FEASIBILITY VERSUS PRACTICALITY OF PHOSPHORUS REDUCTION IN POULTRY: PROGRESS AND FUTURE NEEDS

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ABSTRACT

Substantial research progress has been made in the possibility of reducing phosphorus (P) excretion from poultry. For example, through combinations of feed additives and more precise knowledge of the broiler chicken's requirement, nearly 40 to 50 percent reductions in P excretion can be accomplished. The feed additive options for producers are numerous and include: phytases, probiotics, vitamin D metabolites, low-phytin grains, low-phytin grain byproducts, and organic acids. However, other plausible gains could be accomplished with additional research. For example, the knowledge of P requirements for laying hens, turkeys, and ducks, however, is relatively uncertain, as is knowledge of specific strain, gender, phase feeding programs, and seasonal influences on the P requirement of all poultry specie. Additional practical limitations also exist when applying known P reduction strategies into industry conditions, producers run into practical limitations, including: knowledge of ingredient P content, availability, and variability, limitations of ingredient storage based on P content, yield drag in low-phyin grains, identity preservation of specialty grains, and relative cost of feed additives in relation to the benefit of inorganic P removed from the diet. Knowledge and quantification of these limitations may help in development of strategies to overcome restrictions in practical P reduction from poultry and other livestock operations.

KEYWORDS. Feeding, Manure, Phosphorus, Poultry, Source reduction.

WHY IS PHOSPHORUS HIGH IN POULTRY EXCRETA RELATIVE TO OTHER NUTRIENTS?

The primary constituents of diets for agriculturally important monogastric animals are plant-based ingredients. These ingredients come primarily from the seeds of plants. Most of the stored P in plants is found in seeds and mainly as phytin P (PP). Phytin P is poorly available to monogastric animals, including poultry, and availability varies both within and between ingredients. The enzyme phytase hydrolyzes phosphate groups from the phytin molecule potentially making the hydrolyzed phosphorus from phytin available to the animal.

Phytic acid (myo-inositol 1,2,3,4,5,6-hexakis dihydrogen phosphate), is a phosphorylated cyclic sugar alcohol. The anion form of phytic acid, phytate, is the form present in all plants. Phytate in plants is usually chelated with cations, proteins and/or starches and this chelated form is called phytin. Plant roots contain low amounts of phytin and vegetative parts of plants such as the leaves contain only trace amounts (Ravindran et al, 1995). The location of phytin within seeds differs among the seeds of different plants. Ninety percent of the phytin in corn is found in the germ portion of the kernel, while in wheat and rice most of the phytin is in the aleurone layers of the kernel and the outer bran (O'Dell and De Boland, 1976). In most oilseeds and grain legumes, the phytin is associated with protein and concentrated within subcellular inclusions called globoids that are distributed throughout the kernel; however, in soybean seeds, there appears to be no specific location for phytin (Ravindran et al, 1995). Phytin constitutes between 1% and 3% by weight of many of the cereals and oilseeds used in animal feeds (Cheryan, 1980).

VARIATION IN NUTRIENT UTILIZATION

Present commercial poultry strains are more efficient in utilizing nutrients and the present commercial feeds are better formulated to meet the requirements of the rapidly growing bird (Havenstein et al., 1994). For example, nitrogen (N) and phosphorus (P) excretion per kg live weight was 55 and 69% less, respectively from a 1991

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commercial broiler strain versus a 1957 commercial broiler strain when fed the same diet. Considerable variation exists within the literature, however, for utilization of different nutrients. Much of the variation can be attributable to feeding of different ingredients, ages, or health status. Nutrient retention values for N, P, and dry matter (DM) as summarized from 84 peer-reviewed articles from 1985 to the present are presented in Table 1 (Applegate et al., 2003c). Notably, substantial variation existed within and between specie. For example, for the broiler, N and P retention each had a range of 30 % and DM by 20 %.

Table 1. Profile of peer-reviewed publications (1985-present) summarized for nitrogen (N), phosphorus (P), and dry matter (DM) retention

Specie	Average % N retention	Minimum	Maximum	Number of reports
Broiler	60.2	44.0	73.5	11
Turkey	56.8	47.8	75	8
Duck	65.7	54.6	78.1	4
Laying hen	45.6	30	75.0	5
	Average % P retention			
Broiler, < 32 days	49.3	34	64.1	22
Broiler, > 32 days	41.0	36	51.0	5
Turkey	48.0	33.9	56	9
Duck	46.4	- - -	- - -	1
Laying hen	29.1	13.6	44	20
	Average % DM retention			
Broiler	68.6	52.2	74.5	10
Turkey	74.8	67.1	82.5	2
Duck	69.4	53.7	87	5
Laying hen	79.3	74.6	84	2

PHOSPHORUS AVAILABILITY FOR UTILIZATION FROM INORGANIC SOURCES

Before going any further it is important to clarify terms related to phosphorus (P). Biological value of inorganic sources refers to the relative P availability, relative to a "standardized" P source (typically monosodium phosphate). Often these trials are conducted utilizing a) slope response, b) in vitro solubility, c) water solubility, d) acid solubility, e) solubility in ammonium citrate (Axe, 1998). "Biological value", however, is often confused with "digestibility" of that P source. Waldroup (2002) noted that nearly 50% of excreted P is likely of inorganic origin. Most of the literature base typically utilizes the "biological value" approach for determining the relative "value" of an ingredient, but often does not measure the digestibility of the P source. The few reports that have measured digestibility of P from inorganic sources have noted that they can range from 87% for mono-calcium phosphate to 60% for defluorinated phosphate (Van der Klis et al., 1994, Van der Klis and Versteegh, 1996, Leske and Coon, 2002, Seo and Coon, 2002).

Generally, P must be in the phosphate form to be absorbed by the bird. As phosphates are heated, pyro- and meta-complexes are formed which greatly reduce the inorganic sources availability. Other factors which substantially affect inorganic P source availability include: hydration of source (Gillus et al., 1962; Supplee, 1962), particle size (larger size typically increases availability), and contaminants (complexing with elements such as aluminum can reduce availability).

Inorganic P suppliers will often supply their own safety margins, as to provide a guaranteed minimum to their customers. As an example, it is not uncommon for defluorinated phosphate to have a guaranteed minimum P content of 18 % but have an analyzed content of 18.5-19.5%. The overage, therefore, can compound the P management issue.

PHOSPHORUS AVAILABILITY FOR UTILIZATION FROM ORGANIC SOURCES

Actual P and phytin P (PP) content in different ingredients varies somewhat between different publications (NRC, 1994; Van Der Klis and Versteegh, 1996; Nelson et al., 1968). Data are still limited (Nelson et al., 1968) as to the variability in PP content within an ingredient and how soil and environmental factors may affect this content (Cossa et al., 1997). Work done by Cossa et al. (1997) reported, in 54 maize samples, a total P content of 3.11g/kg on a DM basis and reported a standard deviation (SD) of 0.28 with low and high values of 2.55 and 3.83 g/kg, respectively. Average PP was 2.66 mg/kg (SD of 0.34) with low and high values of 1.92 and 3.54 g/kg DM, respectively. These researchers found no apparent differences between locations and early, medium and late varieties of maize on the PP content of the maize. There is also limited information on potential variability in the availability of PP (Van Der Klis and Versteegh, 1996; Cossa et al., 1997) within an ingredient and on how diet manufacturing process may affect this availability. Variability in PP content in grains and relative bioavailability and digestibility from inorganic P sources has led to substantial safety margins during realistic diet formulation. For all practical purposes, these over-formulations may have the greatest influence on total and soluble P content of in excreta and litter.

DIETARY PHOSPHORUS REQUIREMENTS

Recent research has elucidated substantial differences in the non-phytate P (nPP) requirement of broilers versus those published by the National Research Council (1994). Yan et al. (2001) reported a requirement of 0.33% NPP for Cobb 500 male broilers from three to six weeks (wk) when tibia ash percent was the criterion. As industry may not typically feed in 3 wk intervals, Angel et al. (2000a,b) conducted a series of experiments to determine the nPP requirements of male Ross 308 broilers in a four phase feeding program. The nPP requirements were reported to be between 0.32 and 0.28% nPP (0.80% Ca) in the grower phase (18 to 32 d) based on growth and tibia ash. The nPP requirement in the finisher phase (32 to 42 d) was reported to be between 0.24 and 0.19% nPP (0.70% Ca) and in the withdrawal phase between 0.16 and 0.11% nPP (0.61% Ca; 42 to 49 d of age). When considered together, the nPP requirements for broilers (Angel et al., 2000a,b; Yan et al., 2001) are considerably lower than those published previously (NRC, 1994). In a four-phase feeding program, nPP requirements were reported for Ross 308 males by Angel et al. (2000a,b), Dhandu et al. (2000), and Ling et al. (2000). In these reports, the carry-over effect of previous phases was considered in developing the requirement data, which is not always the case across cited literature. Extrapolation of requirements as reported by these authors can not be done directly with the 3 wk phases as reported by NRC (1994) or with other strains or genders. Other authors, however, have noted that the NRC (1994) nPP requirement is substantially higher than that required for overall performance in 3 wk phases. For example, Waldroup et al. (2000) reported that nPP could be reduced within an age period by 0.075% from 0 to 21, 21 to 42, and 42 to 56 d of age without adverse affects on broiler growth. The dietary reduction of nPP within each age period by 0.075%, however, did significantly reduce tibia ash at all ages.

Knowledge of P requirements of other strains and poultry species (laying hens, breeding stock, turkeys, and ducks), however, is very limited for modern strains and management practices. Therefore, to insure that birds do not encounter deficiencies during production, the poultry industry will often substantially increase the safety margins fed. For example, recent research suggests that modern laying hen strains nPP requirement is only 0.15 to 0.20 %. Industry may, however, routinely feed upwards of 0.40% to ensure that hens receive adequate nutrients. Often discrepancies between research and industry situations may preclude direct application. In this laying hen example, daily intake in research trials were as high as 120-125 g/hen/day versus industry average of 100 g/hen/day.

PHYTASE EFFICACY – HOW MUCH INORGANIC PHOSPHORUS SHOULD BE REMOVED?

Deciding what P concentration to formulate to is difficult due to a lack of clarity on what the P requirements are and the amount of phytate-P liberated with supplemental phytase. In summarizing three battery trials (11 to 21 d or 12 to 22 d of age), Angel et al. (2002) noted a range of values to obtain a 0.1% sparing effect of nPP from 781 to 1413 U phytase/kg diet. In fact, when the dietary Ca was fixed at 0.7%, the additional nPP spared with 500 U phytase/kg diet averaged 0.065% (as calculated from additional toe ash obtained in comparison with graded concentrations of monocalcium phosphate). In turkeys, the additional nPP spared appears to be somewhat higher. In summarizing four battery trials, the additional nPP spared when 500 to 600 U phytase / kg diet averaged 0.091% when calculated from tibia ash and 0.088% when calculated from toe ash (Angel et al. 2001; Applegate et al., 2003a,b).

The difference in the amount of P liberated in research trials with an analyzed 500 to 600 U phytase / kg diet and the 0.1% P that is recommended by the phytase suppliers at the same inclusion rate can easily be explained through product safety margins. As such, most phytases will contain substantial (and frequently variable) safety margins to account for product shelf-life and animal functionality. As such, the safety margins will push the analyzed phytase concentration well into the 781 to 1413 U/kg range where Angel et al. (2002) noted at least 0.1% P spared. As the second generation of phytase products (E. coli-derived AppA phytase expressed in yeast) enter the market place, derivation of sparing data is needed as they have substantially greater efficacies than the Aspergillus and Peniophora derived phytases on the market currently (Applegate et al., 2003a).

OTHER FEED INGREDIENTS THAT CAN LOWER MANURE PHOSPHORUS

New plant genotypes are being developed that contain lower levels of phytate P, such as, the new high available P (HAP) maize. This new genotype contains the same level of total P as normal maize varieties. In HAP maize only 35% of the total P is phytate P versus 75 to 80% in other corn varieties. Chick studies have shown that the P in HAP maize is more available (Waldroup et al., 2000) and when used in combination with phytase can reduce litter P by 58% (Applegate et al., 2003b). Other key ingredients are currently being selected for high availability of P. Soybean phytic acid content could be reduced (Raboy and Dickinson, 1993) with a concomitant decrease in PP from 70% to 24% of total P through breeding efforts (Raboy et al., 1985).

Some lactobacillus-based probiotics have been shown to improve growth and feed conversion in poultry. Research by Angel et al. (1999 a,b) indicates that P retention was 22% higher and N retention was 10% higher in birds fed a low nutrient diet supplemented with a probiotic versus birds fed a control diet. The addition of the probiotic to the low nutrient diet allowed broilers to grow as well as those fed a control diet in part because they were more efficient in retaining nutrients.

Another feed additive that can reduce P excretion is vitamin D_3 metabolites. Not only does vitamin D_3 stimulate P transport mechanisms in the intestine but it also appears to enhance the activity of supplemental phytase (Mohammed et al, 1991). Vitamin D as well as its metabolites, 25-hydroxycholecalciferol (25OH D_3) and 1,25-dehydroxycholecalciferol (Edwards, 1993; Mitchell and Edwards, 1996) have been shown to enhance the efficacy of supplemental phytase.

ECONOMICS OF PHOSPHORUS REDUCTION STRATEGIES

One of the primary drivers of widespread adoption of P reduction strategies by industry is price of the technology for what nutrient reduction could be imposed within dietary formulation. Examples for phytase and 25OH D_3 are given in Table 2 with pricing information as an example of an informal survey of industry on 12/04.

Table 2. Example of feed additive prices versus monocalcium phosphate replacement for broiler production.

Feed additive	Dietary addition	Dietary P reduction, %	Cost of addition, $/ton	Monocalcium phosphate equivalent, $/ton
25OH D_3	70 micrograms/kg diet	0.03	$1.65	$0.33
Phytase	500 U/kg diet	0.065	$0.80	$0.71

Notably, cost of either 25OH D_3 or phytase does not pay for itself through replacement of a portion of monocalcium phosphate in the diet. Within this example, the 500 U phytase / kg diet dosage was based on an analyzed phytase addition to the diet, whereas phytase suppliers typically add safety margins to their products beyond label claims to guarantee product activity and shelf-life. In doing so, the margin between efficacy of product and economics of replacement for inorganic P is nearly negated.

CONCLUSIONS - PROCESS UNCERTAINTY AND FEEDING SAFETY MARGINS

Knowledge of P reduction strategies by the industry is imperative, but often difficult to implement. For example, process variation in sampling, creating diets, ingredient P content as well as bird P utilization still limits reductions by the industry in order that they guarantee their birds never become P deficient. Process uncertainty can be calculated for feed formulation for broiler chickens (square root of the sum of squared coefficients of variations, Funk et al., 2003) from the variation listed for these processes (Table 3). Even if the lesser of the variation is assumed, the overall process uncertainty is 19.8% (or 25.5% at the worst). Even if exact ingredient analysis is known, due to bird utilization and diet manufacturing limitations, the process uncertainty could be no better than 16.8 to 18.9%. The industry, however, has been feeding at considerably lower safety margins than at these levels of uncertainty. For example, Applegate et al. (2003b) reported that the difference in phosphorus intake between birds fed typical industry phosphorus formulations versus those closer to requirements (each with phytase supplementation) was only 2.42 g, or 11.5% greater to market. Processes that reduce variation in individual bird nutrient retention, greatly improve PP hydrolysis, or consistent nutrients within ingredients may hold the most promise in reducing the P excretion by poultry.

Table 3. Summary of variation in processes associated with feeding of phosphorus to broiler chickens

Process variation	Coefficient of variation (%)
Sampling variation	5-10
Analytical variation[1]	5
Mixer variation[2]	5-10
Bird utilization (Table 1)	16
Ingredient variation (corn and SBM)	8-13

[1]Variation was assumed to be better for feedstuffs than that for manure (10-119%) as reported by Funk et al. (2003) in referencing Floren (2002).
[2]Wicker and Poole (1991)

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