Nutritional Approaches to Reducing Phosphorus Excretion by Poultry[1]

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ABSTRACT Phosphorus is an essential mineral for growing poultry, and the consequences of a failure to provide for adequate quantities of this nutrient are physiologically and economically disastrous. Therefore, nutritionists provide a margin of safety for this mineral in their diets. However, because of growing concerns regarding the potential contribution of P in poultry excreta on eutrophication of surface waters, increasing pressure is being placed to limit the amount of excess P in diets and thus reduce fecal output.

In order to significantly reduce fecal P while maintaining economic productivity, the nutritionist must establish and maintain an integrated program of activities, including an effective quality control program for incoming animal protein feeds, selection of P supplements of the highest biological value, use of phytase enzymes, and judicious selection of dietary P levels. Potential benefits of newer isomers of vitamin D and the commercial development of grains with high levels of nonphytate P offer promise in the future. Whatever measures are taken to increase the biological availability of the phytate-bound and nonphytate P portions of the diet, commensurate reductions in overall dietary P content must be made.

(*Key words*: phosphorus, eutrophication, phytase, vitamin D, genetic modifications)

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INTRODUCTION

Phosphorus is an essential mineral for growing broilers. Because of the high demands for adequate skeletal development of the rapidly growing bird, it has long been considered necessary to provide an adequate margin of safety for this mineral. Failure to supply adequate amounts of P may lead to severe consequences in terms of reduced performance, increased condemnations, excessive mortality, and reduction in carcass quality. However, due to growing concerns about the effects of excreted P on eutrophication, it is rapidly becoming essential to provide levels of dietary P that sustain economical performance while reducing P excretion.

One of the primary problems facing nutritionists who wish to reduce P in the excreta is that of determining the biological availability of the various sources of P in the diet. Because of the wide variation in ability of the chick to utilize different sources of P, nutritionists have utilized rather wide margins of safety in order to avoid production problems. Dietary P originates primarily from plant and animal feedstuffs and from inorganic P supplements. Going further, one may partition the P in plant feedstuffs into two separate groups; organically-bound P present as salts of phytic acid (phytate P) and P present in other forms (nonphytate P). For many years, the general assumption has been made that the chick is unable to utilize the phytate-bound P, whereas the remaining plant P, together with P from animal proteins and inorganic P supplements, is readily available. Recent studies have demonstrated that neither of these assumptions is totally correct; broilers are probably capable of using a portion of the phytate-bound P, whereas the availability of inorganic P is less than 100% (Van der Klis and Versteegh, 1996). Nevertheless, most research done to establish the P requirement of the chick is based upon these assumptions.

In order to successfully reduce P excretion by the chick while maintaining productivity, it is only logical that one considers the contribution of the various sources of dietary P that occur in the feces and base their approach on minimizing these where feasible. Fecal P consists of undigested portions of phytate-bound and nonphytate P from plant sources, undigested portions of P from animal byproducts and mineral supplements, and surplus amounts of bioavailable P in excess of the animal's needs. A successful solution to the overall problem of P excretion must consider each of these as an area for improvement. Our research program at the University of Arkansas is based upon this multi-faceted approach and includes the following basic research areas.

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APPROACHES TO REDUCING PHOSPHORUS EXCRETION

Minimizing Excessive Levels of Dietary Phosphorus

It is somewhat surprising that in discussions regarding reduction of P excretion little attention has been focused on the subject of minimizing excessive levels of dietary P. Our research has demonstrated that, as dietary P levels increase from deficient to excessive, fecal P levels increase gradually until the point at which tibia ash is at a maximum, and then increases steeply. Regardless of whether one employs phytase enzymes, genetically modified corn, or any other means of improving P utilization, the biologically available P content of the diet

TABLE 1. Bioavailability of phosphates for turkeys (Waibel *et al.*, 1984)

Source	Percentage Ca	Percentage P	Percentage Na	Relative bioavailability[1] Experiment 1	Experiment 2	Experiment 3
	(%)					
Mono/dicalcium phosphates						
1 (reference)	18.1	20.6	0.11	100.0	100.0	100.0
2	18.4	20.6	0.37	108.5	. . .	111.4
3	17.3	20.0	0.33	99.8	. . .	. . .
4	17.4	20.9	0.10	76.7	. . .	100.5
5	19.4	20.6	0.13	93.9	. . .	. . .
6	18.8	20.5	0.13	101.8	. . .	. . .
7	15.8	21.2	0.06	85.2	. . .	. . .
8	15.0	20.9	0.10	100.5	. . .	. . .
Average	17.5	20.7	0.17	95.8	. . .	104.5
Dicalcium phosphates						
1	21.8	18.8	0.09	100.7	. . .	. . .
2	20.6	19.0	0.08	87.6	. . .	92.6
3	21.4	19.0	0.12	77.2	. . .	. . .
4	20.4	19.1	0.08	85.7	. . .	. . .
5	24.0	18.5	0.13	78.9	. . .	. . .
6	22.2	18.4	0.16	75.1	. . .	84.4
7	23.0	18.6	0.13	87.4	. . .	. . .
8	23.0	19.0	0.14	76.3	. . .	. . .
9	21.2	18.9	0.11	106.3	. . .	98.5
10	20.8	18.9	0.09	98.6	. . .	. . .
11	20.0	19.0	0.11	94.1	. . .	. . .
12	20.6	18.7	0.09	93.1	. . .	. . .
13	22.2	18.0	0.14	104.8	. . .	. . .
14	22.8	17.7	0.14	104.0	. . .	. . .
15	18.1	18.8	. . .	96.0	. . .	. . .
16	18.8	20.1	0.12	95.1	. . .	. . .
17	20.4	19.0	0.12	81.8	. . .	. . .
18	21.4	18.8	0.10	77.7	. . .	. . .
19	20.6	19.1	0.11	91.7	. . .	. . .
20	20.8	18.9	0.09	95.6	. . .	. . .
Average	21.2	18.8	0.11	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	. . .
Average	31.5	18.3	5.9	78.6	76.8	76.7

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

TABLE 2. Bioavailability of commercial phosphate sources estimated by body weight and toe ash measurement (Potter *et al.*, 1995)

				Measurement		
Source	Percentage Ca	Percentage P	Percentage Na	Body weight	Toe ash	Combined
	(%)					
Lucaphos-48[1]	29.0	20.9	0.03	89.8 ± 5.6	88.0 ± 5.0*	88.4*
Lucaphos-40[1]	26.7	18.9	0.005	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	0.07	103.8 ± 6.8	105.8 ± 6.0	104.8
Phosphoric acid[1]	. . .	15.9	0.02	89.0 ± 5.6	97.0 ± 5.6	93.0
$Ca(H_2PO_4)_2{\cdot}H_2O$[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*
$CaHPO_4{\cdot}2H_2O$[1,4]	23.3	18.0	. . .	100	100	100

[1]Produced by Chemische Fabrik Kalk CombH, D-51071, Köln, 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 $CaHPO_4{\cdot}2H_2O$.

**Significantly more available than the phosphorus from $CaHPO_4{\cdot}2H_2O$.

must not exceed the amount needed by the chick to maximize performance.

In relative terms, the amount of P needed to maximize various criteria is in the following order: bone calcification > body weight > feed efficiency > mortality. For a number of years, tibia ash or toe ash has been used as the primary determinant of the P requirement of the chick, being rather sensitive to differences in dietary P content or to differences in biological availability between P sources. Our research suggests that the gap between maximum tibia ash and maximum body weight is much narrower today than in years past, due perhaps to the much more rapid growth of broilers today than in previous years. Although the bulk of the P needs are related to skeletal development, P is also actively involved in energy metabolism in the body; therefore, one might expect that the P demands of the modern bird for support of body weight gain should be much greater than in previous years.

Considerable research exists to support current (NRC, 1994) recommended P requirements of young broiler chicks, during the period of 0 to 3 wk of age; however, research after this age is limited. However, research does suggest that after 3 or 4 wk of age, P needs are greatly reduced. Studies from our laboratory (Waldroup *et al.*, 1963, 1974; Skinner and Waldroup, 1992; Skinner *et al.*, 1992a,b) and elsewhere (Twining *et al.*, 1965; Tortuero and Diez Tardon, 1983) suggest that during the later stages of production, when a significant amount of feed is consumed, that there is little if any need for supplemental P in a typical corn-soybean meal broiler diet. More work is needed to examine the P needs over the entire productive life of the bird grown to market age.

TABLE 3. Bioavailability of commercial phosphates for broilers (Huyghebaert *et al.*, 1980)

				Bioavailability[1]	
Source	Percentage Ca	Percentage P	Percentage Na	Experiment 1	Experiment 2
	(%)				
Monocalcium phosphate A	16.9	23.06	0.28	98	. . .
Monocalcium phosphate B	16.8	23.15	0.07	89	97
Hydrated dicalcium phosphate A	25.65	17.93	0.01	99	103
Hydrated dicalcium phosphate B	27.32	20.48	0.04	90	95
Anhydrous dicalcium phosphate A	29.17	21.38	0.03	86	. . .
Anhydrous dicalcium phosphate B	29.73	21.16	0.03	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	0.6	. ..	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 4. Bioavailability of commercial phosphate sources estimated by body weight and toe ash measurement (Potchanakorn and Potter, 1987)

Source	Percentage Ca	Percentage P	Percentage 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
$\bar{x}$				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
$\bar{x}$				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
$\bar{x}$				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
$\bar{x}$				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.

Use Phosphate Sources With High Biological Value

The majority of the supplemental phosphate sources used in poultry diets are chemically processed materials. One group, generally termed "dicalcium phosphates", are produced by reacting phosphoric acid with limestone to produce mixtures of monocalcium and dicalcium phosphate. The composition of these mixtures is determined by the quantity of limestone that is reacted with the phosphoric acid. The second group, known as "defluorinated phosphates", are produced by reacting phosphate

TABLE 5. Digestion of phosphorus in the lower ileum of turkeys fed different levels and sources of phosphorus (Grimbergen *et al.*, 1985)

Phosphorus source	P added[1]	Weight gain 2 to 6 wk	Feed: gain	P apparently digested at lower ileum
	(%)	(g)	(g:g)	(%)
Monocalcium phosphate	0.10	928	1.932	44.7 ± 3.9
	0.15	1,035	1.894	44.4 ± 4.6
	0.20	1,055	1.862	51.9 ± 4.2
	0.25	1,062	1.891	48.7 ± 3.7
	$\bar{x}$	1,020[a]	1.895[a]	47.4 ± 2.0[a]
Dicalcium phosphate, hydrated	0.10	958	1.929	45.7 ± 2.8
	0.15	1,024	1.895	38.0 ± 2.8
	0.20	1,057	1.849	42.4 ± 5.6
	0.25	1,056	1.874	38.3 ± 4.9
	$\bar{x}$	1,024[a]	1.887[a]	41.1 ± 1.9[b]
Dicalcium phosphate, anhydrous	0.10	891	1.964	38.9 ± 6.0
	0.15	942	1.948	35.4 ± 2.6
	0.20	970	1.913	34.0 ± 3.4
	0.25	1,013	1.922	30.6 ± 1.3
	$\bar{x}$	945[b]	1.937[b]	34.7 ± 1.6[c]

[a–c]Column means with no common superscript differ significantly ($P \leq 0.05$).

[1]Added to corn-soybean meal diet with 0.52% total and 0.06% inorganic P.

TABLE 6. The phosphorus availability in some animal feedstuffs and feed phosphates measured in 3-wk-old broilers (Van der Klis and Versteegh, 1996)

Source of P	Total P	Available P
	(%)	(% of total)
Bone meal	7.6	59
Fish meal	2.2	74
Meat meal	2.9	65
Meat and bone meal	6.0	66
Calcium sodium phosphate	18.0	59
Dicalcium phosphate (anhydrous)	19.7	55
Dicalcium phosphate (hydrous)	18.1	77
Monocalcium phosphate	22.6	84
Mono-dicalcium phosphate (hydrous)	21.3	79
Monosodium phosphate	22.4	92

rock with phosphoric acid and sodium carbonate and then calcining at 1,250 C. It is considered more difficult to control this process than that used to produce dicalcium phosphates; thus, one tends to see greater variability in biological values assigned to defluorinated phosphates than to dicalcium phosphates.

A number of published studies have compared the bioavailability of different phosphate sources for poultry (Bird *et al.*, 1945; Gillis *et al.*, 1948; Grau and Zweigart, 1953; Miller and Joukovsky, 1953; Gillis *et al.*, 1954; Wilcox *et al.*, 1954, 1955; Motzok *et al.*, 1956; Edwards *et al.*, 1958; Summers *et al.*, 1959; Nelson and Walker, 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 reports examine the bioavailability of both experimental and commercial sources available to the poultry industry. As the production of feed phosphates has undergone continual improvement, examination of the most recent studies would be the most informative. Some of the most recent evaluations of feed grade phosphates are shown in Tables 1 through 4. Although exceptions exist, one can generally state that mono-dicalcium phosphates have the highest biological value, with dicalcium phosphates about 5% and defluorinated phosphates about 10% less in comparative value. Given the considerable amount of supplemental phosphate used in broiler diets, these differences could result in a considerable variation in amount excreted.

Several of these studies have examined P supplements obtained from commercial feed mills, and include some products with exceptionally low biological value, which emphasizes the need to constantly evaluate P sources. However, determination of the biological availability of phosphate sources by chick assay remains expensive, labor-intensive, and time-consuming. A number of studies have explored the relationship of *in vitro* solubility tests of feed phosphates with their biological value as estimated by chick trials (Gillis *et al.*, 1948; Halloran 1972; Day *et al.*, 1973; Pensack, 1974; Sullivan *et al.*, 1992; Coffey *et al.*, 1994). Conflicting results have been reported regarding the success of such tests in estimating bioavailability of phosphates. Coon (1997) has suggested a rapid chick assay to determine retainable phytate and nonphytate feed P values that may be useful in minimizing excessive P excretion in the future.

It is worth noting that P bioavailability studies generally compare P sources on a relative basis; that is, performance of test phosphates is compared to that of a reference standard phosphate. Therefore, we often assume that the P in a supplement with high biological availability is nearly totally digested. Few studies have attempted to actually measure digestibility of P in various supplements. However, some studies indicate that the actual digestion or retention of mineral P sources may be much less than commonly assumed. Grimbergen *et al.* (1985) determined P digestion in turkeys utilizing monocalcium and dicalcium phosphates and reported values of only 30.6 to 51.9% (Table 5). De Groote and Huyghebaert (1997) reported that the apparent retention of P from a monobasic calcium phosphate was 78.1% in one study and 85.5% in a second study. Van der Klis and Versteegh (1996) found the P in animal byproduct feeds to range from 65 to 74% and the P in mineral phosphates to range from 55 to 92% (Table 6). Because supplemental phosphates generally provide approximately 60% of the nonphytate P needs of the chick, small differences in bioavailability may have significant impact upon the fecal P content.

Maintain Aggressive Quality Control Program for Animal Byproducts

Animal protein supplements have long been used both for their high quality protein and for their P content. The high biological availability of P from animal proteins such as meat and bone meal, poultry byproduct meal, and fish meal was demonstrated by Waldroup *et al.* (1965) and

TABLE 7. Assay values for meat and bone meal received in North Carolina feed mills (Jones and Ward, 1979)

Nutrient	n	Mean	SD	Low	High
Moisture	114	9.19	2.10	4.48	21.89
Crude fat	208	10.47	1.17	7.24	14.6
Crude protein	314	50.55	2.18	42.44	60.78
Calcium	181	8.61	1.76	3.96	15.0
Phosphorus	186	4.09	0.69	1.08	7.25

TABLE 8. Phosphorus content of meat and bone meal from various suppliers (Shutze and Benoff, 1981)

Source	n	Mean	Adjusted mean[1]	Low	High
All suppliers	2,277	3.93	3.55	1.8	7.0
Supplier 1	983	3.72	3.45	1.9	5.9
Supplier 2	680	3.94	3.60	1.8	6.3
Supplier 3	101	4.42	4.05	2.4	6.5

[1]Mean value is adjusted by –0.5 standard deviation.

Spandorf and Leong (1965) and recently confirmed by Waldroup and Adams (1994). Recent restrictions on utilization of animal byproducts in ruminant diets should provide a greater supply of animal protein to the poultry industry.

The major problem associated with use of animal byproducts is the variability in nutrient content, especially as one attempts to limit dietary excesses. Several industry surveys (Jones and Ward, 1979; Shutze and Benoff, 1981) have demonstrated a wide variation in nutrient content of animal protein byproducts, including P levels (Tables 7 and 8). Use of “average” values for P content of animal byproduct feeds can result in considerable overestimation (resulting in increased P excretion) or underestimation (resulting in potential P deficiency) of the dietary P level. Because of the economics of P nutrition, it does not seem feasible to totally avoid the use of animal byproducts. Rather, it does appear that a more stringent quality control program must be implemented so that the actual mineral content of each shipment is known and verified prior to feed manufacturing.

Enhance the Utilization of Phytate-Bound Phosphorus

A significant portion of the excreted P is contributed by the phytate-bound P portion of the diet. It is feasible to modify the ability of the chick to digest and utilize a portion of this fraction or to modify the amounts that may be present in the diet. Several approaches are available that may be considered.

Phytase Supplementation. A considerable amount of the P in poultry diets is in the form of phytate P, an organically bound form of the mineral (Nelson, 1967; O’Dell *et al.*, 1972; Raboy, 1990). A corn-soybean meal broiler starter diet formulated to meet NRC (1994) recommended standards for nonphytate P would contain 0.45% nonphytate P and 0.23% phytate-bound P. Chickens are lacking or limited in phytase, the endogenous enzyme that is necessary for breakdown of the molecule and subsequent release of P for absorption. It is assumed that the majority of this phytate-bound P would be excreted by the chick and be the primary contributor to fecal P content. Nelson *et al.* (1968a,b, 1971) demonstrated that addition of exogenous phytase enzyme to broiler diets was an effective way of improving the availability of phytate-bound P. Recent commercial development of exogenous phytase enzymes offers promise in reducing overall dietary P levels by increasing the ability of the chick to utilize a portion of the phytate-bound P (Simons *et al.*, 1990; Broz *et al.*, 1994; Kornegay *et al.*, 1996; Mitchell and Edwards, 1996a,b; Qian *et al.*, 1996; 1997).

Vitamin D Isomers. Recent research suggests that the form of vitamin D utilized in the diet may be a factor in reducing P excretion. New isomers of vitamin D have been shown to enhance intestinal phytase or to act additively with microbial phytase to improve P utilization in chick diets (Edwards, 1993; Roberson and Edwards, 1994; Biehl *et al.*, 1995; Mitchell and Edwards, 1996a,b). However, the reported studies deal primarily with compounds that are not commercially available (1 α-hydroxylated cholecalciferol and 1,25-dihydroxycholecalcifcol). Preliminary studies with a commercially available D isomer 25-hydroxycholecalciferol suggest similar activity (R. Blair, University of British Columbia, Vancouver, BC, Canada V6T 1Z4, personal communication, 1998). Further

TABLE 9. Contributions of dietary ingredients to nonphytate and phytate-bound phosphorus in a corn-soybean meal broiler starter diet using normal or high available phosphorus corn (HAPC)

	Normal corn diet		HAPC diet	
Ingredient	Nonphytate P	Phytate P	Nonphytate P	Phytate P
	(% P)			
Normal corn	0.04	0.11	. . .	. . .
HAPC	. . .	. . .	0.11	0.06
Soybean meal	0.07	0.12	0.07	0.12
Dicalcium phosphate	0.34	0.00	0.27	0.00
Total P	0.45	0.23	0.45	0.18

TABLE 10. Effects of dietary nonphytate phosphorus (NPP) levels in diets containing yellow dent corn (YDC) and high available phosphate corn (HAPC) with (+) and without (–) supplementation with phytase on fecal phosphorus content (Kersey *et al.*, 1998)

Diet	Fecal phosphorus[1]				Reduction in fecal phosphorus content due to use of HAPC	
	YDC		HAPC			
NPP	–Phy	+Phy[2]	–Phy	+Phy	–Phy	+Phy
(%)	(%)					
0.09	0.54	0.54	. . .	. . .	. . .	. . .
0.15	0.64	0.58	. . .	. . .	. . .	. . .
0.18	. . .	. . .	0.67	0.40	. . .	. . .
0.20	0.91	0.59	0.58	0.51	36.26	13.56
0.25	0.89	0.86	0.67	0.56	24.72	34.88
0.30	1.03	0.88	0.64	0.66	37.86	25.00
0.35	1.07	0.98	0.71	0.62	29.75	36.73
0.40	1.09	1.04	0.83	0.81	23.85	22.11
0.45	1.21	1.06	1.01	0.94	16.52	11.32
0.50	1.45	1.58	1.00	1.17	31.03	25.94
					28.57	24.22

[1]Phosphorus content of freeze-dried feces from 14-d chicks.

[2]Supplementation with 1,000 pU/kg of phytase (Natuphos).

research is needed to determine the extent to which the use of these isomers may contribute to reduced fecal P output.

High Available Phosphate Corn. Another approach to reducing dietary P levels and minimizing P in the excreta is to develop feedstuffs with modified levels of phytate-bound P. A corn with low phytate P and high available P content has been developed by USDA using the low phytic acid 1-1 (*lpal-1*) allele of the corn LPA1 gene (Gerbasi *et al.*, 1993; Raboy and Gerbasi, 1996) and bred into a hybrid by a major plant breeder. One sample of this hybrid, designated as “high available phosphate corn” (HAPC) contained approximately 0.27% total P, of which 0.17% was estimated to be available to the chicken. In contrast, a near isogenic normal corn hybrid contained similar levels of total P but only 0.03% available P. Substitution of the normal corn with the low-phytate corn would therefore reduce the amounts of phytate-bound corn in the diet and consequently reduce the amount of P excreted in the litter.

A corn-soybean meal broiler starter diet formulated using HAPC would provide approximately 22% less phytate-bound P as compared to a similar diet formulated using a normal corn (Table 9). Preliminary studies in our laboratory using HAPC in broiler diets (Kersey *et al.*, 1998; Yan *et al.*, 1998) indicate that the P in the nonphytate portion of HAPC is utilized as well as that from a commercial dicalcium phosphate and can significantly aid in reducing overall P excretion with similar live performance. Compared to chicks fed diets containing normal corn, the fecal P excretion by chicks fed HAPC diets was reduced by an average in 28.57% in diets without phytase supplementation and 24.22% in diets with phytase supplementation, compared to chicks fed diets with normal corn with similar nonphytate P levels (Table 10).

SUMMARY

Phosphorus is an essential mineral for growing poultry, and the consequences of a failure to provide sufficient amounts of this nutrient are economically disastrous. It is possible to minimize excessive amounts of P excreted in the feces by combining effective quality control programs for incoming animal protein feeds, selection of P supplements of highest biological value, use of exogenous phytase enzymes, and judicious selection of dietary P levels. Potential benefits of newer isomers of vitamin D and the commercial development of grains with high levels of nonphytate P offer promise in the near future. Whatever measures are taken to increase the biological availability of the dietary P, commensurate reductions in overall dietary P content must be made.

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