Animal Sciences

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Variation in Nutrient Utilization by Poultry and Ingredient Composition

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Introduction

This fact sheet has been developed to support the implementation of the Natural Resources Conservation Service Feed Management 592 Practice Standard. The Feed Management 592 Practice Standard was adopted by NRCS in 2003 as another tool to assist with addressing resource concerns on livestock and poultry operations. Feed management can assist with reducing the import of nutrients to the farm and reduce the excretion of nutrients in manure.

Current commercial livestock and poultry breeds/strains are more efficient in utilizing nutrients and the commercial feeds are better formulated to meet the requirements of the rapidly growing animal (Havenstein et al., 1994). For example, nitrogen (N) and phosphorus (P) excretion per unit of live weight were 55 and 69% less, respectively from a 1991 commercial broiler strain versus a 1957 commercial broiler strain fed the same diet. Considerable variation exists within the literature, however, for utilization of different nutrients. Much of the variation can be attributed to feeding of different ingredients and differences in ages or health status. Nutrient retention values for N, P, and dry matter (DM) as summarized from 84 peer-reviewed articles from 1985 to 2003 are presented in Table 1 (Applegate et al., 2003a).

Table 1. Profile of peer-reviewed publications (1985-2003) summarized for nitrogen (N), phosphorus (P), and dry matter (DM) retention (Applegate et al., 2003a).

Specie	Avg. % N retention	Minimum	Maximum	Number of references
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
	Avg. % 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
	Avg. % 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

Notably, substantial variation existed within and between specie. For example, for the turkey, N, P, and DM retention each varied by of 27, 22, and 15%-units, respectively.

Process Uncertainty and Feeding Safety Margins

Knowledge of nutrient reduction strategies by the industry is imperative, but this knowledge is often difficult to implement under commercial conditions. For example, variation in sampling, mixing of diets, ingredient nutrient content as well as nutrient utilization by the animal still limits reductions by the industry in order for them to eliminate the possibility that their animals become deficient.

To illustrate this, process uncertainty can be calculated for P formulation in broilers (square root of the sum of squared coefficients of variations, Funk et al., 2003) from the variation listed for these processes (Table 2). 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%. Much of the poultry industry, however, has been feeding at considerably lower safety margins. For example, Applegate et al., (2003b) reported that the difference in phosphorus intake between birds fed typical industry P formulations versus those fed closer to requirements (each with phytase supplementation) was only 2.42 g, or 11.5% greater to market which is less than the process uncertainty. Tools that reduce variation in nutrient retention by the animal, improvements in nutrient digestibility, or an improvement in nutrient content consistency are the next areas to pursue in reducing nutrient excretion by all livestock and poultry.

Another way to look at this variation is how accurately nutritionists can formulate a corn-soybean meal diet and subsequently analyze for nutrient targets. Cromwell et al., (2003) noted after the same formulation was used to mix and analyze the same diet across 25 university laboratories. Notably, there was just as much variability in formulation targets as there is in ability to analyze for nutrient composition (Table 3).

This publication will explore inherent variations in N, P, and nutrient availability to the animal.

Table 2. 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).

Table 3. Formulation target and nutrient analyses variability of a corn-soybean meal diet from 25 university laboratories (Cromwell et al., 2003).

Nutrient	Diet coefficient of variation	Analyses coefficient of variation
	-------------------- (%) --------------------	
Crude protein	4.3	3.6
Calcium	9.3	12.5
Phosphorus	4.1	10.7
Zinc	17.4	11.1

Variability in Ingredient Nitrogen Content and Availability

For more accurate formulation to the nutrient content of the diet, it is desirable to know precisely what nutrients are within each feedstuff.

However, due to numerous factors, nutrient content can vary considerably. Additionally, certain nutrients such as amino acids, are inordinately expensive and time consuming to analyze. Therefore, the amino acid composition for ingredients such as corn and SBM is often calculated utilizing regression equations based on the crude protein content of the ingredient. However, for many, byproduct ingredients is less predictable.

Numerous factors can influence amino acid digestibility and utilization by the bird. High processing temperatures can cause the binding of sugar moieties with lysine (maillard reaction) making it unavailable to the animal. Other examples are listed in Table 4.

Selection of feedstuffs with relatively high digestibility can help with overall reductions in amino acid formulation. Table 5 contains data for protein sources and their respective standardized and apparent digestibilities. Apparent digestibility values have not accounted for endogenous amino acid loss, whereas, standardized values have. For ingredients that are low in protein, or are lowly digestible, the endogenous amino loss, and thus the "correction" can be quite considerable. Notably, sources such as feather-meal are not typically considered for diet formulation due to their amino acid profile, but also their digestibility. Similarly, formulation for emissions reduction should also consider the protein quality as exemplified in the range of apparent digestibility and where processing temperatures could cause Maillard reactions as well as other conditions that would reduce amino acid availability. Ingredient amino acid digestibility has been extensively measured in the past and data and variability information is available from either the NRC (1994), or from crystalline amino acid suppliers.

Table 4. Protein feed ingredient nutritive considerations.

Protein feed ingredient	Nutritive considerations
Cottonseed meal	Gossypol – complexes with Fe and Lys
Rapeseed	Glucosinolates – goiterogenic (canola is low in)
Soybean meal	Proteolytic enzyme (trypsin) inhibition – heat deactivation; high in potassium and lectins (reduction of performance)
Meat and bone meal	Collagen, hair, and rancid fat reduce digestibility
Poultry by-product meal	Feathers and rancid fat reduce digestibility
Fish meal	Gizzreosine – causes gizzard erosion
Distiller's dry grains plus solubles	Low lysine digestibility – high fiber, mycotoxins, and sodium

Table 5. Standardized and apparent digestible lysine (Lys) from chickens for different feedstuffs.

	Standardized digestible Lys, %[1]		
Feedstuff	**Mean**	**Range**	**Apparent digestible Lys, %[2]**
SBM	90	85-93	86
Canola	80	64-84	72
Sunflower	84	- - -	- - -
Cottonseed	67	- - -	55
DDGS	67	35-84	- - -
Fish-meal	88	- - -	83
Blood-meal	87	50-91	- - -
Poultry byproduct-meal	80	68-90	- - -
Meat and bone meal	80	45-90	58
Feather-meal	65	34-80	54

[1]Parsons, 2005 utilizing cecectomized roosters.
[2]Ravindran et al., 1998. Apparent ileal digestible Lys.

Distiller's Dry Grains Plus Solubles (DDGS)

The process of drying grain can result in damaged proteins that greatly reduce the digestibility of certain amino acids such as lysine. For example, lysine digestibility of DDGS in poultry can range (on average) from 59 to 84%. Also, the amino acid profile of the diet will shift by including a larger percentage of dietary protein from DDGS. A diet including DDGS will likely increase the amount of synthetic lysine added in the diet to account for imbalances and for the reduced digestibility. Therefore, in order to meet limiting amino acid needs, diets containing increasing inclusion of DDGS can impact the total amount of crude protein (and therefore N) fed resulting in higher concentrations of manure and litter N.

In addition to increases in N excretion, sodium concentrations in DDGS can also create wet manure, thereby resulting in the potential for higher ammonia emissions. Sodium chloride (salt) is often added to DDGS to aid in the desiccation/drying process. Considerable variation in the sodium content of DDGS (0.05 to 0.44%; Batal and Dale, 2003) exists, and if not accounted, can be included at greater levels than needed by the bird and can lead to increased water consumption and wet litter or manure. Wet litter and/or manure can also cause additional bacterial growth, which can predispose a flock to an increased susceptibility to intestinal infections. Therefore, sodium content of DDGS should be monitored closely when DDGS is used for poultry.

Variability in Ingredient Phosphorus Content and Availability

Inorganic sources. Before going any further, it is important to clarify terms related to P levels and availability in inorganic feed ingredients. Most reports published on the availability of P in inorganic sources use the concept/method of "biological value."

Biological value of inorganic sources refers to the relative P availability, relative to a "standardized" P source (typically monosodium phosphate), which is usually given a 100% relative biological value. Often these trials are conducted utilizing a) slope response or b) in vitro solubility in water, acid, or ammonium citrate. "Biological value," however, is often confused with "digestibility" or "availability" of that P source.

Most of the literature 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 (Table 6).

Notably, when most of these studies determined apparent retention of P from each of the inorganic sources, the majority of studies were done within the deficiency range. As such, Leske and Coon (2002) noted dramatic reductions in retention from monocalcium phosphate as the P concentration approached the requirement (98% at half of the requirement to 59% retention at requirement). Waldroup (2002) noted that nearly 50% of excreted P, therefore, is likely of inorganic origin (which is mostly water soluble).

Generally, P must be in the phosphate form to be absorbed by poultry and swine. As phosphates are heated, pyro- and meta- complexes are formed which greatly reduce the availability of inorganic sources. Other factors that substantially affect inorganic P

Table 6. Apparent utilization of phosphorus from inorganic sources by broiler chickens.

Reference	Inorganic phosphorus source	Apparent phosphorus retention, %
Van der Klis et al., 1994	Mono-calcium phosphate	87
Van der Klis and Versteegh, 1996	Mono-calcium phosphate	84
Van der Klis and Versteegh, 1996	Mono- / dicalcium phosphate	79
Leske and Coon, 2002	Mono- / dicalcium phosphate	77
Leske and Coon, 2002	Mono- / dicalcium phosphate	80
Leske and Coon, 2002	Mono- / dicalcium phosphate	81
Coon et al., 2007[1]	Dicalcium phosphate	83
Coon et al., 2007[1]	Defluorinated phosphate	86
Coon et al., 2007[1]	Defluorinated phosphate	76

[1]Retainable P determined through broken line slope response.

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).

Organic sources. Total P and phytate P (PP) content in different ingredients varies somewhat depending on publication (NRC, 1994; Van Der Klis and Versteegh, 1996; Nelson et al., 1968) (Tables 7, 8). Data are still limited (Nelson et al., 1968) as to the variability in PP content (Table 7) within an ingredient and how soil and environmental factors may affect this content (Cossa et al., 1997). Also refer to *Phytase and Other Phosphorus Reducing Feed Ingredients* Fact sheet for further description of phytate content and potential for PP hydrolysis.

Work done by Cossa et al., (1997) reported, in 54 corn samples, a P content of 0.31% on a dry matter basis and a standard deviation (SD) of 0.28 with low and high values of 0.255 and 0.383 %, respectively. Average PP was 0.266 % (SD of 0.034) with low and high values of 0.192 and 0.354% dry matter, respectively. These researchers found no apparent differences between locations and early, medium, and late varieties of corn on the PP content of the corn. Similarly, Cromwell et al., (1999) noted that across 16 sources of corn and SBM that P varied by 8.1 and 4.1 (% CV), respectively. There is also limited information on potential variability in the availability of PP (Van Der Klis and Versteegh, 1996; Cossa et al., 1997) (Table 8) within an ingredient and on how

Table 7. Phosphorus availability from plant and animal sources and feed phosphates measured in 3-week-old broilers (NRC, 1994; van der Klis and Versteegh, 1996; Coon and Leske, 1998;; Martinz Amezcua et al., 2004).

Ingredient	[a]TP, %	[a]PP, %	[a]AP (% of TP)	[b]Retainable P % (SD) 34.87 (11.07)	[c]nPP, %	[c]nPP, % of TP
Corn	0.3	0.228	29		0.08	28.0
Corn	- - -	0.396	- - -	34.9 (11.1)		
Distillers' dry grains plus solubles	0.73 (0.62-0.77)		69-100			
SBM (solvent extracted)	0.71	0.433	61		0.22	35.5
SBM	- - -	0.239	- - -	30.8 (8.6)		
Wheat	0.34	0.252	48		0.13	35.1
Wheat	- - -	0.332	- - -	30.7 (4.5)		
Wheat middlings	1.08	0.799	36		0.20	17.4
Wheat middlings	- - -	1.185	- - -	29.1 (4.0)		
Meat and bone meal	6.0	- - -	66			
Fish Meal	2.2	- - -	74			
Dicalcium phosphate	18.1	- - -	77			
Monocalcium phosphate	22.6	- - -	84			

[a] Availability based on standardized balance trials. b Retainable P based on balance trials.
Total phosphorus (TP), available phosphorus (aP), phytate phosphorus (PP), non-phytate phosphorus (nPP)

Table 8. Phytin-phosphorus (PP) content of feed ingredients as a percent of total phosphorus (TP) (Nelson et al., 1968; Cossa et al., 1997; Barrier-Guillot et al., 1996a; Spencer et al., 2000).

Ingredient	Number of Samples	PP, % (SD)	PP (% of TP)
Soybeans *G max* *G soja*	24 24	0.41 (0.22) 0.56 (0.18)	69.5 72.7
SBM (50% protein)	20	0.37	71
SBM (44% protein)	3	0.38	58
Corn	10	0.17 (0.02)	66
Corn	54	0.27 (0.24)	86
Low phytate corn	1	0.10	36
Corn gluten meal	1	0.36	62
Milo	11	0.21 (0.03)	68
Wheat	56	0.218 (.035)	60
Wheat	2	0.18	67
Wheat middlings	1	0.35	74

diet manufacturing process may affect this availability (De Goote and Huyghebeart, 1996).

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.

Distiller's Dry Grains plus Solubles (DDGS). Phosphorus in DDGS can range from 0.62 to 0.77% (versus that of corn at 0.3%). The bioavailability (versus potassium mono-phosphate), however, is at least two to three times greater than that of corn and can range between 62 and 100%. Incorporation of DDGS into diets should account for the additional total and available P. If this adjustment is made, increases in manure P concentrations can be avoided. However, uncertainty as to the bioavailability of P within DDGS has led to an underestimation of bio-availability and can result in excess of P in manure.

Summary

Variation in nutrient utilization by poultry and variability in nutrient composition and availability within feed ingredients has resulted in considerable over-formulation (i.e., safety margins) by the poultry industry. This over-formulation is used to guarantee the adequacy of nutrients for growth and prevention of nutritional deficiencies (an important animal well-being consideration). Routine testing of ingredients for nutrient composition is imperative to be able to reduce feeding safety margins, yet will not provide certainty to what nutrients will be digested and utilized by the bird.

References

Applegate, T.J., L.P.V. Potturi, and R. Angel. 2003a. Model for estimating poultry manure nutrient excretion: a mass balance approach. *Intl. Symp. Animal, Ag. Food Proc. Wastes* 9:296-302.

Applegate, T.J., B.C. Joern, D.L. Nussbaum-Wagler, and R. Angel. 2003b. Water soluble phosphorus in fresh broiler litter is dependent upon phosphorus concentration fed but not on fungal phytase supplementation. *Poult. Sci.* 82:1024-1029.

Barrier-Guillot, B., P. Casado, P. Maupetit, C. Jondreville, and F. Gatel, 1996a. Wheat phosphorus availability: 1-In vitro study; Factors affecting endogenous phytasic activity and phytic phosphorus content. *J. Sci. Food Agric.* 70:62-68.

Batal, A., and N. Dale. 2003. Mineral composition of distillers dried grains with solubles. *J. Appl. Poult. Res.* 12:400-403.

Coon, C. and K. Leske, 1998. Retainable phosphorus requirements for broilers. Maryland Nutr. Conf. p 18-31.

Coon, C.N., S. Seo, and M.K. Manangi. 2007. The determination of retainable phosphorus, relative biological availability, and relative biological value of phosphorus sources for broilers. *Poult. Sci.* 86:857-868.

Cossa, J., K. Oloffs, H. Kluge, and H. Jeroch. 1997. Investigation into the TP and PP content in different varieties of grain maize. 11th European Symp. Poult. Nutr.*, Proc. World's Poult. Sci.* Assoc., Faaberg, Denmark. pp 444-446.

Cromwell, G.L., C.C. Calvert, T.R. Cline, J.D. Crenshaw, T.D. Crenshaw, R.A. Easter, R.C. Ewan, C.R. Hamilton, G.M. Hill, A.J. Lewis, D.C. Mahan, E.R. Miller, J.L. Nelssen, J.E. Pettigrew, L.F. Tribble, T.L. Veum, and J.T. Yen. 1999. Variability among sources and laboratories in nutrient analyses of corn and soybean meal. *J. Anim. Sci.* 77:3262-3273.

Cromwell, G.L., J.H. Brendemuhl, L.I. Chiba, T.R. Cline, T.D. Crenshaw, C.R. Dove, R.A. Easter, R.C. Ewan, K.C. Ferrell, C.R. Hamilton, G.M. Hill, J.D. Hitchcock, D.A. Knabe, E.T. Kornegay, A.J. Lewis, G.W. Libal, M.D. Lindemann, D.C. Mahan, C.V. Maxwell, J.C. McConnell, J.L. Nelssen, J.E.

Pettigrew, L.L. Southern, T.L. Veum, and J.T. Yen. 2003. Variability in mixing efficiency and laboratory analyses of a common diet mixed at 25 experiment stations. *J. Anim. Sci.* 81:484-491.

de Goote, G. and G. Huyghebaert. 1996. The bio-availability of phosphorus from feed phosphates for broilers as influenced by bio-aasay method, dietary calcium level, and feed form. *Animal Feed Science and Technology* 69:329-340.

Floren, J. 2002. Results of manure samples analyses by 48 commercial laboratories. MN Dept. of Agriculture. http://www.mda.state.mn.us/appd/labresults.htm Accessed 4/03.

Funk, T.L., M.J. Robert, Y.Zhang, and R.E. Fonner, 2003. Precision and accuracy in a nutrient management plan utilizing liquid manure application: expectations and reality. *Proc. Amer. Soc. Ag. Engineer.* Conf. Paper#03-7002.

Gillis, M.B., H.M. Edwards, Jr., and R.J. Young. 1962. Studies on the availability of calcium orthophosphates to chickens and turkeys. *J. Nutr.* 78:155.

Havenstein, G.B., P.R. Ferket, S.E. Scheidler, and B.T. Larson. 1994. Growth, livability, and feed conversion of 1991 vs 1957 broilers when fed "typical" 1957 and 1991 broiler diets. *Poult, Sci.* 73:1785-1794.

Leske, K., and C.N. Coon. 2002. The development of feedstuff retainable phosphorus values for broilers. *Poult. Sci.* 81:1681-1693.

Martinez Amezcua, C., C. M. Parsons, and S.L. Noll. 2004. Content and relative bioavailability of phosphorus in distillers dried grains with solubles in chicks. *Poult. Sci.* 83:971-976.

National Research Council, 1994. Nutrient requirements of poultry. 9th revised edition. National Academy Press, Washington, DC.

Nelson, T.S., L.W. Ferrara, and N.L. Storer. 1968. Phytin content of feed ingredients derived from plants. *Poult. Sci.* 67:1372-1374.

Parsons, C. 2005. Variability and causative factors of variability in amino acid digestibility of byproduct ingredients. Poultry Dig. Amino Acid Roundtable. Indianapolis, IN.

Ravindran, V., L.I. Hew, and W.L. Bryden. 1998. *Digestible amino acids in poultry feedstuffs.* Rural Industries Research and Development Corporation: Canberra and Poultry Research Foundation: The University of Sydney, Cambden.

Spencer, J. D., G. L. Allee and T. E. Sauber. 2000a. Phosphorus bioavailability and digestibility of normal and genetically modified low-phytate corn for pigs. *J. Anim. Sci.* 78:675-681

Supplee, W.C. 1962. Anhydrous dicalcium phosphate as a source of phosphorus in poult diets. *Poult. Sci.* 41:1984.

van der Klis, J.D., H.A.J. Versteegh, and C.W. Scheele. 1994. Practical enzyme use in poultry diets: phytase and NSP enzymes. Carolina *Poult. Nutr. Conf. Proc.*pp. 113-128.

van der Klis, J.D. and H.A.J. Versteegh. 1996 Phosphorus nutrition in broilers. Pages 71-83 in: *Recent Advances in Animal Nutrition.* Edit.: P. C. Garnsworty, J. Wiseman, and W. Haresign. Nottingham University press, Nottingham, UK.

Waldroup, P.W. 2002. Phosphorus, phytase, and the environment…a retrospective look. *Proc. MD Nutr. Conf. Feed Manufact.* 49:195-202.

Wicker, D.L., and D.R. Poole, 1991. How is your mixer performing? *Feed Manage*. 42(9):40-44.

Project Information

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