

Enzyme Combinations to Optimize Byproducts Use in Corn-Based Poultry Feed

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Introduction

Although there are a variety of potential substrates for enzymes in poultry diets (see Table 1), the primary ones generally targeted in practical corn-based diets are phytate, arabinoxylans and starch. Mannans and oligosaccharides may also be potential substrates but dietary content of these may be more variable across ingredients than the aforementioned three. Beta-glucans are normally considered when feeding viscous cereals such as barley or oats as the primary cereal or at levels at or above 10% of the diet for either cereal. Due to the level of β -glucans and the insolubility of these nonstarch polysaccharides (NSPs) in typical US ingredients used in corn-based diets, β -glucans are not normally a NSP of concern for most diets. Cellulose is not a practical target in poultry as no enzyme system currently exists that would efficiently and cost-effectively fully release glucose from this NSP within the constraints of the bird's gastrointestinal tract.

Enzyme use is well documented across different types of poultry diets. Example papers on amylase (Ritz et al., 1995; Jiang et al., 2008), protease (Ghazi et al., 2002; Ghazi et al., 2003; Wang et al., 2008), xylanase (Mathlouthi et al., 2002; Cowieson et al., 2005), beta-glucanase (Mathlouthi et al., 2002), mixes of two or more of the aforementioned activities (Pettersson and Åman, 1992; Vranješ et al., 1994; Zanella et al., 1999; Hong et al., 2002; Mathlouthi et al., 2002; Meng et al., 2005; Cowieson and Ravindran, 2008a, b) as well as phytase (Onyango et al., 2005; Liu et al., 2008a, b) are among the many that can be found in the scientific literature. However, trials often examine one type of enzyme in isolation. For example, many of the published phytase papers do not examine relationships between phytase and various carbohydrases or proteases in practical diets. Given that many cereals, cereal byproducts or vegetable protein byproducts can vary in phytate (Table 2) as well as NSPs (Tables 3, 4, 5), it would seem logical that combinations of phytase, nonstarch polysaccharidases (NSPases) or other activities may provide a benefit in practical diets. Some recent papers published in the poultry research press have examined phytase with and without carbohydrase inclusion in corn-based diets (Cowieson and Adeola, 2005; Olukosi et al., 2007) or wheat-based diets (Ravindran, 2001; Wu et al., 2004). From a practical standpoint, many commercial companies in the poultry business are using phytase currently so demonstration of carbohydrase or protease efficacy in the presence of a phytase has become more important. Although many enzyme trials have focused on simple cereal/soy

Table 1. Potential enzyme substrates

Antinutrient	Where found	Problem	Content	Enzyme
Phytate	All plant-based ingredients	Binds P and other cations, increases endogenous loss	Varies but is generally higher in vegetable meals and cereal byproducts	Phytase
Arabinoxylans	Cell walls of plant based ingredients	Relatively resistant to digestion and may reduce nutrient digestibility; soluble causes viscosity	Moderate to low – depending on ingredient	Xylanase, Arabinofuranosidase
β-glucans	Cell wall of cereals such as barley or oats	Soluble form causes extremely high viscosity	Moderate to low and not found in corn, milo	β-glucanase
Mannans	Soybean meal, yeast cell walls	Resistant to digestion	Variable	β-mannanase
Oligosaccharides	Soybean meal, etc.	Resistant to digestion	Variable	α-galactosidase
Cellulose	Plant ingredients	Insoluble and resistant to digestion	High	Cellulase, Cellobiohydrolase
Starch	Cereals, cereal byproducts primarily	Structural resistance, retrogradation or protein binding	High	Amylase, debranching activities (protease)
Protein	Corn, milo, vegetable meals	Resistant proteins to digestion: storage proteins, protein ANFs, etc.	Variable	Targeted proteases

diets (for example: Wu et al., 2004; Cowieson et al., 2005; Olukosi et al., 2007; Cowieson et al., 2008a; Jiang et al., 2008), the responses noted with enzyme addition have ramifications for diets containing byproducts as these diets may have higher levels problem substrate(s) present. There are published papers on corn-based diets containing several different byproducts or vegetable meals, these provide evidence of enzyme efficacy (Dipeolu et al., 2005; Yuan et al., 2008). Unfortunately, there are a limited number of trials that have looked at inclusion of only one byproduct in the presence of feed enzymes.

Table 2. Percent Phytate Phosphorus in Feed Ingredients.

Ingredient	NRC, 1994	Eeckhout & De Paepe, 1994	Kornegay, 2001 ¹	Liao <i>et</i> <i>al.</i> , 2002	Slominski <i>et al.</i> , 2004
Corn	0.20	0.19	0.24	0.24	NA
Wheat	0.24	0.22	0.27	0.26	0.26
Wheat bran	0.95	0.97	0.92	0.81	NA
Wheat millrun ²	NA	NA	NA	NA	0.57
Wheat midds	0.55	0.53	NA	NA	NA
Wheat screenings	NA	NA	NA	NA	0.33
Rice bran	1.28	1.10	NA	1.07	NA
Sorghum	NA	0.19	0.24	0.22	NA
Barley	0.19	0.22	0.27	0.23	NA
Oats	0.22	0.21	0.29	0.26	NA
Millet	0.20	NA	NA	0.17	NA
Triticale	0.20	0.25	NA	0.27	NA
Rye	0.22	0.22	NA	0.22	NA
Rye bran	NA	0.79	NA	0.60	NA
Soybean meal	0.40	0.32	0.39	0.37	NA
Soybeans (heated)	NA	0.26	NA	NA	NA
Canola meal	0.87	0.40	0.70	0.63	NA
Sunflower meal	0.84	0.44	0.89	0.69	NA
Peanut meal	0.50	0.32	0.48	0.46	NA
Cottonseed meal	0.88	NA	0.84	0.82	NA
Peas	NA	0.17	NA	0.23	NA
Flax meal	NA	0.42	NA	0.69	NA
Corn gluten meal	0.36	NA	NA	0.36	NA
Corn gluten feed	NA	0.47	NA	NA	NA
Wheat gluten feed	NA	0.56	NA	NA	NA
Sesame meal	1.03	NA	NA	1.03	NA
Alfalfa dehy. meal	NA	0	NA	0.01	NA
Coconut meal	NA	0.18	NA	0.27	NA
Bakery meal	NA	NA	NA	NA	0.24
Corn DDGS	0.10	0.19	NA	NA	NA

NA = not available

¹ Kornegay's values are adapted from data of Ravindran, V. (1996); Ravindran *et al.*, (1994); Ravindran *et al.*, (1995).

² Midds and millrun are very similar although millrun may have a higher portion of bran.

Vegetable byproducts and antinutritional issues

Typical byproducts used in feed formulation can vary widely by region. But in general, typical problems involve NSPs, phytate, starch and amino acids where plant-based byproducts are concerned. In these ingredients, digestibility and antinutritional factors

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Table 3. Select NSP levels in cereals reported as % dry matter unless otherwise noted

Ingredient	sAX (%)	iAX (%)	tAX (%)	sAX (AF)	iAX (AF)	tAX (AF)	sβ-gl (%)	tβ-gl (%)	iCW (%)	tNSP¹ (%)	Reference
Wheat (Rialto)	0.8	-	-	-	-	-	0.24	-	12.3	-	Mathlouthi et al., 2002
Wheat	-	-	-	-	-	-	-	-	-	10.0	Slominski et al., 2004
Wheat	-	-	4.46	-	-	-	-	-	-	8.8	Meng et al., 2005
Triticale	0.48	-	-	-	-	-	0.18	-	10.4	-	Mathlouthi et al., 2002
Rye	1.44	-	-	-	-	-	0.75	-	14.6	-	Mathlouthi et al., 2002
Rye	2.3 to 2.9	5.3 to 6.9	7.6 to 9.8	-	-	-	-	2.3	-	13	Voragen et al., 1992
Rye	-	-	-	2.6	4.1	6.7	-	-	-	9.0	Cowieson and Adeola, 2005²
Oats	0.13	-	-	-	-	-	4.35	-	31.1	-	Mathlouthi et al., 2002
Barley	0.3	-	-	-	-	-	2.43	-	14.1	-	Mathlouthi et al., 2002
Barley (hulless)	0.48 to 0.56	2.52 to 3.44	3 to 4	-	-	-	4 to 5	4 to 5	-	13	Voragen et al., 1992
Corn	0.03	-	-	-	-	-	0.05	-	9.6	-	Mathlouthi et al., 2002
Corn (US)	-	-	-	0.1	3.8	3.9	-	-	-	6.1	Cowieson and Adeola, 2005²
Corn	-	-	5.35	-	-	-	-	-	-	9.3	Malathi and Devegowda, 2001³
Sorghum	0.28	2.52	2.8	-	-	-	-	0.3	-	5	Voragen et al., 1992
Sorghum	-	-	2.77	-	-	-	-	-	-	9.7	Malathi and Devegowda, 2001³

¹ Total NSP includes both water soluble and insoluble NSPs.

² Cowieson and Adeola, 2005 presented data on an as fed basis

³ Malathi and Devegowda, 2001 reported total pentosans of which arabinoxylans would be classified under.

sAX = soluble arabinoxylan; iAX = insoluble arabinoxylan; tAX = total arabinoxylan; β-gl = soluble beta glucan; tβ-gl = total beta-glucan; iCW = insoluble cell wall components; tNSP = total NSP; AF = % as fed

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Table 4. Select NSP profile of various byproduct ingredients reported as % dry matter unless otherwise indicated

Ingredient	sAX (%)	iAX (%)	tAX (%)	sβ-gl (%)	tβ-gl (%)	iCW (%)	tNSP¹ (%)	Fiber (%)	Reference
DDGS	-	-	11.4	-	-	-	22.7	-	Ward et al., 2008
Bakery byproduct	-	-	-	-	-	-	9.5	14.6	Slominski et al 2004
Wheat screenings	0.35	-	-	0.05	-	19.5	-	-	Mathlouthi et al., 2002
Wheat screenings	-	-	-	-	-	-	11.1	21.6	Slominski et al 2004
Wheat mill run	-	-	-	-	-	-	24.6	42.4	Slominski et al 2004
Wheat bran	0.50	-	-	0.07	-	40.6	-	-	Mathlouthi et al., 2002
Wheat bran	3	27	30	-	-	-	45	-	Voragen et al., 1992
Wheat midds	-	15.04	-	-	-	-	26.0	-	Danisco database
Rice bran	0.06	-	-	0.08	-	19.4	-	-	Mathlouti et al., 2002
Rice bran	-	-	19.2	-	-	-	60	-	Voragen et al., 1992
Rice bran, deoiled	-	-	10.65	-	-	-	59.97	-	Malathi and Devegowda, 2001²
Oat bran	0.39	4.05	4.44	-	7.72	-	15.1	16.9	Pettersson and Åman, 1992
Oat bran, extracted	0.48	4.78	5.26	-	8.40	-	17.6	19.3	Pettersson and Åman, 1992

¹ Total NSP includes both water soluble and insoluble NSPs; ² Malathi and Devegowda, 2001 reported total pentosans of which arabinoxylans would be classified under. sAX = soluble arabinoxylan; iAX = insoluble arabinoxylan; tAX = total arabinoxylan; β-gl = soluble beta glucan; tβ-gl = total beta-glucan; iCW = insoluble cell wall components; tNSP = total NSP;

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Table 5. Select NSP profile of various byproduct ingredients reported as % dry matter unless otherwise indicated.

Ingredient	sAX (%)	tAX (%)	sAX (AF)	iAX (AF)	tAX (AF)	sβ-gl (%)	tβ-gl (%)	iCW (%)	tNSP¹ (%)	Reference
Soybean meal	0.11	-	-	-	-	0.06	-	21.1	-	Mathlouthi et al., 2002
Soybean meal	-	3.22	-	-	-	-	-	-	14.8	Meng et al., 2005
Soybean meal	-	-	0.3	3.0	3.3	-	-	-	12.6	Cowieson and Adeola 2005²
Soybean meal	-	4.21	-	-	-	-	-	-	29.02	Malathi and Devegowda, 2001³
Rapeseed meal	0.27	-	-	-	-	0.05	-	40.9	-	Mathlouthi et al., 2002
Rapeseed meal	-	8.85	-	-	-	-	-	-	39.79	Malathi and Devegowda, 2001³
Canola meal	-	4.69	-	-	-	-	-	-	17.1	Meng et al., 2005
Sunflower meal	0.13	-	-	-	-	0.18	-	52.0	-	Mathlouthi et al., 2002
Sunflower meal	-	11.01	-	-	-	-	-	-	41.34	Malathi and Devegowda, 2001³
Peanut meal	-	6.11	-	-	-	-	-	-	29.50	Malathi and Devegowda, 2001³
Peas	0.07	-	-	-	-	0.11	14.8	-	-	Mathlouthi et al., 2002
Peas	-	2.54	-	-	-	-	-	12.7	-	Meng et al., 2005

¹ Total NSP includes both water soluble and insoluble NSPs.

² Cowieson and Adeola, 2005 presented data on an as fed basis

³ Malathi and Devegowda, 2001 reported total pentosans of which arabinoxylans would be classified under. sAX = soluble arabinoxylan; tAX = total arabinoxylan; β-gl = soluble beta glucan; tβ-gl = total beta-glucan; iCW = insoluble cell wall components; AF = % as fed

are almost always involved in the decision process of when and how much to use to help reduce cost while not jeopardizing performance. Toxic antinutritional factors such as gossypol, mycotoxins, etc. are obvious limiting factors. But issues on NSP-related effects on nutrient uptake, GI passage rate and subsequent bird performance to problems in starch, amino acid or phosphorus (mineral) availability are also key in the decision process. It should be noted in any discussion on usage of byproduct, particularly at higher levels, that good ingredient quality monitoring programs should be in place.

Nonstarch polysaccharides

Nonstarch polysaccharide issues are best addressed by the appropriate NSPase (table 1). However it is fair to note that the degree of and type of benefit of NSP enzymes may depend on the nature of the NSP present, i.e. soluble (Mathlouthi et al., 2002) or insoluble (Jaroni et al., 1999), or even a factors like particle size (Mavromichalis et al., 2000; Aulrich and Flachowsky, 2001). In addition, heat processing can affect physical characteristics of NSPs (Cowieson et al., 2005; González-Alvarado et al., 2008) Viscous fiber prolongs gastric emptying and slows transit time (Malkki, 2001), which in growing animals alters nutrient digestibility and generates performance losses. For corn-based diets, insoluble NSPs predominate in many of the ingredients typically used (see tables 3, 4, 5). Insoluble fiber/NSPs can affect gut transit time, gut motility and may also hinder the ability of endogenous enzymes to gain access to their respective substrates (Choct, 2001). Insoluble NSPs do not cause viscosity but these cell-wall components can encapsulate nutrients inside intact cell walls. Correspondingly, the finer the grind or particle size, the more of these encapsulated nutrients may already be released. Another way of addressing intact cell walls is to add an NSPase such as xylanase to the feed, with the intention of this enzyme acting to open intact cell walls via its action on the NSP arabinoxylan, thus allowing endogenous enzymes access to previously ‘hidden’ nutrients.

The mechanism of action may be related to the ability of insoluble fiber to ‘bind’ or ‘hold’ water, thus influencing gut bulk (physical fill) and potentially motility. Some consider wheat bran or rice bran as possibly beneficial in laxation for humans (Dikeman et al., 2006), although this is typically not the reason for use in poultry diets. *In vitro* tests on water binding and water holding capacity of various feed ingredients has noted differences across major feedstuffs. In general, corn was found to have lower water holding capacity than does soybean meal or other protein meals whereas potato flakes were found to have the highest water holding capacity (Partridge, 2001). All ingredients, but grass meal and sunflower meal, responded with reductions in water holding capacity greater than 10% when a carbohydrase/protease product was added to the *in vitro* test system (Partridge, 2001). Aulrich and Flachowsky (2001) examined the relationship between particle size and water binding as well as water holding capacity of wheat bran. These authors found that as particle size when from 1 mm to 0.25 mm, there was a reduction in both water binding and water holding capacity of wheat bran. In addition, if an NSPase mix of xylanase and β -glucanase were applied to the wheat bran, a linear reduction in water binding and water holding capacity was noted with increasing enzyme inclusion (Aulrich and Flachowsky, 2001). Interestingly enough, these authors also noted in the porcine *in vitro* stomach and small intestine simulations that NSPase supplementation improved release of ‘bound’ protein in wheat bran.

Since nutrient flow to the villi on the gut wall depends on gut motility and corresponding convective movement of water and nutrients, insoluble fiber may affect feed intake, nutrient absorption and ultimately bird performance. So in this scenario, NSP enzymes act to alleviate the negative water binding/holding effects of insoluble fiber/NSPs in the GI tract, which in turn helps to reduce more normal transit time and nutrient flow. A fairly extreme example of how insoluble NSPs can affect growth of the bird in the absence of NSPases can be seen in the work of Pettersson and Åman, 1992. These authors used a diet containing 68% oat bran or extracted oat bran with or without NSPase addition and noted dramatic improvement in chick performance with enzyme addition even considering that they pair fed one of the treatment pairs (see table 6).

Table 6. Can chicks raised to 20 days grow on diets containing 68% oat bran or extracted oat bran if NSPases* are added?¹

Treatment	Gain (g)	FI (g)	F:G	Frequency of sticky droppings (day 7)
Oat bran	195 a	413 bc	2.63 b	33 b
Oat bran + NSPases²	282 b	416 b	1.71 a	4 a
Extracted oat bran	177 a	380 b	2.73 b	27 b
Extracted oat bran + NSPases	452 c	688 a	1.66 a	6 a

Dietary total arabinoxylans = 3.34 (88.6% insoluble) for oat bran diet; 3.66% (88.8% insoluble) for extracted oat bran

Primary ingredients consisted of oat bran, corn starch, fishmeal, soybean meal. Enzyme supplemented birds were pair-fed with corresponding control.

*NSPases = xylanase and β -glucanase added in combination at 0.2% of the diet

a,b, c: means within a column without a common letter differ at P<0.05.

¹ Data is from Pettersson and Åman, 1992.

² The enzyme supplemented oat bran diet was pair fed to match its control. The extracted oat bran + enzyme was not pair fed.

Phytate

Phytic acid has long been known as an antinutrient due to the presence of bound phosphorus on its structure but also its ability to bind positively-charged substances (e.g. Kornegay, 2001 or similar articles for review) and alter secretion of endogenous enzymes (Dilworth et al., 2004; Liu et al., 2008 b). High phytate levels depressed chicks weights and G:F (Liu et al., 2008 b) as well as nutrient digestibility (Ravindran et al., 2006). Plus high phytate reduced activity of disaccharidases and Na⁺K⁺ATPase in the duodenum (Liu et al., 2008 b). The mode of action of phytate in increasing endogenous nutrient loss has become clearer over the last 5 years, which helps explain why phytase may affect nutrients other than those that could be directly bound to phytate. In addition, new research suggests that phytase addition to nutritional marginal diets may help improve lymphocyte numbers as well as antibodies in the sera and mucosa of broilers (Liu et al., 2008a). In all, it should be realized that the higher the dietary phytate level, the greater the potential for phytate to generate digestive issues and potentially increase maintenance cost of digestion. Use of phytase helps alleviate issues with this substrate and is known to generate feed cost savings via lower inclusion of inorganic phosphorus.

However, it should be considered that higher phytate diets have greater potential for negative effects of this substrate, so it may be beneficial to consider higher phytase inclusion per ton feed to help alleviate these effects.

Starch

Starch is the easiest of the carbohydrates to digest but is not fully utilized by poultry at the terminal ileum. Noy and Sklan (1994) estimated that 11 to 18% of the starch may be undigested at the terminal ileum in chicks of 4 to 21 days of age. However, crystalline structure, component ratio of amylase to amylopectin, protein binding, cell wall encapsulation or even gelatinization can all affect how efficiently starch is digested by the bird. Cowieson (2005) reviewed these factors for corn and Weurding and coworkers (2001a, b) noted clear differences in the rate and extent of starch digestion for various feed ingredients.

In cereal byproducts, starch content is often highly variable and may vary widely in quality. In bakery byproducts, care must be taken by the manufacturer to ensure that already cooked items containing starch are not retrograded during the second cooking process. In addition, there is potential for the formation of Maillard reaction products between glucose and amino acids such as lysine, although this depends on the type of bakery goods included in the mix and the content of reactive materials. Maillard reaction products are also a great concern in DDGS. Partially reacted products will assay as lysine but are not wholly bioavailable as lysine. The amino acid lysine is a concern here due to it having two amino groups that can be reactive whereas other amino acids, except proline, have one amino group. Regrettably, there is no enzyme that will counteract the effect of the Maillard reaction on lysine after the Schiff base step.

Protein antinutritional factors

For poultry feed, proteases may target issues in vegetable protein meals, protein antinutritional factors or storage proteins found in plant-origin materials. It is known that a targeted protease(s) can be used to help degrade lectins, trypsin inhibitors (Hessing et al., 1995) and other protein ANFs (Ghazi et al., 2002). Proteases also may be used to target storage proteins. These proteins ‘store’ or bind starch and are one possible cause of starch that is resistant to digestion (Brown, 1996).

Vegetable byproducts: where are we now?

Table 7 shows general recommendations for select byproducts that may be encountered in the field. Some of these are discussed further in this paper but the reader is strongly encouraged, when using higher levels of byproducts, to have a strong quality control program in place to help ensure successful usage. In addition, it may be helpful to evaluate what antinutritional factors that byproduct(s) may be bringing into the diet particularly as level increases. This can help make the decision of the type of enzyme(s) that may be needed to remedy digestive and performance issues clearer. Relatively few trials have examined enzyme use in high byproduct type diets. Logically this may be due historic need to ‘prove’ response in what was the status quo type diet – simple corn/soy. Some byproducts merit a few extra words as these typically exhibit high variance.

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Table 7. Recommended maximum levels of select byproducts and highest levels tested successfully with enzymes (corn-based diets)

Ingredient	Species	Maximum (no enzyme)	Reference	Highest level with enzymes	Successful Parameter	Activities	Reference
Bakery meal	Meat birds	10% to 4 wks, 15% to market	Leeson & Summers, 1997				
	Layers	10%	Leeson & Summers, 1997				
Corn DDGS (modern)	Broiler	6% starter 12 to 15% in other phases; 15% all phases	Lumpkins et al., 2004; Wang et al., 2008	10% in all phases	Gain, F:G, bone breaking strength	X, A, P, Phy	Moran and Lehman, 2008
				40% in starter	Tibia ash	Phy	Martinez-Amezcu et al., 2006
	Turkey	10 to 20% in market birds	Noll, 2004				
	Layer	10 to 15% depending on diet density; Up to 15% but an age issue may be present at 52 wks; 20% light colored DDGS	Lumpkins et al., 2005; Roberson et al., 2005 Cheon et al., 2008	20% (entire cycle)	Egg weight, lay rate in 44-68 wk phase where controls struggled	X, BGL	Świątkiewicz & Koreleski, 2006
Dehydrated alfalfa	Broiler, Turkey	5% to 4 wks, 10% to market	Leeson & Summers, 1997	3%	Performance	X, A, P, Phy	Moran and Lehman, 2008
	Layer	5%	Leeson & Summers, 1997				
Wheat bran	Meat birds	8% to 4 wks, 20% later	Leeson & Summers, 1997	7.9% starter, 14% later (ducks)	Performance, digestibility	X, A, P,	Hong et al., 2002
	Layer	10%	Leeson & Summers, 1997	16% wheat midds	Performance, egg weight, villi height	X, P	Jaroni et al., 1999a, b
Wheat shorts	Meat birds	10% to 4 wks, 20% later	Leeson & Summers, 1997		See above		
	Layers	20%	Leeson & Summers, 1997		See above		

X = xylanase; A = amylase; P = protease; Phy = phytase; BGL = β -glucanase

Bakery Byproducts

As a whole, bakery byproducts can vary considerably in composition depending on the relative sources of raw material around the production plant. Typical bakery byproduct raw materials may consist any of the following: raw doughs, partially cooked doughs, doughnuts, breads, muffins, cookies, crackers, candy, snack foods, chips, cakes, inedible flour, unsalable nuts, etc. Since the component ingredients vary in composition, the final bakery byproduct will vary from plant to plant. In their examination of bakery product originating from different feed manufacturers, Slominski and coworkers (2004) noted that high variability existed in starch fat, NSP and phytate P. These authors noted a difference in NSP content ranging from 3.3 to 17.0% across the 12 samples analyzed (mean = 8.7% with a standard deviation of 5.53 and coefficient of variation of 63.6%). Total fiber showed the highest variance, although the authors only analyzed 8 of the 12 samples. The range in total fiber was 6.9 to 32.7% with a SD of 9.57 and CV of 71.4%. Phytate P content ranged from 0.03 to 0.47% (mean = 0.22%, SD = 0.15 and CV of 69.5%). For starch, the range ran from 24.7 to 49.3% with a mean of 37.8 (SD of 8.29 and CV of 21.9%). Fat content ranged from 4.2 to 10.2% with a mean of 8.0% (SD of 18.2 and CV of 22.7%). Protein was less variable with a mean of 11.9% (SD of 1.35, CV of 11.3%). Dry matter was very consistent at 91.6 (SD of 9.8, CV of 1.06%). Not unsurprisingly, there was an 85% correlation between NSP and starch wherein increases in NSP meant reduced starch levels in bakery meal (Slominski et al., 2004). But no relevant correlation was present for starch vs. fat in this byproduct.

Since it is typical that xylanases and/or amylases are added in the mixing of doughs to enhance the production process, it is an open question as to how little or much these processing enzymes have improved nutrient value of components in bakery meal. Much depends on type of bakery product as raw or partially cooked doughs from bread or pizza crust would logically have different potential for NSPs and starch availability than would cakes, cookies and candies.

The potential for bakery as an energy source in poultry diets is clear. However, users should monitor proximate composition, salt and similar nutrients. But also it may be helpful to periodically measure NSP or at least NDF and ADF content of incoming bakery byproduct from each of their suppliers' plants.

Wheat byproducts

Traditionally wheat byproducts are been restricted to diets for layers, breeders, ducks or older turkeys due to concern about fiber and starch contents. Although Leeson and Summers (1997) suggest that wheat byproducts may be used at up to 10% of diet in young birds. Wheat mill run (similar to midds but with more bran), for example, contains about 22.4% total NSPs (Slominski et al., 2004; CV of 13.2% on 6 samples). The bulk of which are insoluble NSP rather than the viscosity-causing soluble NSP. Phytate P levels also run high in wheat mill run at 0.52% (Slominski et al., 2004). Like wheat midds, starch and fat contents are the most variable components. Starch averaged 26.4% (SD of 5.24, CV of 19.8%) whereas fat had a mean of 4.3% (SD of 1.02, CV of 23.7%; Slominski et al., 2004). The challenge with any of the wheat byproducts is that the starch, NSP level and perhaps even phytate can vary considerably from flour mill to flour

mill. So again, monitoring programs are essential with this byproduct. In table 7, corn-based diets containing midds and feed enzymes have been successfully used in duck and layer to aid bird performance.

DDGS:

For the US, DDGS is mainly made from corn. In Canada, the cereal used in fuel ethanol production can be wheat, corn or blends of the two depending on location. In their NSP screen of US-origin DDGS from modern ethanol plants, Ward and coworkers (2008) noted that arabinoxylans and cellulose were the predominant NSPs. The reported value of 11.4% arabinoxylans (dry matter basis) from Ward and coworkers (2008) agrees with that of the Dansico database which averages 11.7% total arabinoxylans. Insoluble NSPs predominated in US DDGS for all NSPs measured but fucose and ribose (Ward et al., 2008). Lysine is of special concern in this ingredient as it can irreversibly react with starch via the Maillard reaction, which renders the reacted product unavailable to the bird. A screen of 20 Minnesota-origin DDGS samples revealed that while mean lysine digestibility averaged 72%, the range was between 59 and 84% (Parsons, 2006). In a related project examining if P availability could be increased in DDGS, amino acid availability was also examined. Not unsurprisingly, autoclaving or oven drying DDGS reduced lysine availability although it did improve P availability (Parsons, 2006). Thus lysine deserves special consideration when formulating diets with DDGS as enzyme supplementation will not restore availability of Maillard-reacted lysine. As with other byproducts, use of digestible amino acids in formulation is strongly recommended.

Use of DDGS in poultry feeds has varied by age and species of the bird in question (Table 7 or please see the website www.ddgs.umn.edu). But in pelleted feeds for broilers, DDGS has been associated with reduced pellet quality at levels greater than 15% (Wang et al., 2008). Particle size of the DDGS, starch content as well as its oil content affect pellet quality, so all should be considered when using higher levels of DDGS as poorer pellet quality can impact performance. However, research is relatively limited on how NSPases and/or phytase may impact the nutritional value of diets containing this byproduct. Martinez-Amezcuca and coworkers (2006) noted that 1000 or 10000 units phytase/kg feed improved tibia ash and threonine digestibility of broiler chicks fed a corn based diet with 40% DDGS but not AME. Work by Moran and Lehman (2008) using xylanase, amylase, protease and phytase supplementation to a corn/soy/10% DDGS diet for broilers raised to 56 days of age noted improvements in weight gain, weight-corrected F:G as well as bone breaking strength in these birds (Table 8). For laying hens, some trials have reported reduced egg production with feeding 15 to 20% DDGS in older layers (Roberson et al., 2006, Świątkiewicz & Koreleski, 2006). Addition of NSPases in the 44 to 68 wk feed phase helped offset the drop in lay rate and daily egg mass noted by Świątkiewicz and Koreleski (2006) in diets with 20% DDGS vs. in the nonsupplemented diet with 20% DDGS.

The type of fermentation process and possible use of fractionation present in the fuel ethanol industry means the user needs to be certain of the type of corn DDGS they are receiving as the new fractionation products differ in nutrient profile (Kim et al., 2008).

Table 8. Examination of a carbohydrase, protease, phytase product in broiler diets containing 10% DDGS¹

Period	Treatment	Gain (g)	wcF:G*	Tibia breaking strength (kg)
0 to 8 wks	Positive control (PC)	3895 b	1.98 ab	33.8 b
	PC + Enzymes ¹	4078 a	1.87 b	36.8 a
	Negative control (NC)**	3736 c	1.99 a	30.6 c
	NC + Enzymes ¹	4195 a	1.94 ab	38.7 a

a, b, c: separate letters within a column indicate differences at P<0.05 or less.

* Weight corrected feed: gain was calculated using 100 g difference in weight = 3 pts.

**Negative control was reduced in aP, Ca, AME and key amino acids.

¹ Data are adapted from Moran and Lehman, 2008

² Enzymes = 0.05% Avizyme 1502, 500 units Phyzyme XP/kg feed

Monitoring other key factors such as protein, fat, starch, fiber, ash, dry matter, total and bioavailable amino acids (particularly lysine), sodium, phosphorus, phytate and sulfur is strongly recommended. Mycotoxin monitoring is also recommended as those from the corn itself are not destroyed in the fermentation process. Plus, mold growth due to improper storage or drying can occur. Periodic analysis of NSP profile may also be helpful particularly as the productions methods (and fractionation) evolve over the next few years.

Closing thoughts

As higher levels of byproducts are used in diets, problem substrates correspondingly will increase. As enzymes typically have demonstrated efficacy in simple cereal diets, these benefits should continue as target substrates increase for key enzyme activities. However, the user needs to be aware of just what those substrates are and how much is coming into their diets to determine the appropriate enzyme or enzymes use. Regrettably, several key common byproducts are highly variable in composition which means good ingredient monitoring systems need to be in place and that targeted enzymes may have a role to help maintain nutritional uniformity.

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