Intestinal viscosity, broiler performance

Higher costs for corn for poultry feed are making alternates more interesting, but there are things to consider.

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The substandard performance, sticky feces and pasty beaks that occur when feeding sufficient levels of barley, wheat or rye to poultry are attributed to the water-soluble non starch polysaccharide (NSP) component. The negative relationships between the NSP and energy, and nutrient digestibility, provide evidence of its antinutritive character (see Annison and Choct, 1991), while fecal recoveries of 86 percent attest to its poor digestibility (Nicol et al., 1993).

The water-soluble portion of NSPs is notorious for forming a gel-like viscosity in the intestinal tract (Burnett, 1966; Gohl and Gohl, 1977). For sure, the increased intestinal viscosity can suppress the digestibility of ingredients other than the source of NSPs, whether it be added fat (Antoniou et al., 1980), fat soluble vitamins (MacAuliffe et al., 1976), amino acids (Morgan and Bedford, 1995), and possibly minerals, such as sodium (Lee and Campbell, 1983).

Foregut viscosity can explain more than half of the variability in body weights and feed conversion (FIG) of broilers fed wheat/rye (Bedford and Classen, 1992) or barley based diets (Graham et al., 1993a). In a study with broilers fed wheat-based diets with supplemental enzymes, this accountability was as high as 94 percent between 21-day intestinal viscosity and 42-F/G (P<.001, Bedford, 1995). Generally, for diets having a reasonably high initial viscosity, F/G can be improved by about two points with each centipoise decrease in gut viscosity (Graham et al., 1993b).

Viscosity is generally defined as "the internal fluid resistance of a substance," and is envisioned as being glutinous, thick, syrupy or sticky.

In recognition of the negative impact of high intestinal viscosity, research has identified multienzyme supplementation as a foremost means under practical conditions by which to neutralize the effects of high intestinal viscosity on bird performance.

Table 1. Foregut viscosities (centipoise units) determined in 21-day old broilers fed various cereals in combination with soybean meal

Cereal	Average	Minimum	Maximum
Corn	2.4	1.5	4.5
Wheat	12	3	45
Triticale	16	4	50
Barley	25	6	225
Barley	>250	70	>1000

Bedford, 1995

What is viscosity?

Viscosity is generally defined as 'the internal fluid resistance of a substance," and is envisioned as being glutinous, thick, syrupy or sticky. Viscosity is measured as “centipoise units” or cps. As reference, viscosities for potable water, one percent fat milk and four per cent fat milk are approximately 1, 1.5-2 and 4 cps, respectively. Liquid dish detergent has a viscosity of about 350 cps. Intestinal foregut viscosities for corn/SBM tend to be 1.5 4.5, but can exceed 1 000 cps for rye/SBM (Table 1).

Nonstarch polysaccharides

The NSPs exist as a structural carbohydrate in the endosperm cell wall. For wheat, rye and triticale, the arabinoxylans make up the major NSP, and consist of a main chain beta-(1,4)-linked xylose to which sidechains of arabinose are attached. Increased intestinal viscosity is attributed to the water-soluble NSP fraction, and it is the arabinose sidechains that impart a water soluble nature to this NSP. The long polymers entangle and have a highwater-holding capacity, resulting in an increase in intestinal viscosity. With no arabinose, the xylan would essentially precipitate from solution with virtually no change in viscosity.

The molecular weight of the arabinoxylans is directly related to viscosity (Bedford and Classen, 1992; Izydorczyk and Billiaderis, 1992). In their study, Bedford and Classen (1992) found that a high molecular weight (>500,000 kilodaltons) component in a wheat/rye diet accounted for 80 per cent of the digesta viscosity in young chicks, but made up only 10 percent of the total polysaccharides.

On the other hand, for barley and oats, the problem arises from mixed-link beta-glucans. These are of variable length glucose units linked with beta-1,4 and intermittent beta-1,3 bonds. The beta 1,3 links prevent substantial aggregation and minimize precipitation, thereby enhancing solubility.

Generally, intestinal viscosity declines in a descending manner with rye, barley, oats, triticale and wheat (Table 1), although the dietary inclusion level, geneotype and environment can markedly influence the degree of intestinal viscosity (Rose and Bedford, 1995, Campbell et al., 1989). Pelleting and expansion of these grains also increase viscosity (MaeGee and McCracken, 1993), which is usually more pronounced in the younger bird (Petersen et al., 1993).

Effects of increased viscosity

When feeding wheat-, barley- or rye-based diets, that most of the variation in live bird performance can be explained by intestinal viscosity is a testament of its significance. Research has shown that viscosity-inducing NSPs can have several effects on poultry, with the ultimate effect being reduced live performance (Figure 1).

Reduced digesta passage rate

The water-soluble NSP fraction can reduce or prolong digesta passage rate through the intestinal tract by virtue of its gel-like, thickened consistency. The feed consumption of young broilers often declines (Salih et

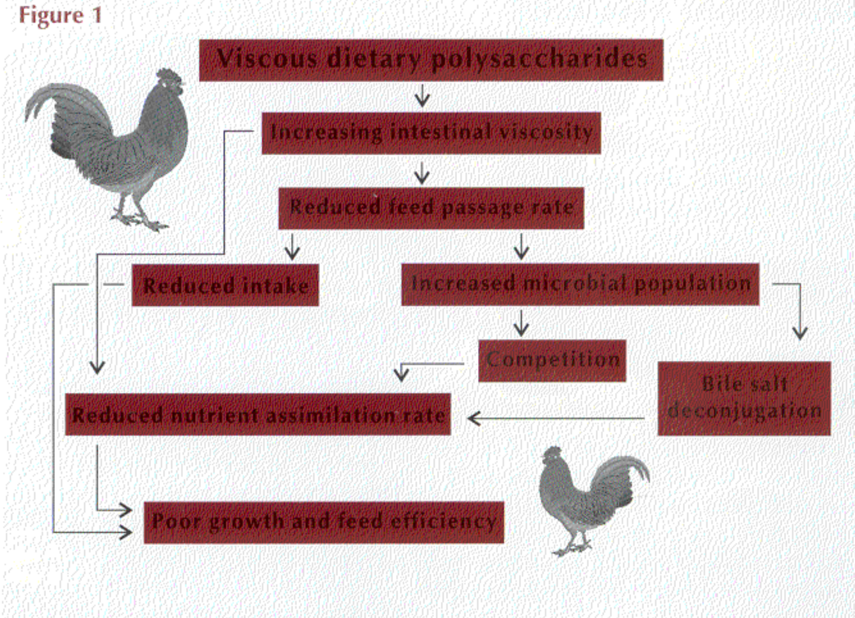

Figure 1

al., 1991, Almirall and Esteve-Garcia, 1994, Airnirall et al., 1995), although not in all cases. In trials with reduced feed consumption, enzyme supplementation usually remedies this problem.

Although feed passage rate is slowed with increased viscosity, gut motility actually may increase (Silah et al., 1991). The increased gut motility may contribute to greater endogenous secretion of proteins, water, minerals, and fatty acids reported by Low (1989). Excessive secretion of these components into the intestinal lumen represents a nutritionally costly event, and may encourage the wet feces when feeding these ingredients at sufficiently high levels.

Enzyme-substrate binding

The viscous NSP can physically complex with intestinal enzymes (Ikeda and Kusano, 1983), keeping them from reacting with substrates. A reduced activity of pancreatic enzymes in the intestinal digesta was blamed on increased viscosity when feeding barley (Almirall et al., 1995), which is consistent with the many reports of reduced digestibility of starch, amino acids, and fat when barley, wheat and rye-based diets are fed.

An enlargement of the pancreas occurred when feeding high betaglucan barley (Brenes et al., 1993; Almirall et al., 1995), conceivably due to increased pancreatic secretion to compensate for enzyme-NSP binding. Pancreatic hypertrophy from raw soybean meal has been similarly rationalized. As well, the induction of a viscous intestinal mileau can decrease intestinal pH (Van der klis et al., 1993), and a low pH stimulates pancreatic secretions (Garcia et al., 1990).

Digesta mixing

High viscosity minimizes the mixing of the digesta. Likewise, the movement of sugars, amino acids and other nutrients to the mucosal sites is impaired (Fengler and Marquardt, 1988). The larger the molecular size of the solute, the more likely is its rate of diffusion to be reduced (McCleary and Glennie-Holmes, 1985). Studies have established that a marked decrease occurs in fat digestibility when intestinal viscosity is high, which in part, may be due to a poor diffusion rate of the large fat micelle.

With wheat arabinoxylan in solution to provide a viscosity varying from 1-6 cps, bradykinin (a low molecular weight protein) was diffused over a 60-minute period. When viscosity was increased from one to three cps, diffusion was decreased by about 20 percent, clearly showing that even small changes in viscosity can have considerable effects on particle diffusion. A 10 percent improvement in the digestibility of amino acids in a wheat/SBM diet was reported to occur with a small reduction of intestinal viscosity, from 5 cps to 3.5 cps, (Bedford and Morgan, 1995).

Reductions in nutrient digestibility take place under conditions of high viscosity, and this is not limited to the source of viscosity (ie, barley, wheat, etc.). A good portion of the increased amino acid digestibility in a wheat/SBM diet was recently attributed to improved SBM digestibility when a multienzyme was supplemented (Morgan and Bedford, 1994). In fact, the amount of digestible cysteine actually exceeded the amount which theoretically could be supplied by the wheat.

Bacterial population changes

The highly nutrified digesta in the warm, moist intestinal environment is an ideal growth media for bacteria. Intestinal microbial counts are higher with wheat-, barley and ryebased diets, as opposed to corn (Fernandez et al., 1973; Wagner and Thomas, 1977; Branton and Reece, 1987, Kaldhusdal and Hofshagen, 1992). Colonization of Salmonella faecium, an intestinal microbe that can deconjugate bile salts, increased when a wheat-based diet was fed to broilers (Fuller, 1984). Insufficient bile salts lowers fat digestibility.

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The slower digesta passage rate probably contributes to this phenomena by preventing a major dislocation of bacterial populations. This would provide a more stable environment for microbial growth and proliferation, thus allowing a major establishment of bacteria to occur in the upper small intestine. This could intensify the host/bacteria competition for nutrients, since the foregut is where most of the digestive processes occur.

Alternatively, a lower viscosity may be leading to conditions for reduced bacterial populations by altering the digesta components.

In addition, high intestinal bacterial populations irritate and thicken the gut lining, damage the microvilli, and decrease nutrient absorption (Visek, 1978). The bacteria can contribute to the significantly heavier intestinal tract weight of broilers fed barley, which was ultimately decreased 16 - 29 percent by enzyme supplementation (Brenes et al., 1993). One of the rationales for growth promotants is that the bacterial population is decreased, followed by a thinning of the gut wall, and improved nutrient absorption; and overall intestinal tract mass is often decreased.

Multienzymes reduce intestinal viscosity

Supplementation of diets with appropriate enzymes minimizes intestinal viscosity. Enzymes work by partially degrading the soluble NSP arabinoxylans and mixed-link beta-glucans into smaller fragments (De Sliva et al., 1983, White et al., 1983). This, in turn, lessens the overlapping and the formation of mesh-like hydrogels. Water-holding capacity is decreased with fragmentation, which leads to a reduction in digesta moisture (Almirall et al., 1995) and wet feces (Gohl et al., 1978), and dirty eggs from hens fed viscosity-inducing ingredients (Graham, 1994)

The improvements (P<.05) in gain, F/G, intestinal viscosity,

Table 2. Effects of enzyme on the performance of 21-day broilers fed 60% barley diets

	Barley 1	Barley 1+ Enzyme	Barley 2	Barley 2+ Enzyme
Daily gain, g	27.3b	29.7a	24.2c	27.4b
F/G	1.49b	1.40c	1.60a	1.53a
Feed intake, g/d	40.4b	41.7b	38.4a	40.7b
Pancreas wt., % bdy. wt.	0.487ab	0.402c	0.515a	0.453abc
Digesta dry matter,%	16.9bc	19.3a	16.5c	1 8.ab
Digesta viscosity, cps	13b	2c	29a	3c
Ileal digestibility, %				
-Starch	89.7c	95.9ab	94.6b	96.5a
-Crude protein	74.1b	83.4a	69.4c	80.9a
-Crude fat	76.7b	80.8a	75.4b	78.8ab

abcP<.05
Barley 1 is low beta-glucan barley; Barley 2 is high beta-glucan barley
Almirall et. al., 1995
Enzyme from Finnfeeds International, Marlborough England

digesta dry matter and digestibility often associated with multienzyme addition to barley diets is shown in Table 2. Enzyme supplementation decreased intestinal viscosity by about 85 percent.

By degrading the NSPs, the added enzymes provide opportunity for the pancreatic enzymes to become more effective. Digestibilities of several amino acids, including the critically essential amino acids, were increased (P<.05) with enzyme supplementation. Pancreas weights also declined (P<.05), suggesting that excessive pancreatic secretion was abated.

Table 3. Effect of liquid feed enzymes added post-pelleting or post-expansion on the performance (7-28 days) and gut digesta viscosity in broilers

	28-day Body Weight, g	7-28 day F/G	Foregut Viscosity, cps
Pelleted	2.544ab	1.50a	6.9a
Pelleted + Enzyme	2.551ab	1.47ab	4.Ob
Expanded	2.476b	1.53a	20.Oe
Expanded + Enzyme	2.593a	1.39b	3.8b

abcP<.05 within columns
Enzyme is a liquid product from Finnfeeds International, Marlborough, England

Even small changes in intestinal viscosity can substantially impact bird performance.

Multienzyme supplementation seems to be effective in heat processed feeds (Teitge et al., 1988; McCracken et al., 1993), possibly due to an increase in NSP solubility brought about by heat. (Graharn et al., 1989). Multienzymes applied to expanded feed showed good results (Table 3). Expansion markedly increased foregut viscosity from 7 cps to 20 eps. The addition of enzymes decreased viscosity (P<.05) to 3.8, and improved (P<.05) body weight and F/G.

Lipase supplementation to a wheat-based diet can improve live performance of birds, but not as well as does a viscosity-reducing multienzyme mixture (Morgan and Bedord, 1995). This implies that a decrease in viscosity is first needed before improvements in performance are recognized. Almirall et al. (1993) reasoned that an increase in feed intake occurred only after enzyme supplementation decreased viscosity.

Viscosity and age of bird

The induction of high intestinal viscosity and the effectiveness of multienzyme supplementation are usually more pronounced in a young bird (Salih et al., 1991; Petersen et al., 1993; Almirall et al., 1995). Older birds often respond to enzyme supplementation. In one study, 1 -year old cockerels fed 60 percent barley diets experienced increased (P<.05) intestinal viscosity which was subsequently decreased (P<.05) with enzymes (Almirall and Esteve-Garcia, 1994; Almirall et al., 1995). The response was more evident in the two-week old broilers when both age groups were fed identical barley and enzyme levels. This could be due to the lower output of gastric and pancreatic enzymes in the juvenile, and an immature intestinal system.

For wheat-based diets fed to broilers, a number of trials find that the greatest benefit of multienzyme supplementation actually occurs during the latter half of the bird's life. A summary of 14 different trials reveals an average of 3.6 percent improvement (6 points) in F/G for

Table 4. Effect of multienzyme supplementation on the performance of broilers fed 60 percent wheat diets

Multienzyme, percent	Gain, lbs	Feed conversion	Feed intake, lbs	21 –day viscosity, cps
Performance from Day 1 to Day 21				
0	1.419	1.621	2.288	12.0
0.2	1.275	1.582	2.018	7.5
0.04	1.396	1.493	2.086	4.5
0.06	1.385	1.491	2.064	5.2
0.08	1.348	1.474	1.985	4.2
0.1	1.348	1.509	2.037	3.4
Performance from Day 22 to Day 42				
0	2.991	2.356b	7.026	
0.02	3.006	2.146a	6.427	
0.04	3.084	2.161 a	6.654	
0.06	3.070	2.186a	6.700	
0.08	2.974	2.139a	6.337	
0.1	3.066	2.097a	6.405	
Performance from Day 1 to Day 42				
0	4.403	2.117b	9.315	
0.02	4.282	1.975a	8.445	
0.04	4.480	1.951a	8.740	
0.06	4.456	1.968a	8.766	
0.08	4.319	1.929a	8.322	
0.1	4.416	1.915a	8.443	

abP<.05
Enzyme used was Avizyme 1300, Finnfeeds International, England
Bedford, 1995

days 1-21 versus 4.9 percent improvement (10 points) during days 22-42 (Bedford, pers. comm.). Here, the comparison is within a 42-day age period, whereas other studies compare broilers with cockerels of approximately 12 months of age.

Choct et al. (1995) believes that NSP from wheat may actually encourage bacterial growth and fermentation. Since viscosity tends to decline as a bird ages, a more complete degradation of NSP may be limiting bacterial growth, and eliminate many of the negative effects caused when bacterial populations become excessive.

Recent data from wheat-based diets are consistent with this possibility, and suggest that broilers may require higher enzyme levels during the latter half of life. Instead of requiring less enzyme, more was needed to significantly minimize F/G during the 22 - 42 day age period, as opposed to days 1-21 (Bedford, 1995; Table 4). Overall, more enzyme was needed to optimize F/G as opposed to weight gain.

Viscosity remained an important consideration throughout this 42 day study. Relative to F/G at days 1-21, 22-42 and 1-42, intestinal viscosity (at 21 days of age) explained 90, 82 and 94 percent of the total variability for these periods, resp.

Final comments

Clearly, intestinal viscosity is an important consideration when feeding sufficient levels of wheat, barley and other viscosity-inducing ingredients. Even small changes in intestinal viscosity can substantially impact bird performance. Multienzyme supplementation is the most economical and effective means available to reduce intestinal viscosity.

Although the response to multienzymes is less pronounced in aged cockerels, a recent study suggests that broilers may actually respond with greater improvements in F/G during the latter half of life with increased levels of multienzymes. Although more data are needed, this study finds that multienzyme fortification may be needed throughout the life cycle of the broiler, and offers some of the first evidence that supplementation rates may need to be increased, not decreased, during the latter half of the feeding period.

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