A REVIEW OF THE ANTINUTRITIONAL EFFECTS OF PHYTIC ACID ON PROTEIN UTILISATION BY BROILERS

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Summary

The antinutritional properties of phytic acid on protein utilisation in broilers and the capacity of microbial phytase to counter these effects are reviewed. The practical significance of these antinutritional effects has been shown in a series of studies in poultry. The relevance of protein-phytate complexes should be taken into account when dietary addition of phytase is considered.

I. INTRODUCTION

Phytic acid is a ubiquitous compound in vegetable feedstuffs where it serves as a phosphorus (P) depot. As monogastrics essentially lack endogenous phytase activity consequently phytate P is poorly digested and is excreted, increasing the P load on the environment. Microbial phytase (Natuphos\textsuperscript{®}) was introduced in the Netherlands in 1992 as a feed enzyme to facilitate the reduction of P levels in effluents from intensive animal operations. However, recent data indicate that phytic acid also has a negative effect on protein utilisation and that this effect can be reduced by the dietary addition of phytase. Available data on these aspects are reviewed in this paper.

II. PHYTIC ACID - PROTEIN COMPLEX

The binding of protein by phytic acid to form protein-phytate complexes which reduces the solubility and digestibility of the complexed proteins has been recognised for some time. Champagne (1988) stated that at pH values lower than 5 (less than the isoelectric point of the protein), the anionic phosphate moieties of phytic acid bind strongly by electrostatic interactions to the cationic groups of protein to form insoluble complexes. The protein binding sites are believed to be provided by residues of lysine, histidine and arginine. At intermediate pH levels above 5, protein-phytate complexes probably are ternary structures where protein, mainly via histidine, is bound by mineral-phytate complexes involving calcium, magnesium and zinc. At pH values greater than 10 this ternary structure is disrupted; the protein is released and the mineral-phytate complex precipitates out.

It is probable that protein-phytate complexes exist inherently in vegetable feedstuffs to varying extents. Champagne (1988) cites evidence that phytic acid binds with proteins of soyabean, wheat, rapeseed and peanut but not with proteins of rice bran, maize germ and cottonseed meal. Cosgrove (1966) reported the extraction of a crystalline protein-phytic acid compound from beans with a P content of 4.8 g/kg which is substantially less than the P component of phytic acid (282 g/kg). This suggests that protein may be bound by phytic acid in a ratio of 50:1.

Recent in vitro data generated by Jongbloed et al. (1997) suggests that the de novo formation of protein-phytate complexes in the gut at pH values of 2-3 may be an important factor. At this pH soluble proteins are substantially precipitated out presumably by phytic

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acid forming complexes. Prior incubation of the feedstuff with phytase largely prevents this reaction. Incubation of the precipitated proteins with pepsin increased their solubility but this reaction was accelerated considerably by the addition of phytase. The implication is that phytase, in addition to releasing bound proteins, may reduce the formation of protein-phytate complexes within the gut by prior hydrolysis of phytic acid.

Considerable in vitro evidence exists which shows that phytic acid inhibits the activity of proteolytic enzymes. Caldwell (1992) reported the negative effects of phytic acid and calcium on the activation of trypsinogen and the stability of trypsin. The formation of protein-phytate complexes by phytic acid binding with endogenous enzymes may decrease the functionality of the enzymes and should be reduced or restored by phytase cleaving phytic acid.

Mroz et al. (1995) manipulated substrate levels in pig diets by substituting soybean meal (3.9 g phytate P/kg) with rapeseed meal (7.0 g phytate P/kg). The resultant increase in dietary phytase P from 2.2 to 2.7 g/kg was associated with a trend towards reductions in both trypsin activity and nitrogen (N) digestibility. However, the main effect of the addition of a crude microbial preparation (800 PTU/kg) was to significantly (P<0.05) increase both N digestibility (from 76.5 to 79.3%) and trypsin activity (from 4.51 to 5.00 units). Although yet to be confirmed, this work suggests that the body of in vitro data may have in vivo relevance.

The possibility that phytic acid may bind with supplemental amino acids to form “synthetic amino acid-phytate complexes” in practical diets was recently investigated in vitro. Rutherford et al. (1997) incubated lysine monohydrochloride with rice pollard as the source of phytic acid with and without added phytase. Incubation without phytase reduced the recovery of free lysine from 112 to 89 mg/100mL whereas with phytase addition the recovery was increased to 101 mg/100mL. Thus, the indication is that lysine was bound by compounds within rice pollard but partially released by phytase, which is consistent with the original hypothesis. Similar data with three amino acids (lysine, methionine and threonine) supplementing conventional diets has subsequently been generated by these workers (unpublished data).

III. EFFECTS OF PHYTASE ON PROTEIN UTILISATION

The hydrolysis of phytic acid by phytase releases phytate-bound proteins and may explain the “protein effect” of phytase. The first report of microbial phytase having a protein effect in poultry (van der Klis and Versteegh, 1991) was in laying hens. Levels of 250 and 300 FTU phytase/kg significantly (P<0.05) increased the ileal absorption of nitrogen from 79.3 to 80.9%. It is well documented that phytase is very effective in improving overall P availability in layers. In this study, about 65% of dietary phytate-P was released by added phytase.

In broilers offered diets based on sorghum and soybean meal, Farrell et al. (1992) showed that the dietary addition of microbial phytase (750 FTU/kg) resulted in a significant (P<0.05) overall increase in N utilisation from 55.9 to 57.6% and an associated trend (P<0.10) towards increased N retention from 56.0 to 57.0%. The protein contents of the diets were 188, 230 and 273 g/kg. The phytase response in N utilisation varied widely but corresponded to an average increase of 3.8 g/kg protein. It was suggested that the phytase response in N utilisation may have led to the increased feed intake by the broilers.

Kornegay (1996) investigated the effect of phytase on the ileal digestibility of amino acids in a factorial design with three levels of protein (170, 200 and 230 g/kg) and four levels of microbial phytase (0, 250, 500 and 750 FTU/kg). The broilers received diets based on
maize and soyabean meal containing 4.5 g/kg nonphytate P (nP) with a Ca : nP ratio of 2:1. Increasing protein levels linearly depressed the digestibility of all amino acids. The ileal digestibility of all essential amino acids, with the exception of methionine, were linearly increased (P<0.05 to 0.001) by the addition of phytase. The average digestibility of methionine in the three control diets (without added phytase) was 94.6% and it was the most digestible essential amino acid.

In a broiler study, Ravindran and Bryden (1997) assessed the effects of phytase on the apparent ileal digestibility of nitrogen, nine essential amino acids and nitrogen retention. Three dietary substrate levels (2.9, 3.7 and 4.4 g/kg phytate P) were offered by increasing the inclusion rate of rice pollard, which contained 17 g/kg of phytate P, to 54 and 108 g/kg at the expense of wheat and sorghum. Increasing levels of phytate P or phytic acid significantly reduced N retention and the ileal digestibilities of N and all amino acids (P<0.03 to <0.001) with the exception of arginine (P<0.07). This demonstrates the importance of dietary substrate levels and the negative effect phytic acid has on protein digestibility.

The addition of phytase (400 and 800 FTU/kg) significantly increased the digestibility of N and the amino acids (P<0.001) and apparent N retention. However, this effect was more pronounced at the lower nP level of 2.3 g/kg than at the adequate level of 4.5 g/kg, resulting in significant interactions between phytase and the dietary nP level. The increase in nP was achieved by the dietary addition of approximately 12 g/kg dicalcium phosphate. Thus, it appears that inorganic Ca and/or P may have a negative, direct or indirect, impact on phytase activity. It is noteworthy that phytase permits the reduction of Ca and P levels in poultry diets.

The analysed crude protein level of the diets was 217 g/kg. Phytase increased the apparent ileal digestibility of N from 80.55 to 82.73% which corresponds to an increase of 4.73 g/kg of crude protein; in the lower nP diets the increase was from 80.50 to 83.05% which corresponds to 5.53 g/kg of N. Interestingly, the phytase responses, when expressed as apparent nitrogen retention (as % of intake), were numerically greater. Overall phytase increased protein retention from 53.1 to 56.2% which corresponds to 6.77 g/kg of N and in the lower nP diets the increase was from 54.9 to 58.3% or 7.36 g/kg of crude protein. There is a clear need to quantify the protein effect of phytase and the above differences suggest that protein deposition/retention data may be a more appropriate basis than ileal digestibility data to achieve this objective.

Biehl and Baker (1997) adopted an alternative approach by feeding broilers maize-based diets deficient in amino acids with either soyabean meal or peanut meal as the primary protein source. With the maize/soya diets, phytase (1200 FTU/kg) improved feed conversion (P<0.05) of the amino acid-deficient diet but not of the adequate diet. It was concluded that phytase had a small, but significant, positive effect on the utilisation of methionine, threonine, lysine and/or valine from soya protein. Importantly, the results were similar irrespective of which amino acids were considered to be limiting. However, phytase failed to generate growth or conversion responses in the amino acid-deficient diets when peanut meal was the protein source. It may be relevant to note that phytic acid is more widely distributed throughout the seeds of soyabean than peanuts. In this study the addition of phytase (1200 FTU/kg) to dehulled soyabean meal numerically increased true amino acid digestibility values for caecotomised roosters of ten amino acids by nearly 2 percentage units (mean: 90.4 to 92.2%) but the differences were not statistically significant.

Schutte et al. (1997) have generated positive amino acid data based on total tract digestibility values in broilers following the addition of phytase. Excreta amino acid digestibility data is routinely used in broiler formulations by the feedmilling industry in the Netherlands.
IV. CONCLUSIONS

Recent evidence indicates that phytic acid has a negative effect on the digestibility of proteins and amino acids in poultry. While the basis of this effect is not completely defined, the capacity of phytic acid to complex with proteins appears to be the core factor. Microbial phytase improves protein digestibility, probably by releasing bound proteins and/or reducing the extent to which they are complexed by phytic acid within the gut environment.

Two recent studies have demonstrated improvements in the ileal digestibility of amino acids in response to phytase supplementation. These responses were more evident in the Australian than in the American study which could be due to the fact that the American diets were inherently more highly digestible and would have contained lower levels of phytic acid than the Australian diets; these two factors may be related. In the Australian study, it is noteworthy that with the inadequate nP diets, which contained less inorganic Ca and P (essentially as dicalcium phosphate), phytase generated better responses than in the adequate nP diets. The adequate nP diets contained similar amounts of dicalcium phosphate and limestone to the American diets. The possible impact of inorganic Ca and P on the effectiveness of phytase requires further investigation but the enzyme does permit their reductions in the diet and narrow Ca:P ratios should be adopted with the addition of phytase.

The “protein effect” of Natuphos phytase needs to be quantified to facilitate its application in practical diets. This effect is likely to be more pronounced in diets of moderate, rather than superior, protein quality and in diets with relatively high levels of phytic acid or phytate-P (>3.0g phytate-P/kg). Clearly these variables must be taken into account in any estimation of protein replacement values for phytase in poultry diets.

REFERENCES


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