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CALCIUM AND PHOSPHORUS SOURCES FOR POULTRY FEEDS

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Minerals comprise about 4% of the composition of most vertebrate animals. Calcium and Phosphorus make up more than half of this amount. Although twelve minerals are known to be essential for the chick, meeting the needs for calcium and phosphorus are perhaps the greatest concern to the nutritionists because of the relative quantity and expense required and the potential for adverse effects in event of failure to provide adequate amounts.

Functions of Calcium and phosphorus

Calcium is the most abundant mineral found in the animal body, with about 99% found in the skeletal systems. Calcium plays an important role in a wide variety of essential functions in metabolism. Some of the most important functions of calcium include:

1. Essential for bone formations and maintenance.
2. Necessary for efficient gain and feed utilization.
3. Essential for egg shell formation.
4. Required for normal blood clotting.
5. Contraction of skeletal, cardiac and smooth muscle.
6. Transmission of nerve impulses.
7. Regulation of heartbeat.
8. Activator or stabilizer of enzymes.
9. Involved in secretion of a number of hormones.

Phosphorus is the second most abundant mineral in the body. About 80% of the total quantity is found in the skeletal system, with the remainder widely distributed throughout the body. It is involved in virtually every metabolic reaction in the body and is considered to be the most versatile of all of the mineral elements. Some of the most important functions of phosphorus include:

1. Essential for bone formation and maintenance.
2. Necessary for building muscle tissue and egg formation.
3. Required for efficient gain and feed utilization.
4. A component of nucleic acids which are important in genetic transmission and control of cellular metabolism.
5. Aids in maintaining osmotic and acid-base balance.
6. Important in many functions in energy metabolism. Energy transfer in most metabolic systems involves phosphate compounds such as adenosine triphosphate and creatine phosphate.
7. Phospholipid formation, one of the major means by which fatty acids are transported through the body.
8. Amino acid metabolism and protein formation.
9. Component and activator of many enzyme systems.

Metabolism of calcium and phosphorus

Many factors influence the utilization and metabolism of calcium and phosphorus in the body. Some of the most important include the ratio of the two elements in the diet, the amount of vitamin D present, the biological availability of the supplements used to provide the elements, and the age and physiological state of the animal. Young animals with a rapidly developing skeletal system tend to use the minerals more efficiently than do older animals; hens in active egg production utilize minerals more effectively than non-layers.

Calcium is absorbed from the intestine through an active transport mechanism that is influenced by vitamin D. It is now known that vitamin D functions in calcium absorption through the direction of a specific "calcium binding protein" or "calbindin". Calcium is also absorbed to a small extent by passive ionic diffusion, which may be sufficient for animals with little calcium demand. It should be noted that different commercial samples of vitaminD_3 used by the poultry industry have been found to have biological values that differ substantially from their chemically determined values (Yang et. al., 1973). As a result, many nutritionists prefer to utilize two different vitamin D sources in their vitamin premix.

Phosphorus is absorbed chiefly in the duodenal area of the small intestine. As in the case of the most nutrients, the greater the need, the more efficient the absorption is. Phosphorus absorbed from the intestine is circulated throughout the body and is readily withdrawn from the blood and bone development. It may be withdrawn from bones to maintain normal blood plasma levels. Plasma calcium and phosphorus levels are regulated by the parathyroid hormone.

Symptoms of calcium and phosphorus deficiency

The primary symptom of calcium and phosphorus deficiency in young growing animals is rickets. Rickets, characterized by abnormal metabolism or calcification of the bones, may be caused by a deficiency of calcium, phosphorus, or vitamin D. Calcium and phosphorus are not digested in the cartilaginous matrix in sufficient quantities to develop a strong, dense bone. Gross symptoms of rickets include swollen tender joints, enlargement of the ends of bones, rubbery beaks, and beading of the ribs.

Osteomalacia is an indication of a calcium or phosphorus deficiency in older animals. Even when bone is mature and stops growing, there is a continual turnover or mobilization of calcium and phosphorus that must be replaced to prevent weakening of bone structure. A continual depletion of minerals will lead to weak and brittle bones, which may break under pressure. In laying hens, thin or weak shells are one of the first indications of calcium deficiency. Severe calcium deprivation may lead to total cessation of egg production.

Sources of Calcium and Phosphorus for Poultry Feeds

A number of products are used worldwide to provide calcium and phosphorus to poultry feeds. Some of the more common of these are shown in Table 1. Sources of concentrated calcium include limestone deposits and marine sources such as oyster shell. Limestone deposits that contain significant portions of magnesium (dolomitic limestones) should be avoided as these may cause diarrhea and reduce performance. However, there is little research to suggest a minimum acceptable level of magnesium in limestone sources.

A wider variety of phosphate sources are used. These include several natural or unprocessed sources such as low-fluorine rock deposits, guano deposits such as Curacao phosphate, colloidal phosphates, and steamed bone meal. While bone meal is typically of high biological quality, the phosphorus content and bioavailability of the other products is generally lower and more variable than processed phosphates. However, depending upon cost and supply, these may be the most economical sources in some areas.

The majority of the feed phosphates used in poultry feeding are chemically processed materials. One group, generally termed "dicalcium phosphates", are produced by reacting phosphoric acid (produced either from burning elemental phosphorus to produce furnace phosphoric acid or from a sulfuric acid digestion of phosphate rock to produce wet process phosphoric acid) with limestone to produce mixtures of monocalcium phosphate and dicalcium phosphate, as seen below:

PRODUCTION OF DICALCIUM PHOSPHATE

Electric Furnace

Raw rock + Silica Pebble + Coke- - - - - - - - > Elemental P

$$P + O_2 - - - - - - - - > P_2O_2 + H_2O - - - - - > H_3PO_4$$

Wet Process

Raw rock + sulfuric acid - - - - - - - - > $H_3PO_{4\ +\ Gypsum}$

H_3PO_4 + Limestone - - - > Dicalcium phosphate + Monocalcium phosphate

The composition of these mixtures is determined by the quantity of limestone that is reacted with the phosphoric acid. Ammonium phosphates are produced in a similar manner by the general reaction between phosphoric acid and anhydrous ammonia. Although having good biological value, ammonium phosphates are seldom used in poultry feeds.

The second major group of feed phosphates are the "defluorinated phosphates". These are produced by reacting phosphate rock with phosphoric acid and sodium carbonate and then calcining at a high temperature (125° C) as seen below:

PRODUCTION OF DEFLOURINATED PHOSPHATE

$$Ca_5 (PO_4)_3F + Na_2CO_3 + H_3PO_4 ----> CaNaPO_4 + Ca_3 (PO_4)_2$$

It is considered to be more difficult to control this process and the quality of the final process than other chemically produced phosphates. Therefore, one tends to see greater variability in biological values assigned to defluorinated phosphates as compared to dicalcium phosphates.

A comparison of the elemental composition of the chemically processed feed phosphates indicates that, in general, the dicalcium phosphates are typically slightly higher in phosphorus content and considerably lower in calcium content than defluorinated phosphates. Defluorinated phosphates typically contain 4 to 6% sodium that has a high biological availability (Nott and Combs, 1969; Damron et. al., 1985). One of the most costly factors in high-density broiler diets is "space", so products that are more "nutrient dense" are more highly prized in least-cost formulation, assuming equal biological value.

THE CONCEPT OF BIOLOGICAL AVAILABILITY

The concept of biological availability implies that the availability of nutrients from different sources varies and that these differences in availability can be measured and, therefore, sources can be compared. While generally applied to phosphorus, the same concept can also be used to compare calcium availability from different sources. Much more emphasis has been placed on phosphorus, as it is the more costly of the two elements. Biological availability (bioavailability, BV) is a measure of the degree to which a phosphorus source can support the physiological processes of an animal.

Although seldom stated, the term implies a "relative" bioavailability. The phosphorus from any source is never completely available or utilized. Some of it is always lost in normal digestive and metabolic processes. Further, many factors influence phosphorus absorption. The "true" or "absolute" availability of the phosphorus from any source is a goal that is often sought but is unlikely to be obtained, due to the myriad of factors that are involved.

Bioavailability of phosphorus sources has generally been determined on a comparative basis with test phosphates being compared with a standard source, which has been given an arbitrary availability value (typically 100). Thus, some studies may indicate a BV greater than 100 for individual phosphates. The use of comparative type assays overcomes many problems related to determination of "true" availability. The main advantage of comparative assays is that the results can be widely applied. Although values obtained from these studies are relative, a "good" phosphate is a good source and a "poor" phosphate is a poor source under virtually all conditions.

Although a number of variations exist in phosphorus bioassays, the basic procedure is common among studies. Although some researchers recommend the use of semi-purified diets to create a greater degree of deficiency, a satisfactory phosphorus-deficient diet can easily be developed using common plant feedstuffs. Chicks of broiler or layer stock are used as the test animal, and are fed the test diet supplemented with graded levels of the test phosphates and a reference

phosphorus material. The levels used in the study should be such that the response (body weight gains, tibia ash, or toe ash) falls in the linear portion of the response curve. Tibia ash has generally been the primary measurement used to estimate BV; however, a number of researchers suggest that toe ash results in similar BV with much less laboratory effort. At the end of the test period (14 to 21 days) the birds are sacrificed and tibia ash or toe ash determined. The BV of the test sources relative to that of the reference is then determined by a slope-ratio assay.

Selection of the reference source for the BV is important for consistency of evaluation. A number of products have been successfully used. Beta-tricalcium phosphate has often been recommended as the standard, as this is the form in which most phosphates occur in nature, is very stable, uniform in composition, and of good biological quality. Reagent grade monocalcium phosphate is often used, as is reagent grade monosodium phosphate. If these products cannot be readily obtained, a sufficient supply of a feed-grade phosphate known to be of high biological value should be set aside for use as a standard. Phosphoric acid has been used in some studies; however its use as a standard is questionable as it often reacts with other minerals in the diet in an uncontrolled reaction forming a variety of different phosphorus products. An excellent review of the historical development of phosphorus availability assays was made by Sullivan and Douglas (1990).

BIOAVAILABILITY OF PHOSPHORUS SOURCES

A number of published studies have compared the bioavailability of different phosphate sources for poultry (Bird et. al., 1945; Gillis et. al., 1948; Miller and Joukovsky, 1953; Grau and Zweigart, 1953; Gillis et. al., 1954; Wilcox et. al., 1954, 1955; Motzok and Branion, 1956; Edwards et. al., 1958; Summers et. al., 1959; Nelson and Peeler, 1961; Nelson and Walker, 1964; Dilworth and Day, 1964; Sullivan, 1966, 1967; Day et. al., 1973; Wozinak et. al., 1977; Huyghebaert et. al., 1980; Jensen and Edwards, 1980; Waibel et. al., 1984; Potchanakorn and Potter, 1987; Potter, 1988; Sullivan et. al., 1989; Nelson et. al., 1990; Potter et. al., 1995). Many of these studies examine the bioavailability of experimental and commercial sources available to the poultry industry. As the production of feed phosphates has undergone continual improvement, examination of the more recent studies would appear to be the most valid. These are shown in Tables 2, 3, 4, and 5. Although exceptions exist, one can generally state that monocalcium phosphates have the highest biological value, with dicalcium phosphates about 5% less and defluorinated phosphates about 10% less in comparative value. Several of these studies examined phosphorus supplements obtained from commercial feed mills, and include some products with exceptionally low biological value. This emphasizes the need to constantly evaluate phosphorus sources.

In some countries, availability of feed-grade phosphates is limited and expensive and questions arise regarding the utilization of raw rock phosphates of fertilizer grade phosphates as sources of phosphorus in poultry diets. A number of studies have demonstrated that such sources may be used, but point out some of the problems and concerns related to the use of such sources. As early as 1945, Matterson et. al. demonstrated that raw rock phosphate was effective as processed rock phosphate for supporting weight gains and body weights in chicks, but emphasized that fluorine levels in various deposits may limit its use. Gerry et. al. (1947, 1949) compared the use of rock phosphates of different fluorine contents for chicks and laying hens, some phosphates with low fluorine levels were acceptable while others were detrimental to performance. Struwe et. al. (1976) reported that the phosphorus availability of a fertilizer grade phosphate was high, but the high (2.8%) Fl content of the product depressed growth of turkeys. In studies with laying hens (3.6% Fl) resulted in delays in sexual maturity, and a reduction in rate of egg production.

Rojas et. al. (1980) reported a biological availability of 65.5% for rock phosphate; when replacing dicalcium phosphate in layer diets egg production was reduced and feed conversion increased. Osirio and Jensen (1986) confirmed that the bioavailability of raw rock phosphate was used as the only source of supplemental phosphate based upon its determined bioavailability, equivalent growth and bone ash was obtained. This product has a Fl content of 1.36% and at the highest level fed contributed 473 ppm Fl to the diet.

It is apparent that some sources of rock phosphate, either raw unprocessed supplies or partially processed fertilizer grade products, can be used to supply part or all of the phosphorus in poultry diets provided that adjustments are made for their bioavailability and concern given to contents of Fl and vanadium (Berg, 1963, Sullivan et. al., 1994). Because of the variation in bioavailability among these products it is essential that each source be tested to determine its potential value and formulation based upon determined bioavailability. Rather than using such sources as sole contributors of supplemental phosphorus, combining them with processed phosphates of high availability or with animal protein sources such as meat and bone meal is highly recommended. Problems with Fl are cumulative, so these products are more suitable in diets for broilers as compared to turkeys or layers. The importance of determining Fl levels in such products is also emphasized. The level of Fl in the final diet should not exceed 500 ppm (NRC, 1994).

BIOAVAILABILITY OF PHOSPHORUS FROM PLANT FEEDSTUFFS

The principle form of phosphorus in most plant feedstuffs is phytate phosphorus. Phytate combines with many elements, including calcium, phosphorus, magnesium, zinc, and manganese, making them largely indigestible by the animal. The biological availability of the phytate P varies, depending upon the age and species of the animal, but in general is poorly available, especially for young growing animals. Studies sometimes suggest higher digestibility of phytate P, but these generally have used chemically isolated phytate P sources, which may differ markedly in digestibility compared to naturally occurring phytate P.

A common "rule of thumb" states that about 70% of the phosphorus in plant feedstuffs is in the form of phytate P, thus leaving about 30% as "available". However, actual assays of phytate P content of different feedstuffs shows that the percentage of total P existing in the phytate form varies among ingredients (Nelson, 1967; Nelson et. al., 1968a). These assay results should be utilized in formulation, rather than assuming a 70:30 ratio (Table 6).

One often overlooked aspect of mineral nutrition is adjustment of dietary Ca level in respect to phytate P levels. His is especially important when feed ingredients high in phytate P are included in the diet, such as rice bran, wheat bran, canola meal, or sunflower meal. Failure to adjust the minimum calcium content of the diet in such situations may lead to a calcium deficiency (Nelson et. al., 1968b). Nelson (1984) suggested the following formula to adjust dietary Ca levels in the presence of phytate P:

$$\text{Dietary Ca (\%)} = 0.6 + (\text{phytate P} \times 1.1)^{1}$$

Inclusion of exogenous phytase enzymes in poultry diets has long been known to improve the utilization of the phytate P by chicks (Nelson et. al., 1968c, 1971). Such products are now being made commercially available for use and have been useful in areas of the world where environmental pollution form animal wastes have been critical. In areas where local ingredients

such as rice bran or wheat bran may be helpful in reducing the cost of providing a part of the phosphorus requirements.

BIOAVAILABILITY OF PHOSPHORUS FROM ANIMAL PROTEINS

Animal protein supplements such as meat and bone meal and poultry byproduct meal have long been used both for their high quality protein and for their phosphorus content. Studies by Waldroup et. al. (1965) and Spandoff and Leong (1965) indicated that phosphorus provided from meat and bone meal, poultry byproduct meal, and fish meal was well utilized by poultry. The bioavailability of P from animal bones was recently challenged (Orban and Roland, 1992); however, in this study bones were cooked in a autoclave and ground prior to feeding, and it was reported that the product contained many large particles of bone chips. It has long been recognized (Gillis, 1954) that particle size of phosphate sources has a significant influence upon their bioavailability. In a recent study, Waldroup and Adams (1994) confirmed the high biological availability of phosphorus from poultry byproduct meal (Figure 1) and meat and bone meal (Figure 2).

PREDICTING BIOAVAILABILITY FROM CHEMICAL ASSAYS

Biological assays with chicks have proven to be a reliable means of estimating the relative bioavailability (BV) of phosphorus from different sources. However, such assays are expensive, labor-intensive, and time-consuming. For many years nutritionists have been exploring the relationship of various in vitro solubility tests of feed phosphates with their biological value as estimated by chick trails. Gillis et. al. (1948) compared the BV of phosphate products to their solubility in a .4% HCl solution. This test was reported to be useful only to identify and eliminate insoluble compounds.

[1]For example, a corn-soy diet formulated to provide a minimum of .45% available phosphorus may have a total phosphorus content of about .70% thus providing about .25% phytate P. Using the equation above, a minimum calcium level of 0.6 + (.25 x 1.1) = .88% would be required. However, using a corn-rice bran-wheat diet with some sunflower or canola meal formulated to provide the same minimum of .45% available phosphorus may result in a total phosphorus content of 1.5%. In this type of diet there would be about 1.05% phytate P, so the minimum dietary calcium needs would be about 0.6 + (1.05 x .1) = 1.75%.

Halloran (1972) compared the BV of four feed-grade samples of phosphate with their solubilities in water. An analytical reagent grade monocalcium phosphate was used as the reference standard. Although tremendous differences in water solubility were noted among the various phosphate sources, there was no correlation of BV with water solubility (Table 7).

Day et. al. (1973) compared the BV of seven different feed grade phosphates determined by chick assay to solubility in either .4% HCl, 2% Citric acid (CA), and neutral ammonium citrate (NAC). These workers found little or no agreement between BV determined by chick assay and their solubility in various solutions (Table 8), and suggested that phosphorus solubility in dilute acids could not be used to reliably predict BV.

Pensack (1974) compared the BV of several feed grade phosphates with their solubility in water. He reported that within phosphates regarded as dicalcium phosphates a high relationship existed between water solubility and BV, but not within phosphates regarded as defluorinated phosphates (Table 9).

Caswell (1984) pointed out that there is a distinct difference in the digestion of chemically formed phosphates (dicalcium and monocalcium phosphate) and thermochemically produced phosphates (defluorinated phosphate). The chemically formed phosphates are inherently acidic, and thus would be less soluble in the upper small intestine. The thermochemically formed phosphates, ranging from neutral to slightly alkaline in pH, would tend to be more soluble in the acidic upper small intestine than in the more neutral lower small intestine. Caswell suggested that, for the thermochemically formed phosphates, products with a decidedly low solubility in neutralized ammonium citrate should be avoided.

Sullivan et. al. (1992) conducted an extensive study with a number of feed-grade phosphates to compare BV determined by turkey poult assay with solubility in a number of chemical solutions (Table 10). They concluded from these tests that: a) correlation of water solubility of feed phosphates to their relative BV is very low. This test has little or no relationship to the relative BV of thermochemically produced defluorinated phosphates (18% P) and di0monocalcium phosphates (18.5%); b) a positive correlation was found between the BV and solubility of feed phosphates in .4% HCl, 2% CA, and NAC. Either the 2% CA or the NAC solubility test could be used as a satisfactory indicator or quick screen of relative BV; c) bioassays of 14 to 21 days duration are the most reliable means of determining relative BV of feed phosphates.

Coffey et. al. (1994) reported that a slight positive relationship exists between the NAC solubility of P for defluorinated phosphates for chicks, but not for pigs (Table 11). Although the authors did not comment on the relative response of chicks and pigs to the different phosphate sources, it appears that the BV of the phosphates determined for chicks was not totally in agreement with the BV determined for pigs.

BIOAVAILABILITY OF CALCIUM SOURCES

Although considerable information is available regarding total calcium content of different plant feedstuffs and different calcium and phosphorus sources, there is little direct information regarding the bioavailability of such products. In contrast to phosphorus, calcium is typically inexpensive to provide to poultry diets and little economic emphasis has been placed on determining biological values for calcium.

Several direct and indirect studies have explored the bioavailability of different calcium sources for poultry and swine. Waldroup et. al. (1964) compared reagent grade sources of calcium carbonate and calcium sulfate against ground oyster shell and two different ground limestones as sources of calcium for chicks. No differences were found between any of these supplements in regard to body weight gain or tibia ash. Dilworth et. al. (1964) estimated the bioavailability of calcium from different phosphorus sources for the chick and concluded that there were significant differences in the calcium availability of feed grade phosphates to the chick, and suggested a positive correlation between the availability of calcium and phosphorus in feed grade phosphate supplements. McNaughton et. al. (1974) demonstrated that calcium utilization of oyster shell and limestone by the chick was dependent upon the particle size of the supplement. From their data it appears desirable to use a medium to fine particle size (USBS sieve 16 or finer) calcium supplement in chick diets. Reid and Weber (1976) evaluated a number of calcium sources and observed a range of bioavailability values from 73.3 to 109.4% in comparison to reagent grade calcium carbonate. No information was given regarding particle size or other factor that might account for the difference in bioavailability. Hillman et. al. (1976) compared different grind sizes for limestone in diets for turkey poults. They reported that finer grinds improved the availability of calcium to the poult and resulted in increased gains and improved

feed utilization at low dietary calcium levels. Conversely, coarser grinds increased gains and improved feed efficiency at higher calcium levels.

The importance of calcium availability to chick performance was demonstrated by McNaughon (1981) who showed that the chick's phosphorus requirement was influenced by particle size of the limestone source used. Anderson et. al. (1984) noted that chicks can shunt excess Ca in the form of medium particles (150 to 1,000 microns) through the digestive tract better than they can more reactive, fine particles.

In pigs, Ross et. al. (1984) found the bioavailability of Ca in calcitic limestone (two sources), oyster shell, gypsum, marble dust, and aragonite was similar, ranging from 93 to 102%. Ca in two dolomitic sources was less available (51 to 78%) than in the other sources. Particle size of the calcium sources did not influence the availability of Ca in this study.

Greater controversy exists regarding bioavailability and relation of particle size of calcium sources for layers. Scott et. al. (1971) suggested that substitution of "hen-sized" oyster shell for two-thirds of the pulverized limestone in the diet resulted in an improvement in average egg shell strength; this was attributed to a "constant metering" of calcium from the gizzard into the blood stream from the more slowly dissolved oyster shell. Kuhl and Sullivan (1977) noted that retention of hen-sized limestone in the gizzard of hens was significantly greater than that of hen-sized oyster shell. In vitro solubility tests in dilute HCl revealed no differences between large-particle limestone or oyster shell.

It appears that the response to calcium source or particle size is sensitive to dietary calcium levels, being of greater concern when dietary calcium levels are minimal or in situations where egg shell quality is stressed. Roland and Harms (1973) reported that substitution of hen- of pullet-sized limestone or oyster shell for two-thirds of the finely ground limestone improved shell quality during the hot summer months but not during cooler weather in the fall. Roland et. al. (1974) observed significant improvements in shell quality when limestone of larger particle size replaced finely ground limestone in diets with low calcium levels but not when the diets contained higher levels of calcium. They concluded that larger particles of limestone would have no influence on shell quality if the hen's diet contained adequate calcium. Similar results were observed by Muir et. al. (1975, 1976), Miller and Sunde (1975), Vogt (1977, 1983), and Watkins et. al. (1977). Conversely, Brister et. al. (1981) reported that addition of large particle oyster shell significantly improved egg shell quality when substituted for a portion of the pulverized calcium source. Even though calcium consumption was considered as adequate. They concluded that calcium from oyster shell, in any form, was more available than that of limestone for egg shell formation. Kuhl et. al. (1977) observed a trend for increased shell strength with larger particle sizes of calcium. Roland (1978) evaluated the existing literature regarding oyster shell versus ground limestone for laying hens and concluded that the vast majority of papers showed no difference between good quality limestone and oyster shell in promoting egg shell quality; the inclusion of "hen-sized" of "pullet-sized" particles of oyster shell or limestone will improve shell quality if hens are consuming inadequate calcium.

Several methods have been proposed to estimate solubility rates of calcium sources (Jensen and Ranvig, 1980; Savage, 1982; Cheng and Coon, 1990a, 1990b). However, Cheng and Coon (1990c) reported that switching from limestone to oyster shell or switching from a higher soluble limestone to a lower soluble limestone and vice versa in short-term laying trials showed no significant differences in shell quality or layer performance. Hens adapted to different sources of

limestone and oyster shell when a large portion of the calcium allocation was in a particle form and when calcium intake was adequate. Thus, no specific recommendation can be made regarding a "desirable" solubility rate for different calcium sources.

Summary

Calcium and phosphorus comprise the greatest amount of the minerals required by poultry and swine and, together, make up the greatest expense of the mineral supplements. As skeletal growth in young animals and egg shell quality and bone strength in mature animals is of significant economic importance, a number of studies have addresses the importance of bioavailability of calcium sources. Although general statements can be made regarding the bioavailability of calcium sources. Although general statements can be made regarding the bioavailability of different feed-grade phosphate sources, sufficient variation exists among and between commercially-available sources that indicate that a continual evaluation program be carried out to ensure that products used in feed manufacturing are of adequate quality. At the present time, no in vitro test appears to be able to adequately estimate phosphorus bioavailability in chicks, poults, or swine; bioassays will remain a necessity.

Calcium availability from phosphate sources appears to parallel that of the phosphorus component. Availability of calcium from different limestone or oyster shell products appears to vary somewhat, and is markedly influenced by fineness of grind of particle size of the product used. Differences appear to diminish when calcium adequacy of the diet is insured. In laying hens, inclusion of coarser-sized particles of limestone or oyster shell appear to be beneficial when egg shell quality is stressed by marginal calcium levels, low feed intake, or other stress conditions. Calcium sources differ in their solubility in acid solutions, but again no specific recommendation can be made regarding a desirable rate of solubility of calcium sources.

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TABLE 1. Common sources of calcium and phosphorus

Source	Ca	16 P
Limestone	38	--
Oyster shell	38	--
I. Calcium phosphates		
A. Natural or unprocessed		
Low fluorine rock phosphate	32-35	12-15
Curacao phosphate (guano)	36	13-15
Colloidal phosphate (Soft phosphate)	18-20	9-10
Bone meal, steamed		
B. Chemically processed		
1. Dicalcium phosphates		
Dicalcium-monocalcium phosphates	15-23	18-23
Monocalcium-dicalcium phosphates	15-18	20-21
Precipitated dicalcium phosphate	24-26	18-22
2. Defluorinated phosphates	30-36	14-18
II. Sodium phosphates		
Monosodium phosphate	--	25
Disodium phosphate	--	21
Sodium tripolyphosphate	--	25
III. Ammonium phosphates		
Monoammonium phosphate	--	24
Diammonium phosphate	--	20
IV. Phosphoric acid		
Fish meals	2-14	2-7
Meat and bone meals	4-14	2-10
Poultry byproduct meals	2-10	2-8

TABLE 2. Bioavailability of commercial phosphates for broilers (Huyghebaert et al. 1980)

Source	%Ca	%P	%Na	Exp 1	Exp 2
Monocalcium phosphate A	16.9	23.06	.28	98	--
Monocalcium phosphate B	16.8	23.15	.07	89	97
Hydrated dicalcium phosphate A	25.65	17.93	.01	99	103
Hydrated dicalcium phosphate B	27.32	20.48	.04	90	95
Anhydrous dicalcium phosphate A	29.17	21.38	.03	86	--
Anhydrous dicalcium phosphate B	29.73	21.16	.03	85	86
Defluorinated phosphate A	31.81	18.50	5.62	96	--
Defluorinated phosphate B	31.81	18.11	4.94	96	94
Ca-Mg-Na Phosphate	9.93	17.34	11.55	101	104
Disodium phosphate 2	--	21.26	28.74	100	100
Meat and bone meal	12.09	5.80	--	90	--
Monosodium phosphate	--	19.8	14.7	96	--
Ca-Al-Fe phosphate	7.5	14.5	.6	--	15

[1] Based on ash content, breaking strength, ash percentage, and P content of tibia relative to disodium phosphate reference standard.

[2] Used as reference standard.

TABLE 3. Bioavailability of phosphates for turkeys (Waibel et al. 1984)

Source	%Ca	%P	%Na	Relative bioavailability[1] Exp 1	Exp 2	Exp 3
Mono/dicalcium phosphates						
1 (reference)	18.1	20.6	.11	100.0	100.0	100.0
2	18.4	20.6	.37	108.5	--	111.4
3	17.3	20.0	.33	99.8	--	--
4	17.4	20.9	.10	76.7	--	100.5
5	19.4	20.6	.13	93.9	--	--
6	18.8	20.5	.13	101.8	--	--
7	15.8	21.2	.06	85.2	--	--
8	15.0	20.9	.10	100.5	--	--
Avg	17.5	20.7	.17	95.8	--	104.5
Dicalcium phosphates						
1	21.8	18.8	.09	100.7	--	--
2	20.6	19.0	.08	87.6	--	92.6
3	21.4	19.0	.12	77.2	--	--
4	20.4	19.1	.08	85.7	--	--
5	24.0	18.5	.13	78.9	--	--
6	22.2	18.4	.16	75.1	--	84.4
7	23.0	18.6	.13	87.4	--	--
8	23.0	19.0	.14	76.3	--	--
9	21.2	18.9	.11	106.3	--	98.5
10	20.8	18.9	.09	98.6	--	--
11	20.0	19.0	.11	94.1	--	--
12	20.6	18.7	.09	93.1	--	--
13	22.2	18.0	.14	104.8	--	--
14	22.8	17.7	.14	104.0	--	--
15	18.1	18.8	--	96.0	--	--
16	18.8	20.1	.12	95.1	--	--
17	20.4	19.0	.12	81.8	--	--
18	21.4	18.8	.10	77.7	--	--
19	20.6	19.1	.11	91.7	--	--
20	20.8	18.9	.09	95.6	--	--
Avg	21.2	18.8	.11	90.3	--	91.8
Defluorinated phosphates						
1	32.7	18.4	6.0	74.8	85.3	79.2
2	32.7	18.4	6.4	85.2	--	--
3	31.9	18.4	7.2	84.4	--	--
4	32.1	18.4	6.4	84.2	--	--
5	30.5	18.3	7.2	74.1	78.3	--
6	31.0	18.1	6.4	78.9	--	--
7	31.3	18.4	5.6	77.2	62.5	67.0
8	31.3	17.9	5.2	81.1	--	--
9	28.5	18.3	6.4	67.6	70.3	67.9
10	32.0	18.7	6.2	--	78.2	--
11	31.6	18.5	7.2	--	86.5	92.8
12	32.2	18.8	6.4	--	77.2	--
13	30.8	17.8	6.3	--	82.9	--
14	31.0	18.2	6.1	--	71.5	--
15	31.8	18.1	6.0	--	76.0	--
16	31.6	18.1	4.0	--	80.7	--
17	31.8	18.5	4.8	--	70.8	--
18	31.6	18.1	3.8	--	77.5	--
19	31.8	18.5	5.0	--	71.8	--
20	32.0	18.2	5.1	--	83.7	--
Avg	31.5	18.3	5.9	78.6	76.8	76.7

[1]Compared to mono/dicalcium phosphate reference standard using tibia ash.

TABLE 4. Bioavailability of commercial phosphate sources estimated by body weight and toe ash measurement (Potchanakorn and Potter, 1987)

Source	%Ca	%p	%Na	Bioavailability[1] Body weight	Toe ash	Combined
Monocalcium phosphate[2]						
1	17.96	20.52	--3	93.8	93.3	93.5
2	15.44	20.49	--	85.8	97.4	91.6
3	15.53	20.78	--	89.5	95.6	92.6
Avg				89.7	95.4	92.6
Dicalcium phosphate[2]						
1	22.96	18.83	--	75.6	85.4	80.5
2	20.32	18.45	--	75.6	78.6	77.1
3	20.46	17.68	--	84.8	87.2	86.0
Avg				78.8	83.7	81.2
Defluorinated phosphate[2]						
1	30.48	18.11	4.90	66.6	73.8	70.2
2	31.99	18.15	5.46	66.7	67.2	66.9
3	30.34	18.26	4.28	70.9	72.8	71.8
Avg				68.1	71.3	69.6
Defluorinated phosphate[4]						
1	31.78	18.52	4.33	77.6	76.5	77.0
2	31.78	18.63	4.63	76.3	73.9	75.0
3	32.16	18.60	4.70	72.6	77.3	75.0
4	31.42	18.77	5.03	73.2	76.6	74.9
Avg				74.9	76.1	75.5

[1]Compared to dicalcium phosphate (dihydrate, purified grade).
[2]Commercial sources.
[3]Values-not determined and considered to be negligible.
[4]Experimental, samples of products proposed for commercial use.

TABLE 5. Bioavailability of commercial phosphate sources estimated by body weight and toe ash measurement (Potter et al. 1995)

Source	%Ca	#P	%Na	Measurement: Body weight	Measurement: Toe ash	Measurement: Combined
Lucaphos –48[1]	29.0	20.9	.03	89.8 ± 5.6	88.0 ± 5.0*	88.4*
Lucaphos -40[1]	26.7	18.9	.005	92.9 ± 5.9	101.3 ± 5.8	95.1
Rukuna[2]	31.6	18.2	6.4	85.7 ± 5.3*	81.7 ± 4.6*	83.7*
Cefkaphos -N[1]	17.4	22.9	.07	103.8 ± 6.8	105.8 ± 6.0	104.8
Phosphoric acid[1]	--	15.9	.02	89.0 ± 5.6	97.0 ± 5.6	93.0
Ca $(H_2PO_4)_2.H_2O$[1]	15.9	24.5	--	112.9 ± 7.6**	110.7 ± 6.3**	111.8**
Biophos[3]	16.5	21.0	--	94.3 ± 6.1	89.6 ± 5.1	92.0*
$CaHPO_4.2H_2O$[1,4]	23.3	18.0	--	100	100	100

[1]Produced by Chemische Fabrik Kalk ContbH, D-51071, Koin, Germany.
[2]Produced by Rudersdorfer Futterphosphate GmbH, D-15562, Rudersdorf, Germany.
[3]Produced by Kemira Kemi AB, Box 902, 5-25109, Helsingborg, Sweden.
[4]Used as reference standard.
* Significantly less available than the phosphorus from $CaHPO_4.2H_2O$.
**Significantly more available than the phosphorus from $CaHPO_4.2H_2O$

Table 6. Phosphorus content of common plan:. feedstuffs (NRC, 1994)

Feedstuffs	Phosphorus content (%): Total	Nonphytate	nonphytate
Alfalfa meal, 17% CP	.22	.22	100.0
Barley	.36	.17	47.2
Buckwheat	.32	.12	37.5
Canola meal, 38% CP	1.17	.30	25.6
Distillers dried grains	.40	.39	97.5
Distillers dried solubles	1.27	1.17	92.1
Corn gluten meal, 60% CP	.50	.14	28.0
Corn, grain	.28	.08	28.5
Cottonseed meal, 41% CP	.97	.22	22.6
Pearl millet	.32	.12	37.5
Oats, grain	.27	.05	18.5
Peanut meal	.63	.13	20.6
Rice bran	1.50	.22	14.7
Rice polishings	1.31	.14	10.7
Rye, grain	.32	.06	18.8
Safflower meal, 43% CP	1.29	.39	30.2
Sesame meal, 43% CP	1.37	.34	24.8
Soybean meal, 44% CP	.65	.27	41.5
Soybean meal, 48% CP	.62	.22	35.4
Sunflower meal, 45% CP	1.00	.16	16.0
Wheat bran	1.15	.20	17.4
Wheat middlings	.85	.30	35.3
Wheat, hard winter	.37	.13	32.0

Table 7. Correlation of water soluble phosphorus and biological availability of feed-grade phosphorus sources with chicks (Halloran, 1972)

Source	%P	%Ca	% Water solubility	RBV[1]
Reference2	25.10	14.84	96.8	100.0
Sample A	18.13	31.17	.14	96.8
Sample B	18.16	32.21	.14	93.5
Sample C	20.86	16.72	80.2	95.2
Sample D	18.11	30.15	.14	84.2

[1] Relative bioavailability using bone ash and weight gain.
[2] Analytical reagent grade monocalcium phosphate.

Table 8. Chemical solubility of phosphorus in feed-grade phosphates versus relative biological availability determined by chick bioassay (Day et al. 1973)

	Defluorinated phosphates						
	1	2	3	4	5	Mono-dical phosphate	Dicalcium phosphate
Total P, %	18.1	18.0	18.3	18.3	18.2	21.4	19.0
Chick BV[1]	80	85	88	92	83	101	85
Solubility in:							
NAC[2]	81.2	77.2	60.1	42.6	77.6	95.3	98.9
2% CA[3]	79.6	81.1	66.7	74.3	81.4	93.9	99.5
.4% HC1	93.9	97.8	96.7	99.5	97.3	94.4	99.5

[1] Relative bioavailability compared to monosodium phosphate using bone ash.
[2] NAC = Neutral ammonium citrate.
[3] CA = Citric acid.

Table 9. Comparison of water solubility of feed-grade phosphates with biological availability determined by chick assay (Pensack, 1974)

Phosphate source	Average water soluble P	Average bioavailability[1]
Dicalcium phosphates, 21% p	(%)	(%)
Cyphos 21%	84	89
Phosphate A	79	87
Phosphate B	69	86
Phosphate C	79	85
Phosphate D	78	85
Dicalcium phosphates, 18.5% p		
Cyphos 18.5%	77	86
Phosphate E	61	81
Phosphate F	45	75
Defluorinated phosphate, 18% p		
Phosphate G	0	69

[1]Relative bioavailability compared to phosphoric acid using bone ash.

Table 10. Chemical solubility of phosphorus in feed-grade phosphates versus biological availability determined by poult bioassay (Sullivan et al. 1992)

Source of P		RBV[1]	% Solubility of P Water	.4% HC1	2% CA[2]	NAC[3]
Mono-dicalcium phosphates[4]						
1	USA	94.7	74.9	100.0	91.3	93.0
2	USA	98.2	45.6	87.5	84.2	81.9
3	USA	98.6	50.7	86.7	84.4	83.1
4	USA	98.7	72.0	97.3	99.6	95.6
5	USA	98.4	70.6	95.2	100.0	100.0
6	USA	97.4	81.4	97.6	98.0	100.0
7	USA	96.4	77.1	94.9	100.0	100.0
8	USA	100.1	64.9	89.1	86.9	85.5
9	USA	95.5	70.2	93.0	97.0	100.0
Di -monocalcium phosphates[5]						
1	USA	94.6	40.1	93.4	91.6	97.7
2	USA	93.4	49.1	95.8	89.5	94.1
3	USA	97.0	63.6	92.3	95.4	98.9
4	Algeria	100.2	13.9	99.3	100.0	81.5
5	USA	93.6	49.0	97.7	97.1	98.0
6	USA	99.7	60.1	97.2	97.3	98.6
7	Peru	75.0	20.6	94.9	45.9	21.5
8	Peru	97.2	65.6	96.3	97.4	90.6
9	USA	94.8	50.8	99.3	100.0	93.8
10	USA	96.2	17.0	98.6	100.0	96.7
11	Holland	91.3	15.6	94.4	89.2	91.6
12	S. Africa	96.3	48.9	95.2	97.3	91.5
13	Reference[6]	100.0	10.7	98.8	100.0	100.0
Defluorinated phosphates[7]						
1	USA	89.6	7.3	95.6	79.8	59.5
2	USA	94.3	8.5	97.8	70.5	77.9
3	USA	90.2	5.3	94.5	70.9	59.5
4	USA	92.0	10.0	99.5	94.6	85.4
5	USA	92.6	6.2	98.6	74.2	61.9
6	Poland	97.2	6.9	100.0	90.9	90.4
7	Russia	75.0	9.2	93.4	25.5	7.5
8	Japan	95.8	11.3	95.7	73.6	68.5
9	USA	91.9	12.1	100.0	81.5	76.7
10	Russia	79.2	8.0	93.8	26.2	8.2
11	USA	90.9	10.9	99.4	68.0	54.9
12	USA	94.2	10.0	98.3	76.9	68.6
13	USA	92.5	15.4	100.0	80.4	80.8
14	USA	95.6	3.2	99.7	78.3	77.7

[1]Relative bioavailability compared to CaHPO4 .2H2O (USP grade).
[2]CA = Citric acid.
[3]NAC = Neutral ammonium citrate.
[4]Mono-dicalcium phosphates (approximately 21% P)
[5]Dimonocalcium phosphates (approximately 18.5% P)
[6]Reference standard phosphate.
[7]Thermochemically produced defluorinated phosphate (approximately 18% P)

Table 11. Comparison of solubility of feed-grade phosphates in neutral ammonium citrate (NAC) with biological availability determined by chick or pig assay (Coffey et al. 1994)

Phosphate source	Average NAC solubility	Bioavailability[1]	
		Chick	Pig
	(%)		
Defluorinated phosphate 1	60	81	90
Defluorinated phosphate 2	70	75	80
Defluorinated phosphate 3	75	84	82
Defluorinated phosphate 4	82	84	90
Defluorinated phosphate 5	91	91	87

[1] Relative bioavailability compared to monosodium phosphate using bone ash and bone breaking strength.