C. 1

# THE NUTRITIVE VALUE OF BARLEY FOR BROILERS

by

ROBERT D.Y. CHAN

B.Sc., University of British Columbia, 1976

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES
(Department of Poultry Science)

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

October 1983



78

Robert D.Y. Chan

Department of Poultry Science

The University of British Columbia
1956 Main Mall
Vancouver, Canada
V6T 1Y3

Date October 14, 1983

## ABSTRACT

Availability of Ca, P, Mg, Mn, Cu and Zn were determined from six barley samples using broiler chicks. Each of the barley samples was compared with corn in respect to growth performance and feed conversion. Metabolizable energy of barley and corn samples were evaluated by using a recently developed method.

The results of this study indicate that six minerals were highly available from barley samples with values of 93.9%, 85.2%, 81.4%, 70.4%, 71.3% and 76.5% for Ca, P, Mg, Mn, Zn and Cu, respectively. Variations in availability of minerals among some of the barley samples were observed.

Supplying each barley sample in the control diet at approximately 20% or 40% of the total cereal grains at the expense of corn resulted in no alteration in growth performance, feed consumption and feed conversion to the control except for one barley sample which differed only in feed conversion at 40% composition of cereal grains.

Metabolizable energy of barley and corn samples were comparable. These values correlate with the performance of the broiler chicks.

The results of this study suggest that the availability values from feedstuffs should be considered in formulating diets and that the values from N.R.C. publications may not accurately represent the nutritive quality of a feedstuff.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF APPENDIX TABLES

## ACKNOWLEDGEMENTS

I am deeply grateful to my research supervisor, Dr. D.B. Bragg, Professor and Chairman, Department of Poultry Science, for his patience, advice and encouragement, during the course of the study.

I also like to thank the other members of my graduate committee: Dr. R.M. Beames, Associate Professor, Department of Animal Science; Dr. R.C. Fitzsimmons, Associate Professor, Department of Poultry Science; Dr. J.S. Sim, Assistant Professor, Department of Poultry Science, for their helpful suggestions in this work.

The author wishes to express his sincere thanks to Dr. Al Leslie, Ritchie Smith Feed Ltd., for supplying the barley samples and providing the necessary information that made this study possible.

Finally, I like to extend my gratitude to the following people for their assistance, encouragement and advice: Mel Hudson, Ray Soong, Carol McMillan, Fred Ming, Matt Wolde-Tsadick, Grant Schierman, Betty Carlson, Dean Crick, Roland Low, Kamily Cheung, Lai-mon Aw-yong and Stanley Chu.

Robert D.Y. Chan

# INTRODUCTION

Cereal grains contribute the major part of the farm animal's diet. Grains are used principally to provide the energy and protein required for body growth, maintenance and productivity of the animal.

The values used in feed formulation are based on the content of various nutrients in feedstuffs and not on the availability of those nutrients. The nutritive value of a feedstuff is determined principally by the degree of availability of its nutrients which may not be accurately represented by its contents. The National Research Council stated minimum requirement levels of various nutrients in various poultry diets. Due to insufficient knowledge in regard to nutrient availability of feedstuffs and interactions among different nutrients, minimum recommended requirement levels are subject to criticism.

There is limited research on nutrient availability of cereal grains, although more work has been completed on energy and amino acid availability than on mineral availability.

The purpose of this study was to determine the availability of various minerals in barley. Also, metabolizable energy was measured in barley and corn by a recently developed method. Practical balanced diets, composed of different combinations of barley and corn were fed to broiler chicks to assess the nutritional value of each cereal grain based on growth performance and feed conversion.

# LITERATURE REVIEW

## NUTRITIONAL VALUE OF VARIOUS CEREAL GRAINS

Cereal grains are a major source of food nutrients in many parts of the world. Many countries consume from 100 to 500 pounds of wheat/capita/year and consequently, obtain from 19 to 62 grams of protein/capita/day from wheat and wheat products ( Anonymous, 1981 ).

In Nigeria, sorghum and pearl millet are staple foods for more than 60 percent of the population ( Olatunji *et al*., 1982 ). Sorghum and millet comprised more than 80 percent of the cereals grown in Nigeria. Cereal grains contribute about 42 percent of the total daily calories and 49 percent of total daily protein to the Nigerian diet. About 80 percent of the calories and 64 percent of the protein from cereals are from sorghum and millet ( Olatunji *et al*., 1982 ).

Production trends for the period 1968-1978 indicate that per capita production of cereal grains such as wheat, rice, maize and sorghum in economically developing countries has increased ( Anonymous, 1981 ). Cereal grains are consumed mainly by humans in economically developing countries with 59 to 98 percent consumed by humans and 7 to 41 percent consumed by animals. In the developed countries, however, animals consumed 58 to 86 percent of the total cereal grains and humans 14 to 42 percent ( Anonymous, 1980 ).

Corn is the most commonly used cereal grain as a source of carbohydrate in commercial poultry rations. Several investigators have tested barley as a substitute for corn in poultry diets but it is difficult to make valid comparisons because of experimental variables. In some studies, the substitutions were made on a weight for weight basis rather than on a protein and energy basis so that there were variations in energy, protein, mineral and vitamin contents among treatments.

Arscott ( 1963 ) found that replacing corn for barley as a sole cereal grain at 67 percent of the diet improves body weights and feed conversion. Also, a decrease in sticky droppings was noted. Sibbald and Slinger ( 1963 ) observed that body weight gains of white leghorn chicks fed wheat, barley or oats at different levels of 20, 40 and 60 percent of the diet, were greater for the wheat diet followed by the barley diet with the oats diet being the lowest. Feed efficiency were also better for wheat followed by barley and then oats.

Various researchers have tried different methods to improve the utilization of barley by poultry. Leong _et al_. ( 1960 ) found that the addition of a fungal enzyme or treatment with water improved the utilization of barley 18 and 25 percent, respectively. Arscott _et al_. ( 1960 ) also presented similar results and theorized that barley treated with the methods probably remove an inhibitor(s) or inhibiting action(s). Lucas _et al_. ( 1973 ) found that acid autoclaving of barley significantly improves the nutritional value of barley but the sticky feces condition was not improved when the chick diets contained 55 percent of the test grain.

The low nutritive value of barley was suggested to be principally due to the highly viscous condition in the alimentary tract of chicks caused by B-D-glucan ( Burnett, 1966 ). Burnett ( 1966 ) pointed out that barley with varying levels of B-D-glucan caused different degrees of viscosity. Barleys with high nutritive values were those which contain high levels of B-D-glucanase. This enzyme decreased the highly viscous material in the intestine to improve digestibility of protein and carbohydrate. Willingham et al. ( 1960 ) noted that barley grown in western parts of the U.S. had higher levels of B-D-glucan than eastern U.S. barley and therefore, lower nutritive value. Burnett ( 1966 ) also showed that Australian barley was more viscous than Irish barley because of the higher level of B-D-glucan. Prentice et al. ( 1980 ) analyzed various cereal grains for B-D-glucan content and the results were as follows: oat 6.6%; wheat 1.4%; rye 2.9%; triticale 1.2%; sorghum 1.0%; and barley ( malting ) 4.6-8.2%.

Many of the early studies with barley did not consider equalizing either the protein or carbohydrate in diets when different cereal grains were compared for nutritive value. Fry et al. ( 1956 ) reported that substitution of barley for corn on a weight by weight basis depressed growth and feed efficiency of chicks. However, the addition of tallow to barley diets to equalize the energy content resulted in growth approximately equal to corn. The results of their studies indicate that difference in available energy content of corn and barley accounted largely for the difference in feeding value of these grains. Arscott et al. ( 1957 ) observed that 50 percent dietary corn can be replaced by Hannchin barley provided three percent fat was included in the diet. Fry et al. ( 1957 ) showed that a combination of pearled barley and corn at a ratio of 50:50 gave comparable results to those of corn alone at similar protein level with or without adding tallow. Both growth and feed efficiency of chicks at four weeks of age were similar. Arscott et al.

( 1955 ) showed that use of barley up to 25 percent of the cereal grain component ( or 15.25 percent of total diet ) in a high efficiency broiler ration exerted no significant adverse effect on growth of chicks while growth depression was observed when 50 percent and 100 percent of the grain was barley.

In a study on two types of barley ( Hiproly and Hiproly normal ) in which they were compared with wheat in diets either low ( 13% and 16% ) or high ( 16% and 20% ) protein during the starter and growing periods for broiler chicks, Moss et al. ( 1975 ) showed in the low protein diets that both types of barley produced a better performance than wheat. Birds fed the two types of barley had similar body weight gain, however, feed conversion was the best for Hiproly barley followed by wheat and Hiproly normal barley, both of which were not significantly different. Chicks on the high protein level diet showed the highest body weight gain and best feed conversion for Hiproly barley, followed by Hiproly normal barley and finally wheat.

Fernandez et al. ( 1974 ) studied various cereal grains ( rye, triticale trailblazer, yellow corn, opaque-2 corn, gaines wheat, high protein wheat, Piroline barley and Hiproly barley ) in diets of one protein level. They found that chicks fed Hiproly barley and opaque-2 corn diets had the best body weight gains among the cereal grains tested. Although body weight gains were not significantly different, Hiproly barley was observed to be slightly better than opaque-2 corn. For the PER ( protein efficient ratio: chick growth/protein intake ), opaque-2 corn was significantly better than Hiproly barley, followed by other cereal grains. There were no significant differences in body weight gain among the other grains tested.

ABSORPTION AND REGULATION OF VARIOUS MINERALS

It has been shown with the everted gut sac technique in rats that active transport of Ca is highly developed in the duodenum ( Schacter *et al*., 1960 ). Harmeyer and DeLuca ( 1969 ) showed that in chicks the main site of active transport was also in the duodenum. At any given concentration of Ca, the duodenum has greater ability to absorb Ca per unit length than the jejunum or ileum when measured by the everted gut sac technique. The mechanics of the Ca uptake have been analyzed in inverted sacs of the rat small intestine which indicated that Ca first accumulates within the mucosal surface and then is transported to the serosal surface.

It was shown by Wasserman and Taylor ( 1973 ) with studies using the ligated loop technique in chicks that $^{32}P$ was rapidly translocated across all segments of the small intestine. When the values were expressed per cm. of intestine, the duodenum absorbed more $^{32}P$ than the jejunum or ileum. In an *in vivo* study in the chick, different results were obtained in which most of the $^{32}P$ was absorbed at the upper jejunum.

Magnesium is generally absorbed throughout the digestive tract. Guenter and Sell ( 1973 ) observed that the majority of dietary Mg was taken up by the duodenum, followed by the ileum, colon and jejunum.

The only single study located in the literature on the absorption sites of zinc in chickens was done by Miller and Jensen ( 1966 ). The purpose of their study was to observe the differences in the effects of dietary protein on absorption and excretion of zinc in different sections of the digestive tract of the chick. Their findings showed that the majority of the $^{65}Zn$ was absorbed by the proventriculus and the small intestine. There was more information on Zn absorption in rat studies. Van Campen and Mitchell ( 1965 ) measured uptake of $^{65}Zn$ by selected tissues three hours after injection of the isotope into ligated intestinal segments of adult rats. They showed that the duodenum had the highest rate of absorption followed by the ileum and jejunum with almost no Zn absorbed from the stomach. The results of Van Campen and Mitchell ( 1965 ) have been confirmed by Methfessel and Spencer ( 1966 ) who reported that the absorption of $^{65}Zn$ was 40 percent of the dose for the ligated duodenum, 15 percent for the mid-jejunum and ileal loops and only one to two percent for the stomach and colon.

No information was located on absorption sites for copper in the chicken. From studies on the rat, Cu was absorbed from the stomach and upper gut ( Van Campen and Mitchell, 1965 ). Two separate mechanisms were described for Cu absorption ( Marceau et al., 1970; Crampton et al., 1965 ). The first involves the transport of a copper-amino acid complex to the mucosa of the small intestine and the second involves passive diffusion which accounts for the majority of the ionic Cu absorbed. Evans and LeBlanc ( 1976 ) isolated and characterized a copper-binding protein from the rat intestine which was different from the conventional metallothionein. It was suggested that this intestinal copper-binding protein plays a role in copper absorption by regulating the passage of Cu from the mucosa to the blood.

There was no information observed in the literature on manganese absorption. Apparently, dietary Mn is generally accepted to be poorly absorbed by the chicken ( Scott et al., 1976 ). From rat studies, it was suggested that variable excretion of Mn rather than absorption probably plays an efficient homeostatic regulatory mechanism for maintaining balanced Mn tissue concentrations ( Abrams et al., 1976 ). The area of Mn absorption is one aspect of Mn metabolism which needs to be studied.

EFFECT ON MINERAL AVAILABILITY BY VARIOUS FACTORS

Minerals play obscure but important roles in animal metabolism. A deficiency or excess of some minerals result in metabolic disturbances in the animal. Interaction between two or more minerals or between minerals and organic compounds such as vitamins and amino acids, may improve or impair efficiency of absorption or metabolic function.

High levels of Ca or P in the diet prevent the deposition of Mg in the bone. Increasing Mg in the diet caused the bone Mg to increase ( Nugara and Edwards, 1963 ). It appears that the high Mg-low Ca diet may have caused Mg to replace Ca by deposition in the bone thereby resulting in the higher Mg content of bone. Feeding of Zn was also associated with an increase in the excretion of Ca and P. On the other hand, added dietary supplements of Ca and P can facilitate the removal of excess Zn from the animal body ( Stewart and Magee, 1964 ).

Olson et al. ( 1972 ) demonstrated that, at low doses in the isolated vascularly perfused rat small intestine, calcitonin markedly inhibited Ca absorption whereas large doses of calcitonin markedly increased Ca absorption. This effect remains unexplained. The authors suggested that calcitonin may play a direct role in preventing hypercalcemia resulting from excessive Ca absorption. An effect of calcitonin was also noted by Swaminathan et al. ( 1974 ) and Fox et al. ( 1974 ) who found in sheep and pigs that large doses of calcitonin caused an initial increase in Ca absorption whereas small doses of calcitonin ultimately caused a significant reduction in Ca absorption.

In everted intestinal loops of the rat, cortisone has been shown to reduce active Ca transport and was thought to antagonize the effect of vitamin D on Ca diffusion ( Harrison and Harrison, 1960 ). This decrease in active Ca transport has been confirmed by other workers ( Kimberg et al., 1971; Favus et al., 1973 ). Another type of corticosteroid, prednisolone, also have shown to reduce active Ca transport ( Lukert et al., 1973 ).

Kimberg et al. ( 1971 ) showed that 25-$OHD_3$ did not reverse the cortisone block of active Ca transport and that there were normal amounts of Ca binding protein in the intestinal mucosa of cortisone-treated rats. Favus et al. ( 1973 ) showed that 1,25-$(OH)_2D_3$ failed to restore Ca absorption to control levels in cortisone-treated rats and that the cortisone effect was not mediated via the intermediate metabolism of vitamin D. They proposed that the antagonism between glucocorticoids and vitamin D may be due to a steroid hormone-related alteration in end-organ functions that are independent of any direct interaction between the hormone and vitamin D or its metabolites. Wasserman and Carridino ( 1973 ) have confirmed that the administration of cortisone to rachitic animals does not inhibit calcium binding protein synthesis in response to vitamin D but does inhibit vitamin D stimulation of Ca absorption.

It has been demonstrated that certain amino acids can increase Ca absorption. Wasserman et al. ( 1956 ) found that L-lysine and L-arginine were particularly effective in increasing Ca absorption. Several other amino acids had this property to a lesser extent such as L-leucine, L-tryptophan and L-methionine but glycine, L-valine and L-phenylalanine were relatively ineffective. It had been suggested that the amino acids were able to solubilize Ca phosphates and hence render them more available for absorption. However, it was found that lysine and glycine solubilized Ca phosphate to about the same degree whereas lysine was more than twice as effective as glycine in enhancing Ca absorption. Also, lysine was found to inhibit Ca absorption in the chick and this species difference cannot be explained if the mechanism depends primarily upon an interaction between amino acids and Ca ( Wasserman and Taylor, 1969 ). Raven et al. ( 1960 ) found that the action of lysine was greater in the ileum and the amino acid must be present in the same segment as Ca for absorption to be enhanced. The mechanism of this phenomenon remains unexplained.

Condon et al. ( 1970 ) have shown by balance studies that incorporation of lactose into the diet increased the absorption and retention of Ca in man. Sugars which are apparently inactive, such as glucose, are those that are rapidly absorbed by the upper small intestine but even glucose increases Ca absorption when injected straight into the lumen of the rat ileum ( Vaughan and Filer, 1960 ). The mechanism of lactose enhancement of Ca absorption is not known but several theories have been proposed. One suggestion was that the sugars chelate or complex Ca and another that they exert a non-specific inhibitory effect on the energy-producing mechanisms of the intestinal cell which in turn leads to an increased permeability to Ca ( Wasserman and Taylor, 1969 ).

The vitamin D metabolite 1,25-dihydroxy-cholecalciferol is recognized as the most potent naturally occurring derivative of the parent vitamin ( Henry et al., 1976 ). There is no evidence which indicates that vitamin D plays a direct role in bone calcification ( Thornton, 1970 ). Nevertheless, it is generally accepted that the vitamin enhances the intestinal absorption of Ca and probably P, thereby assuring an adequate mineral supply for this process. The bulk of Ca and P absorption occurred in the proximal small intestine with both hens and chicks ( Hurwitz and Bar. 1971 ).

The pH in the intestinal tract has shown to be a factor in Ca availability ( Hurwitz and Bar, 1971 ). Almost all Ca flowing into the duodenum was in a soluble form at a pH of one to two. The increase of pH in the duodenum to about 6.5 resulted in a massive precipitation of Ca and P in this segment as evidenced by the appearance of a large non-ultra-filterable fraction.

Morgan ( 1969 ) showed that vitamin D enhanced P absorption in the presence of Ca in the everted chick intestine but obtained no evidence that vitamin D had directly affected P transport. Similarly, Sallis and Holdsworth ( 1962 ) using perfused duodenal loops of rachitic chicks *in vitro* found no evidence that vitamin D affected the intestinal absorption of $^{32}P$. Furthermore, Neville and Holdsworth ( 1968 ) showed that only in the presence of Ca did vitamin D increase phosphate translocation in the rachitic chick intestine. In contrast, evidence has been reported that vitamin D directly affects P absorption. Kowarski and Schacter ( 1969 ) concluded that vitamin D increased phosphate transport selectively in the direction of mucosa to serosa by *in vitro* gut segments and that this was independent of the Ca transport mechanism.

Hurwitz and Bar ( 1972 ) were unable to demonstrate any correlation in the chick between Ca and P absorption. They found that the maximum effect of vitamin D was in the jejunum for phosphate absorption and in the duodenum for Ca absorption, thus indicating separate identities for the two processes. Wasserman and Taylor ( 1973 ) found that $^{32}P$ was not absorbed as a co-ion to calcium. Taylor ( 1974 ) showed that ouabain reduced $^{32}P$ transfer *in vitro* in the chick ileum whereas it did not affect

Ca transport.

Chen et al. ( 1974 ) showed that vitamin D stimulated phosphate transport by everted sacs of rat intestine. In the duodenum, Ca greatly increased phosphate transport but had no effect on phosphate transport in the jejunum. These workers concluded that vitamin D stimulation of phosphate in the jejunum was not related to the Ca transport system of the intestine. Chen et al. ( 1974 ) also showed that in the jejunum, vitamin D, 25-$OH_3$ or 1,25-$(OH)_2D_3$ stimulated phosphate transport but 24,25-$(OH)_2D_3$ was not effective. Failure of 24,25-$(OH)_2D_3$ to activate phosphate transport at 48 hours was observed whereas it clearly activated Ca transport by this time ( Boyle et al., 1973 ) by conversion to 1,24,25-$(OH)_3D_3$. Thus, it was suggested that 1,24,25-$(OH)_3D_3$ is a form of vitamin $D_3$ which can specifically activate intestinal Ca transport without activating phosphate transport. These results provided further evidence for two separate systems for Ca and P transport in the intestine.

Parathyroid hormone is primarily concerned with the regulation of Ca homeostasis but is not part of a homeostatic mechanism for regulating plasma phosphate. Sherwood et al. ( 1968 ) have shown with cows and Reiss et al. ( 1970 ) in man that plasma phosphate does not regulate parathyroid hormone secretion directly but can do so by its effect on plasma Ca.

Evidence for an interaction between calcitonin and phosphate comes from mammalian studies. When the diet of rats is low in P but adequate in Ca, hypocalcemic responses to injected calcitonin are abolished. However, adequate P, in combination with low Ca in the diet, does not inhibit the hormone response ( Massry et al., 1977 ).

Controversial reports have appeared concerning local effects of Ca on Mg absorption and vice versa. It has been reported that Mg depresses intestinal Ca absorption in experimental animals ( Alcock and MacIntyre, 1962 ) and also that Mg augments intestinal Ca absorption ( Clark, 1968 ). Excess Ca seems to be absorbed in dietary Mg deficiency and excess Mg absorbed in dietary Ca deficiency ( Alcock and MacIntyre, 1962 ). The explanation for the discrepancy could partly lie in the relationship outlined by Ebel and Comar ( 1968 ). At extremely low dietary Mg levels ( too low for normal growth ) Ca retention is high. With increasing dietary levels of Mg, Ca retention declines, until the level of dietary Mg necessary for normal growth is reached. The Ca retention then rises abruptly, stays unaltered at even higher Mg levels and rises again at very high dietary Mg levels. The mode of action by which Mg exerts its influence on Ca metabolism may be in its effect on the parathyroid gland ( Chou et al., 1979 ).

There is some evidence that Mg concentration affects parathyroid hormone secretion and that parathyroid hormone affects Mg homeostasis but the results were not conclusive. MacIntyre and Davidsson ( 1958 ) showed that Mg deficiency in rats produced hypercalcemia and nephrocalcinosis and Eliel et al. ( 1969 ) subsequently showed that this response could be prevented by parathyroidectomy. This suggests that Mg depletion causes parathyroid stimulation. Studies also have shown that low Mg concentrations stimulate ( Sherwood et al., 1971 ) and high concentrations suppress ( Gitelman et al., 1968 ) parathyroid secretion. Mg has also been shown to increase calcitonin secretion but only in high concentrations ( Littledike and Arnaud, 1971 ). In studies on Mg levels with broiler chicks, Lee and Britton ( 1980 ) observed that excess amounts of Mg caused diarrhea, lower

28-day body weights, increased mortality and leg problems. Increasing dietary P significantly lessened the detrimental effects of Mg toxicity. The authors suggested that the presence of this element in excess may be a reason why there is controversy as to the P requirements of chickens.

Several suggestions have been made concerning the mechanism whereby Ca exerts its antagonistic effect on Zn absorption ( Heth and Hoekstra, 1965; Hoekstra, 1964 ) but most evidence indicates that this effect is mediated by phytic acid ( Likuski and Forbes, 1965; Oberleas et al., 1966 ). This viewpoint was supported by in vitro experiments which have shown that phytate forms a stable complex with Zn at pH 7.4 ( Vohra et al., 1965 ). Precipitation of Zn from solution is dependent upon the presence of both Ca and phytic acid ( Byrd and Matrone, 1965 ). The uptake of $^{65}Zn$ by the mucosal cells of rat intestinal strips decreased progressively as the ratio of Ca:phytate in the medium increased while control strips with Ca alone showed similar effect ( Oberleas et al., 1966 ). These interactions assume that when insoluble Ca phytate is formed in the presence of adequate dietary Ca and phytic acid, Zn was removed from solution by binding with Ca-phytate and therefore was rendered unavailable for absorption ( Byrd and Matrone, 1965 ). Because phytin ( Ca-Mg phytate ) comprises 60-80 percent of the total P in cereals and other plant seeds, the problem of unavailability of minerals bound to phytate was a significant one, especially for animals which are normally fed cereal grains and for humans in those countries where cereals and seed products make up a large portion of the diet ( Byrd and Matrone, 1965 ). It appears that a Ca depression influence on Zn absorption can occur in the presence of either a high level of phytic acid or inorganic phosphate, although phytic acid may be more effective because of its greater insolubility and its poorer absorption. However, studies with semi-purified diets devoid of phytic acid demonstrated the antagonistic effect of Ca ( Heth et al., 1966 ). This effect was found to be dependent upon the level of dietary inorganic phosphorus. Ca significantly depressed $^{65}Zn$ absorption from diets containing about one percent P but not when P level was 0.3 to 0.5 percent.

Dietary phytate not only reduced the availability of Ca and Zn but also Mg, Fe, Mn and Cu ( Davies and Nightingale, 1975 ). A dietary phytate-Zn molar ratio of 6:1 supplies adequate Zn to maintain serum levels in humans subjects ( Harland and Prosky, 1979 ). Davies and Olpin ( 1979 ) have shown that phytate:Zn values exceeding 15-20 resulted in low hair and plasma Zn concentrations and low growth rates in rats. Franz et al. ( 1980 ) indicated that the phytic acid content of various cereal grains and legume seeds was inversely related to Zn availability. However. phytic acid did not appear to hinder Zn availability in legumes as much as in cereals. The molar ratio of phytate:Zn has been suggested as a means to evaluate the availability to animals of Zn in various foodstuffs ( Davies and Olpin, 1979 ).

Like phytate, fiber also caused diminished bioavailability of minerals from plant sources. High fiber diets lead to increased fecal excretion of Ca, Zn, Mg and P and can therefore cause negative balances of these elements in the body ( Reinhold et al., 1976 ). In studying the influence of dietary fiber on the mineral status in chicks, Thompson and Weber ( 1981 ) noted that dietary fiber sources ( wheat bran, corn bran, soy bran, oat hulls and cellulose ) showed no significant differences in body weights and feed intake with the exception of rice bran which caused depressed growth and feed consumption. Reinhold et al. ( 1975 ) maintain that foodstuffs rich in both phytate and fiber ( whole meal bread and bran-based products ) that fiber rather than phytate largely determines the degree to which polyvalent metals are absorbed through the intestinal walls. However, Davies et al. ( 1977 ) reached the opposite conclusion from growth studies on rats in which phytate rather than fiber appeared to be the major determinant in respect to Zn availability.

There are various minerals that show interrelationships with Cu. Both Zn and Cd are antagonistic to Cu utilization in the chick. When either element is added to Cu deficient diets, the severity of the manifestations of Cu deficiency is heightened. These effects were not observed when the diet is supplemented with Cu ( Hill et al., 1963 ). Excessive dietary Mo produced a depression of growth, anemia and diarrhea in rats fed a low Cu diet. Supplementation of Cu prevented anemia and diarrhea but only when Cu was added with a high level of cysteine was growth brought back to normal using high Mo diets. Thompsett ( 1940 ) observed that less Cu was absorbed from a high Ca than from a low diet. Silver was also found to be antagonistic to Cu where Ag retard the growth of chicks in the absence of dietary Cu ( Hill et al., 1964 ). It was demonstrated that both Cu and Zn can induce a Se deficiency in chicks with relatively low dietary Se levels ( Jensen, 1975 ).

Availability of Mn to chicks was decreased considerably with high levels of Ca and P in the diet ( Schaible and Bandemer, 1942 ). Mn is competitive with Fe and Co for common binding sites in the intestine ( Thomson et al., 1971 ). Mn absorption may be influenced by ethanol in which ethanol enhances the transport of Mn two-fold in the intestine of the rat ( Schafer et al., 1974 ).

## AVAILABILITY OF MINERALS FROM VARIOUS CEREAL GRAINS

Cereal grains constitute a major source of animal feed. Although they contribute most significantly as a source of carbohydrates and to a lesser extent as protein, their potential contribution of other nutrients including minerals is frequently overlooked. In nutritional evaluation of a feedstuff, one must consider the concentration of a particular nutrient as well as the biological availability to the animal.

Few studies have been reported on the availability of minerals from cereal grains. In these studies various methods were used to determine the mineral availability. Therefore, the range in the estimated level of availability of a particular mineral is quite often different from one study to another.

Using breaking strength as a criterion for measuring availability of P from various cereal grains, Hayes et al. ( 1979 ) compiled the following results: corn 12%; hard red winter wheat 43%; soft red winter wheat 58% and barley 50%. The P contents in each of these cereal grains were: corn .27%; hard red winter wheat .37%; soft red winter wheat .30% and barley .44%. In respect to both content and availability, barley seemed to be the best grain as a source of P. Stober et al. ( 1979 ) and Cromwell et al. ( 1974 ) showed that P in barley was more available than corn. Most of the P present in cereal grains is organically bound in the form of phytate ( Nelson et al., 1968 ). According to McCance and Widdowson ( 1944 ) and Mollgaard ( 1946 ) cereal grains such as wheat and rye contain high levels of natural phytase with barley having intermediate levels and oats and corn having trace amounts of phytase.

The biological Zn availabilities of various cereal grains obtained from a chick assay method ( O'Dell et al., 1972 ) were: high lysine corn ( .44% lysine; 10.2% protein ) 65%; control corn ( .30% lysine; 8.1% protein ) 63%; rice 62% and wheat 59%. Availability of Zn using a rat assay were: high lysine corn 55%; control corn 57%; rice 39% and wheat 38%. These results showed that the chick can utilize Zn from cereal grains better than the rat.

Guenter and Sell ( 1974 ), using intramuscular injection of radioactive $^{28}Mg$ and assigning an availability index of 100 to $MgSO_4$ in which the " true availability of Mg is 57.4% ", reported the following results from various cereal grains: oats 144; wheat 99; corn 97; barley 95 and rice 74. Assessing Mg bioavailability based on apparent absorption ( ie. feces collected quantitatively and on tissue concentrations of Mg and Ca ) Ranhotra et al. ( 1976 ) showed that about 70 percent of the dietary Mg and Ca from wheat flour were absorbed by the rat.

A more complete study on mineral availability of different cereal grains was done by Aw-Yong ( 1980 ) using the balance procedure of Nwokolo et al. ( 1976 ) to determine availability in which retention of minerals was calculated as intake less fecal excretion corrected for endogenous components and expressed as percentage of intake. Aw-Yong ( 1980 ) determined Ca, P, Mg, Mn, Zn and Cu availability in wheat, barley, corn and triticale. His results, in percentages, are shown as follows:

| | Ca | P | Mg | Mn | Zn | Cu |
|---|---|---|---|---|---|---|
| Wheat | 69.50 | 67.50 | 53.11 | 47.85 | 48.89 | 77.47 |
| Barley | 68.90 | 68.80 | 54.90 | 54.90 | 49.10 | 77.50 |
| Corn | 70.00 | 60.90 | 51.00 | 60.00 | 57.60 | 87.20 |
| Triticale | 87.50 | 66.90 | 58.10 | 54.20 | 57.10 | 90.00 |

From the results of Aw-Yong ( 1980 ), wheat, barley and corn appear to be quite similar in their mineral availabilities except for Mn, Zn and Cu in which corn was slightly better. Barley was similar to wheat in both Zn and Cu except for Mn in which barley was slightly better in availability. Triticale, compared to the other three cereal grains, have the highest availability of Ca and Cu. The author concluded that minerals were highly available from cereal grains.

## METHODS OF DETERMINING MINERAL AVAILABILITY

Various methods have been reported for determining the availability of dietary minerals for animals. The following are some of the methods that have been used.

### 1) Isotope Dilution Method

Radioisotopic procedures have been widely used for the determination of true digestibilities of dietary minerals, particularly Ca and P ( Evans et al., 1979 ). The isotope dilution method assumes (a) the plasma is uniformly labelled and in equilibrium with the tissues and (b) the endogenous excretion into the intestinal tract has the same specific activity as the plasma. The dilution of the total element in the feces by endogenous excretion can be measured by difference in the plasma and fecal specific activities.

### 2) Comparative Balance Method

This method estimates true digestibility directly, using radioisotope balance data derived from pairs of animals, one dosed intravenously and the other orally with a single trace dose of radioactivity. The main assumption in the method is that the dietary source becomes fully labelled by the orally administered radioisotope for the true digestibility applies strictly to the administered radioisotope element. Aubert et al. ( 1963 ) proposed a modification of this method, eliminating the use of paired animals by injection of two different isotopes of the same element.

3) Apparent Digestibility Method

This method measures the intake and total excretory output of test minerals ( Mitchell, 1964 ). Although this method is simple, it is very inaccurate in measuring digestibility of minerals because it does not take into account the endogenous losses from the animal.

4) Bone Ash Method

This method involves the establishment of a standard response curve using a semi-purified basal diet and graded levels of an inorganic salt of the test element, assumed to be 100 percent utilized at low dietary level. A straight line was obtained by plotting the percentage of bone ash of solvent extracted dry fat-free tibia of the chick and the logarithm of the percentage dietary mineral. The test ingredient was substituted for a small fraction of the basal diet. 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. Nelson ( 1967 ) noted that bone ash was one of the most sensitive, practical criteria for evaluating the availability of dietary phosphorus. However, this method is limited to growing animals.

5) Toe Ash Method

This method is based on a linear relationship between dietary phosphorus and toe ash content ( Yoshida and Hoshii, 1977 ). Availability of phosphorus was determined by using a slope ratio assay. The authors concluded that the toe ash method gave more accurate results than the bone ash method.

6) Carcass Analysis Method

The method involves the use of litter mates, some of which were slaughtered at the beginning of the experiment to determine the ratios of body weight to the retention of test minerals ( Armstrong and Thomas, 1952 ). The other members of the litter were fed a controlled diet in which the test ingredient was the only source of the minerals under study. At end of the experimental period, the test animals are slaughtered, ashed and the mineral content determined. Minerals retained, expressed as a fraction of mineral intake, is an indicator of availability. The disadvantage of this method is that it is limited to small animals.

7) Body Weight Method

The method involves standard response curves which are established by supplemental basal diets with graded levels of the test element in inorganic form, assumed to be 100 percent available ( O'Dell et al., 1972 ). A plot of weight or weight gain versus the logarithm of the supplemental element gives a linear response curve at lower levels of supplementation. The test ingredients are analyzed and subsequently substituted for carbohydrate in the basal diet at low levels. The quantity of biologically available mineral is estimated from the standard curve and divided by the content of the test mineral in the ingredient. The method has shown to give inaccurate measurement of available phosphorus and therefore did not correlate well with body weight ( Nelson, 1967 ).

8) True Digestibility Method

This method ( Nwokolo et al., 1976 ) is most economical in terms of labor spent and feed used when compared to the methods that have already been described. The method takes into account the endogenous mineral excretion besides minerals of feed origin. Estimation of endogenous mineral involves the use of purified mineral-free diets. Because endogenous minerals are taken into account in calculating true digestibility, the results are usually higher than apparent digestibility results and are indicative of mineral availability from feed ingested.

METHODS OF DETERMINING METABOLIZABLE ENERGY OF FEED INGREDIENTS

Hill et al. ( 1960 ) described an assay which involves feeding a reference diet containing 44.1 percent of glucose and a similar diet in which a portion of the glucose was replaced by the test material. This procedure has been used extensively for determining the metabolizable energy of grain and grain products. The metabolizable energy ( ME ) values of the test material is calculated using a value of 15.2 KJ/g for glucose which was adopted by Anderson et al. ( 1958 ). The disadvantage of this assay is that the ME value of glucose being used under different experimental conditions was assumed to be constant and that all samples of glucose are of identical purity. This constant value is open to critism because Anderson et al. ( 1958 ) reported that the ME values for glucose ranged from 14.64 to 15.43 KJ/g on a dry matter basis.

McIntosh et al. ( 1962 ) measured the ME values of cereal grains fed alone or in combination with a basal diet. The overall mean values revealed no major differences between the two procedures but individual treatment comparisons showed some degree of variation which present doubts on the assay of grains alone.

March and Biely ( 1973 ) described a ME bioassay in which three weeks old chicks are fasted for 24 hours and then offered either a reference diet or a test material:reference diet mixture for a period of three days following which the birds were again fasted for 24 hours. Feed intake was measured and excreta collected from the end of the first fast until the end of the second fast. This assay tends to give low estimates of ME according to Sibbald( 1975 ) probably because the fecal metabolic energy and the endogenous urinary energy voided over a period of four days were against the feed consumed in three days.

Sibbald and Slinger ( 1963 ) used reference diets composed of practical ingredients and prepared test diets by replacement of a portion of the reference diet. An important part of their procedure was to add the test material to the reference diet at various levels. This makes it possible to determine whether the ME value was constant irrespective of the level of inclusion and permits the estimation of values by regression analysis. A major advantage of this assay is that the reference diet serves as a standard and is assayed in every experiment. A disadvantage is that the ME value of a feedstuff may vary with the composition of the reference diet.

The following two methods, Sibbald's and Farrell's, have been recently developed in 1976 and 1978, respectively. Both methods consumed similar time to obtain results, use small amount of feed and are faster than the methods that are used in the past years. Some feed manufacturers are currently using either of these two methods for ME determinations of feedstuffs because of their economical application.

The quick bioassay of Sibbald ( 1976 ) for the determination of true metabolizable energy involves force-feeding of a known quantity of feedstuff, usually 30 to 40 grams into the crop of young adult cockerels which were previously starved for 24 hours. The excrement were collected from these birds for 48 hours ( Sibbald, 1982 ). To obtain the endogenous excrement, the procedure uses two or more birds which are to be unfed during the experimental period. The true metabolizable energy ( TME ) is calculated as: $TME=IE-( FE+UE ) + ( F_mE+U_eE )$ where FE and UE is the energy voided by the fed bird and $F_mE$ and $U_eE$ is the average of the energy voided by the unfed birds. Sub-samples of feed and feces ( either of endogenous origin or feed origin ) are determined for their gross energy on a gram dry matter basis.

The rapid method of Farrell ( 1978 ) for ME, which have been revised by Farrell ( 1980 ), involves the use of young adult cockerels ( at least six months of age ) trained to consumed their daily feed allowance ( about 80-110 grams ) within one hour. All feeds were cold-pelleted before feeding to the birds which were starved for 32 hours previously. The test material may be fed alone or as partial replacement for a reference diet. The total amount of feed consumed is noted and the excreta voided during the subsequent 32 hours ( Farrell, 1980 ) is collected quantitatively. Gross energy was determined on sub-samples of feed and excreta on a gram dry matter basis. The advantage of Farrell's over Sibbald's method is that one person can carry out the experimental procedure whereas Sibbald's method requires two people.

METABOLIZABLE ENERGY FROM VARIOUS CEREAL GRAINS

Feed is the largest single cost in animal production and accounts for over 50 percent of the poultry production costs ( Sibbald, 1982 ). The bioavailable energy component of feed is about 70 percent of the feed cost ( Sibbald, 1982 ). It was suggested by Sibbald ( 1982 ) that reduction of bioavailability input costs, through the use of more accurate bioavailable energy values to estimate requirements and to formulate rations, offers the greatest potential for increasing production efficiency.

Various researchers reported different values for various types of cereal grains. McNab and Shannon ( 1974 ), utilizing colostomized laying hens, reported values of 2.66, 3.16, 2.64 and 2.91 Kcal/g ME for barley, maize, oat and wheat, respectively. Giurguis ( 1975 ) used a chick assay method to determine ME of various feedstuffs, with the test feedstuff replacing dextrose in basal diets. Among the feedstuffs tested were wheat, barley, corn and oat. The results that he obtained for the cereal grains were 3.37, 2.98, 3.45 and 2.86 Kcal/g respectively.

Using the rapid method for measuring the ME of feedstuffs, Farrell ( 1980 ) reported values of 3.07, 3.68, 3.75, 3.56, 3.63, 3.68, 3.41 and 3.55 Kcal/g for barley, corn, sorghum #1, sorghum #2, triticale #1, triticale #2, wheat #1 and wheat #2, respectively when testing the cereal grains with young adult white leghorn roosters. Farrell ( 1981 ) in another report, reported similar results compared to his previous study ( Farrell, 1980 ). In this study, he reported values of 3.22, 3.10, 3.75, 3.53 and 3.48 Kcal/g, respectively, for barley, oats, sorghum, triticale and wheat.

Differences in ME values of various feedstuffs as influenced by age of chickens have been reported. Petersen et al. ( 1976 ), using a chick assay method, compared the energy utilization of feedstuffs between four weeks old broiler chicks and mature white leghorn hens. The ME for male broiler chicks were 3.11, 3.06 and 2.35 Kcal/g for corn, wheat and barley, respectively; for female broiler chicks, 3.16, 3.10 and 2.41 Kcal/g, respectively; and for hens, 3.49, 3.14 and 3.05 Kcal/g, respectively. They found that there were no significant differences between male and female chicks on ME utilization of different cereal grains. However, there were significant differences between the chicks and hens on ME utilization for corn and barley but not for wheat. Among those cereal grains with differences in ME utilization, the hens could utilize greater energy than chicks. March et al. ( 1973 ) also found that the laying pullet was more efficient than the growing chick when fed rapeseed meal diets. However, in contrast to the findings of Petersen et al. ( 1976 ), Sibbald et al. ( 1960 ) observed no significant differences between ME values of corn determined with chicks and hens.

AMINO ACID AVAILABILITY OF VARIOUS CEREAL GRAINS

The amount of information on amino acid availability from cereal grains is relatively small. DeMuelenaere and Feldman ( 1960 ) reported availability values of 92.8, 89.5, 95.3 and 88.8 percent, respectively, for isoleucine, lysine, methionine and threonine from corn when using the fecal analysis method on rats. DeMuelenaere et al. ( 1967 ) reported lysine of corn and rice proteins to be highly available. Gupta et al. ( 1958 ) have determined that lysine availability value was only 50 percent by using the growth assay method on weanling rats. Pick and Meade ( 1970 ) reported that lysine of opaque-2 corn is as available as that from a reference diet containing fish meal, soybean meal, dried skimmilk, fat and sugars.

Using regression analysis ( weight gained versus lysine consumed ) and applying a slope ratio technique in a growth assay method, Klein et al. ( 1972 ) estimated that the average lysine availability values for normal, opaque-2 corn $V_1$ and opaque-2 $V_2$ were 70, 80 and 89 percent, respectively.

Sasse and Baker ( 1973 ) used growth assays on eight days old chicks to estimate the availability of sulfur amino acids in corn gluten and corn protein by the slope-ratio technique and also by a standard curve method. The availability estimates for corn gluten meal were 98.9% and 99.2% and for corn, 96.5% and 93.9% using the slope-ratio and standard curve methods, respectively.

Using the true metabolizable energy bioassay for determining the apparent amino acid availability and true amino acid availability, Likuski and Dorrell ( 1978 ) had an average apparent amino acid availability of 82 percent and average true amino acid availability value of 97 percent for corn. True amino acid availability value was higher than apparent amino acid availability value because of the correction for metabolic and endogenous amino acid excretion. For apparent amino acid availability, methionine and lysine values were 88 and 72 percent, respectively.

In contrast, the true amino acid availability was 98 and 96 percent for methionine and lysine, respectively.

Sibbald ( 1979 ) also used the true metabolizable energy assay procedure to measure the availability of amino acids of feedstuffs. When ten grams of each cereal grain was fed to adult cockerels, the true amino acid availability of lysine and methionine for corn was 95 and 93 percent, respectively; wheat 91 and 88 percent; Harmon oats 84 and 81 percent; Hinoat oats 96 and 97 percent; barley 81 and 68 percent.

Sarwar and Bowland ( 1975 ) have determined availability of amino acids in different wheat cultivars ( Neepawa, Glenlea, Norquay and Purple ) for weanling rats. They reported that availability values of amino acids other than lysine and tyrosine were above 90 percent. The values for lysine in different wheat cultivars varied from 80 to 85 percent.

Amino acid availabilities from triticale, wheat and barley for growing pigs weighing 10 and 30 kgs. were determined by the fecal analysis method ( Sauer _et_ _al_., 1974 ). In general, true amino acid availability of each essential amino acid decreased in the following order: triticale, wheat and barley. Lysine was found to be the least available essential amino acid from cereal grains.

Availabilities of amino acid in Hiproly, Galt and three high-lysine experimental lines of barley were examined using rats ( Misir and Sauer, 1979 ). Availabilities of amino acids in the high lysine lines were equal to or greater than those of Galt barley and they ranged from 73 to 92 percent for the essential amino acids. Lysine availability was lowest in all the barley types. The lysine values were 72 and 64 percent for Galt and Hiproly, respectively, and 75, 73 and 75 percent for the three high lysine barleys.

Emebo and Roberson ( 1980 ) reported that the overall true amino acid availability of durham wheat, milo and corn were 96.6, 81.4 and 95.5 percent,respectively. The true lysine availability of wheat, milo and corn were 97.6, 73.1 and 94.6 percent,respectively.

Bragg et al. ( 1970 ) have shown that the average biological availability of amino acids in wheat was 92.1 percent. Stephenson et al. ( 1971 ) determined the amino acid content and availability of twenty-four grain sorghum hybrids and found that there were some variation in content and a large variation in availability. Four hybrids were found to be low in availability of all amino acids. There were also hybrids that were high in availability of all amino acids.

Determinations of amino acid availability data for feedstuffs are needed for the most efficient use of feedstuffs. Elwell and Soares ( 1975 ) found that all diets utilizing available amino acids data resulted in improved feed conversions. In general, amino acids of cereal grains are highly available.

## CHEMICAL ANALYSIS OF SIX BARLEY SAMPLES AND ONE CORN SAMPLE

Six barley samples from various locations in Alberta were received from Ritchie-Smith Feed Company in Abbotsford, B.C. All the barley samples were received by Ritchie-Smith Feed Company during the month of March, 1982 with the following description and location:

| SAMPLE | DESCRIPTION | LOCATION |
|---|---|---|
| 1 | Lambes Trucking Ln-5024 | Fort Saskatchewan |
| 2 | CN-427534 | Bruderheim |
| 3 | ALPX-628376 | Olds |
| 4 | CNWX-396939 | Eckville |
| 5 | CPWX-601062 | Didsbury |
| 6 | Unmarked | Didsbury |

All the barley samples were of whole grain form. One ground corn sample from Surrey Co-op Feed Company was also analyzed. The barley and corn samples were all finely grounded in a Wiley Mill equipped with a one mm. screen in the U.B.C. Poultry Science laboratory before chemical analysis of the cereal grains was carried out. Chemical analysis, using the methods described in A.O.A.C. ( 1965 ) was carried out for determining dry matter, crude protein ( N X 6.25 ), ether extract and ash content. The results are shown in Table 1.

Table 1. Chemical analysis of six barley samples and one corn sample ( dry matter basis )

| Sample | Percent | | | |
|---|---|---|---|---|
| | Dry Matter | Crude Protein | Ether Extract | Ash |
| Lambes Trucking | 85.9 | 14.4 | 2.5 | 2.5 |
| CN-427534 | 85.6 | 11.5 | 3.8 | 2.9 |
| ALPX-628376 | 85.7 | 11.2 | 3.4 | 3.0 |
| CNWX-396939 | 86.5 | 13.7 | 3.1 | 3.3 |
| CPWX-601062 | 87.0 | 13.3 | 3.7 | 2.5 |
| Unmarked | 85.6 | 10.6 | 2.7 | 3.1 |
| Corn | 87.4 | 10.1 | 7.2 | 2.7 |

## EXPERIMENT 1. AVAILABILITY OF MINERALS IN SIX BARLEY SAMPLES TO BROILER CHICKS

### EXPERIMENTAL PROCEDURE

Day old broiler chicks from Horizon Hatchery in Abbotsford, B.C. were used to determine the availability of various minerals from the six barley samples. The chicks were raised in Petersime battery brooder cages to three weeks of age before the start of experiment. The chicks were fed a 20 percent crude protein commercial chick starter diet from Surrey Co-op Feed Company in Abbotsford, B.C. from day old to three weeks of age. Feed and water were supplied to the chicks *ad libitum*. Chicks were weighed at three weeks of age and chicks of approximately similar body weights ( $\pm$ 5 grams ) were used. Ninety-six birds were transferred to the stainless steel metabolism cages with four birds per cage. There were four cages of birds for each barley sample. The birds were given three days to acclimatize to the new environment before starting them on a balance procedure used for determining mineral availability ( Nwokolo *et al*., 1976 ).

At 24 days of age, all birds were supplied with a starter diet containing 0.3 percent ferric oxide as a marker for four hours and fasted for 16 hours. Following the fasting period, birds were fed a synthetic diet ( Table 2 ) for four hours. Birds were then fasted for another hour before returning to the marker diet. Feces derived from the synthetic diet were collected ( starting from the end of the first batch of marked excreta and ending at the beginning of the second batch of marked excreted ). On the twenty-fifth day, the same procedure was repeated except the barley samples replaced the

Table 2. Composition of synthetic diet

| Ingredients | Percent |
|---|---|
| Corn Starch | 40.6 |
| Sucrose | 40.6 |
| Alpha-cell | 13.8 |
| Corn Oil | 5.0 |
| | 100.0 |

synthetic diet. There were four replicates for each tested ingredient. Marked feed, including synthetic and barley diets and water, were offered *ad libitum* during the testing period. Limited water was given during the fasting period. Feed consumption of both synthetic and barley 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 degrees celcius for 48 hours. The dry feces were weighed and finely ground in a Kurzzertbetrieb microgrinder to be analyzed for mineral content.

Barley samples and feces from both synthetic and barley diets were wet ashed to determined the Ca, Mg, P, Mn, Zn and Cu contents by using the Jarrel Ash Atomic Absorption Spectrophotometer. Phosphorus was determined by a Unicam SP1800 Ultraviolet Spectrophotometer following color development with ammonium molybdate. The formula used for calculating the percentage availability of minerals after analysis of ingredients and excreta was developed by Nwokolo *et al*. ( 1976 ) as follows:

$$\text{Percent Mineral Availability} = \frac{\text{TMI} - (\text{ TFME} - \text{EFME })}{\text{TMI}} \text{ X } 100$$

where TMI = Total mineral intake from feed ingredient

TFME = Total fecal mineral excreted

EFME = Endogenous fecal mineral excreted

The availability data was subjected to analysis of variance and the statistical comparison of mean by Duncan's Multiple Range Test ( Little and Hills, 1978 ).

RESULTS

The mineral content of six barley samples is shown in Table 3. The average concentration of Ca, P, Mg, Zn, Mn and Cu were 686, 4397, 6619, 15, 70 and 21 ppm, respectively. The average mineral availability of the barley samples for Ca, P, Mg, Mn, Zn and Cu were 93.9%, 85.2%, 81.4%, 70.4%, 71.3% and 76.5%, respectively. These results are shown in Table 4.

Calcium

Results indicate that among the minerals analyzed, Ca in barley has the highest availability. There were significant differences among barley samples tested. The availability values of the various barleys ranged from 84.9% ( barley #3 ) to 98.7% ( barley #1 ). There were no significant differences among barleys #1, #4, #5 and #6 but barley #2 differed significantly from barleys #1, #3 and #4.

Phosphorus

Phosphorus was analyzed to have the second highest availability among the minerals. The average availability was 85.2%. The average values had a range from 78.1% ( barley #3 ) to 92.9% ( barley #1 ). There were no significant differences among barleys #2, #4, #5 and #6 as well as for barleys #1, #4, #5 and #6. There were no significant differences among barleys #1, #2 and #3.

Table 3. Content of minerals in six barley samples ( dry matter basis )

| Barley # | Sample | ppm | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ca | P | Mg | Mn | Zn | Cu |
| 1 | Lambes Trucking | 668 | 4170 | 6704 | 15 | 76 | 28 |
| 2 | CN-427534 | 982 | 4680 | 7154 | 15 | 81 | 22 |
| 3 | ALPX-628376 | 679 | 4400 | 6450 | 14 | 63 | 20 |
| 4 | CNWX-396939 | 616 | 5200 | 6491 | 17 | 87 | 22 |
| 5 | CPWX-601062 | 519 | 3730 | 6406 | 12 | 59 | 22 |
| 6 | Unmarked | 647 | 4200 | 6510 | 15 | 54 | 14 |
| Average | | 686 | 4397 | 6619 | 15 | 70 | 21 |

Table 4. Availability of minerals from six barley samples ( dry matter basis )

| Barley # | Sample | Percent | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ca | P | Mg | Mn | Zn | Cu |
| 1 | Lambes Trucking | $98.7^{a}$ | $92.9^{a}$ | $90.7^{a}$ | $91.1^{a}$ | $93.7^{a}$ | $85.3^{ab}$ |
| 2 | CN-427534 | $92.3^{cd}$ | $82.3^{bc}$ | $79.4^{bc}$ | $78.3^{ab}$ | $78.9^{ab}$ | $68.5^{c}$ |
| 3 | ALPX-628376 | $84.9^{e}$ | $78.1^{c}$ | $73.3^{c}$ | $46.8^{d}$ | $52.1^{c}$ | $68.1^{c}$ |
| 4 | CNWX-396939 | $96.9^{ab}$ | $88.6^{ab}$ | $86.6^{ab}$ | $76.1^{ab}$ | $73.3^{b}$ | $87.7^{a}$ |
| 5 | CPWX-601062 | $95.3^{abc}$ | $84.1^{abc}$ | $76.0^{c}$ | $57.4^{cd}$ | $56.1^{c}$ | $67.9^{c}$ |
| 6 | Unmarked | $95.2^{abcd}$ | $85.0^{abc}$ | $82.4^{abc}$ | $72.7^{bc}$ | $73.6^{b}$ | $81.3^{ab}$ |
| Average | | 93.9 | 85.2 | 81.4 | 70.4 | 71.3 | 76.5 |

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

Magnesium

Magnesium availability was highest in barley #1 ( 90.7% ) and lowest in barley #3 ( 73.3% ). There were no significant differences among barleys #1, #4 and #6; barleys #2, #4 and #6; and for barleys #2, #3, #5 and #6. Differences were noted between barley #1 and barleys #2, #3 and #5.

Manganese

No significant differences were noted among barleys #1, #2 and #4; barleys #2, #4 and #6; and barleys #3 and #5. Differences were noted among barleys #1, #3 and #6.

Zinc

Three barley samples had availability values in the 70's. These were barleys #2, #4 and #6 and were not significantly different. Two barley samples had values at the 50% level. The highest availability value was found with barley #1 at the 90% level.

Copper

The availability of copper, like the other minerals was high with an average value of 76.5%. The availability values range from 67.9% ( barley #5 ) to 87.7% ( barley #4 ). There were no significant differences among barleys #1, #4 and #6 or for barleys #2, #3 and #5. Significant differences were noted between these two groups of barley.

## DISCUSSION

In general, all minerals were highly available from all barley samples. Mn and Zn in barleys #3 and #5 were somewhat low in comparison to other barley samples. Ca in these barley samples averaged 93.9% in availability which is considerably higher than the 68.9% average value reported by Aw-Yong ( 1980 ). However, among the three barley samples analyzed by Aw-Yong ( 1980 ), the locations of two barley samples were known. The local barley from Chilliwack, B.C. has a Ca availability value of 51.9%; whereas, the barley from Alaska was determined to have a considerably higher availability value of 80.5%. The barley samples from this report came from a small region in the province of Alberta and probably because of this, Ca availability of these barley samples did not differed as greatly as the barley samples reported by Aw-Yong ( 1980 ). The Ca availability of the barley samples from this report were comparable to the 80.5% availability value of the Alaska barley reported by Aw-Yong ( 1980 ).

Other cereal grains can have high availability of Ca as shown for one wheat sample with availability value of 82.9% and triticale, with a value of 87.5% ( Aw-Yong, 1980 ). Furthermore, Armstrong and Thomas ( 1952 ) reported Ca availability from plant sources with values of 84.89%, 83.11% and 79.95% for lucerne, red clover and wild white clover, respectively, using rats as the test animals. Armstrong *et al*. ( 1953 ) found that burnet, chicory and narrow-leaved plantain ( three herbs of grassland ) have availability values for Ca of 80.34%, 87.73% and 95.58%, respectively. Nwokolo *et al*. ( 1976 ) reported that Ca was well utilized from soybean meal with an availability value of 85.6%.

Phosphorus availability of the barley samples in this report was also quite high, having an average value of 85.2%. This was higher than the reported average value of 68.8% for P by Aw-Yong ( 1980 ). However, one barley sample he analyzed had a value of 73.2% compared to 66.0% value for the other two samples. Also, three wheat samples had P availability values ranging from 76% to 79%. Only one corn sample had a P availability value over 70% ( 72% ) with availability values of less than 60% for other corn samples.

Nwokolo et al. ( 1976 ) reported P availability values of 89.3%, 76.9%, 74.8% and 70.8% for soybean meal, rapeseed meal, cottonseed meal and palm kernel meal, respectively. The results of this report and others indicate that high availability values for P from plant sources are not uncommon. This view is in contrast with that of the committee on animal nutrition ( NAS-NRC, 1960 ) in which only approximately 30% of the total P in plant materials is considered to be utilized by non-ruminants.

Magnesium in barley samples was comparable to P in availability, having an average value of 81.4%. This value is considerably greater than the average value of Mg reported by Aw-Yong ( 1980 ) where three barley samples all had availability in the 50% range. One of the eleven wheat samples analyzed had a Mg availability value of 70.5% whereas other wheat samples were in the 40% or 50% range. These results suggest that the probable causes of different availability values from cereal grains may be due to the difference in geographical locations, genetical strains or other factor(s) that may influence mineral interactions and availability. Nwokolo et al. ( 1976 ) reported average Mg availability values of 74.6% and 77.8% for cottonseed meal and soybean meal samples, respectively.

Manganese availability, compared to Ca, P and Mg, is considerably lower with an average value of 70.4%. Aw-Yong ( 1980 ) had one barley sample with an availability value of 65.8% whereas the other two samples had lower values of 42.8% and 56.2%. One wheat sample among the eleven tested, showed a high value of 64.3%. Other wheat samples have values between 30%, 40% or 50%. Two corn samples had values of 70% or greater ( 70.1% and 77.3% ). Nwokolo et al. ( 1976 ) reported soybean meal and cottonseed meal to have average availability values of 76.1% and 76.3%, respectively.

The average availability value for zinc was 71.3% compared to the report by Aw-Yong ( 1980 ) of 49.1% for three different barley samples. However, the average value was based on 39.3%, 37.5% and 70.6% for the three samples. The 70.6% value was from the Alaskan barley and is comparable to the value from this report. Aw-Yong ( 1980 ) also had two corn samples with availability values at the 70% level ( 72.5% and 77.1% ). Nwokolo et al. ( 1976 ) reported an availability value of 66.5% for soybean meal. O'Dell et al. ( 1972 ) reported a similar value for soybean meal ( 67% ).

Barley samples, in this report, have an average availability value of 76.5% for Cu. This value is in agreement with Aw-Yong ( 1980 ) with the average value of 77.5%. This value was based on the range between 73.9% and 81.4% whereas the value in this report was based on a range of 68.1% to 87.7% for the six barley samples. Aw-Yong ( 1980 ) reported a corn sample average value of 87.2% based on high values ranging from 81.5% to 94.5%. However, wheat samples had an average value of 78.5% which varied from 60.6% to 92.9%. Nwokolo and Bragg ( 1977 ) reported an average Cu availability value of 74.3% for rapeseed meal.

In general, the results of this report showed that minerals in barley were highly available and were comparable to other cereal grains such as wheat and corn and protein sources such as soybean meal.

## EXPERIMENT 2. EFFECT OF BARLEY ON GROWTH PERFORMANCE AND FEED CONVERSION OF BROILER CHICKS USING PRACTICAL DIETS

### EXPERIMENTAL PROCEDURE

Three hundred and ninety broiler chicks, one day of age were obtained from a commercial hatchery for this experiment. The chicks were maintained in battery brooders during the four weeks experiment. Diets were prepared and supplied to chicks at one day of age. Feed and water were supplied *ad libitum*. Feed consumption, body weights and mortality were recorded on a weekly basis. There were 13 treatments with three replicates of ten chicks ( equal number of each sex ) placed on each treatment.

### DIETARY TREATMENTS

A corn-soybean diet was used as the control treatment containing no barley ( Table 5 ). The control diet was calculated to supply approximately 23% protein with 3200 Kcal/Kg. Each barley sample was supplied at approximately 20% or 40% of the total cereal grains at the expense of corn. All diets were calculated to have similar protein contents based on nutritional values of barley ( NRC, 1977 ).

### RESULTS AND DISCUSSION

Body weight gain, feed conversion and feed consumption per chick are summarized in Table 6. Chicks fed diets with barley containing 20% or

Table 5. Composition of experimental diets

| | Percent | | |
|---|---|---|---|
| Ingredients | 0% [a] | 20% [b] | 40% [c] |
| Soybean meal | 33.75 | 32.90 | 32.00 |
| Barley | 0.00 | 11.00 | 23.00 |
| Corn | 55.25 | 45.10 | 34.00 |
| Meat meal | 4.00 | 4.00 | 4.00 |
| Animal tallow | 5.25 | 5.25 | 5.25 |
| Dicalcium phosphate | 0.75 | 0.70 | 0.65 |
| Limestone | 0.45 | 0.50 | 0.55 |
| Iodized salt | 0.25 | 0.25 | 0.25 |
| D-L-Methionine | 0.1217 | 0.1295 | 0.1379 |
| Vitamin-mineral premix | ** | ** | ** |
| Metabolizable Energy Kcal/Kg | 3201 | 3123 | 3037 |
| % Protein | 23.34 | 23.34 | 23.34 |
| % Calcium | 0.9022 | 0.9051 | 0.9081 |
| % Phosphorus | 0.6974 | 0.6943 | 0.6918 |
| % Lysine | 1.3099 | 1.3024 | 1.2952 |
| % Methionine | 0.3795 | 0.3718 | 0.3635 |

** Premix supplied per Kg diet: Mn, 38.98 mg; Se, 0.03 mg; Zn, 15.60 mg; nicotinic acid, 15.0 mg; calcium pantothenate, 12.0 mg; riboflavin, 4.0 mg; vitamin A, 4500 IU; Vitamin $D_3$, 400 ICU; Vitamin E, 20 IU; Vitamin K ( menadione ), 1.0 mg; biotin, 0.3 mg; Vitamin $B_{12}$, 9.0 mcg; santoquin, 125.0 mg.

## OUTLINE OF EXPERIMENTAL TREATMENTS

a) Diet #13 Diet with no barley ( ie. 0% of total cereal grain )

b) Diets #1 - #6
Diets containing each barley sample comprising 20% of total grain

c) Diets #7 - #12
Diets containing each barley sample comprising 40% of total cereal grain

Table 6. Feed consumption, body weight gain and feed conversion per chick fed different composition of barley samples.

| Diet # | Sample | Composition of cereal grain (%) | Grams | | |
|---|---|---|---|---|---|
| | | | Average feed consumption | Average body weight gain | Average feed conversion |
| 1 | Lambes Trucking | 20 | 1445.83 | 910.48 | $1.59^{b}$ |
| 2 | CN-427534 | 20 | 1515.29 | 940.67 | $1.61^{b}$ |
| 3 | ALPX-628376 | 20 | 1425.13 | 899.01 | $1.59^{b}$ |
| 4 | CNWX-396939 | 20 | 1421.58 | 900.44 | $1.58^{b}$ |
| 5 | CPWX-601062 | 20 | 1413.22 | 878.77 | $1.61^{b}$ |
| 6 | Unmarked | 20 | 1407.10 | 873.64 | $1.61^{b}$ |
| 7 | Lambes Trucking | 40 | 1348.68 | 830.82 | $1.62^{b}$ |
| 8 | CN-427534 | 40 | 1363.59 | 848.18 | $1.61^{b}$ |
| 9 | ALPX-628376 | 40 | 1437.31 | 889.76 | $1.62^{b}$ |
| 10 | CNWX-396939 | 40 | 1406.66 | 834.14 | $1.69^{a}$ |
| 11 | CPWX-601062 | 40 | 1414.10 | 876.33 | $1.61^{b}$ |
| 12 | Unmarked | 40 | 1457.26 | 896.05 | $1.63^{b}$ |
| 13 | Corn | 100 | 1403.52 | 884.03 | $1.59^{b}$ |

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

40% of the total cereal grain showed no significant differences in body weight gain and feed consumption when compared to chicks fed the diet containing corn without barley.

It is interesting to note that all barley-containing diets were comparable to corn in feed consumption, body weight gain and feed conversion except for diet #10. Diet #10 showed a feed conversion significantly higher from other treatments although there were no significant differences in feed consumption and body weight. This may indicate that there was a factor(s) in this barley sample which caused a slight decrease in absorption of a certain nutrient(s) as the chicks consuming this diet had a low body weight gain but with quite a high feed consumption. It appears that the amount of barley sample ( CNWX-396939 ) which could replace corn in the diet is limited for feed conversion because at 20% of total cereal grains there were no significant differences in feed conversion.

Coon _et al_. ( 1979 ) found that among the 22 varieties of barley tested, only two barley types were different from the other samples in feed efficiency when fed to chicks. Also, there were no significant differences in weight gains of the chicks. Wilson and McNab ( 1975 ) reported that no significant differences in feed efficiency ratios for the various barley samples tested when the diets were formulated similar in protein and energy contents or just protein content alone.

Reasons for the findings of Coon _et al_. ( 1979 ) and the present report regarding variations in chick performance on different barley samples remains unexplained. It was suggested by Burnett ( 1966 ) that the probable cause of the low nutritive value of some barley varieties may be due to their high B-D-glucan and low B-D-glucanase contents because B-D-glucan can decrease the availability of protein and carbohydrate. They also noted that barleys with high levels of B-D-glucanase have greater nutritive value. Coon et al. ( 1979 ) found that some barley types analyzed were low in either lysine or both lysine and threonine when compared to other types.

The results in this report are in agreement with those of Arscott et al. ( 1955 ) who showed that inclusion of barley up to 25% of the grain component in the diet exerted no significant effect on the growth of the chick. Arscott et al. ( 1957 ) also reported that 50% of the corn in the diet can be replaced by Hannchin barley without growth depression. Fry et al. ( 1957 ) reported that a combination of pearled barley and corn at a ratio of 50:50 gave comparable results to those of corn alone using similar protein levels with or without adding tallow. Both growth and feed efficiency of chicks at four weeks of age were similar. Fernandez et al. ( 1974 ) reported that Hiproly barley and opaque-2 corn gave the best body weight gains in chicks fed different cereal grains.

Results of this report and earlier reports indicate that most barley varieties can replace a certain percentage of corn in chick diets. There are some reports showing that barley gives better performances than wheat ( Moss et al., 1975; Fernandez et al., 1974 ). Therefore, the general assumption in the past that barley is inferior to corn and wheat is open to criticism. Because the cost of barley is less than both corn and wheat, it would be profitable to use barley in poultry diets to replace corn and wheat at specified dietary levels. The levels of barley and the specific type of barley to replace corn and wheat should be further studied.

# EXPERIMENT 3. METABOLIZABLE ENERGY OF SIX BARLEY SAMPLES AND ONE CORN SAMPLE

## EXPERIMENTAL PROCEDURE

The rapid assay method of Farrell ( 1980 ) was used in this experiment with minor changes. Twenty months old white leghorn roosters were each placed in individual cages with an empty cage used for spacing. The birds were trained for three weeks to consume the daily feed allowance in one hour. At the start of training, 16% protein commercial layer ration ( grounded ) was given to the roosters. The amount of feed consumed within one hour ranged from 60-100 grams ( only birds consuming more than 60 grams were used in the study ). The birds were starved for 48 hours before given their tested barley or corn samples which were also grounded. There were seven out of twelve original roosters that consumed over 60 grams of feed and six were chosen for the experiment. Because body weights were different, the roosters were paired so that total body weight of the paired birds were similar. After the roosters had eaten their hourly allowance, a collection bag was placed under each rooster cage. Collection of excrement was for 48 hours during the fasting period. Excreta was removed and dried ( $85^{o}C$ ) at the end of the 48 hour period. The oven-dried sample was then cooled to room temperature and grounded using the Kurzzertbetrieb microgrinder. Gross energy using the Parr oxygen bomb calorimeter was determined.

## RESULTS AND DISCUSSION

The average ME values ( Table 7 ) in this report were considerably higher

Table 7. Metabolizable energy of barley and corn samples ( dry matter basis )

| Sample | Kcal/gram | | |
|---|---|---|---|
| | Gross energy of grain | Gross energy of feces | Metabolizable energy of grain |
| Lambes Trucking | 4.715 | 1.614 | 3.101 |
| CN-427534 | 4.797 | 1.974 | 2.823 |
| ALPX-628376 | 4.728 | 1.825 | 2.903 |
| CNWX-396939 | 4.667 | 1.741 | 2.926 |
| CPWX-601062 | 4.668 | 1.813 | 2.855 |
| Unmarked | 4.682 | 1.750 | 2.932 |
| Corn | 4.767 | 1.864 | 2.903 |
| Average for barley samples........................ | | | 2.923 |

than the value stated in NRC ( 1977 ). Barley samples tested have an average value of 2.923 Kcal/g compared to 2.624 Kcal/g from NRC ( 1977 ). Although the value was higher than the NRC ( 1977 ) value, it was lower than the value reported by Farrell ( 1980 ) and Farrell ( 1981 ). Farrell reported average values of 3.07 Kcal/g ( Farrell, 1980 ) and 3.22 Kcal/g ( Farrell, 1981 ) for his tested barleys. The ME value of corn in this report is lower than 3430 Kcal/g stated by NRC ( 1977 ). Farrell ( 1980 ) reported an average value of 3.68 Kcal/g. The difference between the results of this report and those of Farrell ( 1980, 1981 ) may be due to the difference in age and strain of the birds used.

With these ME values, the total ME values of each experimental diet were recalculated. The recalculated ME values of each diet is shown in Table 8. The recalculated ME values of the diets containing different barley samples and corn are quite comparable to one another. The ME of the barley diets are either similar or slightly higher than the corn diet without barley. Also, the ME values of these diets are roughly 200 Kcal/Kg less than the original calculated ME values for these diets. From the new recalculated ME values, the difference between the diets with the lowest ( 2899.76 Kcal/Kg ) and highest ( 2963.70 Kcal/Kg ) values was 63.94 Kcal/Kg whereas the difference among the original ME values ( lowest, 3036.85 Kcal/Kg; highest, 3201.23 Kcal/Kg ) was 164.34 Kcal/Kg. Therefore, the new recalculated values of ME for the experimental diets provide a better view of how the broiler chicks perform because chicks in all diets have similar performances in regard to body weight gain, feed consumption and feed conversion except for Diet #10 chicks which differed only in feed conversion.

Table 8. Recalculated metabolizable energy values

| Diet # | Composition of cereal grain (%) | Sample | Metabolizable energy ( Kcal/Kg ) |
|---|---|---|---|
| 1 | 20 | Lambes Trucking | 2936 |
| 2 | 20 | CN-427534 | 2905 |
| 3 | 20 | ALPX-628376 | 2914 |
| 4 | 20 | CNWX-396939 | 2917 |
| 5 | 20 | CPWX-601062 | 2909 |
| 6 | 20 | Unmarked | 2917 |
| 7 | 40 | Lambes Trucking | 2964 |
| 8 | 40 | CN-427534 | 2900 |
| 9 | 40 | ALPX-628376 | 2918 |
| 10 | 40 | CNWX-396939 | 2923 |
| 11 | 40 | CPWX-601062 | 2907 |
| 12 | 40 | Unmarked | 2925 |
| 13 | 100 | Corn | 2910 |

# SUMMARY AND CONCLUSIONS

Broiler chicks were used to determine the mineral availability of Ca, P, Mg, Mn, Cu and Zn from six barley samples. Effects of partial replacement of corn for barley on growth performance and feed conversion of broiler chicks were examined. Metabolizable energy of the barley and corn samples were also evaluated using adult white leghorn roosters.

The results of this study showed that six minerals were highly available from barley samples. The average availability for Ca, P, Mg, Mn, Zn and Cu were 93.9%, 85.2%, 81.4%, 70.4%, 71.3% and 76.5%, respectively. Variations in mineral availability among some of the barley samples were observed.

Partial replacement of corn by barley samples in the diet did not affect body weight gain or feed consumption among treatments with barley at 20% or 40% of the total cereal grains. Treatments show no significant differences in feed conversion except diet #10 consisting of barley CNWX-396939 at 40% replacement of dietary corn. This indicates that factors related to barley composition may decrease the availability of some nutrients in specific samples. Barley samples tested at two dietary levels were comparable to the corn diet in body weight gain, feed consumption and feed conversion except CNWX-396939 at the 40% replacement of dietary corn.

Metabolizable energy values of the barley and corn samples were comparable. When ME values of each experimental diet were recalculated using the analytical ME values of barley and corn, all experimental diets had comparable ME values and were lower than the original ME values calculated using the N.R.C. table for corn and barley. The ME values for dietary treatments compare well with the performances shown by chicks.

The results of this study suggest that the nutrient availability values of feedstuffs should be considered in formulating poultry diets and that the N.R.C. nutrient values may not accurately represent the nutritive quality of a feedstuff.

REFERENCES


Abrams, E., J.W. Lassier, W.J. Miller, M.W. Neathery, R.P. Gentry and R.D. Scarth. 1976. Absorption as a factor in manganese homeostasis. J. Animal Sci. 42: 630-636.

Alcock, N. and I. MacIntyre. 1962. Inter-relation of calcium and magnesium absorption. Clinical Sci. 22: 185-193.

Anderson, D.L., F.W. Hill and R. Renner. 1958. Studies of the metabolizable and productive energy of glucose for the growing chick. J. Nutrition 65: 561-574.

Anonymous. 1980. Food and Agriculture Organization of the United Nations. Ceres. Rev. Agric. Dev. 13: 6.

Anonymous. 1981. Food and Agriculture Organization of the United Nations. Ceres. Rev. Agric. Dev. 14: 30.

A.O.A.C. 1965. Association of official agricultural chemists. Official methods of analysis.

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 K. Horner. 1953. The availability of calcium in three herbs of grassland. J. Agric. Sci. 43: 337-342.

Arscott, G.H. 1963. Use of barley in high-efficiency broiler rations. 6. Influence of small amounts of corn on improvement of barley. Poul. Sci. 42: 301-304.

Arscott, G.H., R.J. Rose and J.A. Harper. 1960. An apparent inhibitor in barley influencing efficiency of utilization by chicks. Poul. Sci. 39: 268-270.

Arscott, G.H., L.E. Johnson and J.E. Parker. 1955. The use of barley in high efficiency broiler rations. I. The influence of methionine, grit and stabilized animal fat on efficiency of utilization. Poul. Sci. 34: 655-662.

Arscott, G.H., W.H. McCluskey and J.E. Parker. 1957. The use of barley in high efficiency broiler rations. 2. Effect of stabilized animal fat and pelleting on efficiency of feed utilization and water consumption. Poul. Sci. 37: 117-123.

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

Aw-Yong, L.M. 1980. Biological availability of minerals from organic and inorganic sources for the chick. PH.D Thesis. University of British Columbia.

Boyle, I.T., J.L. OmDahl, R.W. Gray and H.F. DeLuca. 1973. The biological activity and metabolism of 24,25-Dihydroxyvitamin $D_3$. J. Biol. Chem. 248: 4174-4180.

Bragg, D.B., C.A. Ivy and E.L. Stephenson. 1969. Methods for determining amino acid availability of feeds. Poul. Sci. 48: 2133-2137.

Burnett, G.S. 1966. Studies of viscosity as the probable factor involved in the improvement of certain barleys for chickens by enzyme supplementation. Br. Poul. Sci. 7: 55-75.

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.

Chen, T.C., L. Castillo, M. Korycka-Dahl and H.F. DeLuca. 1974. Role of vitamin D metabolites in phosphate transport of rat intestine. J. Nutrition 104: 1056-1060.

Chou, H-F , R. Schwartz, L. Krook and R.H. Wasserman. 1979. Intestinal calcium absorption and bone morphology in magnesium deficent chicks. Cornell Vet. 69: 88-103.

Clark, I. 1968. Effects of magnesium ions on calcium and phosphorus metabolism. American J. Physiol. 214: 348-356.

Condon, J.R., J.R. Nassim, A. Hilbe, F.J.C. Millard and E.M. Stainthorpe. 1970. Calcium and phosphorus metabolism in relation to lactose tolerance. Lancet 1: 1027-1029.

Coon, C.N., R. Shepler, D. McFarland and J. Nordheim. 1979. The nutritional evaluation of barley selections and cultivars from Washington State. Poul. Sci. 58: 913-918.

Crampton, R.F., D.M. Matthews and R. Poisner. 1965. Observations on the mechanism of absorption of copper by the small intestine. J. Physiol. 178: 111-126.

Cromwell, G.L., V.W. Hays and J.R. Overfield. 1974. Effects of phosphorus levels in corn, wheat and barley diets on performance and bone strength of swine. J. Animal Sci. 39: 180-181 ( Abstr. ).

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. Nutrition 34: 243-258.

Davies, N.T. and S.E. Olpin. 1979. Studies on the phytate:zinc molar contents in diets as a determinant of Zn availability to young rats. Br. J. Nutrition 41: 591-603.

Davies, N.T., V. Hristic and A.A. Flett. 1977. Phytate rather than fibre in bran as the major determinant of zinc availability to rats. Nutritional Reports International 15: 207-214.

DeMuelenaere, H. and R. Feldman. 1960. Availability of amino acids in maize. J. Nutrition 72: 447-450.

DeMuelenaere, H., M-L. Chen and A.E. Harper. 1967. Assessment of factors influencing estimation of lysine availability in cereal products. J. Agric. Food Chem. 15: 310-317.

Ebel, J.G. and C.L. Comar. 1968. Effect of dietary magnesium on strontium-calcium discrimination and incorporation into bone of rats. J. Nutrition 96: 403-408.

Eliel, L.P., W.O. Smith, R. Chanes and J. Hawrylko. 1969. Magnesium metabolism in hyperparathyroidism and osteolytic disease. Ann. N.Y. Acad. Sci. 162: 810-830.

Elwell, D. and J.H. Soares, JR. 1975. Amino acid bioavailability: A comparative evaluation of several assay techniques. Poul. Sci. 54: 78-85.

Emebo, G.O. and R.H. Roberson. 1980. The true amino acid availability of feedstuffs for poultry. Poul. Sci. 59: 1604 ( Abstr. ).

Evans, G.W. and F.N. LeBlanc. 1976. Copper-binding protein in rat intestine: amino acid composition and function. Nutrition Reports International 14: 281-288.

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

Farrell, D.J. 1978. Rapid determination of metabolizable energy of foods using cockerels. Br. Poul. Sci. 19: 303-308.

Farrell, D.J. 1980. The ' Rapid Method ' of measuring the metabolizable energy of feedstuffs. Feedstuffs 52(45): 24.

Farrell, D.J. 1981. An assessment of quick bioassays for determining the true metabolizable energy and apparent metabolizable energy of poultry feedstuffs. World's Poul. Sci. J. 37: 72-83.

Favus, M.J., M.W. Walling and D.V. Kimberg. 1973. Effects of 1,25-Dihydroxycholecalciferol on intestinal calcium transport in cortisone-treated rats. J. Clin. Invest. 52: 1680-1685.

Fernandez, R., E. Lucas and J. McGinnis. 1974. Comparative nutritional value of different cereal grains as protein sources in a modified chick bioassay. Poul. Sci. 53: 39-46.

Fox, J., S. Tomlinson and A.D. Care. 1974. Adaptation to a low calcium diet in parathyroidectomized pigs. J. Endocrinol. 61: ixxviii-ixxix.

Franz, K.B., B.M. Kennedy and D.A. Fellers. 1980. Relative bioavailability of zinc from selected cereals and legumes using rat growth. J. Nutrition 110: 2272-2283.

Fry, R.E., J. McGinnis and L.S. Jensen. 1956. Influence of diet composition on feed selection and growth of chicks and turkeys. Poul. Sci. 35: 1143 ( Abstr. ).

Fry, R.E., J.B. Allred, L.S. Jensen and J. McGinnis. 1957. Effect of pearling barley of different supplements to diets containing barley on chick growth and feed efficiency. Poul. Sci. 37: 281-288.

Gitelman, H.J., S. Kukolj and L.G. Welt. 1968. Inhibition of parathyroid gland activity by hypermagnesemia. American J. Physiol. 215: 483-485.

Guenter, W. and J.L. Sell. 1973. Magnesium absorption and secretion along the gastrointestinal tract of the chicken. J. Nutrition 103: 875-881.

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

Guirguis, N. 1975. Evaluating poultry feedstuffs in terms of their metabolizable energy content and chemical composition. Aust. J. Exptl. Animal Husbandry 15: 773-779.

Gupta, J.D., A.M. Dakroury, A.E. Harper and C.A. Elevhjem. 1958. Biological availability of lysine. J. Nutrition 64: 259-270.

Harland, B.F. and R.D.L. Prosky. 1979. Development of dietary fiber values for foods. Cereal Foods World 24: 387-393.

Harmeyer, J. and H.F. DeLuca. 1969. Calcium-binding protein and calcium absorption after vitamin D administration. Archives of Biochem. Biophysics 133: 247-254.

Harrison, H.E. and H.C. Harrison. 1960. Transfer of $Ca^{45}$ across intestinal wall in vitro in relation to action of vitamin D and cortisol. American J. Physiol. 199: 265-271.

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. Animal Sci. 49: 992-999.

Henry, H.L., A.W. Norman, A.N. Taylor, D.L. Hartenbower and J.W. Coburn. 1976. Biological activity of 24,25-dihydroxycholecalciferol in chicks and rats. J. Nutrition 106: 724-734.

Heth, D.A. and W.G. Hoekstra. 1965. Zinc-65 absorption and turnover in rats. 1. A procedure to determine Zinc-65 absorption and the antagonistic effect of calcium in a practical diet. J. Nutrition 85: 367-374.

Heth, D.A., W.M. Becker and W.G. Hoekstra. 1966. Effect of calcium, phosphorus and zinc on zinc-65 absorption and turnover in rats fed semipurified diets. J. Nutrition 88: 331-337.

Hill, F.W., D.L. Anderson, R. Renner and L.B. Carew, JR. 1960. Studies of the metabolizable energy of grain and grain products for chickens. Poul. Sci. 39: 573-579.

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., B. Starcher and G. Matrone. 1964. Mercury and silver interrelationships with copper. J. Nutrition 83: 107-110.

Hoekstra, W.G. 1964. Recent observations on mineral interrelationships. Fed. Proc. 23: 1068-1076.

Hurwitz, S. and A. Bar. 1970. The sites of calcium and phosphate absorption in the chick. Poul. Sci. 49: 324-325.

Hurwitz, S. and A. Bar. 1971. Calcium and phosphorus interrelationships in the intestine of the fowl. J. Nutrition 101: 677-686.

Hurwitz, S. and A. Bar. 1972. Site of vitamin D action in chick intestine. American J. Physiol. 222: 761-767.

Jensen, L.S. 1975. Precipitation of a selenium deficiency by high dietary levels of copper and zinc. Proc. Soc. Exp. Biol. Med. 149: 113-116.

Kimberg, D.V., R.D. Baerg, E. Gershon and R.T. Graudusius. 1971. Effect of cortisone treatment on the active transport of calcium by the small intestine. J. Clin. Invest. 50: 1309-1321.

Klein, R.G., W.M. Beeson, T.R. Cline and E.T. Mertz. 1972. Lysine availability of opaque-2 corn for rats. J. Animal Sci. 35: 551-555.

Kowarski, S. and D. Schacter. 1969. Effects of vitamin D on phosphate transport and incorporation into mucosal constituents of rat intestinal mucosa. J. Biol. Chem. 244: 211

Lee, S. and W.M. Britton. 1980. Magnesium toxicity: Effect on phosphorus utilization by broiler chicks. Poul. Sci. 59: 1989-1994.

Leong, K.C., L.S. Jensen and J. McGinnis. 1960. Improvement of the feeding value of wheat fractions for poultry. Poul. Sci. 39: 1269 ( Abstr. ).

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

Likuski, H.J.A. and H.G. Dorrell. 1978. A bioassay for rapid determination of amino acid availability values. Poul. Sci. 57: 1658-1660.

Little, T.M. and F.J. Hills. 1978. Agricultural experimentation. Design and analysis. John Wiley and Sons, Inc. Toronto, Canada.

Littledike, E.T. and C.D. Arnaud. 1971. The influence of plasma magnesium concentrations on calcitonin secretion in the pig. Proc. Soc. Exp. Biol. Med. 136: 1000-1006.

Lucas, E., R. Fernandez and J. McGinnis. 1973. Nutritional value of heat- and acid-treated grains for chicks. Poul. Sci. 52: 2054 ( Abstr. ).

Lukert, B.P., S.W. Stanbury and E.B. Mawer. 1973. Vitamin D and intestinal transport of calcium: Effects of prednisolone. Endocrinology 93: 718-722.

MacIntyre, I. and D. Davidsson. 1958. The production of secondary potassium depletion, sodium retention, nephrocalcinosis and hypercalcaemia by magnesium deficiency. Biochem. J. 70: 456-462.

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

McIntosh, J.I., S.J. Slinger, I.R. Sibbald and G.C. Ashton. 1962. Factors affecting the metabolizable energy content of poultry feeds. 7. The effects of grinding, pelleting and grit feeding on the availability of the energy of wheat, corn, oats and barley. Poul. Sci. 41: 445-456.

McNab, J.M. and D.W.F. Shannon. 1974. The nutritive value of barley, maize, oats and wheat for poultry. Br. Poul. Sci. 15: 561-567.

Marceau, N., N. Aspin and A. Sass-Kortsak. 1970. Absorption of copper-64 from gastrointestinal tract of the rat. American J. Physiol. 218: 377-383.

March, B.E., T. Smith and S. El-Lakany. 1973. Variation in estimates of the metabolizable energy value of rapeseed meal determined with chickens of different ages. Poul. Sci. 52: 614-618.

March, B.E. and J. Biely. 1973. Chemical, physical and nutritional characteristics of different samples of wheat. Canad. J. Animal Sci. 53: 569-577.

Massry, S. G., E. Ritz and A. Rapado. 1977. Homeostasis of phosphate and other minerals. Third international workshop on phosphate and other minerals. Plenum Press, New York and London.

Methfessel, A. H. and H. Spencer. 1966. Intestinal site of absorption and secretion of $Ca^{47}$ and $Zn^{65}$ in adult rats. Fed. Proc. 25: 483 ( Abstr. ).

Miller, J. K. and L. S. Jensen. 1966. Effect of dietary protein source on zinc absorption and excretion along the alimentary tracts of chicks. Poul. Sci. 45: 1051-1053.

Misir, R. and W.C. Sauer. 1979. Amino acid availabilities in high lysine barleys for growing pigs. Canad. J. Animal Sci. 59: 832 ( Abstr. ).

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

Mollgaard, H. 1946. On phytic acid, its importance in metabolism and its enzymatic cleavage in bread supplemented with calcium. Biochem. J. 40: 589-603.

Morgan, D.B. 1969. Calcium and phosphorus transport across the intestine. In: Malabsorption. eds., R.H. Girdwood and A.N. Smith. Williams and Wilkins, Baltimore p. 73.

Moss, B.R., A.F. Beeckler, C.W. Newman and A.M. El-Negoumy. 1975. Hiproly and Hiproly normal barley versus wheat for broiler and growing rations. Poul. Sci. 54: 1799 ( Abstr. ).

National Academy Of Sciences-National Research Council. 1960. Nutrient requirements for poultry. NAS-NRC., Washington, D.C.

National Academy Of Sciences-National Research Council. 1977. Nutrient requirements of poultry. NAS-NRC., Washington, D.C.

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

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

Neville, E. and E.S. Holdsworth. 1968. Phosphorus metabolism during during transport of calcium. Biochimica et Biophysica Acta 163: 362-373.

Nugara, D. and H.M. Edwards, JR. 1963. Influence of dietary Ca and P levels on the Mg requirements of the chick. J. Nutrition 80: 181-184.

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. Canad. J. Animal Sci. 57: 475-477.

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

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

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

Olatunji, O., J.A. Akinrele, C.C. Edwards and O.A. Koleoso. 1982. Sorghum and Millet processing and uses in Nigeria. Cereal Foods World 27: 277-280.

Olson, E.B., JR., H.F. DeLuca and J.T. Potts, JR. 1972. Calcitonin inhibition of vitamin D-induced intestinal calcium absorption. Endocrinol. 90: 151-157.

Petersen, C.F., G.B. Meyer and E.A. Sauer. 1976. Comparison of metabolizable energy values of feed ingredients for chicks and hens. Poul. Sci. 55: 1163-1165.

Pick, R.I. and R.J. Meade. 1970. Nutritive value of high lysine corn: deficiencies and availabilities of lysine and isoleucine for growing swine. J. Animal Sci. 31: 509-517.

Prentice, N., S. Babler and S. Faber. 1980. Enzymatic analysis of Beta-D-glucans in cereal grains. Cereal Chem. 57: 198-202.

Ranhotra, G.S., R.J. Loewe and L.V. Puyat. 1976. Bioavailability of Magnesium from wheat flour and various organic and inorganic salts. Cereal Chem. 53: 770-776.

Raven, A.M., F.W. Lengemann and R.H. Wasserman. 1960. Studies of the effect of lysine on the absorption of radiocalcium and radiostrontium by the rat. J. Nutrition 72: 29-36.

Reinhold, J.G., F. Ismail-Beige and B. Faradji. 1975. Fibre vs phytate as determinant of the availability of calcium, zinc and iron of breadstuffs: wholemeal bread and bran. Nutritional Reports International 12: 75-85.

Reinhold, J.G., B. Faradji, P. Abadi and F. Ismail-Beige. 1976. Decreased absorption of calcium, magnesium, zinc and phosphorus by humans due to increased fiber and phosphorus consumption as wheat bread. J. Nutrition 106: 493-503.

Reiss, E., J.M. Canterbury, M.A. Bercovitz and E.L. Kaplan. 1970. The of phosphate in the secretion of parathyroid hormone in man. J. Clin. Invest. 49: 2146-2149.

Sallis, J.D. and E.S. Holdsworth. 1962. Influence of vitamin D on calcium absorption in the chick. American J. Physiol. 203: 497-505.

Sarwar, G. and J.P. Bowland. 1975. Availability of amino acids in wheat cultivars used in diets for weanling rats. Canad. J. Animal Sci. 55: 579-586.

Sasse, C.E. and D.H. Baker. 1973. Availability of sulfur amino acids in corn and corn gluten meal for growing chicks. J. Animal Sci. 37: 1351-1355.

Sauer, W.C., P.M. Giovannetti and S.C. Stothers. 1974. Availability of amino acids from barley, wheat, triticale and soybean meal for growing pigs. Canad. J. Animal Sci. 54: 97-105.

Schacter, D., E.B. Dowdle and H. Schenker. 1960. Active transport of calcium by the small intestine of the rat. American J. Physiol. 198: 263-268.

Schafer, D.F., D.V. Stephenson, A.J. Barak and M.F. Sorrell. 1974. Effects of ethanol on the transport of manganese by small intestine of the rat. J. Nutrition 104: 101-104.

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

Scott, M.L., M.C. Nesheim and R.J. Young. 1976. Nutrition of the Chicken. M.L. Scott and Associates, Publishers. Ithaca, N.Y.

Sherwood, L.M., G.P. Mayer, C.F. Ramberg, JR., D.S. Kronfeld, G.D. Aurbach and J.T. Potts, JR. 1968. Regulation of parathyroid hormone secretion: Proportional control by calcium, lack of effect of phosphate. Endocrinol. 83: 1043.

Sherwood, L.M., W.B. Lundberg, JR., J.H. Targovnik, J.S. Rodman, and A. Seyfer. 1971. Synthesis and secretion of parathroid hormone in vitro. American J. Medicine 50: 658-669.

Sibbald, I.R. and S.J. Slinger. 1963. A biological assay for metabolizable energy in poultry feed ingredients together with findings which demonstrate some of the problems associated with the evaluation of fats. Poul. Sci. 42: 313-325.

Sibbald, I.R. and S.J. Slinger. 1963. Nutritive values of ten samples of western Canadian grains. Poul. Sci. 42: 276-277.

Sibbald, I.R. 1975. Comparison of metabolizable energy values of cereal grains measured with poultry in three laboratories. Canad. J. Animal Sci. 55: 283-285.

Sibbald, I.R. 1976. A bioassay for true metabolizable energy in feedingstuffs. Poul. Sci. 55: 303.

Sibbald, I.R. 1979. Bioavailable amino acids and true metabolizable energy of cereal grains. Poul. Sci. 58: 934-939.

Sibbald, I.R. 1982. Measurement of bioavailable energy in poultry feedingstuffs: A review. Canad. J. Animal Sci. 62: 983-1048.

Sibbald, I.R., J.D. Summers and S.J. Slinger. 1960. Factors affecting the metabolizable energy content of poultry feeds. Poul. Sci. 39: 544-556.

Stephenson, E.L., J.O. York, D.B. Bragg and C.A. Ivy. 1971. The amino acid content and availability of different strains of grain sorghum to the chick. Poul. Sci. 50: 581-584.

Stewart, A.K. and A.C. Magee. 1964. Effect of zinc toxicity on calcium, phosphorus and magnesium metabolism of young rats. J. Nutrition 82: 287-295.

Stober, C.R., G.L. Cromwell and T.S. Stahly. 1979. Availability of phosphorus in corn and barley for the pig. J. Animal Sci. 49: ( Suppl. 49 ) 97-98.

Swaminathan, R., J. Ker and A.D. Care. 1974. Calcitonin and intestinal calcium absorption. J. Endocrinol. 61: 83-94.

Taylor, A.N. 1974. In vitro phosphate transport in chick ileum: Effect of cholecalciferol, calcium, sodium and metabolic inhibitors. J. Nutrition 104: 489-494.

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

Thompson, S.A. and C.W. Weber. 1981. Effect of dietary fiber sources on tissue mineral levels in chicks. Poul. Sci. 60: 840-845.

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.

Thornton, P.A. 1970. Skeletal and plasma calcium changes in chicks during recovery from vitamin D deficiency with normal and low calcium intakes. J. Nutrition 100: 1197-1204.

Van Campen, D.R. and E.A. Mitchell. 1965. Absorption of $Cu^{64}$, $Zn^{65}$, $Mo^{99}$ and $Fe^{59}$ from ligated segments of the rat gastrointestinal tract. J. Nutrition 86: 120-124.

Vaughan, O.W. and L.J. Filer, JR. 1960. The enhancing action of certain carbohydrates on the intestinal absorption of calcium in the rat. J. Nutrition 71: 10-14.

Vohra, P., G.A. Gray and F.H. Kratzer. 1965. Phytic acid-metal complexes. Proc. Soc. Exp. Biol. Med. 120: 447-449.

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-45 and strontium-89 in the rat. J. Nutrition 59: 371-383.

Wasserman, R.H. and A.N. Taylor. 1969. Some aspects of the intestinal absorption of calcium with special reference to vitamin D. In: Mineral Metabolism, eds., C.L. Comar and F. Bronner. Academic Press, New York, Vol. 3.

Wasserman, R.H. and A.N. Taylor. 1973. Intestinal absorption of phosphate in the chick: Effect of vitamin $D_3$ and other parameters. J. Nutrition 103: 586-599.

Wasserman, R.H. and R.A. Corradino. 1973. Vitamin D, calcium and protein synthesis. Vitamins and Hormones 31: 43-103.

Willingham, H.E., K.C. Leong, L.S. Jensen and J. McGinnis. 1960. Influence of geographical area of production on response of different barley samples to enzyme supplements or water-treatment. Poul. Sci. 39: 103-108.

Wilson, B.J. and J.M. McNab. 1975. Diets containing conventional, naked and high-amylose barleys for broilers. Br. Poul. Sci. 16: 497-504.

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

Appendix Table 1. Analysis of variance for mineral availability from barley

| Source of variance | D.F. | Mean Square | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ca | P | Mg | Mn | Zn | Cu |
| Treatment | 5 | 0.0072[a] | 0.0105[b] | 0.0170[a] | 0.01005[a] | 0.0933[a] | 0.0347[a] |
| Replicates[N.S.] | 3 | 0.0005 | 0.0006 | 0.0017 | 0.0021 | 0.0011 | 0.0023 |
| Error | 15 | 0.0006 | 0.0036 | 0.0034 | 0.0115 | 0.0098 | 0.0059 |

[a] Significant ( $P \leq 0.05$ )

[b] Significant ( $P \leq 0.01$ )

[N.S.] Not significant

Appendix Table 2. Analysis of variance for body weight gain at four weeks of age.

| Source of variance | D.F. | Sum of square | Mean square |
|---|---|---|---|
| Treatment | 12 | 0.0034 | 0.00028 N.S. |
| Replicates | 2 | 0.0005 | 0.00025 N.S. |
| Error | 24 | 0.0052 | 0.00022 |
| Total | 38 | 0.0091 | 0.00024 |

N.S. Not significant ( $P \leq 0.10$ )

Appendix Table 3. Analysis of variance for cumulative feed consumption at four weeks of age.

| Source of variance | D.F. | Sum of square | Mean square |
|---|---|---|---|
| Treatment | 12 | 0.01 | 0.0008 N.S. |
| Replicates | 2 | 0.01 | 0.0050 N.S. |
| Error | 24 | 0.18 | 0.0075 |
| Total | 38 | 0.20 | ).0053 |

N.S. Not significant ( $P \leq 0.10$ )

Appendix Table 4. Analysis of variance for feed conversion at four weeks of age.

| Source of variance | D.F. | Sum of square | Mean square |
|---|---|---|---|
| Treatment | 12 | 0.027 | 0.0023* |
| Replicates | 2 | 0.000 | 0.000 N.S. |
| Error | 24 | 0.023 | 0.00096 |
| Total | 38 | 0.050 | 0.0013 |

* Significant ( $P \leq 0.05$ )

N.S. Not significant ( $P \leq 0.05$ )