

The use of water in diets as an additive to improve performance of poultry?

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Limitation(s) in voluntary feed intake of broiler diets is directly linked to reduced broiler growth and higher feed conversion ratios (FCR). This review illustrates that in many feed scenarios, particularly with wheat-based diets, the rate of digesta passage is limited and this directly limits the intake necessary to support growth potential. This is supported by an unexpected negative or absent relationship between feed intake and energy levels of diets. In some trials feed intake was negatively associated with FCR and believed to be a consequence of a larger portion of consumed diet being used to support maintenance rather than growth – alternatively, with higher feed intake diets a greater portion of nutrients were available for growth; hence, reduced FCR with higher feed intake. Although feed intake was increased with pelleting of cereal and/or enzyme supplementation, considerable variability in feed intake (and broiler performance) was still observed. Marked improvements in feed intake and broiler performance were observed with wet-feeding of wheat-based diets. We propose that the limitations in digesta passage rate of diets are related, at least in part, to variability in diet hydration time which is a consequence of particle size, and as yet unquantified physicochemical properties of the specific grain sources.

Keywords: feed intake; broilers; wheat; wet feeding; hydration rate

Introduction

The modern broiler chicken is capable of extremely rapid growth. An illustration often used to drive this point home is that if a human baby (3 kg) grew as quickly, the infant would weigh more than 180 kg after one month. For nutritionists and poultry scientists/producers the challenge is to facilitate the broiler chicken's ability to consume (intake), digest, absorb, and metabolise the required nutrients to meet the bird's potential growth rate.

Havenstein et al. (2003) indicate that between 1957 and 2003 there has been a three-fold decrease in market age (using a 1.8 kg market weight) of broilers and this is matched by a similar decrease in feed conversion ratio. Leeson (1989) and Pym (2005) indicate that the improvements in FCR are not due to changes in efficiency of nutrients deposited as body mass, but rather a consequence of reduced maintenance costs associated with reduced days to market; this reinforces the importance of faster growth to maximise efficiency. This discussion will be based on the hypothesis that limitations in rate or growth and efficiency are linked to limits in the broiler's ability to consume > digest > absorb and/or > metabolise dietary nutrients for synthesis of body mass, and preferentially muscle; while maintaining homeostasis (i.e., not suffering metabolic disease syndromes (e.g. skeletal and cardio-pulmonary)). By my calculation a one day reduction in market age for any specified market weight will reduce feed requirements by three percent and this is equivalent to a reduction in FCR of 0.06 points. The focus of the present discussion will be on the importance of water on feed intake and how this directly impacts growth rate; and demonstrating that achieving maximum growth rate is necessary to minimise feed conversion ratios.

Limitation of feed intake

Factors that impact feed intake of broiler chickens, and as a consequence growth rate, have been extensively reviewed (Washburn, 1991; Nitsan, 1995; Scott, 2002, 2004 a,b; Ferket, 2002; Ferket and Gernat, 2003; and Forbes, 2005). Morel et al. (2001) indicated that some of the limitations in feed intake could be compensated for by increases in nutrient density of diets; however, the consensus of others (listed above) is that limitations in feed intake have little to do with the nutrient density of diets. Ferket and Gernat (2003) indicate that it may not be possible for the modern broiler to adequately compensate for even short-term limitations in feed intake as they are unable to adjust capacity sufficiently as they are effectively at maximum intake capacity.

Ferket and Gernat (2003) and Forbes (2005) reviewed our understanding of physiological regulation of feed intake by glucostatic, thermostatic, distension of the gastrointestinal tract, circulating amino acid levels and lipostatic mechanisms. However, they concede that the most important physiological factors influencing feed intake are related to gut distension and digesta motility (i.e. digesta passage rate). Bokkers and Koene (2003) compared satiety and hunger set points or triggers of laying hens and broilers. They felt selection for growth of broilers has minimised the satiety set point, so that feed intake is maximised and only limited by physical capacity to consume "a" diet. Neilsen (2004) concluded a review of feed intake behaviour by asking if intake limitation is due to a limitation of gastrointestinal size or if intake constraints are related to the composition of the feed?

In the very young broiler, Nitsan (1995) indicated growth was limited by feed intake more than by limitations to digest (enzyme production) and absorb nutrients (nutrient transporters). Leeson et al. (1996) demonstrated that broilers, during the finisher period, can increase intake as much as 50% when diets were diluted with either sand or oat hulls. In these cases they observed only minimal increases in gut dimensions; hence intake was achieved by higher rates of digesta passage. Pym (2005) selected broilers for higher feed intake, and reported that higher levels of intake were achievable, but unless selection was also applied for feed utilisation (FCR) the birds did not grow substantially faster and were fatter. Also, in this instance higher feed intake was achieved with only minimal change to digestive capacity, hence, rate of digesta passage was increased by selection for intake, or potentially as a consequence of increased intake.

Based on unpublished (personal communication, 2006) data on commercial ducks, we observed faster growth with Pekin duck strains than for commercial broilers to six weeks of age. One of the most notable factors was that the ducks consumed significantly more feed (also had significantly higher FCR) and that the water to feed ratio consumed was 3:1 in ducks as compared to 2:1 for broilers. Of further interest was the casual observation that relative gut size (relative gut length; distension was not measured) was actually lower in ducks as compared to broilers. This again, would signify the importance of digesta passage rate facilitating higher feed intake and higher growth; even though in the case of ducks FCR was 2.3 as compared to 1.6 for broilers. The higher FCR is obviously of concern to commercial duck producers and in part is recognised that this is associated with higher fat deposition (feed required for 1 g of fat is 3-4 fold higher than for 1 g of muscle, due to moisture differences in these tissues). This higher FCR may also be related to a different "strategy" to acquire higher levels of nutrients, and that ducks acquire more nutrients by increased consumption rather than by maximising digestibility.

In an interesting comparison of domestic and wild duck growth rates, Watson et al. (2004) concluded that the significant increase in growth through selection was related to a higher feed intake, and this was accommodated with a relatively smaller gastrointestinal tract; on an absolute mass basis, the small intestine of domestic ducks (at five weeks of age) was 38% less than for unselected wild ducks. Although relative intestinal size was smaller in the fast growing domestic duck, surface area (villi development) and brush border enzyme activity were higher and compensated for lower relative size. What facilitates the higher growth of commercial ducks as compared to broilers? Is it due to the higher intake of feed by ducks? Is the higher feed intake of ducks related to a higher intake of water?

Water consumption / intake is directly related to feed intake (Marks, 1981, 1985; Houpt 1987; Schoorlemmer and Evered, 2002). Carre (2000) suggests that ingredient particle size (including whole grain feeding) may result in variation in water uptake and that this may have a significant effect on intake, digestion, passage rate and litter moisture; there isn't a clear definition of how particle size

impacts water requirements or water utilisation. Hoerr (2001) indicated that under thermo neutral ambient temperatures broilers would consume approximately twice the amount of water as feed on a weight:weight ratio; however under temperature stress water intake may increase to three fold (keeping in mind this is also associated with lower feed intake under temperature stress). In order to facilitate actual digestion, the diet (containing approximately 10% moisture in feed and a further 10% released during digestion and metabolism) and consumed water are further supplemented with 2 g water for each g of dry feed from plasma in the form of mucus and as a carrier for electrolytes. In a healthy animal a significant amount of this water is reabsorbed, primarily in the lower gut. In cases where water is not reabsorbed we have problems with wet litter, for which a true cause is often difficult to diagnose. Although we accept that water is necessary to facilitate digestion, I do not feel we really understand the complexities of diet hydration and its impact on digestion, digesta passage and ultimately feed intake, growth rate and feed efficiency.

Variation in feed intake

Canadian (Scott et al., 1998; Scott 2000, 2002, 2004 a,b, 2005; Scott and Silversides 2003) and Australian (Black et al., 2005; Scott, 2006) researchers have reported significant variability in voluntary feed intake of wheat-based diets with or without enzyme by broilers (Table 1). Likewise, there were significant variability in performance of broilers fed these diets. It is apparent that enzyme supplementation increased feed intake; however, enzyme supplementation did not reduce the variability in feed intake and performance of broilers. Furthermore, these studies show that there are significant relationships between feed intake and body weight. The lack of consistent and expected significant correlations between feed intake and AME and FCR signify that broilers were unable to adjust intake of the grain-based diets to attain a required nutrient intake to support growth (Table 2).

Data presented in Tables 1 and 2 were obtained from a broiler chick bioassay developed to measure variability in nutrient availability between cereal sources and their response to enzyme supplementation. The bioassay has been described in detail elsewhere (Scott et al., 1998), but briefly it is based on an 80% inclusion of test cereal (balanced with a basal diet containing soybean isolates, corn gluten, minerals, vitamins and 1% acid insoluble ash as a digestibility marker). Each test diet is split and one portion supplemented with an appropriate NSPase (Danisco Animal Nutiriton), and all diets were fed as a mash (those indicated as pelleted, contained pelleted, re-ground wheat). Diets were fed *ad libitum* to four pens of six male broilers from 4 to 17 d of age, and feed intake, growth and FCR (corrected for mortality) was determined. At 16 d an excreta sample was collected from each pen and used to determine AME.

A number of grain sources were evaluated; those presented here were measured between 1995 and 2005. The following briefly outlines the history of the samples highlighted in Tables 1 and 2.

- UGG-2003 – 25 sources of wheat from the 2002 crop season (one of the driest growing seasons on record in western Canada). One portion of each wheat was ground, pelleted, and then reground and then these were compared with unpelleted ground sources. Each diet was fed with or without NSPase to produce 100 diets that were fed to one pen of six male broilers and this was repeated four times in consecutive three week bioassays.
- 95-wheat – 54 sources of wheat representing nine seed-grade cultivars (provided by plant breeders; Scott et al., 1998) grown in duplicate at three locations in western Canada in 1995. Extensive physiochemical measures of these samples have been reported (Classen et al., 1995; Scott et al., 1998).
- USyd2005 – represent 34 wheat samples (15 tested previously in an extensive study by Australian Premium Grains for Livestock Program), the 64 diets were compared in four consecutive bioassay series using different sources of male broilers.
- PGLP2005 – represent 22 wheat samples reported by Black et al. (1995) tested in a bioassay used in the Premium Grains for Livestock Program (PGLP) evaluation of feed grains. The bioassay in this series used male and female broilers at 28 – 35 d of age and total collection for determination of AME. All diets were cold pelleted and fed as pellets; no enzyme supplementation of the diets was tested in the PGLP analysis.

Table 1. A summary of the variability in broiler bioassay measurements of *ad libitum* fed male broilers. Studies varied in source of cereal grain (80% inclusion in bioassay diets), processing (pelletting of grain portion of diet) and appropriate NSP enzyme supplementation.

Study	Grain	Enz-yme	n	Feed Intake g/bird/ 4 to 17d				Body Weight g at 17d of age				Feed Conversion 4 to 17 d				AME MJ/kg of diet							
				Mean	Std Dev	Min	Max	Diff	%	Mean	Std Dev	Min	Max	Diff	%	Mean	Std Dev	Min	Max	Diff	%		
UGG-2003	Pellet	+	25	44.8	1.92	39.6	48.1	21.5	478	20.6	412	506	22.8	1.45	0.031	1.38	1.53	10.9	13.8	0.53	12.9	15.1	16.5
UGG-2003	Mash	+	25	40.5	1.18	38.0	42.8	12.6	436	11.0	412	456	10.7	1.46	0.045	1.38	1.57	13.8	13.4	0.91	10.3	14.9	44.3
95- Wheat	Wheat	+	54	39.3	1.72	35.4	42.6	20.3	448	14.0	406	485	19.5	1.40	0.037	1.35	1.50	11.1	13.9	0.40	12.8	14.6	14.1
USyd2005	Wheat	+	34	43.4	2.19	40.0	49.5	23.8	533	24.2	476	574	20.6	1.37	0.061	1.30	1.54	18.5	12.0	0.86	9.6	14.0	45.8
UGG-2003	Pellet	-	25	42.2	1.56	39.6	45.3	14.4	431	17.8	402	466	15.9	1.55	0.049	1.49	1.64	10.1	13.0	0.77	11.0	14.3	29.7
UGG-2003	Mash	-	25	39.1	1.99	35.8	42.6	19.0	413	20.4	382	454	18.8	1.52	0.044	1.46	1.63	11.6	12.8	0.84	10.8	14.5	33.6
95- Wheat	Wheat	-	54	38.6	1.60	35.0	41.8	19.4	433	18.2	385	465	20.8	1.44	0.046	1.36	1.56	14.7	13.4	0.46	12.1	14.3	18.8
USyd2005	Wheat	-	34	34.9	2.83	34.9	45.7	30.9	481	34.2	409	543	33.5	1.45	0.085	1.27	1.60	26.0	11.6	0.85	8.5	14.3	68.2
PGLP2005	Wheat	-	22	98.9	5.09	84.8	108.6	28.0	57.1	5.22	41.0	65.0	58.5	1.74	0.130	1.59	2.21	27.4	13.8	0.13	11.7	14.9	39.2
				Feed Intake g/bird/d 28 – 35 d				Gain (g/b/d) 28 – 35 d				FCR 28 – 35 d				AME MJ/kg of diet 31 – 35 d							
				98.9	5.09	84.8	108.6	28.0	57.1	5.22	41.0	65.0	58.5	1.74	0.130	1.59	2.21	27.4	13.8	0.13	11.7	14.9	39.2

Table 2. The correlations between feed intake and measurements of body weight, FCR and AME of diets for the respective samples of grain fed with or without enzyme.

Study	Grain	n	With Enzyme			Without Enzyme		
			Body Wt	FCR	AME	Body Wt	FCR	AME
UGG-2003	Pellet	25	0.91**	-0.16	-0.04	0.83**	-0.21	-0.09
UGG-2003	Mash	25	0.57**	0.24	-0.22	0.88**	0.01	-0.46*
95- Wheat	Wheat	54	0.79**	0.46**	-0.60**	0.79**	-0.03	-0.15
UGG-2000	Wheat	14	0.85**	0.48	-0.62*	0.77**	0.04	-0.64*
USyd2005	Wheat	34	0.75**	-0.38*	-0.14	0.74**	-0.37*	0.02
PGLP2005	Wheat	22	n/a	n/a	n/a	0.75**	-0.32*	0.34*

*, ** - signify significance of Pearson correlations (P<0.05, P<0.01, respectively)

Concern that unidentified factor(s) exist in wheat that limit voluntary feed intake and growth of broilers was highlighted by Scott et al. (1998) and Scott (2000) who demonstrated that none of the many physical and chemical measurements analyzed for the various wheat sources adequately predicted feed intake.

Possible explanations for variation in feed intake

Scott (2002, 2004a,b) and Scott and Silversides (2003) suggest that variation in feed intake is related to hydration rate of the grain in a diet and until a grain becomes hydrated the process of digestion, and subsequently digesta passage cannot occur. Scott's work showed that limitations in feed intake of wheat-based diets were reduced by pre-soaking diets. However, the same work also indicated that for some types of wheat, wet feeding facilitated excessively high intake (Table 3). These observations on improvements in feed intake and growth with wet feeding of diets are supported by others (review by Forbes, 2003; Whitehead and Scott, 2005; Afsharmanesh et al., 2006). Likewise, the disparity between utilisation of diets with wet feeds had been acknowledged, but not adequately explained. In a subsequent study, Scott and Silversides (2003) reported that moderate levels of feed restriction helped increase the efficiency of diet utilisation of Hard Red Spring as compared to Durum wheat-based diets when fed as a wet-mash. It was also acknowledged that when endogenous grain enzymes were intact (i.e. not destroyed by heat) wet feeding activated these enzymes and reduced the requirement for exogenous enzymes.

Table 3. The effect of wheat type and wet or dry feeding on broiler performance and AME determinations of diets using a broiler chick bioassay (0 to 21 d of age).

	Feed Intake g/b/d 0-21d	Body Wt g 21 d	FCR 0-21d	AME MJ/kg diet / 20d	Feed:Water Ratio 0-21d
Total (144 cages)	41.4+4.14	637+57.7	1.57+0.142	11.2+1.28	0.52+0.074
Wheat Type (Significance)	**	NS	**	**	NS
Durum (72 cages)	37.5	638	1.42	12.6	0.53
Hard Red Spring (72 cages)	45.3	636	1.72	9.9	0.53
Dry vs Wet (1.2 g water: 1 g feed)	**	**	**	**	NS
Dry (72 cages)	35.7	591	1.47	12.0	0.52
Wet (72 cages)	47.2	682	1.67	10.5	0.51
Wheat Type x Dry vs Wet	NS	**	**	**	NS
Durum x Dry	34.1d	591	1.40c	12.7a	0.54
Durum x Wet	40.9b	685	1.44c	12.5a	0.52
Hard Red Spring x Dry	37.2c	592	1.55b	11.2b	0.51
Hard Red Spring x Wet	53.4a	679	1.89a	8.5c	0.49

*, **, NS Indicate significance at P<0.05, P<0.05, and not significant, respectively

a-d Means of the interactions without a common letter differ significantly (P<0.05)

It has been difficult to get industry support to pursue wet feeding studies for broilers, although it is evident that it may offer insight as to what factor(s) limit voluntary feed intake in broiler chickens and how this may ultimately lead to alternative strategies (additives, processing, pre-selection of grains (genetic cultivars and/or end-use differentiation)) to overcome these limitations. Wet feeding has been accepted in commercial pig production. It is interesting that limitations in voluntary feed intake of wheat-based diets has also been reported in pigs by Australian researchers (Cadogan et al., 2003).

There is a breadth of research on the use of physicochemical measures of cereal grains to predict the quality of grains for food and malting. A key aspect of these measures is water hydration rate and/or capacity. In particular, it was noted that hydration rate can vary considerably between sources of wheat due to cultivar and growing conditions (Grant, 1998; Metho et al., 1999) and this can be alleviated to a large extent by degree of processing or as described by Daniels (1975) "starch and protein damage". Buffo et al. (1998) observed that absorption rate decreased with increasing starch content of sorghum, in some cases water saturation of a flour sample could take 8 hrs, with the 50% saturation point taking up to 2 hrs. It is acknowledged that these water uptake times for sorghum would be expected to change with digesta mixing. In determining the importance of variability in hydration rate of feed in the gut and its subsequent digestion it will be important to develop a strong

relationship with the food and malt scientists. Swift and Scott (2005) reported good NIR calibrations could be developed for predicting variation in performance of broilers fed wheat-based diets. The spectra that predicted voluntary feed intake were acknowledged to be very similar as those that predict grain moisture. Is this in effect a prediction for water binding capacity / rate that would influence the bird's rate of digestion and hence, its feed intake?

Digestion and digesta flow

Lentle (2004, 2005) recently presented information that counters our acceptance that digesta in poultry may be predominately governed by reflux (for current review, Sacranie et al., 2005), especially in broilers that are consuming feed at high levels. Lentle views the digesta as a semi solid plug and the consistency of the digesta plug is dependent on the rheology (the branch of physics that studies deformation and flow of matter) of the digesta. The rheology of digesta, as described by Lentle, would be impacted by viscosity, particle size and interactions between chemical components (e.g. level of starch in sorghum as discussed above) of a diet. Variation in these components would in turn control digestive fluid movement into and through the digesta plug, thereby influencing the rate of digestion, absorption and potentially passage (possibly, in some cases not fully digested, as described for some types of wet-fed wheat-based diets?).

These insights by Lentle may also provide an explanation for improvements in feed value of wheat-based diets by using oat hulls (Rogel et al., 1987; Hetland et al., 2003). Hetland et al. (2003) explained these positive effects of oat hulls as increasing digesta reflux, whereas Lentle's theory would indicate the added particle size would increase rheology and facilitate better flow of digestive fluids across the digesta plug and thereby increase starch digestion and absorption.

I find that I am still grappling with what we actually need to measure (e.g. particle size, viscosity and/or hydration capacity) of cereal grains in order to explain and optimise their rate of gut transit, intake and retention of nutrients to support the high nutrient requirement of rapidly growing broilers. We expect that particle size and physicochemistry of a diet is dramatically influenced by processing (e.g. pelleting, expanding, extrusion, etc) and we need to know how this may be beneficial for some sources of grain and potentially harmful for others (relative to feeding value). Likewise, it is necessary to know why rankings with respect to intake of different sources of grain change with enzyme supplementation, yet the overall variability remains. With feed intake restricting growth of broilers it is apparent that nutrition will become an increasingly more important factor in the broiler's ability to attain its genetic potential for growth.

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