Feed Grain Partnership

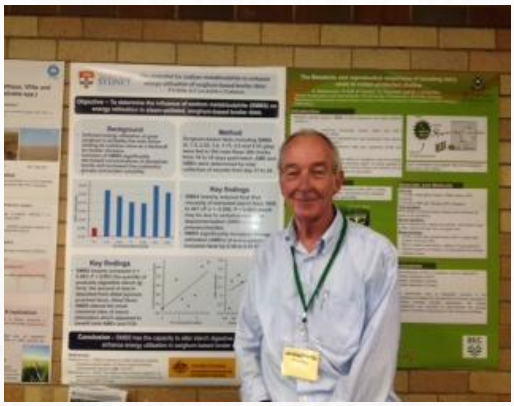
TECHNOTE

[Sorghum TechNote PRF 2-14]

Phytate in sorghum

Why are responses to phytase as modest as they appear?

Peter Selle, Ha Truong and Sonia Liu,
Poultry Research Foundation, The University of Sydney
425 Werombi Road Camden NSW 2570



In common with all plant-sourced feed ingredients grain sorghum contains phytate (*myo*-inositol hexaphosphate; IP_6). Sorghum contained somewhat more phytate than other grains (Figure1, Table 1) in an Australian survey of feedstuffs (Selle *et al.*, 2003). In a North American survey of 24 sorghum varieties (Doherty *et al.*, 1982) there was a strong linear relationship (r^2 = 0.737) between total P and phytate-P concentrations (Figure 2). Furthermore phytate concentrations in red and white sorghums were remarkably similar (Table 2).

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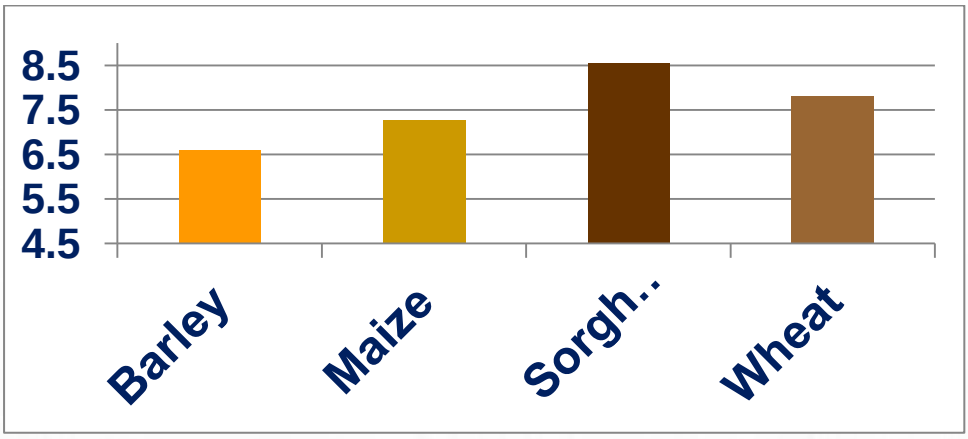

Figure 1 Concentrations of phytate (*myo*-inositol hexaphosphate; IP_6), expressed as g/kg, in four grains (Selle *et al.*, 2003)

Table 1 Concentrations of total phosphorus (P), phytate-P, phytate and proportion of phytate-P of total P in four grains (Selle *et al.*, 2003)

Grain	Number (n)	Total P (g/kg)	Phytate-P (g/kg)	Phytate (g/kg)	Proportion (%)
Barley	6	2.73	1.86	6.60	67.3
Maize	2	2.40	2.05	7.27	85.4
Sorghum	15	2.92	2.41	8.55	82.7
Wheat	37	3.08	2.20	7.80	74.9

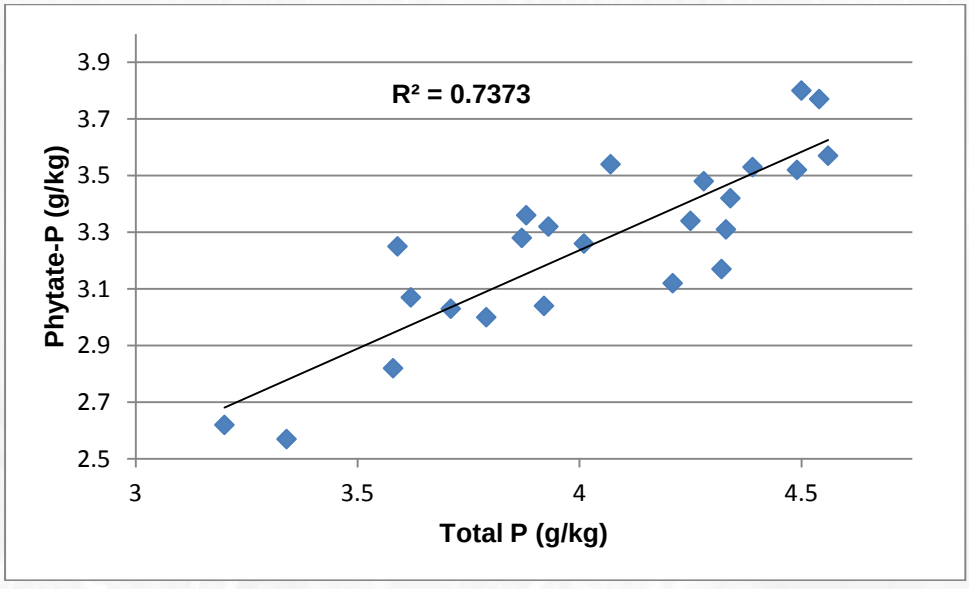

Figure 2 Linear relationship between concentrations of total P and phytate-P in 24 sorghum varieties (Doherty *et al.*, 1982)

Table 2 Concentrations of total phosphorus (P), phytate-P, phytate and proportion of phytate-P of total P in red and white sorghum varieties (Doherty *et al.*, 1982)

Grain	Number (n)	Total P (g/kg)	Phytate-P (g/kg)	Phytate (g/kg)	Proportion (%)
Red	3	4.04	3.28	11.64	81.3
White	18	3.97	3.21	11.39	81.1

Phytate is invariably present in pig and poultry diets at concentrations in the order of 10 g/kg. The P component of IP_6 phytate (282 g/kg) is largely unavailable in practical diets as perhaps only 15% is utilised, although this is heavily dependent on dietary Ca levels. Therefore, P supplements such as dicalcium phosphate must be included in pig and poultry diets but this presents environmental dilemmas. On the one hand the globe's finite reserves of rock phosphate are being eroded and we are approaching a P supply crisis (Cordell *et al.*, 2009) similar to that of oil. On the other, non-utilised P that is lost to the environment in pig and poultry excreta pollutes fresh-water reserves leading to eutrophication and algal blooms (Correll, 1998).

A phytate-degrading feed enzyme, or phytase, was introduced in The Netherlands in 1991, fundamentally, because it had the capacity to reduce P lost in excreta by approximately 30% (Simons *et al.*, 1990). After a much extended lag phase the inclusion of phytase enzymes in pig and poultry diets is now a routine practice as these feed enzymes release extra P and are an effective and economic source of P.

However, the negative effect of dietary phytate is not limited to poor P availability as phytate possesses a range of anti-nutritive impacts, which are being increasingly recognised in both pigs (Selle and Ravindran, 2008) and poultry (Selle and Ravindran, 2008). The attenuation of these anti-nutritive impacts by phytase results in positive performance outcomes, which has been described as the "extra-phosphoric effects" of phytase feed enzymes (Ravindran, 2005).

Phytate has the capacity to form both binary and ternary protein-phytate complexes dependent on isoelectric points (iP) of protein and pH in the gut (Cosgrove, 1966; Selle *et al.*, 2000). As a consequence, phytase has been shown to increase ileal digestibility of amino acids (eg. Ravindran *et al.*, 2001) although the results of phytase amino acid digestibility assays in pigs, especially, and poultry are not consistent. Phytate also has the capacity to interact with starch both directly and indirectly via starch granule-associated proteins and phytase has been shown to improve energy utilisation (AME, AMEn) and ileal starch digestibility, although the outcomes are somewhat equivocal (Selle *et al.*, 2012).

It appears that phytate has the capacity to impede the digestion of both protein and starch. However, and this may be more important, phytate probably also has the capacity to impede the absorption, or the intestinal uptakes of amino acids and glucose. As shown by Selle *et al.* (2009), phytate drags Na into the gut lumen to a remarkable extent and this egress of Na is addressed by phytase. It follows that by dragging Na into the gut lumen, phytate compromises the intestinal uptake of nutrients, including amino acids and glucose, by Na-dependent transport mechanisms and the activity of the sodium pump (Selle *et al.*, 2012).

In a recent experiment (Liu *et al.*, 2014) the effects of phytase supplementation of maize-, sorghum and wheat-based broiler diets were compared. The performance of broilers offered sorghum-based diets were fully comparable to maize and superior to wheat. However, phytase generated more pronounced responses in maize-based diets than sorghum and this was particularly the case for nutrient utilisation parameters (AME, N retention, AMEn). Moreover, these unequivocal nutrient utilisation responses in maize-based diets were apparently associated with enhanced intestinal uptakes of amino acids and glucose.

In the Liu *et al*. (2014) study phytase did not enhance AME, N retention and AMEn in broilers offered sorghum-based diets. This outcome was consistent with our prior impression that the magnitude of extra-phosphoric responses to phytase supplementation of sorghum-based diets is somewhat muted (Selle *et al*., 2010). This view is supported by a consideration of two feeding studies completed earlier by the Poultry Research Foundation.

The results of the first study by Selle *et al*. (1999) are shown in Table 3. Phytase responses of birds offered cold-pelleted, sorghum-based diets (695 g/kg) formulated to standard specifications were essentially limited to a 0.38 MJ increase in AME with a numerical decline in feed efficiency from 1.52 to 1.54. In contrast, with birds offered sorghum-based diets (671 g/kg) in which nutrient specifications were reduced, phytase improved FCR by 7.73%, N retention by 9.57%, AME by 0.58 MJ and toe ash was increased from 12.53 to 12.92%. In retrospect, the genesis of the more robust phytase responses observed in modified diets may have been at least partially due ‘phosphoric’ rather than ‘extra-phosphoric’ effects.

Table 3 The effect of 600 FTU/kg phytase on growth performance, nutrient utilisation and toe ash of broilers offered sorghum-based diets from 7 to 25 days post-hatch (Selle *et al.*, 1999)

	Standard diet			Modified diet		
	Control	Phytase	Response	Control	Phytase	Response
Gain (g/bird)	880	918	4.32%	824	887	7.65%
Intake (g/bird)	1335	1409	5.54%	1392	1427	2.51%
FCR (g/g)	1.52	1.54	[1.32%]	1.69	1.61	4.73%
N retention (%)	58.3	57.7	[1.03%]	51.2	56.1	9.57%
AME (MJ/kg DM)	14.67	15.05	0.38 MJ	14.36	14.94	0.58 MJ
Toe ash (%)	12.76	12.76	0.00%	12.53	12.92	3.11%

The results of the second study by Cadogan *et al.* (2005) are shown in Table 4 where broilers were offered nutritionally-adequate, steam-pelleted sorghum-based diets from 1-21 days (541 g/kg) and 22-42 days (602 g/kg) post-hatch. Phytase did not tangibly improve FCR from 1 to 21 and 1 to 42 days post-hatch. The 0.27 MJ uplift in AME was significant ($P < 0.01$) but not substantial and, while increases in ileal digestibility coefficients of starch, essential and total amino acids approached significance, their magnitudes were subtle.

Table 4 The effect of 750 FTU/kg *E. Coli* phytase on growth performance and nutrient utilisation broilers offered sorghum-based diets from 1 to 42 days post-hatch (Cadogan *et al.*, 2005)

Parameter	Control	Phytase	Response
Growth performance			
1-21 days post-hatch			
Weight gain (g/bird)	748	791	5.75% (P = 0.002)
Feed intake (g/bird)	1003	1062	5.88% (P = 0.003)
Gain-corrected FCR (g/g)	1.34	1.33	0.75% (P = 0.165)
1-42 days post-hatch			
Weight gain (g/bird)	2616	2698	3.13% (P = 0.033)
Feed intake (g/bird)	4388	4557	3.85% (P = 0.254)
Gain-corrected FCR (g/g)	1.68	1.66	1.19% (P = 0.239)
AME (MJ/kg DM)	14.19	14.46	0.27 MJ (P = 0.009)
Ileal digestible energy (MJ/kg)	11.59	11.78	0.19 MJ (P = 0.332)
Ileal digestibility coefficients			
Starch	0.919	0.932	1.41% (P = 0.066)
Essential amino acids (n = 10)	0.779	0.789	1.28% (P = 0.044)
Total amino acids (n = 15)	0.759	0.768	1.19% (P = 0.054)

Thus, responses to phytase supplementation of sorghum-based diets do appear to be muted and the reasons for this are no clear. Phytate is mainly located in the aleurone layer of sorghum (Doherty *et al.*, 1982) and perhaps its fibrous nature impedes the access of phytate to its substrate. Another possibility is that kafirin, the dominant protein fraction in sorghum, contains a paucity of basic amino acids (Selle *et al.*, 2010). From first principles (Cosgrove, 1966), this suggests that the propensity for phytate to form binary protein-phytate complexes with kafirin would be limited. In addition, however, kafirin is located in discrete protein bodies in sorghum endosperm and the physical structure of the protein body may also limit complex formation. Also, as reported by Csonka *et al.* (1926), the iP of kafirin (5.90) is less than that of zein in maize (6.20) and gliadin in wheat (6.45). This means that the differential between the iP of kafirin and gut pH in the proventriculus and gizzard should be narrower than with maize and wheat and this may influence the intensity of protein-phytate complex formation and discount their anti-nutritive effects. Arguably, protein-phytate complex formation, and their direct and indirect effects, is the prime underlying cause of the extra-phosphoric effects of phytase. Therefore, it follows that if the extent of protein-phytate complex formation in pigs and poultry offered sorghum-based diets is modest then this would apply equally to the reciprocal, extra-phosphoric responses to phytase.

Sorghum is, of course, a 'non-viscous' grain and would not be expected to respond to NSP-degrading feed enzymes but it is curious that sorghum-based diets do not usually respond robustly phytase feed enzymes as sorghum usually contains relatively high phytate concentrations. However, it does appear that responses to all categories of feed enzymes in broilers offered sorghum-based diets are muted. Therefore, it is tempting to speculate that there are anti-nutritional factors in sorghum that are not being addressed by the presently used feed enzymes, which are limiting responses. This is one aspect that is under investigation by the Poultry Research Foundation.

Acknowledgement
The Poultry Research Foundation gratefully acknowledges the encouragement and ongoing financial support of RIRDC Chicken-meat for a series of sorghum orientated projects.

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