# BIOAVAILABILITY OF PHOSPHORUS IN SELECTED FEEDSTUFFS FOR YOUNG CHICKS AND PIGS

by

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# CHAPTER I

## GENERAL INTRODUCTION

Phosphorus is classified as an essential major elements in animal nutrition. Approximately 75% of the total body phosphorus is found in bones which serve as the supportive framework for the body and as a reservior of phosphorus, calcium and other minerals. The balance is located in teeth, soft tissue, blood, and extracellular fluid. It plays an important part in muscle function; nutrient metabolism; nervous tissue metabolism; maintenance of blood chemistry homeostasis; skeletal growth and transport of fatty acids and other lipids. Phosphate is an important part of the nucleic acids, DNA and RNA. It is a component of many enzymes and is involved in the storage and transfer of energy in phosphorylated compounds of glucose and its derivatives, and such high energy compounds as adenosine di- and triphosphate, and creatine phosphate. The blood contains approximately 35-45 mg of phosphorus per 100 ml. Only about 10% is in the form of inorganic phosphate. Normally there is an inverse relationship between serum diffusable calcium and serum inorganic phosphate.

Because phosphorus is involved in many important metabolic processes, it is extremely important that adequate levels of phosphorus be provided in the diet in order that animals can grow efficiently and economically.

Most of the feed ingredients for swine come from the plant sources but the extent of phosphorus availability in natural feedstuffs for pigs is inconclusive. Many scientists suggest that nonruminants will metabolize about one-third of the phosphorus in plant materials. The proportion of the phosphorus that has been considered to be available is non-phytate phosphorus. This assumption is based on the report by the NRC in 1971. However, recent research at Kansas State University, University of Kentucky, and University of Illinois are not consistent with NRC assumption. Therefore, further studies on the bioavailability of phosphorus in feedstuffs for pigs are necessary in order to provide adequate phosphorus levels.

Objectives of the studies reported herein were to evaluate bioavailability of phosphorus of nine feedstuffs for growing pigs and chickens.

# CHAPTER II

## REVIEW OF LITERATURE

As early as 1842, researchers studied the effect of low minerals in animal diets. Chossat (1842,1843) initially used pigeons in his investigations, but later included chickens, rabbits and other animals. Among other early investigators were: Boussingault (1846) who observed the effects of a diet low in minerals upon the growth of the skeleton of pigs; Weiske and Wildt (1873), who used goats and lambs; Forster (1873), who employed pigeons and later dogs; Voit (1880), who also used pigeons and dogs; and Aron and Sebauer (1908), who worked with rabbits and dogs. These workers were primarily concerned with the importace of minerals in the diet and not specifically with low-phosphorus diets.

Hofmeister (1873), experimenting with lambs and low-phosphorus diets, noted an increase in phosphorus in the bones when precipitated bone phosphate was added to the basal diet. Henry (1889,1890) also demonstrated the value of phosphorus on the bone strength of young pigs fed corn when the diet was supplemented with bone meal. Arnstadt (1893) discussed the effect of lack of phosphorus in the diet on the bone development and strength in cattle and other farm animals. Burnett (1906,1908, 1910) showed the mineral content of the bone of pigs may be modified in accordance with the composition of the diet.

After the mineral problem in general and the specific influence of phosphorus in the diet had been recognized, it was only natural that workers in the field of swine nutrition should turn to problems involving the actual requirements of phosphorus in the diet.

Phosphorus Requirement

There is substantial variation among the many estimates of requirements. In many of the early studies, factors other than phosphorus were limiting the rate of growth; hence, the animals could not respond to higher levels of phosphorus. This is particularly true if growth rate rather than skeleton mineralization was the response criteria used to measure adequacy. The quality of certain phosphate supplements have improved as a result of changes in processing methods. Increased availability of phosphorus reduces the total amount of phosphorus needed to maximize growth or mineralization of the skeleton. The major factor contributing to differences in requirement estimates relate to the criteria of response. Some researchers base their estimate primarily on growth rate and feed efficiency; whereas, others use bone ash, breaking strength, or normality of bone growth as measured histologically or histochemically. Requirement estimates certainly depend on the emphasis placed on the various criteria of adequacy.

Summarizing a number of studies that involve a variety of diets and phosphorus levels, the average minimum phosphorus requirement for maximum rate of gain for the starter stage of production is near .60 to .65% (Coalson et al., 1968, 1970, 1972; Combs et al., 1960, 1962a., Livingstone et al., 1962; Miller et al., 1961, 1964a, 1964b; Mudd et al., 1967; Vanderpopuliere et al., 1959; Washam et al., 1968; and Zimmerman et al., 1961, 1963). Much of the above data are from experiments that involved semipurified diets with a relatively high proportion of milk protein. Thus, the National Research Council (1979) lists .65% for the phosphorus requirement for the starter pigs (up to 10 kg) and .55% in grower diets (10 to 20 kg). These levels of phosphorus are suggested in combination with .80% and .65% calcium for the two stages, respectively.

There has also been a great deal of research on the phosphorus needs of pigs during growing-finishing stage. The estimates of requirements range from .4% to as high as .7% with an average figure of about .54% for the entire growing-finishing period. Some of the estimates were based on growth rate, or skeletal development, and some on the combination of the two parameters (Allee et al., 1975; Chaney et al., 1968; Chapman et al., 1955, 1962; Cromwell et al., 1969, 1970, 1972a, 1972b; Forsyth et al., 1969; Jordan et al., 1957; Kayongo-Male et al., 1974; Libal et al., 1969; Parker et al., 1975a, 1975b; and Peo et al., 1963, 1969). The National Research Council (1979) lists .50%, .45% and .40% for pigs of 20-35 kg, 35-60 kg live weight, respectively (with a calcium requirement of .60%, .55%, and .50%, respectively).

Kornegay et al. (1973) found that sows fed 15.5 grams of calcium and 15.0 grams of phosphorus stayed in the herd longer than did sows fed 10.3 and 11.0 grams of calcium and phosphorus, respectively. The conception rate, farrowing rate and number completing 5 gestation-lactation cycles were all higher for the sows fed the higher levels. Harmon et al. (1974,1975) found that sows fed .31% phosphorus from plant sources were subject to posterior paralysis. Noonan and Danielson (1974) compared the reproductive performance of sows fed 11.6 grams of calcium and 9.8 grams of phosphorus per day with that of sows fed double these amounts (23.4 and 19.4, respectively) and found that number of pigs per litter did not differ. Weaning weight of the individual pigs and weaning weight of the total litter averaged heavier for the sows fed the higher levels, suggesting that milk production was higher for those sows fed the higher levels of calcium and phosphorus. The National Research Council (1979) lists the phosphorus requirement of bred gilts and sows as 10.8 grams per day.

There is tremendous variation in estimates of milk yield and phosphorus content of milk. Harmon et al. (1975) measured milk production levels of near 2.7 kilograms per day; whereas, Blair et al. (1963) measured levels of approximately 6.4 kilograms per day. The phosphorus content of milk increases with time post parturition. Several researchers (Blair et al., 1963; Harmon et al., 1975; and Perrin, 1955) have reported that the average for the first 28 days of lactation, phosphorus levels ranged from .15 to .25%. Assuming that sows produce 6.4 kilograms of milk per day and the average phosphorus content is .20%, the daily amount excreted in milk would be 12.8 grams. Harmon et al. (1975) found that sows fed .45% phosphorus were in negative phosphorus balance during the second week of lactation. Their level of feed intake was 3.0 kilograms per day and phosphorus intake was only 13.5 grams per day. They concluded that .55% (16.5 grams per day) was adequate to maintain body stores as measured by rib ash levels. The National Research Council (1979) lists .50% as the phosphorus requirements for lactating gilts and sows. That is a phosphorus intake from 20.0-27.5 grams per day depending on feed intake.

Schroeder et al. (1974) concluded that .5% phosphorus is adequate for young boar maximum gain and feed conversion, but that a higher level, .75 to 1.0% is needed for maximum breaking strength of metacarpals or femurs. Bayley et al. (1971,1975a) concluded that .6% is adequate for growth rate in growing boars. They also observed that a higher level was needed for maximum skeletal development. The National Research Council (1979) lists young and adult boars phosphorus requirement is .60% (10.8 grams per day).

## Factors Affecting Phosphorus Availability

1. Sources of phosphorus

1). Mineral and animal phosphorus sources

Gillis et al. (1948) conducted studies on the utilization of phosphorus from various sources by the chick. They reported that the chemically pure orthophosphorus; mono-, di-, and tri-calcium phosphate; sodium acid phosphate and potassium acid phosphate; were highly available. The acid salts, monocalcium phosphate and potassium acid phosphate, were better utilized than the other pure orthophosphates. Feeding grade materials of excellent availability were dicalcium phosphate, defluorinated phosphate and steamed bone meal. Other bone products such as bone char, bone ash and imported bone meal had slightly lower availability. None of the pyrophosphates or metaphosphates was satisfactory, although significant amounts of phosphorus were utilized from calcium acid pyrophosphate and vitreous metaphosphate.

Plumlee et al. (1958) determined the availability of the phosphorus in various phosphate materials for growing swine and reported that the sources ranked in the following order: dicalcium phosphate, monocalcium phosphate, and phosphoric acid were about equal followed by steamed bone meal and defluorinated phosphate, then Curacao Island phosphate and finally soft phosphate with colloidal clay (soft rock phosphate) the poorest. Several other studies have indicated that the soft rock phosphate is poorly available to farm animals and poultry. Such results were reported for the chick by Johnson et al. (1953), Miller and Joukovsky (1953), and Motzok et al. (1956); and for swine by Chapman et al. (1955). Aldinger et al. (1959) found a linear decrease in performance as soft rock phosphate was substitued for dicalcium phosphate as a source of supplemental phosphorus.

Shrewsbury and Vestal (1945) comparing different phosphate sources for swine found that steamed bone meal was superior to either defluorinated phosphate or rock phosphate as mineral supplement. Superphosphate compared favorably with steamed bone meal. In diets for bred sows and gilts, steamed bone meal was only slightly superior to defluorinated phosphate and rock phosphate. Spandorf and Leong (1965) determined the availability of phosphorus from menhaden fish meal and found the biological availability to range from 96 to 103% when compared to dicalcium phosphate. Waldroup et al. (1965) reported excellent utilization of phosphorus from fish meal, poultry by-product meal and meat and bone meal. Comparisons were made with monosodium phosphate or dicalcium phosphate. Relative performance ranged from 95 to 99% with body weight as a criterion and 101 to 102% with bone ash as a criterion. Christmas et al. (1972) found that dicalcium phosphate and fish meal were comparable phosphorus sources. Cromwell et al. (1976) indicated the phosphorus in meat and bone meal had similar availabilities to dicalcium phosphate.

According to a summary by Hays (1976), the phosphorus sources (dicalcium phosphate, defluorinated rock phosphate and steamed bone meal) most commonly used in swine diets, have similar availabilities (table 1). Curacao Island phosphate and soft rock phosphate are lower in phosphorus availability.

TABLE 1. RELATIVE BIOLOGICAL VALUE OF VARIOUS PHOSPHORUS SOURCES

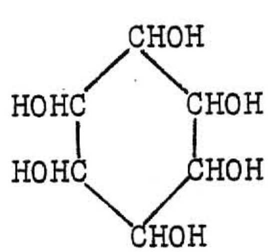
| Source | Relative value |
|---|---|
| Monocalcium phosphate (standard) | 100 |
| Monosodium phosphate | 100 |
| Fish meal | 100 |
| Meat and bone meal | 100 |
| Dicalcium phosphate | 98 |
| Steamed bone meal | 95 |
| Diammonium phosphate | 95 |
| Defluorinated rock phosphate | 92 |
| Curacao Island phosphate | 69 |
| Soft rock phosphate | 34 |

The chemical form of the phosphate is critical to its availability. Because the ortho-form is the metabolic form in animal system, the ortho-phosphates ($-PO_4$) are, in general, of much higher availability than are the meta-phosphates ($-P_2O_7$) or the pyro-phosphates ($-PO_3$). Bone phosphorus, mono-, di- and tri-calcium phosphates and the mono- and di-sodium phosphates of the feed grade are of the ortho-structure (Hays, 1976).

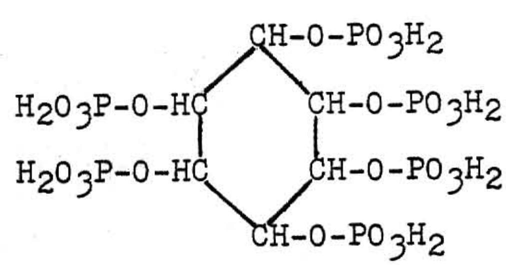
Defluorinated rock phosphate products have been standardized in fluorine content and processing methods and at present are reliable sources of phosphorus. Those sold as feed grade phosphates are standardized to less than one part fluorine to 100 parts phosphorus. This fluorine level is well within the tolerance levels for swine.

Ammonium phosphates have been found to give satisfactory results (Peo, 1975; Clawson and Alsmeyer, 1971); however, there are no advantages to having the ammonia ion with the phosphate for nonruminants.

2). Plant phosphorus




Cyclohexanol ($C_6H_{12}O_6$)
(Inositol)




Inositol-hexaphosphoric acid
($C_6H_{18}O_{24}P_6$) (Phytic acid)

Phytic acid is an ester formed by combination of the 6 alcoholic groups of inositol (cyclohexanol), with 6 molecules of orthophosphoric acid, whence its name of inositol-hexaphosphoric acid. It was discovered in cereals towards the end of the last century and is the only natural substance containing one atom of phosphorus for each carbon.

Because phytic acid has in its structure a large number of phosphoric radicals, it can form simple salts (with one metal) or mixed salts (with several metals in the same molecule), as well as metallic or protein complexes. While the compounds with alkali metals (sodium, potassium) are soluble in water, those resulting from combination with calcium, iron, magnesium, copper, zinc, and lead are practically insoluble, even at pH 3-4. The salt of phytic acid is phytate. The mixed salt with calcium and magnesium is phytin.

Phytic acid and phytate can be decomposed by boiling in an acid solution. From the acid hydrolysis 6 molecules of orthophosphoric acid and 1 molecule of inositol result. Phytin is stable at 115 C, but in presence of water at 155 C is resolved into phosphoric acid and inositol (Armstrong et al., 1934).

At least one-half of the phosphorus in seeds and feed grains are in the compound phytate form; whereas, leaves and stems of plants contain none of their phosphorus in that form (Underwood, 1966). Nahapetian and Bassiri (1975), studying the changes in concentration of phosphorus forms in wheat heads, found that phytate P concentration increased and nonphytate P concentration decreased as the wheat head matured.

Common (1940) reported the phytic acid phosphorus content of feedstuffs derived from processed oil seeds, including soybean meal, was one-half to two-thirds of the total phosphorus. Phytic acid phosphorus accounted for two-thirds to three-fourths of the total phosphorus in cereal grains. Mollgaard (1946) showed slightly higher concentrations of phytate phosphorus in processed oil seeds (70-80%) and in cereal grains (65-85%). Estimates of the total phosphorus and non-phytate phosphorus in common feedstuffs are presented in table 2.

At the end of the last century it was generally thought that only organic forms of phosphorus could be assimilated by the body and used for synthesis of the many phosphorus-containing compounds in the tissues. Hart _et al_. (1909) at Wisconsin designed a study with pigs to evaluate the level of organic form of phosphorus on nutritive value. They concluded that phytin as the source of phosphorus was no better than inorganic phosphates. This was contrary to earlier views. Forbes and Keith (1914) at Ohio reviewed the research on phosphorus up to that date and confirmed that inorganic forms of phosphorus were at least equal to organic phosphorus. Some 70-90% of the phosphorus in cereal grains was shown to be in the form of phytin. Since that time many studies have been carried out evaluate the utilization of phytin phosphorus.

Lowe _et al_. (1939) supplemented a low phosphorus basal chick diet with phytate isolated from wheat bran and obtained no increase in bone calcification. These results were obtained in the

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

TABLE 2. TOTAL PHOSPHORUS, PHYTATE PHOSPHORUS, AND NON-PHYTATE PHOSPHORUS IN COMMON FEEDSTUFFS

| Ingredients | Total phosphorus[a] % | Portion of total phosphorus as phytate phosphorus % | Portion of total phosphorus as non-phytate phosphorus % | Reference |
|---|---|---|---|---|
| Barley | .36 | 38 | 62 | Hart *et al*. (1911) |
| Barley | .36 | 56 | 44 | Nelson *et al*. (1968a) |
| Barley | .36 | 65 | 35 | Mollgaard (1946) |
| Barley meal | | 61 | 39 | Common (1940) |
| Corn | .28 | 45 | 55 | Hart *et al*. (1911) |
| Corn | .28 | 66 | 34 | Nelson *et al*. (1968a) |
| Corn | .28 | 75 | 25 | Common (1940) |
| Corn | .28 | 80 | 20 | Mollgaard (1946) |
| Milo | .28 | 68 | 32 | Nelson *et al*. (1968a) |
| Oats | .27 | 48 | 52 | Hart *et al*. (1911) |
| Oats | .27 | 56 | 44 | Nelson *et al*. (1968a) |
| Oats | .27 | 62 | 38 | Lolas *et al*. (1976) |
| Oats | .27 | 63 | 37 | Common (1940) |
| Oats | .27 | 66 | 34 | Mollgaard (1946) |
| Wheat | .37 | 67 | 33 | Nelson *et al*. (1968a) |
| Wheat | .37 | 72 | 28 | Lolas *et al*. (1976) |

TABLE 2. TOTAL PHOSPHORUS, PHYTATE PHOSPHORUS, AND NON-PHYTATE PHOSPHORUS IN COMMON FEEDSTUFFS-CONTINUED

| Ingredients | Total phosphorus[a] % | Portion of total phosphorus as phytate phosphorus % | Portion of total phosphorus as non-phytate phosphorus % | Reference |
|---|---|---|---|---|
| Wheat | .37 | 86 | 14 | Mollgaard (1946) |
| Wheat meal | | 66 | 30 | Common (1940) |
| Wheat bran | 1.15 | 70 | 30 | Nelson _et_ _al_. (1968a) |
| Wheat bran | 1.15 | 81 | 19 | Hart _et_ _al_. (1909) |
| Wheat bran | 1.15 | 86 | 14 | Mollgaard (1946) |
| Alfalfa meal | .22 | 0 | 100 | Nelson _et_ _al_. (1968) |
| Alfalfa meal | .22 | 21 | 79 | Common (1940) |
| Cottonseed meal | .97 | 70 | 30 | Nelson _et_ _al_. (1968) |
| Cottonseed meal | .97 | | | |
| Brazil | | 78 | 22 | Mollgaard (1946) |
| Siam | | 82 | 18 | Mollgaard (1946) |
| Soybean meal | .65 | 58 | 42 | Spitzer _et_ _al_. (1945) |
| Soybean meal | .65 | 61 | 39 | Nelson _et_ _al_. (1968) |
| Soybean meal | .65 | 68 | 32 | Mollgaard (1946) |

[a]National Research Council (1979).

absence of supplementary vitamin D. Gillis et al. (1949) studied the effects of phytate on the phosphorus requirement of chicks. Replacement of an adequate level of available inorganic phosphorus by progressively higher levels of phytate resulted in a rapid decline in bone calcification and marked increase in the vitamin D requirement. Heuser et al. (1943), McGinnis et al. (1944), and Sunde and Bird (1956) observed that natural phytate was a poor source for various species of poultry. Conversely, Sieburth et al. (1952) reported the phosphorus in finely ground whole wheat flour was almost completely available to chicks for growth but was less available than inorganic phosphate for bone deposition. Maddaiah et al. (1963) reported that sodium and calcium phytate were better absorbed and utilized for growth than for bone mineralization. Waldroup et al. (1964a,b) indicated that the phosphorus from phytic acid was equal in availability to that of dicalcium or reagent grade monosodium phosphate. Sodium phytate was less available than phytic acid and calcium phytate phosphorus was relatively unavailable for growth but somewhat more utilization for bone mineralization. Laying hens utilized about 30% of the phosphorus in plants (National Research Council, 1966).

Woodman and Evans (1948) had shown that pigs 50 to 90 kg in weight absorbed 30 to 40% of the phosphorus in a barley-wheat bran diet with no added inorganic phosphorus. Gueguen et al. (1968) estimated 37.5% as the availability of wheat phosphorus. Noland et al. (1968) used growing swine to evaluate the availability of phosphorus in a corn-soybean meal based diet. They found that the phosphorus was 30-60% available; whereas Bayley and Thomson (1969) stated that 27-kg pigs were able to absorb 19% of the phosphorus contained in corn-soybean meal diets containing .90% calcium and .35% total phosphorus (no supplemental phosphorus) when fed in meal form.

Besecker et al. (1967) found the apparent digestibility of the phosphorus in barley was calculated to be 17.68 and 24.29%, respectively, from diets containting .3 and .5% total phosphorus. Tonroy et al. (1970,1973) observed apparent digestibility value of the phosphorus in grain sorghum was 5% and 27% for 44% crude protein soybean meal. Bayley et al. (1975b) fed corn-soybean meal diets containing .62% calcium and .31% phosphorus (no supplemental phosphorus) to 25-kg pigs and obtained phosphorus absorbability values of 30%. Calvert et al. (1978) found the apparent phosphorus availability of corn to be 8.3% when pigs were fed a diet containing .3% total phosphorus and 96.8% of the phosphorus present was from the corn grain. It is obvious that the estimates of availability vary widely. These values are summarized in table 3.

TABLE 3. ESTIMATED AVAILABILITY OF PLANT PHOSPHORUS FOR PIG

| Source | Apparent digestibility,% | Reference |
|---|---|---|
| Barley-wheat bran | 30-40 | Woodman and Evans(1948) |
| Barley | 17.68-24.29 | Besecker et al.(1967) |
| Corn | 8.3 | Calvert et al.(1978) |
| Corn+soybean meal | 30-60 | Noland et al.(1968) |
| Corn+soybean meal | 19 | Bayley et al.(1969) |
| Corn+soybean meal | 30 | Bayley et al.(1975b) |
| Grain sorghum | 1.9-4.5 | Tonroy et al.(1970,1973) |
| Soybean meal | 27.0 | Tonroy et al.(1973) |
| Wheat | 37.5 | Gueguen et al.(1968) |

The slope-ratio technique for the estimation of phosphorus availability was developed by Hurwitz (1964) in Israel. It gives the best linear fit to test grain phosphorus relative availability. Phosphorus availability of several commonly fed feedstuffs is summarized in table 4.

2. Phytase enzyme

A phytic acid-splitting enzyme, called phytase, was first found in rice bran in 1907. It has a wide distribution in plant, in many species of fungi and in certain bacteria (Peers, 1953).

Hill and Tyler (1954) indicated that wheat phytase had an optimum pH of 5.0-5.1 and functioned at pH values down to 3.0. When hydrolysis had been arrested by acidifying to pH 2.5 for 5 minutes or longer, the phytase did not recover when the pH was raised to 5.0 by the addition of sodium bicarbonate. There was an almost uniform increase in the rate of hydrolysis between 15 and 50 C.

McCance _et_ _al_. (1944) and Mollgaard (1946) demonstrated wheat, rye and barley are high in phytase activity; whereas oats, maize and various seed materials contain little or none of the enzyme. Therefore, it is assumed that the phytate phosphorus should be more available in ingredients containing this enzyme or in diets containing ingredients with high phytase content.

McGinnis _et_ _al_. (1944) found that chicks made inefficient use of phytate phosphorus in a diet which contained 20% wheat bran and 10% wheat flour middlings. These two ingredients supposedly contain phytase activity. It was probable that plant-source ingredients either varied in their original phytase

TABLE 4. RELATIVE BIOAVAILABILITY(%) OF PHOSPHORUS IN FEEDSTUFFS OF PLANT ORIGN FOR PIGS AND CHICKS

| Species | Corn | Milo | Oats | Wheat | Barley | Rice bran | Wheat bran | Cotton-seed meal | Soy-bean meal | Wheat mid-dlings | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pig[a] | 16 | - | - | 51 | - | - | - | - | 18 | - | Miracle _et_ _al_.(1977) |
| Pig[a] | 9,7 | - | - | - | 31 | - | - | - | - | - | Stober _et_ _al_.(1979) |
| Pig[a] | - | 19 | - | - | - | - | - | - | - | - | Trotter _et_ _al_.(1979a) |
| Pig[a] | - | - | - | - | - | - | - | 0 | - | - | Stober _et_ _al_.(1980a) |
| Pig[a] | - | - | 23 | - | - | - | 29 | - | - | 34 | Stober _et_ _al_.(1980b) |
| Chick[a] | - | - | - | - | - | 18 | 23 | - | - | - | Corley _et_ _al_.(1980) |
| Chick[a] | - | - | - | - | 28,43 | - | - | - | - | - | Harrold _et_ _al_.(1979) |
| Chick[a] | 12 | - | - | 43[c],58[d] | 50 | - | - | - | - | - | Hayes _et_ _al_.(1979) |
| Chick[b] | - | 25 | - | - | - | - | - | - | - | - | Trotter _et_ _al_.(1979a) |
| Chick[b] | 19 | - | - | 48 | - | - | - | - | 28 | - | Trotter _et_ _al_.(1979b) |

[a]Based on slope-ratio of bone breaking strength with monosodium phosphate or monopotassium phosphate as the standard.

[b]Based on slope-ratio of bone ash weight with monosodium phosphate as the standard.

[c]Soft wheat.

[d]Hard wheat.

content or that the enzyme was labile under the handling conditions of the feed ingredients. It appears that specific feed ingredients cannot be considered to be a consistent source of phytase. Courtois and Valentino (1947) found that purified phytase, extracted from wheat bran, was ineffective in the rat.

Warden and Schaible (1962) established that bacterial phytase can be active in the digestive tract. They found that the addition of lysed E. coli cellular material to the diet improved both growth and bone development, and suggested that this was a response to phytase or similiar enzymes.

Nelson et al. (1968b) reported that phytase produced by Aspergillus ficuum and other molds hydrolyzed the phytate phosphorus in soybean meal. They also found that chicks utilized this hydrolyzed phytate phosphorus as efficiently as they did inorganic phosphorus. Chicks did not utilize phytate phosphorus in the untreated soybean meal. In a subsequent study, Nelson et al. (1971) found that the addition of phytase to chick diets produced an increase in percent bone ash indicating hydrolysis of phytate by the enzyme. Total hydrolysis of phytate occurred when 3 grams of phytase supplement were used per kilogram of diet. Chicks utilized the hydrolyzed phytate phosphorus as well as supplemental inorganic phosphorus. Phytate was hydrolyzed in the alimentary tract of the chick and not in the feed prior to ingestion.

Though phytase activity has been found in the mucosa of the small intestine of the pig (Spitzer and Phillips, 1945), it is generally agreed that utilization of phytate by pigs is limited.

3. Vitamin D

Harris and Innes (1931) concluded that an increased vitamin D intake promoted an increased absorption of calcium and/or phosphorus from the gut. Morgareidge and Manly (1939) found no evidence that vitamin D controlled phosphorus absorption. Kowarski and Schachter (1969) studied the problem both in vitro and in vivo. In the case of in vitro experiments, they found that previous dosage with vitamin D increased the transfer of phosphorus from mucosa to serosa in rachitic rats. Using closed loops in vivo and injecting the vitamin in the loops, phosphorus absorption was increased without prior activation by other organs. On the other hand, Sallis and Holdsworth (1962) found that under conditions when vitamin D could increase calcium transport threefold in rachitic chicks, it had no action on the transport of phosphorus.

Both Thompson and DeLuca (1964) and Neville and Holdsworth (1968) have reported that vitamin D increased the incorporation of radioactive phosphorus into phospholipids (and also into acid-soluble phosphorus and ATP) of the mucosa, provided calcium was also present. The total amount of phospholipids was not increased and the vitamin had no effect upon phospholipid metabolism, but in the presence of calcium there was increased phosphorus translocation and thus augmentation in the specific activity of phosphorus compounds in the mucosa.

Groth and Frey (1967) found that a lack of vitamin D caused both calcium and phosphorus in the serum to fall and the alkaline phosphatase to rise. They concluded that rickets resulting from vitamin D deficiency was basically a calcium deficiency. This conclusion was based on the fact that, in calcium deficiency, parathyroid activity was also increased. Thyroid function was reduced when both phosphorus and vitamin D were limiting.

Scott et al. (1976) in reviewing studies using $P^{32}$ in everted loops of rat or chick intestine, noted that vitamin $D_3$ was shown to have no influence upon intestinal phosphorus absorption. This statement was echoed by Swenson (1970), who indicated that phosphate absorption was not directly affected by vitamin D.

Hughes et al. (1975) studied the changes in serum concentration of $1\alpha,25\text{-}(OH)_2D_3$ in rats fed diets low in calcium or phosphorus. Deficiencies of either calcium or phosphorus resulted in a 5-fold increase in the circulating concentration of $1\alpha,25\text{-}(OH)_2D_3$. The effect of calcium deficiency was dependent on the presence of the parathyroid or thyroid gland (or both), suggesting that this effect requires parathyroid hormone. However, the response to phosphorus deficiency occurred in the absence of the parathyroid and thyroid glands and appeared to result solely from a low serum phosphate concentration. This indicates that phosphate depletion may induce renal synthesis of $1\alpha,25\text{-}(OH)_2D_3$.

It is now clear that vitamin $D_3$, either from dietary sources or from ultraviolet irradiation of skin is transported to the liver where it is converted to $25\text{-}OH\text{-}D_3$. This metabolite is then transported via the blood system to kidney, where it is converted either into the steroid "hormone" $1\alpha,25\text{-}(OH)_2D_3$ or into one of two other metabolites, 24, 25-dihydroxyvitamin $D_3$ or $1\alpha,24,25$-

trihydroxyvitamin $D_3$ (Scott et al., 1976).

According to DeLuca (1979), low blood phosphorus in some way stimulation production and accumlation of 1,25-$(OH)_2D_3$. In addition, low blood phosphorus increases the level of ionized calcium that in turn suppressed the parathyroid gland, resulting in low parathyroid hormone secretion. Lack of parathyroid hormone results in increased phosphate retention by the kidney or the absence of the parathyroid hormone-induced block in phosphate reabsorption. These two factors then contribute to elevated plasma phosphorus concentration since 1,25-$(OH)_2D_3$ stimulates the mobilization of phosphate from bone stimulates phosphate absorption in the small intestine.

4. Calcium to phosphorus ratio

The composition of bone remains rather constant and the calcium : phosphorus ratios approximate that in the basic apatite salt in bone which is represented by the fromula : $Ca_{10}(PO_4)_6(OH)_2$ which has a calcium to phosphorus ratio of 2.16:1.0 by weight. Early recommendation on optimum calcium to phosphorus ratios were based primarily on the ratio of calcium to phosphorus in bones; therefore, approximated to be 2:1 (two parts calcium to one part phosphorus). Approximately 99% of the total body calcium, whereas only 75% of the total body phosphorus is found in the skeletal tissue. On this basis, the total body ratio of calcium to phosphorus approximates 1.66:1. Mudd et al. (1969) found that the ratio of calcium to phosphorus in pigs weighing 46 pounds body weight did average 1.66:1.

Combs and Wallace (1962) observed decreasing growth rates with increasing calcium: phosphorus ratios, the highest being 1.82:1.00 (.80% calcium and .44% phosphorus). Zimmerman et al. (1963) found that low phosphorus levels and high calcium levels in the ration slowered the rate of gain. Lloyd et al. (1961) found that levels as high as 4.0% calcium had relatively minor adverse effect on performance provided that the diet contained adequate phosphorus. Chapman et al. (1962) found that the calcium : phosphorus ratio for swine was more important when minimal dietary levels of phosphorus were fed. Similar results were observed for swine by Cromwell et al. (1970) and for poultry by Vanderpopuliere et al. (1961). Forsyth et al. (1969), Pond et al. (1975), and Prince et al. (1974) have also found that the adverse effects of high calcium is primarily dependent on low or inadequate phosphorus or other nutrients. Bethke et al. (1933) also concluded that adequate phosphorus is more critical than calcium to phosphorus ratio and suggested that .6% phosphorus is the minimal level for growing finishing pigs regardless of calcium level.

Libal et al. (1969) found that calcium and phosphorus levels and ratios can vary considerably without significantly affecting daily gain and feed conversion of pigs. Levels and ratios of the two elements do affect bone formation as shown by bone breaking strength and bone weight data.

Doige et al. (1975) employed a factorial design with three levels of calcium and three levels of phosphorus to study calcium and phosphorus deficiencies and imbalances. Extreme calcium : phosphorus ratios in diets impaired both performance and skeletal development. All change were minimal if low levels of either element were accompanied by a calcium : phosphorus ratio near 1.25:1.0. Low calcium-high phosphorus ratios resulted in parathyroid enlargement, reduced bone mass, increased numbers of osteoclasts and fibrous replacement of bone. In animals fed high calcium-low phosphorus diets, hypophosphatemia (reduced bone ash and overgrowth of epiphyseal plates) was observed.

Vipperman et al. (1974) concluded that calcium to phosphorus ratios were not as important in the utilization of those two elements as the dietary levels per se.

Bethke et al. (1933) obtained best results with a calcium : phosphorus ratio between 1-2:1. Peo and Hudman (1963) recommended that the ratio should approach 1.0:1.0. The National Research Council (1979) lists ratios average about 1.25:1.0 for growing-finishing swine and about 1.36:1.0 for breeding animals. The reported variation can be explained on the basis of differences in the relative availability of calcium and phosphorus from the various diets employed and of differences in the vitamin D status of the diets and the animals under investigation. The calcium : phosphorus ratio of diets does not necessarily coincide with ratio of these elements available to the tissues because calcium and phosphorus are not always absorbed with equal readiness from all sources.

According to Scott et al. (1976), the ratio of calcium to phosphorus in diets of chickens may be varied over a fairly wide range without serious harm. However, when either element is present in large excess, it interferes with the absorption of the other from the digestive tract. For the growing chick the most desirable ratio of calcium to available phosphorus appears to live between 1.5:1 and 2:1. For laying hens the ratio is considerably wider due to their higher requirement for calcium.

Adequate or excess phosphorus in presence of calcium deficiency will allow for continued soft tissue growth, which in turn taxes the homeostatic mechanism for controlling blood calcium, resulting in continuous demineralization of the bone. On the other hand, deficient phosphorus in the presence of adequate calcium results in poor growth and if the growth is sufficiently impaired there may be a less marked effect on bone mineralization (Hays, 1976).

5. Feed processing

Slinger _et al_. (1966) using average daily gain and tibia ash as criteria found pelleting increased phosphorus availability of low phosphorus diets for chicks. Bayley _et al_. (1968b) fed a corn, soybean meal diets with either 0, .2 or .3% added inorganic phosphorus to young growing chicks as mash or after the ingredients had been steam pelleted and reground. Growth and bone development was poor on the mash with no added phosphorus, but were improved by steam pelleting. However, steam pelleting and regrinding either the corn or the soybean meal alone before incorporation into the diet had no effect on growth or bone development. Bayley and Thomson (1969) and Bayley _et al_. (1975b) also reported increased use of phosphorus for swine by pelleting diets low in phosphorus.

Harmon et al. (1970) observed increased absorption of phosphorus following pelleting; however, the differences were small for both growing and finishing swine and subsequent feeding trials did not show any improvements in gain, efficiency or bone values when low phosphorus diets were pelleted. Summers et al. (1967) reported pelleting wheat bran improved the availability of phytate phosphorus for chicks, but Corley et al. (1980) reported no effect in a recent study. Trotter and Allee (1979c) indicated pelleting or extruding a low phosphorus-sorghum soybean meal diet did not improve phosphorus availability.

It would be difficult to explain a mechanism for a response of increased phytate phosphorus availability as a result of pelleting the diet. *In vitro* studies show that phytic acid, particularly that contained in cereal grains, is some what resistant to destruction by autoclaving unless the autoclaving runs for extended periods. O'Dell (1962) found a marked increase in the inorganic phosphorus content of isolated soybean meal, but only after autoclaving for 1-4 hours. Lease (1966) reported a similar change in the inorganic phosphorus content of sesame meal with autoclaving. McCane and Widdowaon (1944) demonstrated that wet heat quickly destroyed phytate, whereas dry heat did not, thus the increase in inorganic phosphorus could be the breakdowm of phytate rather than reaction of phytase enzyme. Regardless of the action it is unlikely that the increase in phosphorus availability due to pelleting would be due to the same mechanism since the pelleting process is for such a short time. Bayley et al. (1968a), however, studying the influence of steam pelleting conditions, obtained no increased phosphorus utilization by chicks when pelleting was done without steam but did obtain significant improvements when pelleting was done with steam.

Cornelius and Harmon (1974) studied different phosphorus sources with high moisture corn. Pig fed supplemental phosphorus gained more rapidly and efficiently than the unsupplemented groups. However, pigs fed unsupplemented high moisture corn gained significantly faster and more efficiently than those fed unsupplemented dry corn. Bone data and also showed significant improvement for the high moisture corn over dry corn. Abrams et al. (1975) added 0, .05 and .12% phosphorus to a corn supplement diet feeding both wet and dry corn. The pigs fed the low phosphorus dry corn diet gained slower and less efficiently than all other groups. Bone ash and serum phosphorus were also reduced. Pigs fed the high moisture low phosphorus corn had increased rates of gain, serum phosphorus levels and percent bone ash and improved feed efficiency. Trotter and Allee (1979a) demonstrated that biological availability of phosphorus was greater in acid-treated-high-moisture sorghum grain or in high-moisture sorghum stored under anaerobic conditions than in dry grain (42 and 43 versus 19% in pig study; 46 and 48 versus 25% in chick study, respectively).

The improved utilization of phytate phosphorus may be due to a smaller proportion of phytate phosphorus in the more immature grain, an activation of the small amounts of natural phytase in the high-moisture grain, or it may be due to the action of microbial phytases in the partially fermented grain. However, they would not account for the increased availability of phosphorus in reconstituted corn as was shown in the study by Abrams et al. (1975). In their study, dry corn was reconstituted and ensiled for a minimum of 21 days. The action occuring in the anaerobic environment of ensiling would lower the pH and solubilize components within the grain. This would also account for the improved use of dry matter, energy and protein shown by Holmes et al. (1973) for high-moisture ensiled corn compared to dry corn in swine feeding studies.

6. Protein source

Miller et al. (1965) and Hendricks et al. (1969,1970) have reported that phosphorus and calcium utilization are affected by the level of soybean protein in the diet. Reinhard et al. (1974) also noted that increasing dietary protein level by increasing level of soybean meal resulted in a reduction in bone mineralization. The higher the level of soybean protein in the diet the less calcium and phosphorus absorbed. This effect is likely the result of the high levels of phytic acid in soybean meal which forms insoluble complexes with calcium and other minerals in the digestive tract, rendering them unavailable to the animal.

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# CHAPTER III

# BIOAVAILABILITY OF PHOSPHORUS IN SELECTED FEEDSTUFFS FOR YOUNG CHICKS AND PIGS

## SUMMARY

Three trials were conducted to evaluate phosphorus bioavailability using the slope-ratio technique with monosodium phosphate as the standard. The determined values for chicks were: corn 33%, milo 42%, oats 37%, wheat 31%, and alfalfa leaf protein concentrate 77% in the first trial; corn 32%, milo 30%, oats 35%, wheat 42%, cottonseed meal 42%, soybean meal 40%, meat and bone meal 99%, and dicalcium phosphate 95% in the second trial. The values for the pig trial were: corn 29%, milo 25%, oats 36%, wheat 51%, cottonseed meal 42%, soybean meal 36%, meat and bone meal 93%, and dicalcium phosphate 102%.

## INTRODUCTION

Phosphorus is involved in many important metabolic processes. In order for animals to grow efficiently and economically, phosphorus must be provided in the diet in adequate amounts. Knowing the phosphorus availability of ingredients is the base of providing adequate phosphorus in diets.

Many attempts have been made to determine the phosphorus availability of plant ingredients, but there is little agreement in the literature. Noland *et al.* (1968) used growing pig to evaluate the availability of phosphorus in a corn-soybean meal basal diet. They found that the phosphorus was 30-60% available; whereas, Bayley and Thompson (1969) stated that 27-kg pigs were able to absorb 19% of the phosphorus contained in corn-soybean meal diets containing .90% calcium and .35% total phosphorus (no supplemental phosphorus) when fed in meal form. Vipperman et al. (1974) reported that apparent digestibility of phosphorus of corn-soybean meal is 36, 15, and 16% for pigs fed .25, .50, and .75% calcium, respectively. Bayley et al. (1975) fed corn-soybean meal diets containing .62% calcium and .31% phosphorus (no supplemental phosphorus) to 25-kg pigs and obtained phosphorus absorbability value of 30%. Calvert et al. (1978) found the apparent phosphorus availability of corn to be 8.3% when pigs were fed a diet containing .3% total phosphorus and 96.8% of the phosphorus present was from the grain.

Estimates of the availability of total plant phosphorus range from 20 to as high as 60 percent (NRC, 1979).

Studies with slope-ratio technique, Miracle et al. (1977) estimated the availability of phosphorus from soybean meal was 18% for swine, and Trotter et al. (1979b) reported 28% for chicks. Stober et al. (1979) reported the relative phosphorus bioavailability of corn was 8% for swine and Miracle et al. (1977) reported 16%. Hayes et al. (1979) and Trotter et al. (1979b) reported 12% and 19% phosphorus availability of corn for chicks, respectively. Although cottonseed meal is high in phosphorus content, Stober et al. (1980a) reported its relative phosphorus

availability was 0% for swine.

Obviously, there has been a wide difference in estimation of the availability of phosphorus from plant ingredient evaluated with similar methods.

The purpose of this study was to evaluate relative phosphorus bioavailability of corn, milo, oats, wheat, cottonseed meal, soybean meal, meat and bone meal, dicalcium phosphate, and alfalfa leaf protein concentrate for young chicks and pigs.

## EXPERIMENTAL PROCEDURE

Trial 1:

Three hundred day-old male White Leghorn chicks were placed in 10 electrically heated brooder battery cages. The chicks were supplied with water and a regular diet *ad libitum*. On day 11 post-hatching, chicks were weighed and allotted into weight groups from 71 to 87 grams by culling extreme small and big ones. Chicks were allotted by weight to the 22 cages with 10 birds in each cage. Each chick was wing-banded before being placed into electrically heated brooder battery cage. Each cage (treatment) was randomly assigned to a diet. The chicks were supplied with water and diet *ad libitum*. After a 13-day experimental period, chicks were weighed and sacrificed by cervical dislocation and both legs were removed. The right tibias were removed from legs and their adherent muscle tissue was removed manually. The tibia fat was extracted with ether for 10 hours before tibias were ashed at 550 C in a muffle furnace for 18 hours.

The composition of the basal diet is presented in table 1. Monosodium phosphate was included at .46% in the basal diet to prevent chicks from dying. The standard curve was established by feeding the basal diet and three graded levels of monosodium phosphate as shown in table 2. The response curve of test ingredient was established with basal diet response data and three levels of each test ingresient as shown in table 3. The test ingredient was incorporated at the expense of dextrose. The standard curve was tibia ash weight as a function of monosodium phosphate phosphorus intake and neglected the effects of different isolated soybean protein phosphorus intake. The response curve was established using adjusted tibia ash weight as a function of test ingredient phosphorus intake and also neglected the effects of different isolated soybean protein phosphorus intake as shown in table 4. Linear regression analysis was performed. Monosodium phosphate phosphorus was assumed to be 100% available. Dividing the slope of the test ingredient phosphorus response curve by the slope of standard curve and multiplying 100 yielded relative phosphorus availability. Weight gain, feed intake and feed conversion of birds used to establish the standard curve were used for linear regression analysis to test the effects of phosphorus intake on performance.

Phosphorus content of the test ingredient was determined by direct colorimetric analysis (AOAC, 1980). Phosphorus contents were: .2965% for corn, .3206% for milo, .3648% for oats, .4024% for wheat, .6843% for soybean meal, and .6492% for alfalfa leaf protein concentrate (ALPC).

Trial 2:

Four hundred day-old male White Leghorn chicks were placed in 12 electrically heated brooder battery cages. The chicks were supplied with water and a regular diet *ad libitum*. On day 12 post-hatching, chicks were weighed and allotted into weight groups from 76 to 92 grams as previously described. Chicks were allotted by weight to the 28 cages with 10 birds in each cage.

The composition of the basal diet and the diets for establishing standard curve were the same as used in trial 1. The diets for establishing response curve were shown in table 5. The standard curve was tibia ash weight as a function of monosodium phosphate phosphorus intake and neglected the effects of different isolated soybean protein phosphorus intake. The response curve was established with adjusted tibia ash weight as a function of test ingredient phosphorus intake and also neglected the effects of different isolated soybean protein phosphorus intake as shown in table 6. Weight gain, feed intake and feed conversion of birds used to establish standard curve were used for linear regression analysis to test the effects of phosphorus intake on performance.

The phosphorus contents were: .3625% for corn, .4201% for milo, .5168% for oats, .4918% for wheat, .9539% for cottonseed meal, .5554% for soybean meal, 5.03% for meat and bone meal, and 17.21% for dicalcium phosphate.

Trial 3:

One hundred and forty crossbred pigs averaging 13.8 kg were randomly allotted by litter and sex to five groups by weight. Each pig in a group randomly allotted to a pen. Each pen (treatment), 1.8 x 1.8 $m^2$ totally slatted plastic floor, had 5 pigs and was randomly assigned to a diet. Pigs had free access to both feed and water throughout the experiment. After the 35 days feeding trial pigs were sacrificed and the front legs removed. After removing meat manually, connective tissue was removed from bones and ulnas were used to determine breaking force. Each ulna was positioned on a U-shaped support with 5.8 cm distance between two beams. The force loaded on the marked middle line using a Riehle F. S. 20 Testing Machine. The loading speed was set on .2.

Composition of the basal diet is presented in table 7. The standard curve was constructed by feeding a basal diet and three graded levels of $NaH_2PO_4$ diets as shown in table 8. The curve of test ingredient was established using the basal diet data and three graded levels of each test ingredient as shown in table 9. The test ingredient was incorporated at the expense of dextrose. The standard curve was ulna breaking force as a function of monosodium phosphate phosphorus intake and neglected the effects of different soybean meal phosphorus intake. The response curve was established with ulna breaking force as a function of each test ingredient phosphorus intake and also neglected the effects of different soybean meal phosphorus intake as shown in table 10. Linear regression analysis was performed. Monosodium phosphate phosphorus was assumed to be 100% available. Dividing the slope of the test ingredient phosphorus response curve by the slope of standard curve and multiplying 100 yielded relative phosphorus availability. Weight gain, feed intake and feed conversion of pigs used to establish the standard curve were used for linear regression analysis to test phosphorus effects on performance.

The test ingredient phosphorus was determined by direct colorimetric analysis (AOAC, 1980). The phosphorus contents were: .276% for corn, .268% for milo, .350% for oats, .385% for wheat, 1.16% for cottonseed meal, .635% for soybean meal, 3.81% for meat and bone meal, and 18.5% for dicalcium phosphate.

## RESULTS

Trial 1:

Linear regression analysis was conducted on the standard curve data which yielded correlation coefficient .991 ($P<.01$) and a slope of .2366 mg tibia ash/mg $NaH_2PO_4$ phosphorus intake as shown in table 11. The correlation coefficients and slopes for the six test ingredients were: .956 ($P<.05$) and .0774 mg adjusted tibia ash/mg corn phosphorus intake; .959 ($P<.05$) and .0990 mg adjusted tibia ash/mg milo phosphorus intake; .964 ($P<.05$) and .0876 mg adjusted tibia ash/mg oats phosphorus intake; .998 ($P<.01$) and .0722 mg adjusted tibia ash/mg wheat phosphorus intake; .879 ($P>.05$ when df=2) or .991 ($P>.05$ when df=1) for soybean meal; .998 ($P<.01$) and .1816 mg adjusted tibia ash/mg alfalfa leaf protein concerntrate phosphorus intake. These slope yielded relative availability values of 33% for corn, 42% for milo, 37% for oats, 31% for wheat, and 77% for alfalfa leaf protein concentrate (table 12).

Total diet intake responded linearly to total available phosphorus intake ($r=.983$, $P<.05$). Growth rate responded linearly to both total available phosphorus intake ($r=.990$, $P<.01$) and total diet intake ($r=.994$, $P<.01$). Feed conversion decreased as total available phosphorus increased ($r=-.956$, $P<.05$). These results are shown in table 13.

Trial 2:

Linear regression analysis conducted on the standard curve data which yielded correlation coefficient .976 ($P<.05$) and a slope of .2081 mg tibia ash/mg $NaH_2PO_4$ phosphorus intake as shown in table 14. The correlation coefficients and slopes for the eight test ingredients were: .983 ($P<.05$) and .0666 mg adjusted tibia ash/mg corn phosphorus intake; .977 ($P<.05$) and .0624 mg adjusted tibia ash/mg milo phosphorus intake; .991 ($P<.01$) and .0736 mg adjusted tibia ash/mg oats phosphorus intake; .997 ($P<.01$) and .0867 mg adjusted tibia ash/mg wheat phosphorus intake; .990 ($P<.01$) and .0879 mg adjusted tibia ash/mg cottonseed meal phosphorus intake; .996 ($P<.01$) and .0830 mg adjusted tibia ash/mg soybean meal phosphorus intake; .995 ($P<.01$) and .2068 mg adjusted tibia ash/mg meat and bone meal phosphorus intake; .984 ($P<.05$) and .1977 mg adjusted tibia ash/mg dicalcium phosphate phosphorus intake. These slopes yielded relative bioavailability values of 32% for corn, 30% for milo, 35% for oats, 42% for wheat, 42% for cottonseed meal, 40% for soybean meal, 99% for meat and bone meal, 95% for dicalcium phosphate (table 15).

Total diet intake responded linearly to total available phosphorus intake (r=.992, $P<.01$). Growth rate responded linearly to both total available phosphorus intake (r=.997, $P<.01$) and total diet intake (r=.989, $P<.05$). Feed conversion was not significantly related to available phosphorus intake (r=-.898, $P>.05$). These results are shown in table 16.

Trial 3:

Linear regression analysis was conducted on the standard curve data which yielded correlation coefficient .994 ($P<.01$) and a slope of .6994 kg ulna breaking force/gm $NaH_2PO_4$ phosphorus intake as shown in table 17. The correlation coefficients and slopes for the eight test ingredients were: .982 ($P<.05$) and .2023 kg ulna breaking force/gm corn phosphorus intake; .982 ($P<.05$) and .1738 kg ulna breaking force/gm milo phosphorus intake; .990 ($P<.01$) and .2499 kg ulna breaking force/gm oats phosphorus intake; .987 ($P<.05$) and .3595 kg ulna breaking force/gm wheat phosphorus intake; .991 ($P<.01$) and .2957 kg ulna breaking force/gm cottonseed meal phosphorus intake; .997 ($P<.01$) and .2545 kg ulna breaking force/gm soybean meal phosphorus intake; .996 ($P<.01$) and .6505 kg ulna breaking force/gm meat and bone meal phosphorus intake; .984 ($P<.05$) and .7099 kg ulna breaking force/gm dicalcium phosphate phosphorus intake. These slope yielded relative bioavailability values of 29% for corn,

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25% for milo, 36% for oats, 51% for wheat, 42% for cottonseed meal, 36% for soybean meal, 93% for meat and bone meal, and 102% for dicalcium phosphate (table 18).

Total diet intake was not significantly related to total available phosphorus intake ($r=.931$, $P>.05$). Growth rate responded linearly to both total available phosphorus intake ($r=.990$, $P<.01$) and total diet intake ($r=.972$, $P<.05$). Feed conversion decreased as total available phosphorus intake increased ($r=-.952$, $P<.05$). These results are shown in table 19.

## DISCUSSION

Plant phosphorus can be partitioned into phytate phosphorus and nonphytate phosphorus. Phytate phosphorus cannot be used by nonruminants such as pigs and chicks. (Gillis et al., 1949; Heuser et al., 1943; McGinnis et al., 1944; and Sunde and Bird, 1956). It is generally assumed the quantity of nonphytate phosphorus is associated with phosphorus availability. Whether or not the nonphytate phosphorus is totally available is not really known. But, in general, the plant phosphorus availability in our finding is higher than most of previous findings except wheat (Hayes et al., 1979; Miracle et al., 1977; Ross et al., 1980; Russell et al., 1980; Stober et al., 1979; Stober et al., 1980a, 1980b; Trotter et al., 1979a, 1979b).

Wheat had higher phosphorus availability, which may stem from its increased phytase activity (McCane et al., 1944; and Mollgaard, 1946). It is assumed that enzyme phytase hydrolyze phytate to phosphoric acid in the animal gastrointestinal tract (Nelson et al., 1971). But wheat probably either varies in its original phytase content or the enzyme is labile under the handling conditions (Nelson, 1967). Alfalfa leaf protein concentrate is the highest phosphorus availability of the plant ingredients tested because leaves and stems of plant contain none or little phytate phosphorus of total phosphorus (Mollgaard, 1946; Nelson, 1968; and Underwood, 1966). A wide range of plant phosphorus availability within a kind of feedstuff probably associates with a wide range of nonphytate content (Common, 1940; Hart et al., 1911; Lolas et al., 1976; Mollgaard, 1946; Nelson et al., 1968; Spitzer et al., 1945).

Gillis et al. (1948, 1954) conducted the studies on the utilization by the chick of phosphorus from various sources. They reported that dicalcium phosphate, sodium acid phosphate and potassium acid phosphate were highly available. Plumlee et al. (1958) determined the availability of the phosphorus in various phosphate material for growing swine and reported that dicalcium phosphate, monocalcium phosphate, and phosphoric acid about equal followed by steam bone meal. Cromwell et al. (1976) indicated the phosphorus in meat and bone meal was as available as that in dicalcium phosphate. According to a summary by Hays (1976), relative value is 100 for meat and bone meal, and dicalcium phosphate is 98. These findings all consist with ours. Dicalcium phosphate and meat and bone meal were equal in availability to monosodium phosphate because they all contain the metabolic form of phosphorus in animal system.

Voluntary feed intake was linear to available phosphorus intake with chicks but not with pigs. That gain responded linearly to available phosphorus intake was consistent with the finding of Burns _et al_. (1976) and Combs _et al_. (1962). Feed/gain did not linearly decrease as available phosphorus intake increased in trial 2. Similar results were reported by Burns _et al_. (1976). However, in trial 1 and trial 3 feed/gain was linear to available phosphorus intake.

TABLE 1. COMPOSITION OF BASAL DIET[a] FOR TRIAL 1 AND TRIAL 2

| Ingredient | International reference number | Percent |
|---|---|---|
| Dextrose | | 71.52 |
| Promine-F[b] (Isolated soybean protein) | | 20.00 |
| DL-Methionine | | .25 |
| Choline chloride | | .20 |
| Corn oil | | 2.00 |
| Vitamin premix[c] | | 1.50 |
| Trace mineral premix[d] | | .10 |
| $KC_2H_3O_2$ | | .80 |
| $MgSO_4$ | | .40 |
| Salt | | .40 |
| Limestone | 6-02-632 | 2.37 |
| Monosodium phosphate ($NaH_2PO_4$) | 6-04-228 | .46 |
| | | 100.00 |

[a]As fed basis:
Protein 18.45% Calcium .94% Phosphorus .26%
Calcium:Phosphorus=3.6:1

[b]Promine-F

1. Moisture 4.5%
2. Protein (as-is basis) 91.5%
3. Calcium .2%
4. Phosphorus .7%

[c]Each kilogram of vitamin premix contained the following: vitamin A 500,000 IU; vitamin $D_3$ 28,500 IU; vitamin E 12,000 IU; vitamin $K_1$ 40 mg; riboflavin 660 mg; d-pantothenic acid 2,600 mg; nicotinic acid 4,400 mg; vitamin B-12 4 mg; folacin 200 mg; thiamin 260 mg; pyridoxine 250 mg; biotin 20 mg; choline chloride 220 mg; ascorbic acid 30 g.

[d]Containing .1% cobalt; 1% copper; .3% iodine; 10% iron; 10% manganese; 10% zinc; .02% selenium.

TABLE 2. DIETS FOR ESTABLISHING STANDARD CURVE FOR TRIAL 1 AND TRIAL 2

| |
|---|
| 1. Basal + .19% monosodium phosphate[a] |
| 2. Basal + .38% monosodium phosphate |
| 3. Basal + .57% monosodium phosphate |

[a]Containing 25.5% phosphorus.

TABLE 3. DIETS FOR TEST INGREDIENT PHOSPHORUS FOR TRIAL 1

| |
|---|
| 1. Basal + 23% corn |
| 2. Basal + 46% corn |
| 3. Basal + 69% corn |
| 1. Basal + 23% milo |
| 2. Basal + 46% milo |
| 3. Basal + 69% milo |
| 1. Basal + 23% oats |
| 2. Basal + 46% oats |
| 3. Basal + 69% oats |
| 1. Basal + 20% wheat |
| 2. Basal + 40% wheat |
| 3. Basal + 60% wheat |
| 1. Basal + 14% soybean meal |
| 2. Basal + 28% soybean meal |
| 3. Basal + 42% soybean meal |
| 1. Basal (2.00% limestone) + 12% ALPC |
| 2. Basal (1.47% limestone) + 24% ALPC |
| 3. Basal ( .94% limestone) + 36% ALPC |

TABLE 4. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE TIBIA ASH WEIGHT, AND ADJUSTED TIBIA ASH WEIGHT OF TRIAL 1

| | Total diet intake per chick (as fed basis) | Total P intake per chick | | | Per tibia ash weight | Adjusted tibia ash weight[a] |
|---|---|---|---|---|---|---|
| | | From isolated soybean protein | From $NaH_2PO_4$ | From test ingredient | | |
| | g/13 days | mg/13 days | mg/13 days | mg/13 days | mg | mg |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 145.9 | 145.9 |
| Basal+23% corn | 193.2 | 270.5 | 226.6 | 131.8 | 164.3 | 163.7 |
| Basal+46% corn | 213.6 | 299.0 | 250.6 | 291.3 | 182.8 | 176.5 |
| Basal+69% corn | 213.6 | 299.0 | 250.6 | 437.0 | 186.1 | 179.8 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 145.9 | 145.9 |
| Basal+23% milo | 200.0 | 280.0 | 234.6 | 147.5 | 152.0 | 149.5 |
| Basal+46% milo | 209.1 | 292.7 | 245.3 | 308.4 | 184.0 | 178.9 |
| Basal+69% milo | 211.4 | 296.0 | 248.0 | 467.6 | 193.2 | 187.5 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 145.9 | 145.9 |
| Basal+23% oats | 225.0 | 315.0 | 263.9 | 188.8 | 182.3 | 172.9 |
| Basal+46% oats | 195.5 | 273.7 | 229.3 | 328.1 | 185.9 | 184.6 |
| Basal+69% oats | 220.5 | 308.7 | 258.6 | 555.0 | 203.5 | 195.3 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 145.9 | 145.9 |
| Basal+20% wheat | 206.8 | 289.5 | 242.6 | 166.4 | 165.1 | 160.7 |
| Basal+40% wheat | 218.2 | 305.5 | 255.9 | 351.2 | 179.6 | 172.0 |
| Basal+60% wheat | 229.5 | 321.3 | 269.2 | 554.1 | 197.4 | 186.7 |

TABLE 4. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE TIBIA ASH WEIGHT, AND ADJUSTED TIBIA ASH WEIGHT OF TRIAL 1-CONTINUED

| | Total diet intake per chick (as fed basis) g/13 days | Total P intake per chick: From isolated soybean protein mg/13 days | From $NaH_2PO_4$ mg/13 days | From test ingredient mg/13 days | Per tibia ash weight mg | Adjusted tibia ash weight[a] mg |
|---|---|---|---|---|---|---|
| Basal | 190.9 | 267.3 | 223.9 | 0 | 145.9 | 145.9 |
| Basal+14% soybean meal | 225.0 | 315.0 | 263.9 | 204.5 | 196.6 | 187.2 |
| Basal+28% soybean meal | 231.8 | 324.5 | 271.9 | 421.4 | 189.9 | 178.6 |
| Basal+42% soybean meal | 234.1 | 327.7 | 274.6 | 638.3 | 218.3 | 206.3 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 145.9 | 145.9 |
| Basal+12% ALPC | 209.1 | 291.7 | 245.3 | 162.9 | 184.3 | 179.2 |
| Basal+24% ALPC | 222.7 | 311.8 | 261.2 | 347.0 | 222.5 | 213.7 |
| Basal+36% ALPC | 243.2 | 340.5 | 285.3 | 568.4 | 263.7 | 249.2 |

[a]Adjusted tibia ash weight = Tibia ash weight - ($NaH_2PO_4$ phosphorus intake - 223.9) x .2366.

TABLE 5. DIETS FOR TEST INGREDIENT PHOSPHORUS FOR TRIAL 2

| |
|---|
| 1. Basal + 23% corn |
| 2. Basal + 46% corn |
| 3. Basal + 69% corn |
| 1. Basal + 23% milo |
| 2. Basal + 46% milo |
| 3. Basal + 69% milo |
| 1. Basal + 23% oats |
| 2. Basal + 46% oats |
| 3. Basal + 69% oats |
| 1. Basal + 23% wheat |
| 2. Basal + 46% wheat |
| 3. Basal + 69% wheat |
| 1. Basal + 8% cottonseed meal |
| 2. Basal + 16% cottonseed meal |
| 3. Basal + 24% cottonseed meal |
| 1. Basal + 13% soybean meal |
| 2. Basal + 26% soybean meal |
| 3. Basal + 39% soybean meal |
| 1. Basal (2.16% limestone) + 1% meat and bone meal |
| 2. Basal (1.95% limestone) + 2% meat and bone meal |
| 3. Basal (1.74% limestone) + 3% meat and bone meal |
| 1. Basal (2.16% limestone) + .4% dicalcium phosphate |
| 2. Basal (1.95% limestone) + .8% dicalcium phosphate |
| 3. Basal (1.74% limestone) + 1.2% dicalcium phosphate |

TABLE 6. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE TIBIA ASH WEIGHT, AND ADJUSTED TIBIA ASH WEIGHT OF TRIAL 2

| | Total diet intake per chick (as fed basis) | Total P intake per chick | | | Per tibia ash weight | Adjusted tibia ash weight[a] |
|---|---|---|---|---|---|---|
| | | From isolated soybean protein | From $NaH_2PO_4$ | From test ingredient | | |
| | g/13 days | mg/13 days | mg/13 days | mg/13 days | mg | mg |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+23% corn | 213.6 | 299.0 | 250.6 | 133.1 | 176.6 | 171.1 |
| Basal+46% corn | 206.8 | 289.5 | 242.6 | 257.8 | 188.2 | 184.3 |
| Basal+69% corn | 211.4 | 296.0 | 248.0 | 395.3 | 195.3 | 190.3 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+23% milo | 209.1 | 292.7 | 245.3 | 155.8 | 185.2 | 180.8 |
| Basal+46% milo | 218.2 | 305.5 | 255.9 | 325.2 | 197.1 | 190.4 |
| Basal+69% milo | 215.9 | 302.3 | 253.3 | 482.7 | 202.1 | 196.1 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+23% oats | 234.1 | 327.7 | 274.6 | 215.9 | 197.5 | 187.0 |
| Basal+46% oats | 231.8 | 324.5 | 271.9 | 427.6 | 205.2 | 195.2 |
| Basal+69% oats | 268.2 | 375.5 | 314.6 | 742.1 | 241.2 | 222.3 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+23% wheat | 218.2 | 305.5 | 255.9 | 198.2 | 191.4 | 184.7 |
| Basal+46% wheat | 225.0 | 315.0 | 263.9 | 408.8 | 207.1 | 198.8 |
| Basal+69% wheat | 229.5 | 321.3 | 269.2 | 625.5 | 230.5 | 221.1 |

TABLE 6. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE TIBIA ASH WEIGHT, AND ADJUSTED TIBIA ASH WEIGHT OF TRIAL 2-CONTINUED

| | Total diet intake per chick (as fed basis) g/13 days | Total P intake per chick From isolated soybean protein mg/13 days | From $NaH_2PO_4$ mg/13 days | From test ingredient mg/13 days | Per tibia ash weight mg | Adjusted tibia ash weight[a] mg |
|---|---|---|---|---|---|---|
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+8% cottonseed meal | 227.3 | 318.2 | 266.6 | 173.5 | 196.0 | 187.1 |
| Basal+16% cottonseed meal | 240.9 | 337.3 | 282.6 | 367.7 | 215.6 | 203.4 |
| Basal+24% cottonseed meal | 261.4 | 366.0 | 306.6 | 598.5 | 236.1 | 218.9 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+13% soybean meal | 218.2 | 305.5 | 255.9 | 157.4 | 188.1 | 181.4 |
| Basal+26% soybean meal | 243.2 | 340.5 | 285.3 | 350.9 | 206.1 | 193.3 |
| Basal+39% soybean meal | 256.8 | 359.5 | 301.2 | 555.8 | 229.2 | 213.1 |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+1% meat and bone meal | 218.2 | 305.5 | 255.9 | 109.8 | 196.6 | 189.9 |
| Basal+2% meat and bone meal | 220.5 | 308.7 | 258.6 | 221.8 | 224.8 | 217.6 |
| Basal+3% meat and bone meal | 240.9 | 337.3 | 282.6 | 363.5 | 251.5 | 239.3 |

TABLE 6. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE TIBIA ASH WEIGHT, AND ADJUSTED TIBIA ASH WEIGHT OF TRIAL 2-CONTINUED

| | Total diet intake per chick (as fed basis) g/13 days | Total P intake per chick | | | Per tibia ash weight | Adjusted tibia ash weight[a] |
|---|---|---|---|---|---|---|
| | | From isolated soybean protein mg/13 days | From $NaH_2PO_4$ mg/13 days | From test ingredient mg/13 days | mg | mg |
| Basal | 190.9 | 267.3 | 223.9 | 0 | 165.5 | 165.5 |
| Basal+ .4% dicalcium phosphate | 218.2 | 305.5 | 255.9 | 150.2 | 216.2 | 209.5 |
| Basal+ .8% dicalcium phosphate | 240.9 | 337.3 | 282.6 | 331.7 | 258.5 | 246.3 |
| Basal+1.2% dicalcium phosphate | 259.1 | 362.7 | 303.9 | 535.1 | 289.1 | 272.5 |

[a]Adjusted tibia ash weight = Tibia ash weight - ($NaH_2PO_4$ phosphorus intake - 223.9) x .2081.

TABLE 7. COMPOSITION OF BASAL DIET[a] FOR TRIAL 3

| Ingredient | International reference number | Percent |
|---|---|---|
| Dextrose | | 62.70 |
| Soybean meal | 5-04-612 | 34.00 |
| Salt | | .50 |
| Vitamin premix[b] | | 1.00 |
| Trace mineral premix[c] | | .05 |
| Antibiotic[d] | | .25 |
| Limestone | 6-02-632 | 1.50 |
| | | 100.00 |

[a]Protein 16.1% Calcium .64% Phosphorus .23%

[b]Amount per kg: vitamin A 500,000 IU; vitamin $D_3$ 28,500 IU; riboflavin 660 mg; d-calcium pantothenate 2,800 mg; niacin 4,400 mg; choline chloride 220 mg; vitamin B-12 4 mg; vitamin E 12,000 IU; folacin 200 mg; thiamin 260 mg; pyridoxine 250 mg; biotin 20 mg; ascorbic acid 30 g; vitamin K 550 mg.

[c]Containing .1% cobalt; 1% copper; .3% iodine; 14% iron; 20% zinc; 10% manganese; .04% selenium.

[d]Supplied as 110 mg each of chlortetracycline and sulfamethazine and 55 mg of penicillin per kg of diet.

TABLE 8. DIETS FOR ESTABLISHING STANDARD CURVE OF TRIAL 3

| |
|---|
| 1. Basal + .22% monosodium phosphate[a] |
| 2. Basal + .44% monosodium phosphate |
| 3. Basal + .66% monosodium phosphate |

[a]Containing 25.5% phosphorus.

TABLE 9. DIETS FOR TEST INGREDIENT PHOSPHORUS OF TRIAL 3

| |
|---|
| 1. Basal + 20% corn |
| 2. Basal + 40% corn |
| 3. Basal + 60% corn |
| 1. Basal + 20% milo |
| 2. Basal + 40% milo |
| 3. Basal + 60% milo |
| 1. Basal + 20% oats |
| 2. Basal + 40% oats |
| 3. Basal + 60% oats |
| 1. Basal + 20% wheat |
| 2. Basal + 40% wheat |
| 3. Basal + 60% wheat |
| 1. Basal + 15% cottonseed meal |
| 2. Basal + 30% cottonseed meal |
| 3. Basal + 45% cottonseed meal |
| 1. Basal + 10% soybean meal |
| 2. Basal + 20% soybean meal |
| 3. Basal + 30% soybean meal |
| 1. Basal (1.1% limestone) + 1% meat and bone meal |
| 2. Basal ( .8% limestone) + 2% meat and bone meal |
| 3. Basal ( .5% limestone) + 3% meat and bone meal |
| 1. Basal (1.2% limestone) + .28% dicalcium phosphate |
| 2. Basal (1.0% limestone) + .56% dicalcium phosphate |
| 3. Basal ( .8% limestone) + .84% dicalcium phosphate |

TABLE 10. PARTITION OF TOTAL PHOSPHORUS INTAKE AND RESPONSE ULNA BREAKING FORCE OF TEST INGREDIENT OF TRIAL 3

| | Total diet intake per pig (as fed basis) kg/35 days | Total P intake per pig | | Per ulna breaking force kg |
|---|---|---|---|---|
| | | From soybean meal g/35 days | From test ingredient g/35 days | |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+20% corn | 34.2 | 86.4 | 18.8 | 44.0 |
| Basal+40% corn | 37.6 | 95.0 | 41.6 | 46.6 |
| Basal+60% corn | 33.8 | 85.4 | 56.0 | 51.6 |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+20% milo | 35.0 | 88.4 | 18.8 | 44.0 |
| Basal+40% milo | 38.6 | 97.6 | 41.4 | 46.0 |
| Basal+60% milo | 36.0 | 91.0 | 57.8 | 50.2 |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+20% oats | 36.0 | 91.0 | 25.2 | 48.4 |
| Basal+40% oats | 37.8 | 95.4 | 53.0 | 53.2 |
| Basal+60% oats | 37.0 | 93.4 | 77.8 | 59.6 |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+20% wheat | 37.4 | 94.4 | 28.8 | 46.6 |
| Basal+40% wheat | 36.8 | 93.0 | 56.6 | 62.0 |
| Basal+60% wheat | 40.4 | 102.0 | 93.4 | 71.4 |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+10% cottonseed meal | 36.0 | 91.0 | 41.8 | 48.2 |
| Basal+20% cottonseed meal | 31.4 | 79.4 | 72.8 | 57.0 |
| Basal+30% cottonseed meal | 36.0 | 91.0 | 125.2 | 76.2 |

TABLE 10. PARTITION OF TOTAL PHOSPHORUS INTAKE AND RESPONSE ULNA BREAKING FORCE OF TEST INGREDIENT OF TRIAL 3-CONTINUED

| | Total diet intake per pig (as fed basis) | Total P intake per pig | | Per ulna breaking force |
|---|---|---|---|---|
| | | From soybean meal | From test ingredient | |
| | kg/35 days | g/35 days | g/35 days | kg |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+15% soybean meal | 37.8 | 95.4 | 36.0 | 49.8 |
| Basal+30% soybean meal | 36.4 | 92.0 | 69.4 | 56.2 |
| Basal+45% soybean meal | 36.2 | 91.4 | 103.4 | 66.4 |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+1% meat and bone meal | 36.6 | 92.4 | 14.0 | 46.2 |
| Basal+2% meat and bone meal | 35.2 | 89.0 | 26.8 | 57.0 |
| Basal+3% meat and bone meal | 41.6 | 105.0 | 47.6 | 69.6 |
| Basal | 33.6 | 84.8 | 0 | 39.4 |
| Basal+ .28% dicalcium phosphate | 37.8 | 95.4 | 19.6 | 60.0 |
| Basal+ .56% dicalcium phosphate | 42.4 | 107.2 | 44.0 | 78.4 |
| Basal+ .84% dicalcium phosphate | 46.8 | 118.2 | 72.8 | 91.6 |

TABLE 11. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE TIBIA ASH WEIGHT, AND LINEAR REGRESSION CORRELATION COEFFICIENT AND SLOPE OF STANDARD CURVE OF TRIAL 1

| | Total diet intake per chick (as fed basis) | Total P intake per chick | | Per tibia ash weight | Linear regression (tibia ash weight as a function of monosodium phosphate P intake) | |
|---|---|---|---|---|---|---|
| | | From isolated soybean protein | From $NaH_2PO_4$ | | Correlation coefficient | Slope |
| | g/13 days | mg/13 days | mg/13 days | mg | | |
| Basal | 190.9 | 267.3 | 223.9 | 145.9 | | |
| Basal+ .19% $NaH_2PO_4$ | 193.2 | 270.5 | 320.2 | 173.4 | | |
| Basal+ .38% $NaH_2PO_4$ | 213.6 | 299.0 | 457.5 | 212.9 | .991 | .2366 |
| Basal+ .57% $NaH_2PO_4$ | 243.2 | 340.5 | 638.8 | 243.5 | | |

TABLE 12. RELATIVE PHOSPHORUS AVAILABILITY OF CORN, MILO, OATS, WHEAT, SOYBEAN MEAL, AND ALFALFA LEAF PROTEIN CONCENTRATE OF TRIAL 1

| | Linear regression (adjusted tibia ash weight as a function of test ingredient phosphorus intake) | | Relative phosphorus availability |
|---|---|---|---|
| | Correlation coefficient | Slope | % |
| Corn | .956 | .0774 | $\frac{.0774}{.2366}$x100=33 |
| Milo | .959 | .0990 | $\frac{.0990}{.2366}$x100=42 |
| Oats | .964 | .0876 | $\frac{.0876}{.2366}$x100=37 |
| Wheat | .998 | .0722 | $\frac{.0722}{.2366}$x100=31 |
| Soybean meal | .879 (ns at 5% level)<br>.991[a](ns at 5% level) | ——— | ——— |
| ALPC | .998 | .1816 | $\frac{.1816}{.2366}$x100=77 |

[a]Calculated with data as following:

| Wheat phosphorus intake (mg/13 days) | Adjusted tibia ash weight (mg) |
|---|---|
| 0 | 145.9 |
| 421.4 | 178.6 |
| 638.3 | 206.3 |

TABLE 13. RELATIONSHIPS BETWEEN TOTAL DIET INTAKE AND TOTAL AVAILABLE PHOSPHORUS INTAKE, GROWTH RATE AND TOTAL AVAILABLE PHOSPHORUS INTAKE, GROWTH RATE AND TOTAL DIET INTAKE, AND FEED CONVERSION AND TOTAL AVAILABLE PHOSPHORUS INTAKE IN YOUNG CHICK OF TRIAL 1

| | Total available P intake[a] per chick in 13 days | Total diet intake per chick in 13 days (dry matter basis) | Growth rate per chick in 13 days | Feed conversion | Linear regression correlation coefficient | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Total diet intake as a function of total available P intake | Growth rate as a function of total available P intake | Growth rate as a function of total diet intake | Feed conversion as a function of total available P intake |
| | mg | mg | g | g/g | | | | |
| Basal | 330.8 | 183.0 | 72.0 | 2.54 | | | | |
| Basal+ .19% $NaH_2PO_4$ | 428.4 | 185.3 | 74.4 | 2.49 | .983 | .990 | .994 | -.956 |
| Basal+ .38% $NaH_2PO_4$ | 577.1 | 204.8 | 89.2 | 2.30 | | | | |
| Basal+ .57% $NaH_2PO_4$ | 775.0 | 233.3 | 103.7 | 2.25 | | | | |

[a]Total available phosphorus intake = Isolated soybean protein phosphorus intake x .40 + $NaH_2PO_4$ phosphorus intake.

TABLE 14. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE TIBIA ASH WEIGHT, AND LINEAR REGRESSION CORRELATION COEFFICIENT AND SLOPE OF STANDARD CURVE OF TRIAL 2

| | Total diet intake per chick (as fed basis) | Total P intake per chick | | Per tibia ash weight | Linear regression (tibia ash weight as a function of monosodium phosphate P intake) | |
|---|---|---|---|---|---|---|
| | | From isolated soybean protein | From $NaH_2PO_4$ | | Correlation coefficient | Slope |
| | g/13 days | mg/13 days | mg/13 days | mg | | |
| Basal | 190.9 | 267.3 | 223.9 | 165.5 | | |
| Basal+ .19% $NaH_2PO_4$ | 220.5 | 308.7 | 365.5 | 214.5 | .976 | .2081 |
| Basal+ .38% $NaH_2PO_4$ | 238.6 | 334.0 | 511.1 | 239.0 | | |
| Basal+ .57% $NaH_2PO_4$ | 259.1 | 362.7 | 680.5 | 263.3 | | |

TABLE 15. RELATIVE PHOSPHORUS AVAILABILITY OF CORN, MILO, OATS, WHEAT, COTTONSEED MEAL, SOYBEAN MEAL, MEAT AND BONE MEAL, AND DICALCIUM PHOSPHATE OF TRIAL 2

| | Linear regression (adjusted tibia ash weight as a function of test ingredient phosphorus intake) | | Relative phosphorus availability |
|---|---|---|---|
| | Correlation coefficient | Slope | % |
| Corn | .983 | .0666 | $\frac{.0666}{.2081}$x100=32 |
| Milo | .977 | .0624 | $\frac{.0624}{.2081}$x100=30 |
| Oats | .991 | .0736 | $\frac{.0736}{.2081}$x100=35 |
| Wheat | .997 | .0867 | $\frac{.0867}{.2081}$x100=42 |
| Cottonseed meal | .990 | .0879 | $\frac{.0879}{.2081}$x100=42 |
| Soybean meal | .996 | .0830 | $\frac{.0830}{.2081}$x100=40 |
| Meat and bone meal | .995 | .2068 | $\frac{.2068}{.2081}$x100=99 |
| Dicalcium phosphate | .984 | .1977 | $\frac{.1977}{.2081}$x100=95 |

TABLE 16. RELATIONSHIPS BETWEEN TOTAL DIET INTAKE AND TOTAL AVAILABLE PHOSPHORUS INTAKE, GROWTH RATE AND TOTAL AVAILABLE PHOSPHORUS INTAKE, GROWTH RATE AND TOTAL DIET INTAKE, AND FEED CONVERSION AND TOTAL AVAILABLE PHOSPHORUS INTAKE IN YOUNG CHICK OF TRIAL 2

| | Total available P intake[a] per chick in 13 days | Total diet intake per chick in 13 days (dry matter basis) | Growth rate per chick in 13 days | Feed conversion | Linear regression correlation coefficient | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Total diet intake as a function of total available P intake | Growth rate as a function of total available P intake | Growth rate as a function of total diet intake | Feed conversion as a function of total available P intake |
| | mg | mg | g | g/g | | | | |
| Basal | 330.8 | 183.0 | 73.6 | 2.49 | .992 | .997 | .989 | -.898 |
| Basal+ .19% $NaH_2PO_4$ | 489.0 | 211.4 | 85.3 | 2.48 | | | | |
| Basal+ .38% $NaH_2PO_4$ | 644.7 | 228.8 | 93.3 | 2.45 | | | | |
| Basal+ .57% $NaH_2PO_4$ | 825.6 | 248.5 | 107.6 | 2.31 | | | | |

[a] Total available phosphorus intake = Isolated soybean protein phosphorus intake x .40 + $NaH_2PO_4$ phosphorus intake.

TABLE 17. PARTITION OF TOTAL PHOSPHORUS INTAKE, RESPONSE ULNA BREAKING FORCE, AND LINEAR REGRESSION CORRELATION COEFFICIENT AND SLOPE OF STANDARD CURVE OF TRIAL 3

| | Total diet intake per pig (as fed basis) | Total P intake per pig | | Per ulna breaking force | Linear regression (ulna breaking force as a function of monosodium phosphate P intake) | |
|---|---|---|---|---|---|---|
| | | From soybean meal | From $NaH_2PO_4$ | | Correlation coefficient | Slope |
| | kg/35 days | gm/35 days | gm/35 days | kg | | |
| Basal | 33.6 | 84.8 | 0 | 39.4 | | |
| Basal+ .22% $NaH_2PO_4$ | 36.4 | 92.0 | 20.4 | 54.8 | | |
| Basal+ .44% $NaH_2PO_4$ | 45.0 | 113.6 | 50.4 | 79.2 | .994 | .6994 |
| Basal+ .66% $NaH_2PO_4$ | 43.2 | 109.2 | 72.8 | 89.0 | | |

TABLE 18. RELATIVE PHOSPHORUS AVAILABILITY OF CORN, MILO, OATS, WHEAT, COTTONSEED MEAL, SOYBEAN MEAL, MEAT AND BONE MEAL, AND DICALCIUM PHOSPHATE OF TRIAL 3

| | Linear regression (ulna breaking force as a function of test ingredient intake) | | Relative phosphorus availability |
|---|---|---|---|
| | Correlation coefficient | Slope | % |
| Corn | .982 | .2023 | $\frac{.2023}{.6994}$x100=29 |
| Milo | .982 | .1738 | $\frac{.1738}{.6994}$x100=25 |
| Oats | .990 | .2499 | $\frac{.2499}{.6994}$x100=36 |
| Wheat | .987 | .3595 | $\frac{.3595}{.6994}$x100=51 |
| Cottonseed meal | .991 | .2957 | $\frac{.2957}{.6994}$x100=42 |
| Soybean meal | .997 | .2545 | $\frac{.2545}{.6994}$x100=36 |
| Meat and bone meal | .996 | .6505 | $\frac{.6505}{.6994}$x100=93 |
| Dicalcium phosphate | .984 | .7099 | $\frac{.7099}{.6994}$x100=102 |

TABLE 19. RELATIONSHIPS BETWEEN TOTAL DIET INTAKE AND TOTAL AVAILABLE PHOSPHORUS INTAKE, GROWTH RATE AND TOTAL AVAILABLE PHOSPHORUS INTAKE, GROWTH RATE AND TOTAL DIET INTAKE, AND FEED CONVERSION AND TOTAL AVAILABLE PHOSPHORUS INTAKE IN GROWING PIG

| | Total available P intake[a] per pig in 35 days | Total diet intake per pig in 35 days (dry matter basis) | Growth rate per pig in 35 days | Feed conversion | Linear regression correlation coefficient | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Total diet intake as a function of total available P intake | Growth rate as a function of total available P intake | Growth rate as a function of total diet intake | Feed conversion as a function of total available P intake |
| | g | kg | kg | kg/kg | | | | |
| Basal | 30.5 | 31.4 | 12.1 | 2.60 | .931 | .990 | .972 | -.952 |
| Basal+ .22% $NaH_2PO_4$ | 53.5 | 34.0 | 13.7 | 2.48 | | | | |
| Basal+ .44% $NaH_2PO_4$ | 91.3 | 42.1 | 17.4 | 2.42 | | | | |
| Basal+ .66% $NaH_2PO_4$ | 112.1 | 40.4 | 18.1 | 2.23 | | | | |

[a]Total available phosphorus intake = Soybean meal intake x .36 + $NaH_2PO_4$ phosphorus intake.

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APPENDIX I

CORRELATION COEFFICIENTS AT THE 5% AND 1% LEVELS OF SIGNIFICANCE

| Degrees of freedom | 5% | 1% | Degrees of freedom | 5% | 1% |
|---|---|---|---|---|---|
| 1 | .997 | 1.000 | 16 | .468 | .590 |
| 2 | .950 | .990 | 17 | .456 | .575 |
| 3 | .878 | .959 | 18 | .444 | .561 |
| 4 | .811 | .917 | 19 | .433 | .549 |
| 5 | .754 | .874 | 20 | .423 | .537 |
| 6 | .707 | .834 | 21 | .413 | .526 |
| 7 | .666 | .798 | 22 | .404 | .515 |
| 8 | .632 | .765 | 23 | .396 | .505 |
| 9 | .602 | .735 | 24 | .388 | .496 |
| 10 | .576 | .708 | 25 | .381 | .487 |
| 11 | .553 | .684 | 26 | .374 | .478 |
| 12 | .532 | .661 | 27 | .367 | .470 |
| 13 | .514 | .641 | 28 | .361 | .463 |
| 14 | .497 | .623 | 29 | .355 | .456 |
| 15 | .482 | .606 | 30 | .349 | .449 |

Adapted from Statistical Methods, Snedecor and Cochran, sixth edition. The Iowa State University Press, Ames, Iowa, U.S.A.

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# BIOAVAILABILITY OF PHOSPHORUS IN SELECTED FEEDSTUFFS FOR YOUNG CHICKS AND PIGS

by

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B.S., National Taiwan University, 1969

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AN ABSTRACT OF A MASTER'S THESIS

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# ABSTRACT

The slope-ratio technique was used to evaluate relative phosphorus bioavailability of nine selected feedstuffs. The standard curve was established by feeding a basal diet and three graded levels of monosodium phosphate. The response curve of each test ingredient was established with the basal diet response data and three levels of each test ingredient.

Two hundred twenty, and two hundred eighty male White Leghorn chicks were used for trial 1 and trial 2, respectively. Each treatment had 10 birds. After a 10-day pretest and a 13-day experimental period, chicks were sacrificed and right tibias were removed from legs. Fat-free tibias were ashed. One hundred and forty growing crossbred pigs were used for the pig experiment. Each treatment had 5 pigs. After the 35-day feeding trial, pigs were sacrificed and the front legs removed. The right ulna was used to determine breaking force.

The standard curve was tibia ash weight as a function of monosodium phosphate phosphorus intake, and the response curve was adjusted tibia ash weight as a function of test ingredient phosphorus intake for two chick trials. The standard curve was ulna breaking force as a function of monosodium phosphate phosphorus intake, and the response curve was ulna breaking force as a function of each test ingredient phosphorus intake for the pig trial. Linear regression analysis was performed. Monosodium phosphate phosphorus was assumed to be 100% available. The slope

of the test ingredient phosphorus response curve divided by the slope of standard curve and multiplying 100 yielded relative phosphorus availability.

The determined values for chicks were: corn 33%, milo 42%, oats 37%, wheat 31%, and alfalfa leaf protein concentrate 77% in the first trial; corn 32%, milo 30%, oats 35%, wheat 42%, cottonseed meal 42%, soybean meal 40%, meat and bone meal 99%, and dicalcium phosphate 95% in the second trial. The values for the pig trial were: corn 29%, milo 25%, oats 36%, wheat 51%, cottonseed meal 42%, soybean meal 36%, meat and bone meal 93%, and dicalcium phosphate 102%.