 20: Availability of Minerals in Three Barley Samples Collected from Different Places

Samples	Availability (%)[1]					
	Ca	P	Mg	Mn	Zn	Cu
Barley #1 (Commercial)	74.4[b]	66.4[a]	54.1[a]	65.8[c]	39.3[a]	73.9[a]
Barley #2 (Chilliwack)	51.9[a]	73.2[b]	53.1[a]	42.8[a]	37.5[a]	77.2[ab]
Barley #3 (Alaska)	80.5[c]	66.9[a]	57.5[a]	56.2[b]	70.6[b]	81.4[b]
Average	68.9±15.1[2]	68.8±3.8	54.9±2.3	54.9±11.6	49.1±18.6	77.5±3.8

[1]Means with different superscripts within a column are significantly different ($P \leq 0.05$)

[2]Standard deviation of sample mean

(a) Calcium

Results indicated that there were significant variations among samples from the three different sources in calcium availability. The calcium availability was highest from Alaska barley (80.5%), lower for commercial barley (74.4%) and lowest in the Chilliwack barley (51.9%). The commercial barley (barley number 1) was also significantly higher than Chilliwack barley (barley number 2). The average calcium availability for barley (68.9%) was similar to wheat (71.0%) and corn (70.0%) in Trials 1 and 2, respectively. The results suggest that the source of grains contributes to the variability in mineral availability.

(b) Phosphorus

The results showed that the phosphorus availability in barley was moderately high (68.8%) for three-week old growing broiler chicks. Barley number 2 (73.2%) was significantly higher than barley number 1 (66.4%) and number 3 (66.9%) whereas there was no significant difference between the later two barley samples. Similar phosphorus availability values were observed in wheat (Trial 1) and corn (Trial 2). Little information has been reported for phosphorus availability in barley for chicks. Hayes *et al.* (1979), using survival rate, growth rate, efficiency of feed utilization, breaking strength and ash content of the tibia as response criteria, reported that phosphorus availability of barley was 50%. Besecker *et al.* (1967) reported that the apparent digestibility of phosphorus in barley was 17.7% to the growing pig. The value was rather low since endogenous excretion was not taken into account. Therefore phosphorus availability for barley appears to be underestimated.

(c) *Magnesium*

There was no significant difference in magnesium availability among the three barley samples from different sources. The availability of barley numbers 1, 2 and 3 were 54.1, 53.1 and 57.5%, respectively with the mean of 54.9%. This value was in agreement with the result (54.2%) reported by Guenter and Sell (1974) using muscular injection of radioisotope Mg^{28}. The magnesium availability was also similar to wheat (53.5%) and corn (51.0%) in Trials 1 and 2, respectively.

(d) *Manganese*

The results showed that there was significant variation among barley samples regarding manganese availability. Barley number 1 gave highest manganese availability (65.8%), followed by barley number 3 (56.2%) and barley number 2 (42.8%). The average manganese availability for three barley samples was 54.9%. No data is available in the literature concerning manganese availability in barley. The manganese availability in barley was higher than in wheat (48.8%) and lower than in corn (60.0%) reported in Trials 1 and 2, respectively. Nwokolo *et al.* (1976) reported that the manganese availabilities in soybean, rapeseed, cottonseed and palm kernel meals were 76.1, 56.7, 76.3 and 45.7%, respectively for growing chicks.

(e) Zinc

Zinc availability was significantly lower in barley number 1 (39.3%) and barley number 2 (37.5%) compared to barley number 3 (70.6). The zinc availability of Alaska (i.e. barley number 3) was about two-fold higher than the other two barley samples from different sources. The results indicated that barley from different locations can be expected to differ in zinc availability values. However, the average zinc availability for these three barley samples was 49.1% which was similar to the value of wheat (49.6%) and slightly lower than corn (57.5%) reported in earlier trials.

(f) Copper

The results showed that the availability of copper was the highest compared to other minerals. The average availability of these barley samples was 77.5%. Although the range between the low and high value samples was not great, it was shown to be significantly different between barley number 1 (73.9%) and barley number 3 (81.4%). Barley number 2 (77.2%) did not differ significantly from other samples. The content of copper appears to be low compared to other minerals tested. The low requirements of copper in poultry explain the lack of copper deficiency in general feeding without inorganic copper supplementation.

General Discussion of Trials 1, 2 and 3

Wheat, corn and barley are the most common feedstuff in North America and Europe. However, the mineral availability studies for these cereals have been very limited. Limited research may be due to the low cost of the inorganic minerals on the market and lack of rapid techniques to evaluate the true availability. Most previous work on availability was concentrated on phosphate or phytate phosphorus because of the high cost of phosphorus. The increased cost of all feed ingredients, both at present and in the foreseeable future, may increase interest in more precise knowledge related to availability of nutrients in the feedstuffs.

In general, the minerals (Ca, P, Mg, Mn, Zn and Cu) tested ranged from moderate to high in availability for wheat, corn and barley in the growing broiler chick. Copper appeared to be the most available in these cereals for chicks. The phosphorus availability in these cereals was most interesting because higher available phosphorus was observed than those reported in the literature.

The average results of wheat, corn and barley mineral availability are summarized in Table 21. It is apparent that calcium availability from these cereals are similar. Wheat was the highest (71.0%) followed by corn (70.0%) and barley (68.9%). The results of these studies were in agreement with dietary retention studies using radioactive isotopes by Drigger and Comar (1949) and Bragg *et al.* (1971). These investigators reported that approximately 70% of the dietary calcium was retained by the laying bird. More recently, Nwokolo *et al.*

TABLE 21: Summary of Mineral Availability from Wheat, Corn and Barley

Sample	Availability (%)					
	Ca	P	Mg	Mn	Zn	Cu
Wheat	71.0	67.4	53.5	48.4	49.6	78.5
Corn	70.0	60.9	51.0	60.0	57.5	87.2
Barley	68.9	68.8	54.9	54.9	49.1	77.5

(1976), using broiler chicks, showed that the average calcium availability for vegetable protein concentrate (soybean, rapeseed, cottonseed and palm kernel means) was 72.6%. These results are comparable to the reports by Armstrong *et al.* (1953) in three grasses and Devadatta and Appana (1954) in various vegetable sources.

Phosphorus availability for these cereals was 65.7% on average. Corn appeared to have lower availability (60.0%) in comparison to wheat (67.4%) and barley (68.8%). It has long been reported that phosphorus from animal sources is highly available. Gillis *et al.* (1954) reported that available phosphorus for bone meal, bone char, bone ash and dicalcium phosphate was 87, 84, 89 and 100%, respectively. Similar results were reported by Nelson and Walker (1964) and Dilworth and Day (1964). Conversely, phosphorus of plant origin is considered poorly available due to the influence of phytate (Taylor, 1965; Nelson *et al.*, 1968) in the feed ingredients. However, conflicting reports existed in this regard. Nelson *et al.* (1968) reported that phytate phosphorus of commercial soybean meal was completely unavailable. Ashton *et al.* (1960) showed that four-week old chicks retained approximately 20% of phytate phosphorus while six-week old chicks retained 36 to 49% of the phosphorus. Hayes *et al.* (1979) reported that availability of phosphorus in corn, hard wheat, soft wheat and barley was estimated at 12, 43, 58 and 50%, respectively. Temperton and Cassidy (1964) demonstrated that the phosphorus utilization was 60% of phytate phosphate. Salmon and McGinnis (1968) also showed a high availability of phosphorus in vegetable sources. Most recently, Nwokolo *et al.* (1976) reported that phosphorus availability from soybean, rapeseed, cotton seed and palm kernel meals was 89.3, 76.9, 74.8 and 70.8%, respectively for the growing broiler chicks. The present results also showed that the phosphorus availability in cereals was quite high. Therefore, it may be concluded that the phosphorus availability from plant origin was not as low as previously indicated and that phosphorus availability from plants has been greatly underestimated.

Availabilities of magnesium in wheat, corn and barley were 53.5, 51.0 and 54.9%, respectively with the mean of 53.1%. The results of wheat and corn were higher than the values of 48.1 and 47.5%, respectively reported by Guenter and Sell (1974). These authors also reported the value for barley (54.9%) similar to the present experiment. However, the present results were also lower than the report by Nwokolo *et al.* (1976) on the vegetable protein source. Although the availability of magnesium is only approximately 50%, its deficiency is not a common problem in practical diets for poultry. This may be explained by the relatively high content of magnesium in the feed ingredients for poultry.

Little is known on the availability of manganese in cereals. The present studies showed that manganese availability was higher in corn (60.0%) followed by barley (54.5%) and wheat (48.4%) with the average of 54.5% for the cereals. The content of manganese in the cereals was generally low, therefore manganese deficiency is a problem in the conventional diet and requires supplementation with inorganic manganese. Nwokolo *et al.* (1976) showed that the availability of manganese in the soybean, rapeseed, cottonseed and palm kernel meals were 76.1, 56.7, 76.3 and 45.7%, respectively for the growing broiler chicks.

The average zinc availability (52.1%) for three cereals was similar to magnesium (53.1%) and manganese (54.5%). Zinc in corn appeared to be more available than that of wheat and barley. Very limited availability data was observed in the literature for plants. Evan and Johnson (1977) reported that zinc availability in raw corn endosperm flour was 51%. O'Dell *et al*, (1972) observed that zinc availability in sesame, soybean and fish meal was 57, 67 and 75%, respectively. Nwokolo *et al*. (1976) showed that soybean, rapeseed, cottonseed and palm kernel meals had a zinc availability of 66.5, 44.0, 38.0 and 13.9%, respectively. The high crude fibre and phytate content in cottonseed and palm kernel meals was suggested to be the factor rendering the low availability of zinc in these meals (Nwokolo and Bragg, 1977). O'Dell and Savage (1960) indicated that monogastric animals required higher levels of dietary zinc on diets containing plant proteins than on diets containing animal protein because of the phytate content in plant proteins. Phytate has been known to bind the zinc in a complex form which is not readily released for absorption in animals.

The copper availability appeared to be the highest in cereal grains compared to other minerals tested with an average of 81.0%. Little is known about the chemical form in which copper exists in food. Copper absorption and utilization may be markedly affected by several other mineral elements and dietary components (Underwood, 1977). Phytate appeared to reduce absorption and retention of copper (Davis *et al.*, 1962; Davies and Nightingale, 1975). Nwokolo *et al.* (1976) reported that the copper availability of plant protein supplements, soybean, rapeseed, cotton seed and palm kernel meals was fairly low. Cereals contained little phytate compared to plant protein supplements. The fibre content of the plant protein source reported by Nwokolo and Bragg (1977) was higher than the cereals tested in these studies. The high fibre content is also known to significantly decrease the copper availability. (Nwokolo and Bragg, 1977). This may explain why the cereals with lower phytate and crude fibre content resulted in higher copper availability. Other dietary factors associated with proteins and cereals may also influence the difference in absorption and utilization of copper.

Trial 4

The overall mineral availability in different levels of soybean in the diet is shown in Table 22. The results showed that the value of mineral availability improved as the soybean level decreased. It was apparent that a dilution effect was influencing the availability. The increased retention with decreasing soybean meal concentration may be explained by the improvement of digestibility and less competition for the binding sites for mineral transport.

TABLE 22: Availability of Minerals in Diets Containing Different Levels of Soybean Meal

Treatment	Availability (%)[1]					
	Ca	P	Mg	Mn	Zn	Cu
1. Soybean meal (SBM)	54.2[a]	73.8[a]	47.9[ab]	43.1[a]	57.3[a]	47.5[a]
2. S.D.[2] + 75% SBM	57.7[a]	75.9[a]	46.8[a]	44.2[a]	60.8[a]	57.7[b]
3. S.D. + 50% SBM	67.5[b]	83.9[b]	50.0[ab]	55.6[b]	66.8[b]	63.6[c]
4. S.D. + 25.0% SBM	76.1[c]	85.8[b]	52.2[bc]	56.0[b]	73.4[c]	65.3[c]
5. S.D. + 12.5% SBM	77.8[c]	88.4[b]	56.0[c]	55.4[b]	81.0[d]	67.8[c]

[1]Means with different superscripts within a column are significantly different ($P \leq 0.05$).
[2]Synthetic diet as indicated in Table 1.

(a) *Calcium*

The calcium availability of treatment 1, 2, 3, 4, and 5, (T1, T2, T3, T4, and T5) was 54.2, 57.7, 65.5, 76.1 and 77.8%, respectively. T1 and T2 did not differ significantly from each other and neither did T4 and T5. T3, however, was significantly higher than T1 and T2 but lower than T4 and T5. The cause of improvement in calcium availability may be due either to the decrease in mineral concentration of the mixture or the protein concentration of the diet.

(b) *Phosphorus*

The phosphorus availability for T1, T2, T3, T4 and T5 was 73.8, 75.0, 83.9, 85.8 and 88.0%, respectively. T1 and T2 did not differ significantly from each other but were significantly lower than T3, T4 and T5. The latter three treatments did not significantly differ from each other but availability order was T5 > T4 > T3.

The results showed that phosphorus in soybean meal was highly available to growing chicks. Although phosphate of plant origin is considered poorly available due to the influence of phytate (Taylor, 1965), conflicting reports have appeared in the literature as discussed earlier.

Phosphorus availability also increased with the decrease of phosphorus concentration in the treatment. The whole soybean meal (T_1) diet showed 73.8% available phosphorus whereas the low soybean concentration diet(T5) had 88.4% available phosphorus.

(c) *Magnesium*

Although magnesium (Mg) availability improved with decreasing Mg concentration of the diet, there was no significant improvement until the level of soybean meal dropped to 12.5% of the mixture. The Mg availability with 12.5% soybean meal diet, T5 (56.0%), was significantly higher than the T1 (47.9%), T2 (46.8%) and T3 (50.0%). No significant difference was observed between T4 (52.2%) and T5 (56.0%).

The present study also showed that the availability of Mg appeared to be low in soybean meal. The improvement of Mg availability did not increase drastically even though the Mg concentration was reduced quite significantly from T1 to T5. The results obtained was lower than that reported by Nwokolo *et al.* (1976) and Guenter and Sell (1974), to be 77.4 and 60.4%, respectively.

(d) *Manganese*

Results indicated that the manganese (Mn) availability for T1, T2, T3, T4 and T5 were 43.1, 44.2, 55.6, 56 and 55.4%, respectively. Mn availability in T1 and T2 was significantly lower than T3, T4 and T5, while there was no significant difference within the former or the latter treatment groups. No further improvement of Mn availability lower than the 50% soybean treatment was observed. It appeared that manganese in soybean meal was quite poorly utilized. Gallup and Norris (1935a,b) and Wilgus and Patton (1939) also noted the poor utilization of mineral diets. Inorganic Mn is usually supplemented in conventional diets for poultry to prevent Mn deficiency. It can be understood with the low content and poor availability of Mn from plants.

(e) Zinc

The availability of zinc (Zn) in treatment 1 (T1) was 57.3%. The available value increased with the decrease of zinc concentration in these diets. Zn availability of T2, T3, T4 and T5 were 60.8, 66.8, 73.4 and 81%, respectively. T1 did not differ significantly from T2. T3 was significantly higher than T1 and T2 but significantly lower than T4 and T5. T5 was also significantly higher than T4. Nwokolo *et al.* (1976) reported that Zn availability of soybean was 66.5% which is similar to T3. Homeostasis of body Zn regulates the degree of Zn absorption and endogenous excretion (Underwood, 1977). The low Zn concentration in the diet seemed to enhance the Zn absorption, thus increasing availability.

(f) Copper

The results showed that copper (Cu) availability improved with decreasing Cu concentration in the diet from soybean. The 100% soybean meal diet (T1) gave 47.5% available Cu to the growing chicks whereas 12.5% soybean meal diet (T5) offered 67.8% available Cu. T2 (57.7%) was significantly higher than T1 (47.5%) but significantly lower than T3 (63.6%), T4 (65.3%) and T5 (67.8%). The latter treatment groups were not different statistically from one another. Nwokolo *et al.* (1976) reported a similar Cu availability value (51%) of soybean meal for the growing chicks.

Trial 5

The results of the mineral availability are presented in Table 23. There is a gradual increase in mineral availability as the concentration of wheat decreased. It appeared that there was a dilution effect influencing the availability. The increased retention with decreasing of grain concentration (i.e. mineral concentration) may be explained by the improvement of digestibility and less competition for the binding sites of the protein ligands for mineral transport.

(a) Calcium

Calcium availability of T5 (90%) and T1 (66%) were the highest and lowest, respectively to all the dietary treatments. T3 (75.4%) was significantly higher than T1 and T2 (70.1%) but significantly lower than T4 (85.9%) and T5. There was no significant difference between T1 and T2 or between T4 and T5.

Many factors have been recognized to affect the intestinal absorption of calcium such as vitamin D, calcium and phosphorus ratio. It is reasonable to believe that at lower calcium concentrations in the diet there is improved efficiency of calcium absorption and retention as indicated by Bragg *et al.* (1971). It has been shown that calcium absorption relies on the vitamin D dependent calcium binding protein (CaBP) in the intestinal mucosa of chicks (Wasserman and Taylor, 1968). This protein was intimately involved in the translocation of calcium across the intestinal epithelium.

Hurwitz and Bar (1969) have shown that in laying fowls, the CaBP is independent of the level of calcium fed, but in chicks dietary levels below 0.7% increased CaBP. Walling and Rothman (1970) also reported that dietary calcium restriction caused increased affinity for calcium in the carrier. In the present studies the calcium levels for all the dietary treatments were well below the requirement level. This may suggest that CaBP is actively involved in the absorption process. The higher calcium availability for the lower calcium concentration diet may be due to higher CaBP production to enhance the calcium absorption.

(b) *Phosphorus*

The phosphorus availability (Table 23) in T1 was 65.4% whereas T5 was 92.5%. Significant differences were observed among T1 (65.4%), T2 (75.9%), T3 (81.3%), T4 (91.4%) and T5 (92.5%) with the exception of T4 and T5 which did not differ from each other. It is apparent that phosphorus availability could be very high at low phosphorus concentration in the diets.

TABLE 23: Availability of Minerals in Diets Containing Different Levels of Wheat

Treatment	Availability (%)[1]					
	Ca	P	Mg	Mn	Zn	Cu
1. Whole wheat	66.0[a]	65.4[a]	48.4[a]	34.9[a]	62.3[a]	60.6[a]
2. S.D.[2] + 75% wheat	70.1[a]	75.9[b]	52.2[a]	38.6[a]	66.7[ab]	63.5[a]
3. S.D. + 50% wheat	75.4[b]	81.3[c]	65.6[b]	51.6[b]	72.6[bc]	75.2[b]
4. S.D. + 25% wheat	85.9[c]	91.4[d]	71.4[b]	57.0[bc]	75.7[c]	78.0[b]
5. S.D. + 12.5% wheat	90.1[c]	92.5[d]	88.5[c]	60.2[c]	77.7[c]	90.6[c]

[1] Means with different superscripts within a column are significantly different (Tukey test $P \leq 0.05$).

[2] Synthetic diet as indicated in Table 1.

(c) Magnesium

The results indicated that the available magnesium in the diets increased with the decrease of dietary magnesium concentration. The magnesium availability of T1, T2, T3, T4 and T5 (Table 23) were 48.4, 52.2, 65.6, 71.4 and 88.5%, respectively. There was no significant difference between T1 and T2 and between T3 and T4. However, the latter two treatments were significantly higher than the former two. T5 was significantly higher than all other treatments.

Although a number of factors have been known to affect the magnesium absorption, no single factor appears to play a dominant role in the magnesium absorption. Several studies using ^{28}Mg suggest that absorption of magnesium is influenced by the load presented to the intestinal mucosa (Aikawa, 1959; Graham *et al.*, 1960). Graham *et al.* (1960) demonstrated that on an ordinary diet containing 20 m Eq of magnesium, 44% of the ingested radioactivity was absorbed per day; on low magnesium diets (47 m Eq per day), absorption was decreased to 24%. This seems to agree with the present study, i.e. the absorption increases with the decrease of dietary concentration of magnesium in wheat.

(d) Manganese

Results showed that there was significantly different manganese availability among treatments (Table 23). T3 (51.6%) was significantly higher than T1 (34.9%) and T2 (38.6%) but significantly lower than T5 (60.2%). T4 (57.0%) and T5 did not differ from each other but were significantly higher than T1 and T2.

The precise gastrointestinal loci which are concerned with the absorption of manganese are still unknown. The evidence indicates that the amount of element absorbed is proportional to that presented for absorption (Underwood, 1977). The present results indicate that low manganese concentration in the diet produced the higher efficiency of absorption, although the highest availability is low compared with other minerals tested.

(e) *Zinc*

Similar to other minerals, the availability of zinc in the diet is inversely related to the zinc concentration in the diet (Table 23). Results of the present study indicated that 62.3% of zinc in the all wheat (T1) was available for retention while 77.7% zinc was available in the 12.5% all wheat diet. No significant difference was observed between T1 (62.3%) and T2 (66.7%), T2 and T3 (72.6%) or T4 (75.0%) and T5 (77.7%). However, zinc availability in T3 was significantly lower than T4 and T5 which were also significantly higher than T1 and T2.

It has been recognized that homeostatic control of body zinc in accordance with needs is achieved through regulation of zinc absorption (Miller, 1969; Wilkin *et al.*, 1972) as well as endogenous excretion by the way of feces. Less zinc will be absorbed into the body of animals fed an adequate dietary level of zinc (Miller *et al.*, 1966). The homeostatic control of zinc absorption and excretion may explain the increase of zinc availability in the decreasing amount of zinc concentration in the diets.

(f) Copper

The copper content of the wheat tested was 16 ppm. The copper availability of whole wheat was 60.6%. Copper availability increased as the amount of copper in the diets decreased (Table 23). T1 (60.6%) and T2 (63.5%) did not differ significantly from each other; neither did T3 (75.2%) and T4 (78.0%). The latter was, however, significantly higher than the former group. T5 (90.6%) was significantly higher than any other treatments.

The results suggest that chicks seem to be able to absorb according to the copper concentration of the diets. Although little information is present in the literature on this type of study, there is evidence that copper absorption from the intestine is regulated in accordance with bodily need, at least at the low dietary copper levels. Schwartz and Kirchgessner (1974) demonstrated that both copper uptake by the intestinal wall and its transfer to the serosal solution were elevated in copper deficiency. Under the condition of decreasing copper concentration in the diet, similar mechanism may also occur to improve the absorption and transferring of copper. Consequently, the availability of the diluted copper diets have improved markedly.

Trial 6

The results of calcium (Ca) and phosphorus (P) availability from varying concentrations of calcium phosphate (dibasic) are shown in Table 24. Results indicate that the dietary level of calcium and phosphorus can significantly affect the bioavailability of these minerals.

(a) Calcium

Calcium is highly available at a low level of Ca supplementation as shown in treatments 1, 2, 3, 4, 5 and 6 when the Ca was supplemented up to 0.4% of the diet. Its availability reduced significantly to 63.5% at 0.8% of the diet. A further decrease of Ca availability was observed in treatment 8 (51.2%) and 9 (35.2%). There were significant differences among all levels of Ca supplementation except T1 and T2 and T2 and T4. Treatments 8 and 9 contained 1.2% and 1.6% Ca, respectively and had the lowest available valus. The reduction of availability at the higher levels of supplementation was due to the excess. Studies in rats also showed a very high Ca absorption when animals were on a low Ca intake level and the absorption rate dropped as the intake of calcium increased (Hansard *et al.*, 1954). These results are in agreement with the present experiment.

Although considerable amounts of research have been done onthe bioavailability of various calcium inorganic sources, investigations of seversl researchers failed to reveal any difference in biological availability between different calcium

TABLE 24: Availability of Calcium and Phosphorus from Calcium Phosphate in the Growing Chicks

Treatment		Ca %		P %	Availability (%)[1] Ca	Availability (%)[1] P
1. S.D.	+	0.0125	+	0.0097	99.1[a]	99.0[a]
2. S.D.	+	0.025	+	0.0194	98.9[a]	98.5[a]
3. S.D.	+	0.050	+	0.0388	95.1[b]	98.3[a]
4. S.D.	+	0.100	+	0.0776	94.3[b]	97.9[a]
5. S.D.	+	0.200	+	0.1553	86.1[c]	91.0[b]
6. S.D.	+	0.400	+	0.3105	82.5[d]	83.4[c]
7. S.D.	+	0.800	+	0.6210	63.8[e]	70.0[d]
8. S.D.	+	1.200	+	0.9315	51.2[f]	60.0[e]
9. S.D.	+	1.600	+	1.2420	35.2[g]	47.1[f]

[1]Means with different superscripts within a column are significantly different (Tukey test $P \leq 0.05$).

[2]Synthetic diet as indicated in Table 1.

sources using bone ash and weight gain as a criteria of response in chicks. The sources studied in these various comparisons, included calcium carbonate, calcium sulfate, oyster shell, limestone, various calcium phosphate, gypsum, calcium gluconate and fish meal (Bethke *et al.*, 1929; Waldroup *et al.*, 1964; Sandrof and Mulla, 1965; Spandorf and Leong, 1965). In contrast to these reports, however, a number of researchers have reported differences in biological availability between various calcium carriers for young chicks. Motzok *et al.* (1965), observed that the calcium in soft phosphate was 70% as available as that in calcium carbonate assuming that calcium carbonate was 100% available. Hurwitz and Rand (1965) reported that the calcium in gypsum was 90%, as available as limestone when feed intake was equal. Dilworth *et al.* (1964), showed that the relative calcium availability in various feed grade calcium phosphate ranged from 68 to 95% as compared to calcium carbonate. Reid and Weber (1976) observed the percent calcium availability of ground limestone samples varied from 73.3 to 109.4% in comparison with calcium carbonate. Most of these studies were based on body weight and bone ash content and calcium carbonate was assumed to be 100% available. Therefore, the result obtained was the relative availability rather than "true" availability.

The current studies demonstrated the true availability of calcium fron calcium phosphate at various levels when calcium phosphate was the sole source of Ca in the diet.

(b) Phosphorus

A similar pattern of availability was obtained for phosphorus compared to calcium availability as shown in Table 24. Phosphorus in dicalcium phosphate was highly available to the growing broiler chicks when the supply was not in excess. There was a drastic drop of phosphorus availability values when the dietary concentration of phosphorus was in excess of 0.3%. Very high available phosphorus was observed in treatment (T1) 99%, T2 (98.5%), T3 (98.3%) and T4 (97.9%). No statistical difference was found among these low phosphorus dietary treatments. In the diet containing 0.155% (T5) and 0.32% (T6) phosphorus, the phosphorus availability decreased to 91.0% and 83.4%, respectively. These values were significantly lower than the low phosphorus diets (T1, T2, T3 and T4) and significantly higher than T4 (70.0%), T8 (60.0% and T9 (47.1%). T5 was also significantly higher than that of T6.

A large number of studies have been conducted to determine the relative biological value of the various inorganic phosphate sources for chicks. Assuming beta-tricalcium phosphate to be 100% available, Gillis and associates (1954) reported that the relative value for monocalcium phosphate, dicalcium phosphate, defluorinated phosphate were 113, 98, 98, and 87%, respectively. Similar results were obtained by Nelson and Walker (1964) and Dilworth and Day (1964), however, little information was reported concerning the relationship between the levels of phosphorus regarding bioavailability. The present trial indicates that the phosphorus from calcium phosphate was highly available to the growing broiler chicks. The excess phosphorus offered in the diet is excreted in the feces of the birds.

Trial 7

The results of magnesium (Mg) availability from magnesium carbonate ($4MgCO_3 \cdot Mg(OH)_3 \cdot 5H_2O$) to the growing chicks are shown in Table 25. Results indicated that significantly different availability values were observed at various dietary levels. The Mg requirement recommended by NRC (1977) is 500 ppm. High Mg availability was observed in treatments 1 (T1), 2 (T2) and 3 (T3). The degree of availability decreased gradually with higher Mg concentration. There was no significant difference between T1 (82.3%) and T2 (81.4%) at 150 ppm and 300 ppm Mg diet, respectively. However, Mg availability of T3 (79.4%) was significantly lower than T1 and T4 (73.4%) was significantly higher than T5 (67.1%) and T6 (61.9%). The high level Mg diet, i.e. T5 (750 ppm) and T6 (900 ppm) was significantly lower than other treatments, although Cook (1973) reported that magnesium carbonate was the most available form among magnesium salts. The present experiment indicated that only 82.4% of Mg was available from magnesium carbonate offered at the lowest level (150 ppm). This was determined under the condition of maximum absorption, i.e. no interference from other dietary minerals in the intestine.

TABLE 25: Availability of Magnesium from Magnesium Carbonate in the Growing Chicks

Treatment		Mg level (ppm)	Availability (%)[1] Mg
1. S.D.[2]	+	150	82.3[e]
2. S.D.	+	300	81.4[e]
3. S.D.	+	450	79.4[d]
4. S.D.	+	600	73.6[c]
5. S.D.	+	750	67.1[b]
6. S.D.	+	900	61.9[a]

[1]Means with different superscripts are significantly different between treatments ($P \leq 0.05$).

[2]Synthetic diet as indicated in Table 1.

Limited information has been reported concerning inorganic magnesium salt utilization by poultry. Guenter and Sell (1974), using a radioisotop technique, showed that the availability of Mg from $MgSO_4 \cdot 7H_2O$ was 57.4%. No significant difference was observed between two levels of Mg (i.e. 200 ppm and 400 ppm) supplementation in the diet. The present study was conducted on the nitrogen and mineral-free basis. The high levels of dietary Mg caused a significant decrease in availability. This may be explained by the excess dietary Mg which cannot be absorbed efficiently in the gut or by dietary levels higher than required for metabolism and therefore being excreted in the feces.

Several studies using ^{28}Mg suggest that the absorption of magnesium is influenced by the load presented to the intestinal mucosa (Aikawa, 1959; Graham *et al.*, 1960). Graham *et al.* (1960) demonstrated that a diet containing 20 m Eq of Mg absorbed 44% of the ingested radioactivity per day. On a low magnesium diet (1.9 m Eq/day) 76% was absorbed. On a higher magnesium diet (47 m Eq/day) absorption was decreased to 24%. The trend of Mg absorption with quantity is in agreement with the present studies where excess amounts of Mg were supplied.

Trial 8

Limited information is available in the literature regarding the manganese availability from inorganic sources. Most of the data published concerning inorganic Mn were qualitative rather than quantitative. The present study provides information on Mn availability of manganese sulfate ($MnSO_4 \cdot H_2O$) for the growing broiler chicks. Results (Table 26) indicated that Mn as manganese sulfate was poorly available to the growing broiler. The levels of treatment varied from 25 ppm to 125 ppm which includes levels above and below the NRC (1977) Mn requirement for growing broilers (75 ppm). The values for availability of Mn from manganese sulfate in treatment 1 to treatment 5 ranged from 44.5 to 47.3%. There was no significant difference among all the treatments. Results suggest that Mn from manganese sulfate is poorly available for growing chicks. Therefore, larger quantities of manganese sulfate are needed to meet the dietary requirement.

Schaible and Bandemer (1942) reported that manganese oxide, manganese carbonate, manganese sulfate, manganese chloride were equally valuable as sources of Mn in poultry, however, differences do exist. Watson *et al.* (1970) and Henning *et al.* (1967), using radioactive ^{54}Mn demonstrated that $^{54}MnCl_2$ was incorporated into the body of chicks to a greater extent than that supplied as $^{54}MnSO_4$ or ^{54}MnO. Watson *et al.* (1971), using biological assay also showed that the availability of Mn was different between carbonate and the oxide form.

Since Mn is an important trace mineral in broiler feed, the poor availability and content of Mn in plant sources does not meet the requirements of chickens for maintaining optimum growth and preventing deficiencies. Inorganic supplement is required to meet these needs. The poor availability from manganese sulfate in this trial indicates that larger quantities of manganese sulfate are needed for optimum requirement.

TABLE 26: Availability of Manganese from Manganese Sulfate in the Growing Chicks

Treatment		Mn level (ppm)	Availability (%)[1] Mn
1. S.D.[2]	+	25	44.6[a]
2. S.D.	+	50	44.5[a]
3. S.D.	+	75	47.3[a]
4. S.D.	+	100	46.4[a]
5. S.D.	+	125	46.1[a]

[1] Means with different superscripts are significantly different between treatments ($P \leq 0.05$).

[2] Synthetic diet as indicated in Table 1.

Trial 9

The values for zinc (Zn) availability are shown in Table 27. Results indicated that zinc from zinc oxide was well utilized by growing broiler chicks. The availability of Zn ranged from 84.4 to 93% for all the treatments containing 25 ppm to 125 ppm of zinc. Zn availability was not significantly different among T2 (90.6%), T3 (85.7%), T4 (84.4%) and T5 (84.9%). However, T1 (93%) which contained the lowest Zn concentration (25 ppm) was significantly higher than T4 and T5 which had the higher Zn concentration (100 ppm and 125 ppm, respectively). It appears that the availability of Zn from zinc oxide seems to level off at 100 to 125 ppm. Evans *et al.* (1979), using radioactive dilution techniques with rats showed that the percentage of Zn absorption decreased with the daily Zn obtained. This seems to be in agreement with the present study. A controversial opinion has been expressed on the mechanism of body Zn homeostasis. Several investigators suggested that Zn homeostasis was regulated at the site of Zn absorption (Schwarz and Kirchaessner, 1974; Wilkin *et al.*, 1972). However, work by other investigators (Evans *et al.*, 1979; Miller *et al.*, 1966) demonstrated that homeostasis in rats is maintained by zinc secretion from the intestine rather than by regulation of Zn absorption.

Trials 10 and 11

The availability of copper (Cu) from copper sulfate is presented in Table 28. These results indicate that Cu in copper sulfate at levels of 2 to 30 ppm was well absorbed by growing broiler chicks. It appeared

TABLE 27: Availability of Zinc from Zinc Oxide in the Growing Chicks

Treatment		Zn level (ppm)	Availability (%)[1] Zn
1. S.D.[2]	+	25	93.0[b]
2. S.D.	+	50	90.6[ab]
3. S.D.	+	75	85.7[ab]
4. S.D.	+	100	84.4[a]
5. S.D.	+	125	84.9[a]

[1]Means with different superscripts are significantly different between treatments ($P \leq 0.05$).

[2]Synthetic diet as indicated in Table 1.

that Cu was more available at the lowest level (2 ppm) than at the higher level. T1 (80.2%) was significantly higher than T4 (72.2%) and T5 (72.1%). No significant difference was observed among T2, T3, T4 and T5 as well as between T1, T2 (74.8%) and T3.

Definitive data on the minimum Cu requirement of chicks for growth and egg production have not been established. Diets containing 4-5 ppm Cu can be considered adequate so long as these diets do not contain excessive amounts of elements that are antagonists of Cu such as iron, zinc, cadmium and molybdenum (Underwood, 1977). Cu is absorbed from the stomach and all portions of the small intestine, particularly the upper small intestine (Owen, 1964
1964; Van Camper and Mitchell, 1965). In most species, dietary copper is poorly absorbed (Comar, 1950). The extent of absorption is influenced by the amounts and chemical form of the Cu ingested, by the dietary level of several other metal ions and organic substances and by the age of the animal (Underwood, 1977).

The present study showed that available Cu from copper sulfate was about 72 to 75% when levels of Cu fed were from 4-32 ppm. As previously mentioned, Cu availability is affected by many factors. The influencing factor, however, did not exist in this particular study in which a copper purified diet was employed. The Cu availability from Cu sulfate remained quite similar although the absolute quantity of absorption for this ion increased.

Results of higher dietary copper levels were tested in Trial 11. Results of this trial (Table 29) indicated that there was no

TABLE 28: Availability of Copper from Low Dietary Levels of Copper Sulfate in the Growing Chicks

Treatment		Cu level (ppm)	Availability (%)[1] Cu
1. S.D.[2]	+	2	80.2[b]
2. S.D.	+	4	74.9[ab]
3. S.D.	+	8	74.4[ab]
4. S.D.	+	16	72.2[a]
5. S.D.	+	32	72.1[a]

[1]Means with different superscripts are significantly different between treatments ($P \leq 0.05$).

[2]Synthetic diet as indicated in Table 1.

TABLE 29: Availability of Copper from High Dietary Levels of Copper Sulfate in the Growing Chicks

Treatment	Cu level (ppm)	Availability (%)[1] Cu
1. S.D.[2]	50	62.6[a]
2. S.D.	100	62.6[a]
3. S.D.	150	63.6[a]
4. S.D.	200	62.7[a]
5. S.D.	250	61.8[a]

[1]Means with different superscripts are significantly different between treatments ($P \leq 0.05$).

[2]Synthetic diet as indicated in Table 1.

significant difference in availability of Cu when the dietary level increased from 50-250 ppm. The availability values ranged from 61.8-63.6%.

SUMMARY AND CONCLUSIONS

The availability of six minerals (Ca, P, Mg, Mn, Zn, and Cu) in commercial wheat, triticale, corn and barley samples was determined with three-week old growing broiler chicks. Effects of the level of dietary soybean and of dietary wheat on mineral availability from these two feedstuffs was also evaluated. Furthermore, availability of these minerals from various inorganic saltsssuch as calcium phosphorus (diabasic), magnesium carbonate, manganese sulfate, zinc oxide and copper sulfate was also determined. The cereals under test included eleven samples of wheat, one sample of triticale, ten samples of corn and three samples of barley from various sources. The inorganic minerals were purchased from local chemical suppliers.

The concentration of phosphorus and magnesium fron all the cereal grains was high whereas the concentration of calcium, manganese, zinc and copper was generally low. Results indicate that the availability of copper (78.5%), calcium (71.0%), and phosphorus (67.4%) from wheat and triticale samples ranged from moderate to high for the broiler chicks. However, magnesium (53.5%), zinc (49.6%) and manganese (48.4%) were low in availability. Significant variation ($P \leq 0.01$) was observed among the samples tested. Corn samples showed the highest availability for copper (87.2%), followed by calcium (70.0%), phosphorus(60.9%), manganese (60.0%), zinc (57.5%) and magnesium (51.0%). Similar to the wheat samples, there was significant variation among the corn samples for all the minerals tested. The availability of calcium, phosphorus, magnesium, manganese, zinc and copper in barley was 68.9, 68.8, 54.9, 54.9, 49.1 and 77.5%, respectively. Copper appeared to be the most available for chicks whereas the zinc was the least available. The study of barley also indicates that mineral availability is influenced by the origin of the samples.

Growing broiler chicks appear to have different capacities to digest and absorb nutrients. Availability values of minerals were significantly different when various levels of the feed ingredient were tested. Five levels (100, 75, 50, 25, and 12.5%) of soybean meal and wheat were tested in separate mixtures. The results show that availability of minerals increases with lower levels of the feed ingredient although the relationships between mineral availability and feed-stuff levels is not linear. It is apparent that chicks have greater ability to digest and absorb minerals from the lower feed stuff levels. The increase in retention with a decrease of soybean or wheat concentration (i.e. mineral concentration) may be due to the improvement of digestibility and less competition for the binding sites of protein ligands for mineral transports in the gut.

Availability of calcium and phosphorus from calcium phosphate indicated that each element was highly available to growing chicks. Values of availability decrease with increasing calcium and phosphorus concentration. The availability of calcium ranged from 99.1% to 35.2%, respectively for 0.0125% and 1.6% calcium in the diet. The phosphorus availability ranged from 99.0 to 47.1% for 0.009% and 1.242% phosphorus, respectively. The reduction in availability value with the increase of calcium and phosphorus in the diet was due, in part, to the excess mineral intake rather than to digestibility and retention *per se*. Availability of magnesium from magnesium carbonate indicated that magnesium was highly available to growing broilers. The availability of magnesium ranged from 82.3 to 61.9% for 150 to 900 ppm dietary magnesium, respectively. The magnesium absorption was better with low concentration than with excess magnesium in the diets. Manganese from manganese sulfate was poorly available for growing chicks. The availability of manganese ranged from 44.5 to 47.3%. Various levels of manganese sulfate did not influence the availability value. Therefore, a larger quantity of manganese sulfate is needed as a supplement to meet the nutrient requirements. Zinc availability from zinc oxide was highly available for growing boiler chicks. The availability of zinc ranged from 84.4 to 93% for all the diets containing 25 to 125 ppm of zinc. Copper from copper sulfate was moderately available to growing broiler chicks. The availability values ranged from 80.2 to 72.1% for the supplementation of 2 ppm to 32 ppm of copper, respectively. The higher level of copper supplementation (i.e. 50 to 250 ppm) resulted in copper availability values ranging from 61.8 to 63.6%. The availability of copper tended to decrease at higher dietary levels.

REFERENCES

Aikawa, J. K. 1959. Gastrointestinal absorption of Mg^{28} in rabbits. Proc. Soc. Exp. Biol. Med. 100: 293-295.

Alcock, N. and I. MacIntyre. 1960. Interrelation of calcium and magnesium absorption. Biochem. J. 76: 19P.

Ammerman, C. B., L. R. Arrington, J. T. McCall, J. P. Feaster, G. E. Combs and G. K. Davis. 1963. Inorganic phosphorus utilization by swine as measured by an isotope technique. J. Anim. Sci. 22: 890-893.

Ammerman, C. B., C. F. Chicco, P. E. Loggins and L. P. Arrington. 1972. Availability of different inorganic salts of magnesium to sheep. J. Anim. Sci. 34: 122-126.

Ammerman, C. B., R. M. Forbes, U. S. Garrigus, A. L. Neumann, H. W. Norton and E. E. Hatfield. 1957. Ruminant utilization of inorganic phosphates. J. Anim. Sci. 16: 796-809.

Ammerman, C. B., F. G. Martin and L. R. Arrington. 1970. Mineral contamination of feed samples by grinding. J. Dairy Sci. 53: 1514-1515.

Ammerman, C. B., H. W. Norton and H. M. Scott. 1960. Rapid assay of inorganic phoshpates for chicks. Poultry Sci. 39: 245-250.

A.O.A.C. 1965. Association of Official Agricultural Chemists. Official methods of Analysis. Tenth edition, Washington, D.C.

Anderson, R. J. 1915. The hydrolysis of phytin by the enzyme phytase contained in wheat bran. J. Biol. Chem. 20: 475-481.

Anderson, R., E. Cheng and W. Burroughs. 1956. A laboratory technique for measuring phosphorus availability of feed supplements fed to ruminants. J. Anim. Sci. 15: 489-495.

Armstrong, R. H. and B. Thomas. 1952. The availability of calcium in three legumes of grassland. J. Agric. Sci. 42: 454-460.

Armstrong, R. H., B. Thomas and D. G. Armstrong. 1957. The availability of calcium in three grasses. J. Agric. 49: 446-453.

Armstrong, R. H., B. Thomas and K. Horner. 1953. The availability of calcium in three herbs of grassland. J. Agric. Sci. 43: 337-342.

Ashton, W. M., C. Evans and P. C. Williams. 1960. Phsophorus compounds of oats. II. The utilization of phytic phosphorus by growing chicks. J. Sci. Food Agric. 11: 722-727.

Aubert, J. P., F. Bronner and L. J. Richelle. 1963. Quantitation of calcium metabolism theory. J. Clin. Invest. 42: 858-897.

Balloun, S. L. and W. W. Marion. 1962. Relative efficiency of calcium lactate and calcium carbonate in promoting sound egg shells. Poultry Sci. 41: 1625. (Abstract)

Baruah, J. N., R. E. Davies, B. L. Reid and J. R. Couch. 1960. Phosphorus availability from the ash of unidentified factors sources. Poultry Sci. 39: 840-842.

Bayley, H. S., J. Pos and R. G. Thomson. 1975. Influence of steam pelleting and dietary calcium level on the utilization of phosphorus by the pig. J. Anim. Sci. 40: 857-863.

Bayley, H. S. and R. G. Thomson. 1969. Phosphorus requirements of growing pigs and effect of steam pelleting on phosphorus availability. J. Anim. Sci. 28: 484-491.

Bethke, R. M., D. C. Kennard and C. H. Kick. 1929. The availability of calcium in calcium salts and minerals for bone formation in the growing chick. Poultry Sci. 9: 45-50.

Besecker, R. J., Jr., M. P. Plumbee, R. A. Pickett and J. H. Conrad. 1929. Phosphorus from barley grain for growing swine. J. Anim. Sci. 26: 1477.

Blair, R., P. R. English and W. Michie. 1965. Effect of calcium source on calcium retention in the young chick. Brit. Poul. Sci. 6: 355-356.

Bowland, J. P., R. Braude, A. G. Chamberlain, R. I. Glascock and K. G. Mitchell. 1961. The absorption distribution and excretion of labelled copper in young pigs given different quantities as sulphide orally or intraveneously. Brit. J. Nutr. 15: 59-72.

Bragg, D. B., J. Floyd and E. L. Stephenson. 1971. Facotrs affecting the transfer of calcium (^{45}Ca) from the hen's diet to egg shell. Poultry Sci. 50: 167-173.

Bruce, H. M. and R. K. Callow. 1934. Cereals and rickets. The role of Inositol hexaphosphoric acid. Biochem. J. 28: 517-528.

Brune, H. and H. Bredehorn. 1962. On the physiology of bacterial degradation of calcium oxalate and the ability to utilize calcium from calcium oxidate in the pig. Chem. Abst. 56: 5190a.

Buckner, G. D., J. H. Martin and A. M. Peter. 1929. Calcium metabolism in the laying hen (3). Calcium carbonate and hatchability. Kentucky Agr. Exp. Sta. Bull. 291.

Byrd, C. A. and G. Matrone. 1965. Investigations of chemical basis of zinc-calcium phytate interaction in biological systems. Proc. Soc. Exp. Biol. Med. 119: 347-349.

Cabell, C. A. and I. P. Earle. 1965. Additive effect of calcium and phosphorus on utilization of dietary zinc. J. Anim. Sci. 24: 800-809.

Care, A. D. and Ross, D. B. 1963. The role of adrenal cortex in magnesium homeostasis and in the aetiology of hypomagnesalmia. Res. Vet. Sci. 4: 24-38.

Coleman, B. W., E. M. Reimann, R. H. Grummer and W. G. Hoekstra. 1969. Antagonistic effect of dietary arginine on zinc deficiency in chicks. Fedn. Proc. 28: 761 (Abstract).

Comar, C. L. 1950. *In:* Symposium on Copper Metabolism. (W. D. McElroy and B. Glass, eds.) p. 191. Johns Hopkins Press, Baltimore, Maryland.

Common, R. H. 1939. Phytic acid in mineral metabolism in poultry. Nature 143: 379-380.

Compere, R. 1966. Digestibility in the pig. Factors influencing the digestion of components of the feed and the digestibility of the amino acids. Nutr. Abstr. Rev. 35: 1169.

Cook, D. A. 1973. Availability of magnesium: balance studies in rats with various inorganic magnesium salt. J. Nutr. 103: 1365-1370.

Davies, N. T. and R. Nightingale. 1975. The effects of phytate on intestinal absorption and secretion of zinc, and whole-body retention of zinc, copper, iron and manganese in rats. Br. J. Nutr. 34: 243-258.

Davies, N. T. and H. Reid. 1979. An evaluation of the phytate, zinc, copper, iron and manganese contents of, and Zn availability from soya-based textured-vegetable protein meat substitutes or meat-extenders. Br. J. Nutr. 41: 579-589.

Davis, P. N., L. C. Norris and F. H. Kratzer. 1962. Interference of soybean proteins with the utilization of trace minerals. J. Nutr. 77: 217-223.

Deobald, H. J., C. A. Elvehjem, E. B. Hart and J. G. Halpin. 1936. Availability of calcium salts for chicks. Poultry Sci. 15: 42-47.

Devadatta, S. C. and T. C. Appana. 1954. Availability of calcium in some of the leafy. Proc. Ind. Acad. Sci. 39: 236-242.

Dilworth, B. C. and E. J. Day. 1964. Phosphorus availability studies with feed grade phosphates. Poultry Sci. 43: 1039-1044.

Dilworth, B. C., E. J. Day and J. E. Hill. 1964. Availability of calcium in feed grade phosphate to the chick. Poultry Sci. 43: 1132-1134.

Driggers, J. C. and C. L. Comar. 1949. The secretion of radioactive calcium (Ca^{45}) in the hen's egg. Poultry Sci. 28: 420-424.

Eastwood, M. A. 1973. Vegetable fibre: its physical properties. Proc. Nutr. Soc. 32: 137-143.

Edelstein, S., A. Harell, A. Bar and S. Hurwitz. 1975. The functional metabolism of vitamin D in chicks fed low-calcium and low phosphorus diets. Biochem. Biophy. Acta 385: 438-442.

Edward, H. M. 1959. The availability to chicks of zinc in various compounds and ores. J. Nutr. 69: 306-308.

Elwood, P. C. 1965. Bread and other foods of plant origin as a source of iron. Proc. Nutr. Soc. 24: 112-120.

Emtage, J. S., D. E. Lawson and E. Kodick. 1974. Vitamin D-induced synthesis of mRNA for calcium binding protein. Nature 246: 100-101.

Evans, G. W., C. I. Grace and C. Hahn. 1973. Homeostatic regulation of zinc absorption in the rat. Proc. Soc. Exp. Biol. Med. 143: 723-725.

Evans, G. W. and P. E. Johnson. 1977. Determination of zinc availability in foods by the extrinsic label techniques. Am. J. Clinic. Nutr. 30: 873-878.

Evans, G. W., E. C. Johnson and P. E. Johnson. 1979. Zinc absorption in the rat determined by radio isotope dilution. J. Nutr. 109: 1258-1264.

Fassett, D. W. 1966. Oxalates. *In:* Toxicants Occurring Naturally in Foods. First edition. National Academy of Sciences, Washington, D.C.

Field, A. C. 1961. Studies on magnesium in ruminant nutrition. 3. Distribution of ^{28}Mg in the gastro-intestinal tract and tissues of sheep. Brit. J. Nutr. 15: 349-359.

Fincke, M. L. and H. C. Sherman. 1935. The availability of calcium from some typical food studies on the biological value of inorganic phosphate. J. Biol. Chem. 110: 421-428.

Forbes, R. M. 1963. Mineral utilization in the rat. Effect of varying ratios of calcium, magnesium and phosphorus. J. Nutr. 80: 321-326.

Fritz, J. C. 1973. Effect of processing on the availability and nutritional value of trace mineral elements. *In:* Effect of Processing on the Nutritional Value of Feeds. National Academy of Science. pp. 109-118.

Fritz, J. C. and G. W. Pla. 1972. Application of the animal hemoglobin repletion test to measurement of iron availability in foods. J. Assoc. Off. Anal. Chem. 55: 1128-1132.

Fritz, J. C., G. W. Pla and J. W. Boehne. 1971. Influence of chelating agents on utilization of calcium, iron and magnanese by chick. J. Poultry Sci. 50: 1444-1450.

Fritz, J. C., G. W. Pla, T. Roberts, J. W. Boehne and E. L. Hover. 1970. Biological availability in animals of iron from common dietary sources. J. Agric. Food Chem. 18: 647-651.

Gallup, W. D. and L. C. Norris. 1939a. The amount of manganese required to provent perosis in the chick. Poultry Sci. 18: 76-82.

Gallup, W. D. and L. C. Norris. 1939b. The effect of a deficiency of manganese in the diet of the hen. Poultry Sci. 18: 83-88.

Gillis, M. B., L. C. Norris and G. F. Heuser. 1953. Phosphorus metabolism and requirements of hens. Poutlty Sci. 32: 977-984.

Gillis, M. B., L. C. Norris and G. F. Heuser. 1954. Studies on the biological value of inorganic phosphates. J. Nutr. 52: 115-125.

Gillis, M. B., K. W. Keane and R. A. Collins. 1957. Comparative metabolism of phytate and inorganic P^{32} by chicks and poults. J. Nutr. 62: 13-26.

Gillis, M. B., H. M. Edwards, Jr. and R. J. Young. 1962. Studies on the availability of calcium or the phosphate to chickens and turkeys. J. Nutr. 78: 155-161.

Graham, L. A., Caesar, J. J. and A. S. V. Burgen. 1960. Gastro-intestinal absorption and excretion of Mg^{28} in man. Metabolism 9: 646-659.

Greenberg, D. M. 1945. Studies in mineral metabolism with the aid of artificial radioactive isotopes. VIII. Tracer experiments with radioactive calcium and strontium on the mechanism of vitamin D action in rachitic rats. J. Biol. Chem. 157: 99-104.

Guenter, W. and J. L. Sell. 1974. A method for determining "true" availability of magnesium from feedstuff using chicken. J. Nutr. 104: 1446-1457.

Hanna, S. and I. MacIntyre. 1960. The influence aldosterone on magnesium metabolism. Lacet 2: 348.

Hansard, S. L., C. L. Comar and M. P. Plumlee. 1952. Absorption and tissue distribution of radio calcium in cattle. J. Animal Sci. 11: 524-535.

Hansard, S. L., C. L. Comar and M. P. Plumlee. 1954. The effect of age upon calcium utilization and maintenance requirements in the bovine. J. Anim. Sci. 13: 25-36.

Hayes, S. H., G. L. Cromwell, T. S. Stably and T. H. Johnson. 1979. Availability of phosphorus in corn, wheat and barley for the chick. J. Anim. Sci. 49: 992-999.

Heckman, M. 1967. Minerals in feeds by atomic absorption spectrophotometer. J. AOAC 50: 45-50.

Heywang, B. W. and R. W. Lowe. 1962. Eggshell quality during hot weather with calcium gluconate in the diet. Poultry Sci. 41: 1213-1215.

Henning, A., M. Anke, H. Jeroch, H. Kaltwasser, W. Wiedner, G. Hoffman, M. Diettrich and H. Murray. 1967. Utilization of manganese from different compounds and its distribution in the body of chicks. Biol. Abstr. 48: 75618.

Hijikuro, S., Y. Mohri and H. Morimoto. 1967. The studies on phosphorus availability of various phosphorus sources for laying-type growing chickens. I. Phosphorus availability of some phosphorus sources for starting chicks. Japan Poultry Sci. 4: 19-23.

Hill, C. H., G. Matrone, W. L. Payne and C. W. Barber. 1963. *In vivo* interactions of cadmium with copper, zinc and iron. J. Nutr. 80: 227-235.

Hill, C. H. and B. Starcher. 1965. Effect of reducing agent on copper deficiency in the chick. J. Nutr. 85: 271-274.

Hoff-Jorgensen, E. 1946. The influence of phytic acid on the absorption of calcium and phosphorus. I. In dogs. Biochem. J. 40: 189-192.

Hoshii, H. and M. Yoshida. 1978a. Phosphorus availability of 25 feed ingredients determined by bioassay on toe ash content. Japan Poultry Sci. 14: 274-278.

Hoshii, H. and M. Yoshida. 1978b. Comparison of phosphorus availabilities estimated on toe ash and carcass phosphorus retention. Japan. Poultry Sci. 15: 279-283.

Huisingh, J., G. G. Gomez and G. Matrone. 1973. Interactions of copper, molybdenum and sulfate in ruminant nutrition. Fed. Proc. 32: 1921-1924.

Hunt, C. E. and W. W. Carlton. 1965. Cardiovascular lesions associated with experimental copper deficiency in the rabbit. J. Nutr. 87: 385-393.

Hurwitz, S. and A. Bar. 1969. Relation between the Lumen-blood electrochemical potential difference of calcium, clacium absorption and calcium-binding protein in the intestine of the fowl. J. Nutr. 99: 217-224.

Hurwitz, S. and N. T. Rand. 1965. Utilization of calcium from calcium sulfate by chicks and laying hens. Poultry Sci. 44: 177-183.

Kienholz, E. W., L. S. Jensen and J. McGinnis. 1959. Improvement in nutritional value of peas by cooking. Proc. Soc. Exp. Biol. Med. 102: 35-38.

Kienholz, E. W., L. S. Jensen and J. McGinnis. 1962. Evidence for chick growth inhibitors in several legume seeds. Poultry Sci. 41: 367-371.

Kienholz, E. W., M. L. Sunde and W. G. Hoekstra. 1964. Influence of dietary zinc, calcium and vitamin D for hens on zinc content of tissues and eggs and on bone composition. Poul. Sci. 43: 667-675.

Kirchgesner, M. 1965. Availability of some trace elements. Proc. Nutr. Soc. 24: 89-99.

Kirchgessner, M. and E. Grassman. 1969. The dynamics of copper absorption. *In:* Trace Element Metabolism in Animals. (C. F. Mills, ed.) Proceedings of WAAP/IBP. International Symposium, Aberdeen, Scotland.

Kirchgessner, M., W. Oelschlager and W. Munz. 1961. Effect of chlortetracycline supplement on retention of different minerals and trace elements by growing pigs. Nutr. Abstr. Rev. 31: 1048.

Kratzer, F. H., J. B. Allred, P. N. Davis, B. J. Marshall and P. Vohra. 1959. The effect of autoclaving soybean protein and the addition of ethylene diamine tetraacetic acid on the biological availability of dietary zinc for turkey poults. J. Nutr. 68: 313-322.

Kratzer, F. H. and B. Starcher. 1963. Quantitative relation of EDTA to availability of zinc for turkey poults. Proc. Soc. Exp. Biol. Med. 113: 424-426.

Kratzer, F. H. and P. Vohra. 1966. Some factors influencing the availability of minerals for poultry. Proc. 12th World Poultry Congress, pp. 166-169.

Larsen, B. A., G. S. Bidwell and W. W. Hawkins. 1960. The effect of ingestion of disodium ethylene diamine tetraacetate on the absorption and metabolism of radioactive iron by the rat. Can. J. Biochem. Physiol. 38: 51-55.

Lassiter, J. W., J. W. Morton and W. J. Miller. 1969. Influence of manganese on skeletal development in sheep and rat. *In:* Trace Element Metabolism in Animals. Proceedings of WAAP/IBP International Symposium, Aberdeen, Scotland.

Lease, J. G. 1966. The effects of autoclaving sesame meal on its phytic acid content and on the availability of its zinc to the chick. Poultry Sci. 45: 237-241.

Lease, J. G., B. D. Barnett, E. J. Lease and D. E. Turk. 1960. The biological unavailability to the chick of zinc in a sesame meal ration. Poultry Sci. 39: 1269 (Abstract).

Lease, J. G. and W. P. Williams, Jr. 1967a. The availability of zinc and comparison of *in vitro* and *in vivo* zinc uptake of certain oilseed meals. Poultry Sci. 46: 233-241.

Lease, J. G. and W. P. Williams, Jr. 1967b. The effect of added magnesium on the availability of zinc with some high protein feedstuffs. Poultry Sci. 46: 242-248.

Lengemann, F. W. 1959. The site of action of lactose in enhancement of calcium utilization. J. Nutr. 69: 23-27.

Likuski, H. J. and R. M. Forbes. 1964. Effect of phytic acid on the availability fo zinc in amino acid and casein diets feed chicks. J. Nutr. 84: 145-148.

Likuski, H. J. and R. M. Forbes. 1965. Mineral utilization in the rat. IV. Effects of calcium and phytic acid on the utilization of dietary zinc. J. Nutr. 85: 230-234.

Long, T. A., A. D. Tillman, A. B. Nelson, B. Davis and W. D. Gallup. 1956. Dicalcium phosphate and soft phosphate with coloidal clay as sources of phosphorus for beef heifers. J. Anim. Sci. 15: 1112-1118.

Lowe, J. T., H. Steenbock and C. H. Krieger. 1939. Cereals and rickets. IX. The availability of phytin-P to the chick. Poultry Sci. 18: 40-44.

McCance, R. A., C. N. Edgecombe and E. M. Widdowson. 1943. Phytic acid and iron absorption. Lancet 11: 126-128.

McCance, R. A., E. M. Widdowson. 1944. Activity of the phytase different cereals and its resistance to dry heat. Nature 153: 650.

McConnell, A. A., M. A. Eastwood and W. D. Mitchell. 1974. Physical characteristics of vegetable foodstuffs that could influence bowels function. J. Sci. Food Agric. 25: 1457.

Meintzer, R. B. and H. Steenbock. 1955. Vitamin D and magnesium absorption. J. Nutr. 56: 285-294.

Miller, W. J. 1969. Absorption, tissue distribution endogenous excretion, and homeostatic control of zinc in ruminants. Am. J. Clin. Nutr. 22: 1323-1331.

Miller, W. J., D. M. Balckman, G. W. Powell, H. P. Gentry and J. M. Hiers. 1966. Effects of zinc deficiency *per se* and of dietary zinc level on urinary and endogenous fecal exrection of ^{65}Zn from a single intravenous dose by ruminants. J. Nutr. 90: 335-341.

Ministry of Agriculture, Fisheries and Food. (U.K.) 1973. The analysis of agricultural materials. Technical Bulletin 27.

Miracle, G. L., G. L. Cromwell, T. S. Stahly and D. D. Kratzer. 1977. Availability of phosphorus in corn, wheat and soybean meat for pigs. Abstracts of 69th Annual Meeting, American Society of Animal Science. p. 101.

Miski, A. M. A. and F. H. Kratzer. 1977. Effect of dietary protein glycium and tryptophan on iron metabolism in the growing chick. J. Nutr. 107: 24-34.

Mitchell, H. H. 1964. Comparative Nutrition of Man and Domestic Animals. Vol. II. Academic Press, New York and London.

Mitchell, H. H. 1939. The Dietary Requirement of Calcium and its Significance. Herman Press.

Mittler, S. and G. H. Benham. 1954. Nutritional availability of iodine from several insoluble iodine compounds. J. Nutr. 53: 53-58.

Motzok, K., D. Arthur and H. D. Branion. 1965. Factors affecting the utilization of calcium and phosphorus from soft phosphate by chicks. Poul. Sci. 44: 1261-1269.

Murillo, A., M. S. Campos and G. Varela. 1973. Factors affecting digestibility, absorption and retention of calcium. Effect of oxalate, ethylenediamine tetraacetic acid (disodium salt) nitrilotriacetic acid, lysine and protein quality. Nutr. Abstr. Rev. 43: 134.

Musuhara, T. and B. B. Migicovsky. 1963. Vitamin D and the intestinal absorption of iron and cobalt. J. Nutr. 80: 332-336.

National Research Council. 1969. United States - Canadian tables of feed composition. 2nd revised ed. National Academy of Sciences, Washington, D.C. p. 96.

National Academy of Sciences - National Research Council. 1973. Nutrient requirement of swine. 7th revised ed. NAS-NRC, Washington, D.C. [illegible]

National Academy of Sciences - National Research Council. 1977. Nutrient requirement of poultry. 7th revised ed. NAS-NRC, Washington, D.C.

Nelson, T. S. 1967. The utilization of phytate phosphorus by poultry - A review. Poultry Sci. 46: 862-871.

Nelson, T. S., L. W. Ferrara and N. L. Stores. 1968. Phytate phosphorus content of feed ingredients derived from plants. Poultry Sci. 47: 1372-1374.

Nelson, T. S. and H. T. Peeler. 1961. The availability of phosphorus from single and combined phosphates to chicks. Poultry Sci. 40: 1321-1328.

Nelson, T. S. and A. C. Walker. 1964. The biological evaluation of phosphorus compounds. A summary. Poultry Sci. 43: 94-98.

Nielsen, F. H., M. L. Sunde and W. G. Hoekstra. 1966a. Effect of dietary amino acid source on the zinc deficiency syndrome in the chick. J. Nutr. 89: 24-34.

Nielsen, F. H., M. L. Sunde and W. G. Hoekstra. 1966b. Effect of some dietary synthetic and natural chelating agents on the zinc deficiency syndrome in the chick. J. Nutr. 89: 35-42.

Nugara, D. and H. M. Edwards, Jr. 1962. The interrelationships of calcium, phosphorus and magnesium on growth intestinal absorption and skeletal metabolism. Proc. 12th World's Poultry Congress. pp. 223-229.

Nwokolo, E. N. 1977. Availability of nutrients in vegetable protein supplements for the chick. Ph.D. Thesis. The University of British Columbia.

Nwokolo, E. N. and D. B. Bragg. 1977. Influence of phytic acid and crude fibre on the availability of minerals from four protein supplements in growing chicks. Can. J. Anim. Sci. 57: 475-477.

Nwokolo, E. N., D. B. Bragg and W. D. Kitts. 1976. A method for estimating the mineral availability in feedstuffs. Poultry Sci. 55: 2217-2221.

Oberlease, D. 1973. Toxicants occurring naturally in foods. Washington, D.C., National Academy of Sciences. p. 363.

Oberleas, D. and G. R. Harland. 1977. Nutritional agents which affect metabolic zinc status. *In:* Zinc Metabolism Current Aspects in Health and Disease. (G. J. Brewer amd A. S. Prasad, eds.) Alan R. Liss, Inc., N.Y. p. 11.

Oberleas, D., M. E. Murber and B. L. O'Dell. 1966. Dietary metal complexing agents and zinc availability in the rat. J. Nutr. 90: 56-62.

O'Dell, B. L. 1962. Mineral availability and metal-binding constituents of the diet. Proc. Cornell Nutrition Conf. 1962. pp. 77-83.

O'Dell, B. L., C. E. Burpo and J. E. Savage. 1972. Evaluation of zinc availability in foodstuffs of plant and animal origin. J. Nutr. 102: 653-660.

O'Dell, B. L., E. R. Morris and W. O. Regan. 1960. Magnesium requirement of guinea pigs and rats. Effects of calcium and phosphorus on symptoms of magnesium deficiency. J. Nutr. 70: 103-111.

O'Dell, B. L. and J. E. Savage. 1960. Effect of phytic acid on zinc availability. Proc. Soc. Exp. Biol. Med. 103: 304-306.

O'Dell, B. L., L. M. Yohe and J. E. Savage. 1964. Zinc availability in the chick as effected by phytate, calcium and ethylenediamine tetraacetate. Poultry Sci. 43: 415-419.

Owen, C. A. 1964. Absorption and excretion of Cu^{64}-labelled copper by the rat. Am. J. Physiol. 207: 1203-1206.

Patel, B. M., C. A. Patel and B. J. Patel. 1967. Total phosphorus, phytin phosphorus and oxalate in some common feeds and fodders. India J. Dairy Sci. 20: 14-18.

Patrick, H. and J. A. Bacon. 1957. The effect of viatmin D upon bone mineralization of Ca^{45} and Sr^{89} as chlorides and phosphopeptides. J. Biol. Chem. 228; 569-572.

Peeler, H. T. 1972. Biological availability of nutrients in feeds: availability of major mineral ions. J. Anim. Sci. 35: 695-712.

Pierie, A. B., C. E. Doige, J. M. Bell and B. D. Owen. 1977. Availability of phytate phosphorus to the growing pig receiving isonitrogenous diets based on wheat or corn. Can. J. Anim. Sci. 57: 573-583.

Pla, G. W. and J. C. Fritz. 1971. Collaborative study of the haemoglobin repletion test in chicks and rats for measuring availability of iron. J. Ass. Off. Anal. Chem. 54: 13-17.

Pla, G. W. and J. C. Fritz. 1972. Human plasma iron responses following test doses of iron from known sources. J. Assoc. Off. Anal. Chem. 55: 197-199.

Reid, B. L., A. A. Kurnick, R. L. Svacha and J. R. Couch. 1956. Effect of molybdenum on chick and poult growth. Proc. Soc. Exp. Biol. Med. 93: 245-248.

Reid, B. L. and C. W. Weber. 1976. Calcium availability and trace mineral composition of feed grade calcium supplements. Poultry Sci. 55: 600-605.

Reinhold, H. A. 1975. *In:* Trave Elements in Human Disease. (A. S. Prasad, ed.) Nutrition Foundation, New York.

Reinhold, J. G., P. A. Faraji and F. Ismail-Beigi. 1976. Decreased absorption of calcium, magnesium, zinc and iron to increased fiber and phosphorus consumption as wheat bread. J. Nutr. 106: 493-503.

Reinhold, J. G., F. Ismail-Beigi and B. Faradji. 1975. Fibre vs phytate as determinant of the availability of calcium, zinc and iron of breadstuff. Nutr. Rept. Int. 12: 75-85.

Ritchie, H. D., R. W. Leucke, B. V. Baltzer, E. R. Miller, D. E. Ullrey and J. A. Hoefer. 1963. Copper and zinc interrelationships in the pig. J. Nutr. 79: 117-123.

Roberts, A. H. and J. Yukdin. 1961. Effect of phytate and other dietary factors on intestinal phytase and bone calcification in the rat. Brit. J. Nutr. 15: 457-471.

Rock, J. A. F. and R. C. Campling. 1962. Magnesium metabolism in the dairy cow. IV. The availability of magnesium in various feedingstuffs. J. Agric. Sci. 59: 225-232.

Rucker, R. B., H. E. Parker and J. C. Rogler. 1968. Utilization of calcium and phosphorus from hydrous and anhydrous dicalcium phosphate. J. Nutr. 96: 513-518.

Sandorf, P. E. and M. Mulla. 1965. Performance of meat strain chicks fed various levels and sources of calcium and phosphorus. Poultry Sci. 44: 1413 (Abstr.).

Salman, A. J. and J. McGinnis. 1968. Availability of phosphorus from plant origin to layers. Poultry Sci. 47: 1712 (Abstr.).

Schaible, P. J. and S. L. Bandemer. 1942. The effect of mineral supplements on availability of manganese. Poultry Sci. 21: 8-14.

Schultze, M. O., C. A. Elvehjem and E. B. Hart. 1936. Further studies on the availability of copper from various sources as a supplement to iron in hemoglobin formation. J. Biol. Chem. 115: 453-457.

Schwarz, F. J. and M. Kirchgessner. 1974. Interaction in the intestinal absorption of ^{64}Cu, ^{65}Zn and ^{59}Fe after Cu, Zn or Fe depletion. Int. J. Vitam. Nutr. Res. 44: 116-126.

Scott, M. L., M. C. Nesheim and R. J. Young. 1969. Nutrition of Chicken. M. L. Scott and Associates, Ithaca, New York.

Scott, M. L., H. E. Butters and G. O. Ranit. 1962. Studies on the requirements of young poults for available phosphorus. J. Nutr. 78: 223-230.

Singsen, E. P. 1948. The phosphorus requirements of the chick; with special reference to the availability of phytin phosphorus. Storss. Agr. Exp. Sta. Bull. 260.

Singsen, E. P., L. D. Matterson, J. J. Tlustobwicz and W. J. Pudelkiewicz. 1969a. Phosphorus in the nutrition of the hen. 1. Minimum phosphorus requirements. Poultry Sci. 48: 1401-1414.

Singsen, E. P., C. Riddell, L. D. Matterson and J. J. Tlustohowicz. 1969b. Phosphorus in the nutrition of the adult hen. 3. The influence of phosphorus source and level on cage layer asteoporosis (cage layer fatigue). Poultry Sci. 48: 394-401.

Skorkowska-Zieleniewska, J., C. Ogonowski and J. Bartnik. 1974. Effect of some anti-nutritive substances on the utilization of calcium, magnesium and iron from food. Nutr. Abstr. Rev. 44: 537.

Smith, R. H. 1961. Effect of the ingestion of wood shavings on magnesium and calcium utilization by milk fed cows. J. Agric. Sci. 56: 343-350.

Smith, S. E. and E. J. Larson. 1946. Zinc toxicity in rats. Antagonistic effects of copper and liver. J. Biol. Chem. 163: 29-38.

Snedecar, G. W. 1956. Statistical methods. The Iowa State University Press, Ames, Iowa.

Sobel, A. E. and M. Burger. 1955. Calcification. XIII. The influence of calcium, phosphorus and vitamin D on the removal of lead from blood bone. J. Biol. Chem. 212: 105-110.

Spandorf, A. H. and K. C. Leong. 1965. Biological availability of calcium and phosphorus in menhaden fishmeals. Poultry Sci. 44: 1107-1113.

Stillmak, S. J. and M. L. Sunde. 1970. The use of high magnesium limestone in the diet of the laying hen. 2. Calcium and availability. Poultry Sci. 50: 504-572.

Sullivan, T. W. 1966. A triple resonse method for determining biological value of phosphorus sources with young turkeys. Poultry Sci. 45: 1236-1245.

Summers, J. D., S. J. Slinger and G. Cisneros. 1967. Some factors affecting the biological availability of phosphorus in wheat by-products. Cereal Chem. 44: 318-323.

Suso, F. A. and H. M. Edwards, Jr. 1968. Influence of various chelating agents on absorption of ^{60}Co, ^{59}Fe, ^{54}Mn and ^{65}Zn by chickens. Poultry Sci. 47: 1417-1425.

Suttle, N. F. 1975. *In:* Trace Element in Soil-Plant-Animal Systems. (D. J. D. Nicholas and A. R. Egan, eds.) Academic Press, New York. p. 271.

Taylor, T. G. 1962. The availability of calcium and phosphorus of plant materials for animals. Proc. Nutr. Soc. 24: 105-112.

Temperton, H. and J. Cassidy. 1964. Phosphorus requirements of poultry. I. The utilization of phytin phosphorus by the chick as indicated by balance experiment. Brit. Poult. Sci. 5: 75-80.

Theurer, R. C., K. S. Kemmerer, W. H. Martin, B. L. Zoumas and H. P. Sarett. 1971. Effect of processing on availability of iron salts in liquid infant formula products experimental soy isolate formulas. J. Agric. Food Chem. 19: 555-558.

Thomson, A. B. R., D. Olatunbosun and L. S. Valberg. 1971. Interrelation of intestinal transport system for manganese and iron. J. Lab. Clin. Med. 78: 642-655.

Thompson, A. and A. M. Raven. 1959. The availability of iron in certain grass, clover and herb species. I. Perennial rye grass, cocksfoot and timothy. J. Agric. Sci. 52: 177-186.

Thompson, A. B. R. and Valberg, L. S. 1972. Intestinal uptake of iorn, cobalt and magnanese in the iron deficient rat. Am. J. Physiol. 232: 1327-1329.

Tillman, A. D. and J. R. Brethour. 1958. Dicalcium phosphate and phosphoric acid as phosphorus sources for beef cattle. J. Anim. Sci. 17: 104-112.

Titus, H. W. and J. C. Fritz. 1971. The scientific feeding of chickens. 5th ed. The Interstate, Danville, Ill.

Tompsett, S. L. 1940. Factors influencing the absorption of iron and copper from the alimentary tract. Biochem. J. 34: 961-969.

Tonroy, B., M. P. Plumlee, J. H. and J. T. Cline. 1973. Apparent digestibility of the phosphorus in sorghum grain and soybean meal for growing swine. J. Anim. Sci. 36: 669-673.

Tukey, J. W. 1953. The problem of multiple comparisons. Ditto, Princeton University, Princeton, N. J.

Underwood, E. J. 1977. Trace elements in human and animal nutrition. 4th Edition. Academic Press, New York, San Francisco, London.

van Campen, D. 1969. Competition between copper and zinc during absorption in trace element metabolism in animals. (C. F. Mills, ed.). Proceedings of WAAP/IBP International Symposium, Aberdeen, Scotland.

van Campen, D. 1973. Enhancement of iron absorption from ligated segments of rat intestine by histidine, cysteine and lysine: effects of removing ionizing groups and of stereoisomerism. J. Nutr. 103: 139-142.

van Campen, D. and E. Gross. 1969. Effect of histidine and certain amino acids on the absorption of iron-59 by rats. J. Nutr. 99: 68-74.

van Reen, R. 1953. Effects of excessive dietary zinc in the rat and the interrelationship with copper. Archs. Biochem. Biophys. 46: 337-344.

Visek, W. J., R. A. Morre, E. W. Swanson and C. L. Comar. 1953. Determination of endogenous fecae calcium in cattle by a simple isotope dilution method. J. Nutr. 50: 23-33.

Waldern, D. E. 1971. A rapid micro-digestion procedure for neutral and acid detergent fiber. Can. J. Anim. Sci. 51: 67-69.

Waldroup, P. W., C. B. ammerman and R. H. Marms. 1964. The utilization by the chick of calcium from different sources. Poultry Sci. 43: 212-216.

Walling, M. W. and S. S. Rothman. 1970. Phosphate-independent carrier mediated active transport of calcium by rat intestine. Am. J. Physiol. 217: 1144-1148.

Wasserman, R. H. 1962. Studies on vitamin D3 and the intestinal absorption of calcium and other ions in the nachitic chick. J. Nutr. 77: 69-80.

Wasserman, R. H. and C. L. Comar. 1959. Carbohydrates and gastro-intestinal absorption of radiostrontium and radio-calcium in the rat. Proc. Soc. Exp. Biol. Med. 101: 314-317.

Wasserman, R. H., C. L. Comar and M. M. Nold. 1956. The influence of amino acids and other organic compounds on the gastrointestinal absorption of calcium and strontium. J. Nutr. 59: 371-383.

Wasserman, R. H. and A. N. Taylor. 1968. Vitamin D-dependent calcium binding protein. J. Biol. Chem. 243: 3987-3993.

Watson, L. T., C. B. Ammerman, S. M. Miller and R. H. Harms. 1970. Biological assay of inorganic manganese for chicks. Poultry Sci. 49: 1548-1554.

Watson, L. T., C. B. Ammerman, S. M. Miller and R. H. Harms. 1971. Biological availability to chicks of manganese from different inorganic sources. Poultry Sci. 50: 1693-1700.

Webling, D. D'A and E. S. Holdsworth. 1966. Bile salts and calcium absorption. Biochem. J. 100: 652-660.

Wilcox, R. A., C. W. Carlson, W. Kohlmeyer and G. G. Gastler. 1954. The availability of phosphorus from different sources for poults fed purified diets. Poultry Sci. 33: 1010-1014.

Wilcox, R. A., C. W.Carlson, W. Kohlmeyer and G. G. Gastler. 1955. The availability of phosphorus from different sources for poultry fed practical-type diets. Poultry Sci. 34: 1017-1023.

Wilder, O. H. M., R. M. Bethke and P. R. Record. 1933. The iodine content of hens' eggs as affected by the ration. J. Nutr. 6: 407-412.

Wilgar, H. S., Jr. and Patton, A. R. 1939. Factors affecting manganese utilization in the chicken. J. Nutr. 18: 35-45.

Wilkens, P. J., P. C. Grey and I. E. Dreosti. 1972. Plasma zinc as an indicator of zinc status in rats. Br. J. Nutr. 27: 113-120.

Woodman, H. E. and R. E. Evans. 1948. Nutriton of the bacon pig. XIII. The minimum level of protein intake consistent with the maximum rate of growth. J. Agr. Sci. 38: 354-365.

Worker, N. A. and B. B. Migicovsky. 1961a. Effect of vitamin D on the utilization of beryllium, magnesium, calcium, strontium and barium in the chick. J. Nutr. 74: 490-494.

Worker, N. A. and B. B. Migicovsky. 1961b. Effect of vitamin D on the utilization of zinc, cadmium and mercury in the chick. J. Nutr. 75: 222-224.

Yoshida, M. and H. Hoshii. 1977. Improvement of biological assay to determine available phosphate. Japan Poultry Sci. 14: 33-43.

APPENDIX 1: Analysis of Variance for Mineral Availability from Wheat and Triticale

Source of variance	d.f.	Mean Square					
		Ca	P	Mg	Mn	Zn	Cu
Treatment	11	0.7594**	0.7161**	1.3077**	1.6990**	1.3865**	1.6416**
Replicates	3	0.0152	0.0242	0.0186	0.0063	0.0397	0.0061
Error	33	0.0131	0.0242	0.0296	0.0326	0.0181	0.0148

**Significant ($P \leq 0.01$)

APPENDIX 2: Analysis of Variance for Mineral Availability from Corn

Source of variance	d.f.	Mean Square					
		Ca	P	Mg	Mn	Zn	Cu
Treatment	9	0.4055**	0.9894**	0.3572**	1.4896**	2.8001**	0.2288**
Replicates	3	0.0435	0.0086	0.0878	0.0212	0.0209	0.0293
Error	27	0.0090	0.0237	0.0273	0.0266	0.0177	0.0102

**Significant ($P \leq 0.01$)

APPENDIX 3: Analysis of Variance for Mineral Availability from Barley

Source of variance	d.f.	Mean Square					
		Ca	P	Mg	Mn	Zn	Cu
Treatment	2	3.5267**	0.2031**	0.0949^{NS}	2.5077**	6.5378**	0.1978*
Replicates	3	0.0208	0.0213	0.0194	0.0888*	0.0050	0.0176
Error	6	0.0077	0.0163	0.0406	0.0183	0.0228	0.0172

^{NS}Not Significant

*Significant ($P \leq 0.05$)

**Significant ($P \leq 0.01$)

APPENDIX 4: Analysis of Variance for Mineral Availability in Diets Containing Different Levels of Soybean Meal

Source of variance	d.f.	Mean Square					
		Ca	P	Mg	Mn	Zn	Cu
Treatment	4	1.7008**	0.5037**	0.2644**	0.8861**	1.3312**	1.1582**
Replicates	3	0.0052	0.0168	0.0292	0.0161	0.0142	0.0084
Error	12	0.0230	0.0231	0.0242	0.0455	0.0115	0.0274

**Significant ($P \leq 0.01$)

APPENDIX 5: Analysis of Variance for Mineral Availability in Diets Containing Different Levels of Wheat

Sourve of variance	d.f.	Mean Square					
		Ca	P	Mg	Mn	Zn	Cu
Treatment	4	1.3538**	1.6117**	3.8814**	2.7110**	0.5872**	1.9568**
Replicates	3	0.0206	0.0159	0.0120	0.0328	0.0095	0.0068
Error	12	0.0122	0.0161	0.0298	0.0401	0.0257	0.0296

**Significant ($P \leq 0.01$)

APPENDIX 6: Analysis of Variance for the Availability of Calcium and Phosphorus from Calcium Phosphate (Dibasic)

Source of variance	d.f.	Mean Square	
		Ca	P
Treatment	8	8.1496**	5.1131**
Replicates	3	0.0036	0.0072
Error	24	0.0055	0.0029

**Significant ($P \leq 0.01$)

APPENDIX 7: Analysis of Variance for the Availability of Magnesium from Magnesium Carbonate

Source of variance	d.f.	Mean Square Mg
Treatment	5	0.9629**
Replicates	3	0.0077
Error	15	0.0090

**Significant ($P \leq 0.01$)

APPENDIX 8: Availability of Analysis of Variance for the Manganese Sulfate, Zinc Oxide and Copper Sulfate

Source of variance	d.f.	Mean Square			
		Mn from manganese sulfate (Trial 8)	Zn from zinc oxide (Trial 9)	Cu from copper sulfate (Trial 10)	Cu from copper sulfate (Trial 11)
Treatment	4	0.0327[NS]	0.1654**	0.1436*	0.0066[NS]
Replicates	3	0.0103	0.0170	0.0164	0.0054
Error	12	0.0369	0.0297	0.0290	0.0203

[NS] Not significant

*Significant (P ≤ 0.01)

**Significant (P ≤ 0.05)