ENZYMES IN POULTRY NUTRITION

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ABSTRACT

The biggest single expense in any system of poultry production is feed accounting for up to 70% of total production cost per bird. Poultry naturally produces enzymes to aid the digestion of feed nutrients. However, they do not have enzyme to break down fibre completely and need exogenous enzymes in feed to aid digestion. This review covers the information on enzymes and their uses in poultry nutrition. Enzymes are biological catalyst composed of amino acids with vitamins and minerals. They bring about biochemical reactions without themselves undergoing any change. The benefits of using enzymes in poultry diets include not only enhanced bird performance and feed conversion but also less environmental problems due to reduced output of excreta. In addition, this review demonstrates that enzymes are a very useful tool in the study of physiological and metabolic mechanisms. Such studies will enhance our understanding regarding the role of dietary enzymes in poultry nutrition. The information presented here serves to demonstrate the significant potential of enzymes in poultry feeds.

Key words: Poultry nutrition; enzyme supplementation.

INTRODUCTION

Feeding enzymes to poultry is one of the major nutritional advances in the last fifty years. It is the culmination of something that nutritionists realized for a long time but until 1980's it remained beyond their reach. Indeed, the theory of feed enzymes is simple. Plants contain some compounds that either the animal cannot digest or which hinder its digestive system, often because the animal cannot produce the necessary enzyme to degrade them. Nutritionists can help the animal by identifying these indigestible compounds and feeding a suitable enzyme. These enzymes come from microorganisms that are carefully selected for the task and grown under controlled conditions (Wallis, 1996).

The poultry industry readily accepts enzymes as a standard dietary component, especially in wheat and barley-based rations. But still many questions are partially answered. For example, how do enzymes work? Do growth rates reflect differences in the potency of different enzyme preparations? What is the link between gut viscosity, enzyme action and growth rates? and are enzymes necessary in all poultry rations?. This review article aims to supply some background information about enzyme and its usage in poultry nutrition and also help to answer some of commonly asked questions regarding enzymes.

Enzymes: Enzymes are one of the many types of protein in biological systems. Their essential characteristic is to catalyze the rate of a reaction but is not themselves altered by it. They are involved in all anabolic and catabolic pathways of digestion and metabolism. Enzymes tend to be very specific catalysts that act on one or, at most, a limited group of compounds known as substrates. Enzymes are not living organisms and are not concerned about viability or cross infection. They are stable at 80-85 degree centigrade for short time.

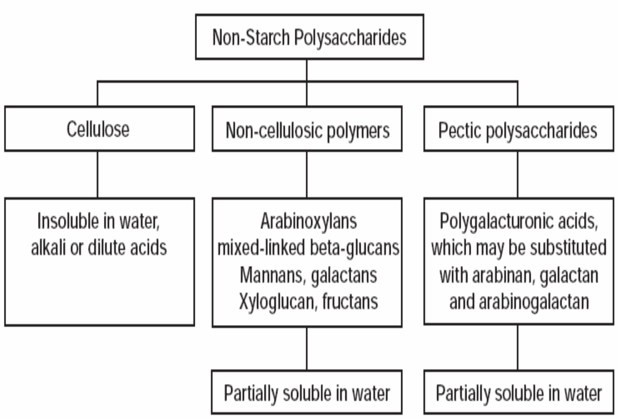
Another important feature of enzymes is that the rate of an enzyme catalyzed reaction increases with increasing substrate concentration, to the point where there is no further response and the enzyme is said to be saturated. Therefore, we need to match the amount of enzyme with the quantity of substrate (Acamovic and McCleary, 1996).

It is common practice to name enzymes by adding the suffix ase to the name of the principal substrate. For example, β-glucanase is an enzyme that splits β-glucans, and proteases break protein. We may also broadly categorize the digestive enzymes as endogenous or exogenous - referring to those produced by the animal and those administered from outside, respectively. For example, pancreatic lipase, which splits fat or lipid into glycerol and fatty acids, is an endogenous enzyme. Those enzymes added to feed as a supplement are exogenous (Classen, 1996; Classen and Bedford, 1991).

Sources of Enzymes: Enzymes were used in the preparation of foods long before there was any awareness of enzymes as such, possibly as long ago as 10,000 years. The industrial exploitation of microbial enzymes in the Western world started 100 years ago with the patenting of a process for the production of alpha-amylase (Taka mine) from the fungus *Aspergillus oryzae.* Enzymes are produced in every living organism from the highest developed animals and plants to the simplest unicellular forms of life, as they are essential for metabolic process. Most of the enzymes currently used in the food and beverage industry are from *Aspergillus*, but hemicellulases and cellulases are derived from *Trichoderma*. Recently, genes encoding for different enzymes, including phytases, ß-glucanases, and xylanases, have been cloned and expressed in different commercial systems (microorganisms and plants). It is possible to produce large amounts of cheap enzyme by continually selecting favorable microbes, growing them in advanced fermentation systems and by streamlining the extraction and purification of the enzyme (Wallis, 1996).

Microorganisms that generally involved in production of enzymes are; Bacteria (*Bacillus subtilis, Bacillus lentus, Bacillus amyloliquifaciens* and *Bacillus stearothermophils*), Fungus (*Triochoderma longibrachiatum, Asperigillus oryzae* and *Asperigillus niger*) and Yeast (*S. cerevisiae*)

Enzymes in Poultry Nutrition: The use of enzymes in animal feed is of great importance. Consistent increase in the price of feed ingredients has been a major constraint in most of the developing countries. As a consequence cheaper and nonnconventional feed ingredients have to be used which contain higher percentage of Non-Starch Polysaccharides (soluble and insoluble/crude fibre) along with starch. Non Starch Polysaccharides (NSPs) are polymeric carbohydrates which differ in composition and structure from starch (Morgan *et al.,* 1995) and possess chemical cross linking among them therefore, are not well digested by poultry (Adams and Pough, 1993; Annison, 1993). A part of these NSPs is water-soluble which is notorious for forming a gel like viscous consistency in the intestinal tract (Ward, 1995) thus by reducing gut performance. Predominantly water soluble



and viscous arabinoxylans, which belong to pentosan group, are assumed to be the factor responsible. These pentosans also greatly increase the water intake by the birds, which lead to unmanageable litter problems caused by wet and sticky droppings. This deteriorates the hygienic conditions and carcass quality (Dunn, 1996). On the other hand, ß-glucans adversely affect all nutrients, especially protein and starch utilization and are known to give rise highly viscous conditions in the small intestine of the chicks (Hasselman and Aman, 1986).

Poultry do not produce enzymes for the hydrolysis of Non-Starch Polysaccharide present in the cell wall of the grains and they remain un-hydrolyzed. This results in low feed efficiency. Research work has suggested that the negative effects of NSPs can be overcome by dietary modifications including supplementation of diets with suitable exogenous enzyme preparations (Creswell, 1994). Enzymes break down the NSPs, decreases intestinal viscosity and eventually improve the digestibility of nutrients by improving gut performance.

Types of Enzyme Available for Poultry : Some of the enzymes that have been used over the past several years or have potential for use in the feed industry include cellulase (ß-glucanases), xylanases and associated enzymes, phytases, proteases, lipases, and galactosidases (Table 1). Enzymes in the feed industry have mostly been used for poultry to neutralize the effects of the viscous, nonstarch polysaccharides in cereals such as barley, wheat, rye, and triticale. These antinutritive carbohydrates are undesirable, as they reduce digestion and absorption of all nutrients in the diet, especially fat and protein. Recently, considerable interest has been shown in the use of phytase as a feed additive, as it not only increases the availability of phosphate in plants but also reduces environmental pollution. Several other enzyme products are currently being evaluated in the feed industry, including protease to enhance protein digestion, lipases to enhance lipid digestion, ß-galactosidases to neutralize certain antinutritive factors in noncereal feedstuffs, and amylase to assist in the digestion of starch in early-weaned animals.

Table 1. Enzymes Used in Poultry Feeds

Enzymes	Substrate
ß-glucanases	Barley Oats
Xylanases	Wheat, Rye, Triticale Rice bran
ß-galactosidases	Grain legumes Lupins
Phytases	Plant feedstuffs
Proteases	Proteins
Lipases	Lipids
Amylases	Starch

Benefits of Enzymes: Benefits of using feed enzymes to poultry diets include; reduction in digesta viscosity, enhanced digestion and absorption of nutrients especially fat and protein, improved Apparent Metabolizable Energy (AME) value of the diet, increased feed intake, weight gain, and feed–gain ratio, reduced beak impaction and vent plugging, decreased size of gastrointestinal tract, altered population of microorganisms in gastrointestinal tract, reduced water intake, reduced water content of excreta, reduced production of ammonia from excreta, reduced output of excreta, including reduced N and P (Campbell *et al*. 1989; Jansson *et al*. 1990; Annison and Choct, 1991; Bedford *et al*. 1991; Benabdeljelil 1992; Jeroch and Dänicke 1993; Marquardt *et al*. 1994; Leeson and Proulx, 1994; Bedford, 1995; Choct *et al*. 1995; Classen *et al*. 1995; Dunn 1996 Marquardt *et al*. 1996; Esteve-Garcia *et al*, 1997; Ouhida *et al*, 2000; Gill, 2001; Odetallah, 2002; Gracia, *et al.,* 2003; Saleh, *et al.,* 2003; Odetallah, *et. al.,* 2005 and Wang *et al*., 2005).

Reduction in Digesta Viscosity: Enzymes added to poultry diets; especially diets containing cereals rich in NSP such as wheat, barley, and rye, reduced viscosity in the diet and digesta. Morgan *et al.,* (1995) and Muramatsu *et al*., (1992) found that that enzyme supplementation of wheat based diets significantly reduced foregut digesta viscosity of birds. The reduction in foregut digesta viscosity was achieved primarily by reducing the molecular weight through hydrolysis of xylan backbone by endo-xylanase into smaller compounds and thus reduction in viscous effects of the feed because foregut digesta viscosity is directly proportional to the molecular weight of wheat arabinoxylans (Bedford and Classen, 1993). As a result of endo-xylanase and ß-glucanase supplementation, the long backbones of the arabinoxylans and ß-glucans are cleaved into shorter fragments, thereby reducing their viscosity (Gruppen *et al*. 1993).

Similar findings on digesta viscosity were also reported by Bedford and Classen (1993); Bhatt *et al.,* (1991) and Dunn, (1996) who inferred that the high viscosity in the gut contents caused by the pentosans led to increased water intake of the birds, which resulted in the wet and sticky droppings.

Increase in Available Energy: One of the main reasons for supplementing wheat- and barley-based poultry diets with enzymes is to increase the available energy content of the diet. Increased availability of carbohydrates for energy utilization is associated with increased energy digestibility (Partridge and Wyatt 1995; Van der Klis *et al*. 1995). The AME of wheat has been extensively studied and found to have a considerable range i.e 9 500–16 640 kJ/kg (Mollah *et al*. 1983; Rogel *et al*. 1987; Annison 1993; Choct *et al*. 1995; Ward 1995). Enzyme supplementation improves this range by enhancing carbohydrate digestibility, reducing gut viscosity, and improving fat utilization (Almirall *et al*. 1995). The improvements in AME resulting from enzyme supplementation are variable because of the variability in the NSP content of wheat. Classen *et al*. (1995), Schutte *et al*. (1995), and Van der Klis *et al*. (1995) reported improvements of 5–16, 3.1–4.5, and 4.5–12.4%, respectively. The increase in AME with the use of enzymes is difficult to predict, as nutrient ratios, such as energy–protein, and other factors also play an important part in poultry-feed formulations. The AME value of wheat has been correlated with its content of water-soluble NSPs (Annison 1991), which in turn affects gut viscosity (Bedford *et al*. 1991). Unfortunately, NSP analyses are relatively lengthy processes, and in a commercial situation rapid testing of incoming grains is required. No chemical test or detectable physical characteristic can be used to rapidly predict the AME value of wheat or to estimate the improvements to be expected from the use of enzymes. This is part of the difficulty in trying to accurately estimate the energy content of wheat or barley in poultry feeds and compensate for the deficiency by adding enzymes.

Adding adequate activity levels of *α*-amylase, *β*-glucanase, and xylanase to broiler starter and grower corn-soybean diets with a 3% reduction in dietary ME allowed full restoration of growth performance of broilers comparable to those fed the adequate energy (Yu and Chung, 2004).

Improvement in Nutrient Digestibilities: Enzymes have been shown to improve performance and nutrient digestibility when added to poultry diets containing cereals, such as barley (Hesselman *et al*. 1982; Hesselman and Åman 1986; Friesen *et al*. 1992; Marquardt *et al*. 1994), maize (Saleh et al., 2003), oats (Friesen *et al*. 1992), rye (Fengler and Marquardt 1988; Fengler *et al*. 1988; Friesen *et al*. 1991, 1992; Bedford and Classen 1992; Marquardt *et al*. 1994), and wheat (Fengler *et al*. 1988; Friesen *et al*. 1991; Marquardt *et al*. 1994), and to those containing pulses, such as lupins (Brenes *et al*. 1993). The effect of enzyme supplementation on Dry Matter Digestibilities (DMD) in pigs and poultry depends on the type of diet and the type of animal: increases in DMD range from 0.9 (Schutte *et al*. 1995) to 17% (Annison and Choct 1993) in poultry.

The enzymes currently used in monogastric diets are predominantly glycanases, which cleave NSPs into smaller polymers, thereby removing their ability to form viscous digesta and enhancing nutrient digestibilities. The effects of glycanases are generally nonspecific, except for their effect on fat (greater effect on saturated fat than on unsaturated fat). Another enzyme used in feed is phytase, which increases the utilization of phytate phosphorus. The ability of phytase to improve the digestion of phytate phosphorus and subsequently to reduce the output of organic phosphorus to the environment has attracted a great deal of scientific and commercial interest. In poultry use of phytase was reported to reduce phosphorus excretion by as much as 40% for broilers. When phytase was added to layer diets, increased egg production and positive effects on egg weight and tibia ash were also noted (Simons and Versteegh, 1991).

Reduction in Excreta Moisture: A reduction in the moisture content of poultry excreta is often noted when glycanases are included in the diet. Supplementing the NSP-enriched diet with three different commercial glycanase products improved performance, but their effectiveness in reducing the moisture levels of the excreta differed from 10 to 29%. This supports the view that different glycanases have similar performance-enhancement effects in monogastric animals but the site of the breakdown of the NSPs in the gut and the molecular sizes of the released products differ (Choct and Annison, 1990). Graham, (1996) also reported an increased water uptake and excretion in broilers given diets containing higher levels of viscous cereal grains.

Health improvement: Morgan and Bedford (1995) reported that coccidiosis problems could be prevented by using enzymes. Birds fed a wheat-based diet with and without glycanase supplementation showed vastly different responses to coccidiosis challenge. Growth was depressed by 52.5% in the control group but by only 30.5% in the enzyme group, which also had a much better lesion score. An increase in digesta passage rate and a reduction in excreta moisture are often noted when glycanases are added to poultry diets, which may be detrimental to the life cycle of the organism.

Precision and Flexibility in Least Cost Feed Formulation: Enzymes provide greater flexibility in feed formulation and allow the use of a wide range of ingredients without compromising bird performance and hence provide great flexibility in least-cost feed formulation. The nutritive value of cereal grains for poultry varies greatly, and no suitable assays are currently available for rapid in-mill testing. For instance, the variability in the AME of wheat for poultry can be as great as 4 MJ/kg DM (Sibbald and Slinger 1962; Rogel *et al*. 1987). This problem can be largely overcome by using glycanases to bring the AME of different wheats to comparable levels (Choct *et al*. 1995).

Impact on Environment: Enzymes have been approved for use in poultry feed because they are natural products of fermentation and therefore pose no threat to the animal or the consumer.

Enzymes not only will enable livestock and poultry producers to economically use new feedstuffs, but will also prove to be environmentally friendly, as they reduce the pollution associated with animal production. As well as contributing to improved poultry production, feed enzymes can have a positive impact on the environment. In areas with intensive poultry production, the phosphorus output is often very high, resulting in environmental problems such as eutrophication. This happens because most of the phosphorus contained in typical feedstuffs exists as the plant storage form phytate, which is indigestible for poultry. The phytase enzyme frees the phosphorus in feedstuffs and also achieves the release of other minerals (e.g. Ca, Mg), as well as proteins and amino acids bound to phytate. Thus, by releasing bound phosphorus in feed ingredients, phytase reduces the quantity of inorganic phosphorus needed in diets, makes more phosphorus available for the bird, and decreases the amount excreted into the environment.

Factors Affecting the Benefits of enzyme: The degree of improvement obtained by adding enzymes to the diet depends on many factors (Bedford, 1996), including the type and amount of cereal in the diet; the level of antinutritive factor in the cereal, which can vary within a given cereal (for example, low- versus high-ß-glucan barley); the spectrum and concentration of enzymes used; the type of animal (poultry tend to be more responsive to enzyme treatment than pigs); and the age of the animal (young animals tend to respond better to enzymes than older animals); type of gut micro flora present and the physiology of the bird. Older birds, because of the enhanced fermentation capacity of the micro flora in their intestines, have a greater capacity to deal with negative viscosity effects (Allen *et al*. 1995; Choct *et al*. 1995; Vukic Vranjes and Wenk 1993).

Use of enzymes in layers: Although the majority of research trials were conducted on broilers. However, the responses of laying hens to enzyme-supplemented feeds are also well documented. Typically, enzymes added to layer feed appear to have little effect on egg mass but improve feed efficiency (Benabdeljelil and Arbaoui 1994; Vukic Vranjes and Wenk 1993), energy utilization (Wyatt and Goodman 1993). Wyatt and Goodman (1993) reported that corn-fed layers exhibited better feed efficiency than those fed enzyme-supplemented barley-based diets. Nevertheless, enzyme supplementation improved the utilization of barley diets. Increased energy utilization in laying hens appears to be due to microbial fermentation of solubilized NSPs and the subsequently higher absorption of volatile fatty acids (Choct *et al*. 1995). Wet litter arising from the use of barley and newly harvested wheat can result in an increased incidence of dirty egg shells and in ammonia buildup in poultry barns. Adding enzymes to both wheat- and barley-based diets has been shown to reduce the moisture content of fecal matter in layers (Marquardt *et al*. 1994).

Conclusion: The use of enzymes as a feed additive has rapidly expanded. In the last decade, extensive studies have been conducted to study the effects of feeding exogenous enzymes on the performance of poultry. By compiling these studies into a single focused work, this review provides evidence that enzyme is a significant instrument for the use in poultry feed.

Although the economic and social benefits of enzymes have been well established and the future of feed enzymes is a bright one. However, further research is required if enzymes are to reach their full potential in the industry and to answer some of the questions that this article raises, particularly those regarding the mode of action of enzymes, how best to match the levels of enzyme and substrate and how enzymes counter the variable environments in the animal's gut. Ultimately, in vitro tests will tell us not only whether we need exogenous enzymes, but also the correct enzyme cocktail for a specific batch of a feed ingredient. This will allow the formulation of better rations using a wider range of ingredients. Any advances in this field must ultimately improve the welfare of chickens, reduce the production of wastes and conserve resources.

REFERENCES

Acamovic, T. and B. McCleary. (1996). Enzyme Special Series-Optimising the response. Feed Mix 4: 14-19.

Adams, E.A. and R. Pough. (1993). Non-starch polysaccharides and their digestion in poultry. Feed Compounder 13: 19-21.

Allen, C.M., M. R. Bedford and K. J. McCracken. (1995). A synergistic response to enzyme and antibiotic supplementation of wheat-based diets for broilers. Proceedings, 10th European Symposium on Poultry Nutrition, 15–19 Oct, Antalya, Turkey. World's Poultry Science Association. pp. 369–370.

Almirall, M., M. Francesch, A. M. Perez-Venderell, J. Brufau, and E. Esteve-Garcia. (1995). The differences in intestinal viscosity produced by barley and ß-glucanase alter digesta enzyme activities and ileal nutrient digestibilities more in broiler chicks than in cocks. Journal of Nutrition 125: 947–955.

Annison, G. (1993). The role of wheat non-starch polysaccharides in broiler nutrition. Australian Journal of Agricultural Research 44(3): 405-422.

Annison, G. and M. Choct. (1991). Antinutritive activities of cereal non-starch polysaccharides in broiler diets and strategies for minimizing their effects. World's Poultry Science Journal 47: 232–242.

Annison, G. and M. Choct. (1993). Enzymes in poultry diets in : Enzymes in Animal Nutrition. Proceedings Ist Symposium, Switzerland. Oct 13-16. pp: 61-63.

Bedford, M.R. (1995). Mechanism of action and potential environmental benefits from the use of feed enzymes. Animal Feed Science and Technology 53: 145–155.

Bedford, M.R. (1996). The effect of enzymes on digestion. Journal of Applied Poultry Research 5: 370-378.

Bedford, M.R. and H. L. Classen. (1992). Reduction of intestinal viscosity through manipulation of dietary rye and pentosanase concentration is effected through changes in the carbohydrate composition of the intestinal aqueous phase and results in improved growth rate and food conversion efficiency of broiler chicks. Journal of Nutrition 122: 560–569.

Bedford, M.R. and H. L. Classen. (1993). An in-vitro assay for prediction of broiler intestinal viscosity and growth when fed rye based diets in the presence of exogenous enzymes. Poultry Science 72: 137-143.

Bedford, M.R., H. L. Classen and G. L. Campbell. (1991). The effect of pelleting, salt and pentosanase on the viscosity of intestinal contents and the performance of broilers fed rye. Poultry Science 70: 1571–1577.

Benabdeljelil, K. (1992). Improvement of barley utilization for layers: effects on hen performance and egg quality. Proceedings, 19th World's Poultry Congress, Amsterdam, Netherlands. pp. 405–410.

Benabdeljelil, K. and M. I. Arbaoui. (1994). Effects of enzyme supplementation of barley based diets on hen performance and egg quality. Animal Feed Science and Technology 48: 325–334.

Bhatt, R.S., S. Manoj. and B. S. Katoch. (1991). Effect of supplementation of diet with fibre degrading enzyme on performance and nutrient utilization in broilers. Indian Journal of Animal Nutrition 8(2): 135-138.

Brenes, A., W. Guenter., R.R. Marquardt and B. A. Rotter (1993). Effect of -glucanase/ pentosanase enzyme supplementation on the performance of chickens and laying hens fed wheat, barley, naked oats and rye diets. Canadian Journal of Animal Science 73: 941–951.

Campbell, G.L., B. G. Rossnagel., H. L. Classen and P. A. Thacker. (1989). Genotypic and environmental differences in extract viscosity of barley and their relationship to its nutritive value for broiler chickens. Animal Feed Science and Technology 226: 221–230.

Choct, M. and G. Annison. (1990). Anti-nutritive activity of wheat pentosans in broiler diets. British Poultry Science 30: 811–821.

Choct, M., R. J. Hughes., R. P. Trimble., K. Angkanaporn and G. Annison. (1995). Non-starch polysaccharide-degrading enzymes increase the performance of broiler chickens fed wheat of low apparent metabolizable energy. Journal of Nutrition 125: 485–492.

Classen, H. L. (1996). Successful application of enzymes relies on knowledge of the chemical reation to be affected and conditions under which the reaction will occur. Feed Mix 4: 22-28.

Classen, H. l. and M. R. Bedford. (1991). The use of enzymes to improve the nutritive value of poultry feed. In recent advances in animal nutrition. (eds. W. Haresign and D. J. A. Cole. Butterworth, London, pp79-102.

Classen, H.L., T.A. Scott., G. Irish., P. Hucl., M. Swift and M. R. Bedford. (1995). The relationship of chemical and physical measurements to the apparent metabolisable energy (AME) of wheat when fed to broiler chickens with and without a wheat enzyme source. Proceedings of the Second European Symposium on Feed Enzymes, Netherlands.

Creswell, D.C. (1994). Upgrading the nutritional value of grains with the use of enzymes. Technical bulletin, American Soybean Association, 341 Orchard Road No.11-03 Liat Towers, Singapore.

Dunn, N. (1996). Combating the pentosans in cereals. World Poultry 12(1): 24-25.

Esteve-Garcia, E., J. Brufau., A. Perez-Vendrell., A. Miouei and K. Buven. (1997). Bioefficiency of enzymes preparation containing ß-glucanases and xylanase activities in broiler diets based on barley or wheat in combination with Flavomycin. Poultry Science 76: 1728-1737.

Fengler, A.I. and R. R. Marquardt. (1988). Water-soluble pentosans from rye. II. Effects on the rate of dialysis and on the retention of nutrients by the chick. Cereal Chemistry 65: 298–302.

Fengler, A.I., J. R. Pawlik. and R. R. Marquardt. (1988). Improvements in nutrient retention and changes in excreta viscosities in chicks fed rye-containing diets supplemented with fungal enzymes, sodium taurocholate and penicillin. Canadian Journal of Animal Science 68: 483–491.

Friesen, O.D., W. Guenter., B. A. Rotter and R. R. Marquardt. (1991). The effect of enzyme supplementation on the nutritive value of rye grain (Secale cereale) for the young broiler chick. Poultry Science 70: 2501–2508.

Friesen, O.D., W. Guenter., R. R. Marquardt and B. A. Rotter. (1992). The effect of enzyme supplementation on the apparent metabolizable energy and nutrient digestibilities of wheat, barley, oats, and rye for the young broiler chick. Poultry Science 71: 1710–1721.

Gill, C. (2001). Enzymes for broilers. Reducing maize energy variability. Feed International 12-16.

Gracia, M. I., M. J. Aranı´bar., R. La´zaro., P. Medel and G. G. Mateos. (2003). Amylase supplementation of broiler diets based on corn. Poultry Science 82: 436-442.

Graham, H. (1996). Mode of action of feed enzymes and application to poultry feeds. Internal paper Animal Nutrition Group Meeting, Finnfeeds International Ltd., Marlborough, Wiltsure, SNB 1AA, UK.

Gruppen, H., F. J. M. Kormelink., and A. G. J. Voragen. (1993). Differences in efficacy of xylanases in the breakdown of wheat flour arabinoxylans due to their mode of action. In Wenk, C.; Boessinger, M., ed., Enzymes in animal nutrition. Kartause Ittingen, Thurgau, Switzerland. pp. 276–280.

Hasselman, K. and P. Aman. (1986). The effect of ß-glucanase on the utilization of starch and nitrogen by broiler chicks fed on barley of low or high viscosity. Animal Feed Science and Technology 15: 83-93.

Hesselman, K., K. Elwinger. and S. Thomke. (1982). Influence of increasing levels of -glucanase on the productive value of barley diets for broiler chicks. Animal Feed Science and Technology 7: 351–358.

Jansson, L., K. Elwinger., B. Engstrom., O. Fossum. and B. Telgof. (1990). Test of the efficacy of virginiamycin and dietary enzyme supplementation against necrotic enteritis disease in broilers. Proceedings, 8th European Poultry Conference, Barcelona, Spain. pp. 556–559.

Jeroch, H. and S. Dänicke. (1993). Barley in poultry feeding. Proceedings 9th European Symposium on Poultry Nutrition, 5–9 Sep, Jelenia Gora, Poland. World's Poultry Science Association. pp. 38–66.

Leeson, S and J. Proulx. (1994). Enzymes and barley metabolizable energy. Journal of Applied Poultry Research 3: 370-378.

Marquardt, R.R., A. Brenes., Z. Zhiqun and D. Boros. (1996). Use of enzymes to improve nutrient availability in poultry feedstuffs. Animal Feed Science and Technology 60: 321–330.

Marquardt, R.R., D. Boros., W. Guenter and G. Crow. (1994). The nutritive value of barley, rye, wheat and corn for young chicks as affected by use of a Trichoderma reesei enzyme preparation. Animal Feed Science and Technology 45: 363–378.

Mollah, Y., Bryden, W.L., Wallis, I.R., D. Balnave and E. F. Annison. (1983). Studies on low metabolisable energy wheats for poultry using conventional and rapid assay procedures and the effects of processing. British Poultry Science 24: 81–89.

Morgan, A.J. and M. R. Bedford. (1995). Advances in the development and application of feed enzymes. Australian Poultry Science Symposium 7: 109–115.

Muramatsu, T., T. Morishita., N. Niva., M. Furuse and Okumura, J. (1992). Growth improvement by fibre degrading enzyme supplement in chicken.

Animal Feed Science and Technology 63: 368-375.

Odetallah, N. H. (2002). Enzymes in corn-soybean diets. Proceedings of the 29th Annual Carolina Poultry Nutrition Conference. North Carolina State University, Raleigh, NC.

Odetallah, N. H., J. J. Wang.,. J. D. Garlich and J. C. H. Shih. (2005). Versazyme Supplementation of Broiler Diets Improves Market Growth Performance. Poultry Science 84: 858–864

Ouhida, I., J. F. Perez., J. Gasa., and F. Puchal. (2000). Enzymes (ß-glucanase and arabinoxylanase and/or Sepiolite supplementation and nutritive value of maize-barley-wheat based diets for broiler chickens. British Poultry Science 41: 617-624.

Partridge, G. and C. Wyatt (1995). More flexibility with new generation of enzymes. World Poultry 11(4), 17–21.

Rogel, A.M., E.F., W. L. Bryden. and D. Balnave. (1987). The digestion of wheat starch in broiler chickens. Australian Journal of Agricultural Research 38: 639–649.

Saleh, F., A. Ohtsuka., T. Tanaka and K. Hayashi. (2003). Effect of enzymes of microbial origin on in vitro digestibilities of dry matter and crude protein in maize. Journal of Poultry Science 40: 274-281.

Schutte, J.B., J. de Jong. and D. J. Langhout. (1995). Effect of a xylanase enzyme supplementation to wheat-based diets in broiler chicks in relation to dietary factors. Proceedings of the Second European Symposium on Feed Enzymes, Noordwijkerhout, Netherlands, pp. 95–101.

Simons, P.C.M. and H. A. J. Versteegh. (1991). Application of microbial phytase in poultry nutrition. Poultry Science 70: (Suppl. 1), 110.

Van der Klis, J.D., C. Schelle. and C. Kwakernaak. (1995). Wheat characteristics related to its feeding value and to the response of enzymes. Proceedings 10th European Symposium on Poultry Nutrition, Antalya, Turkey. World's Poultry Science Association. pp. 160–168.

Vukic Vranjes, M. and C. Wenk. (1993). Influence of dietary enzyme complex on broiler performance in diets with and without antibiotic supplementation. Enzymes in animal nutrition. Kartause Ittingen, Thurgau, Switzerland. pp. 152–155.

Wallis, I. (1996). Enzymes in poultry Nutrition. Technical Note, SAC.West Mains road, Edinburgh.

Wang, Z. R., S. Y. Qiao., W. Q. Lu and D. F. Li. (2005). Effects of Enzyme Supplementation on Performance, Nutrient Digestibility, Gastrointestinal Morphology, and Volatile Fatty Acid Profiles in the Hindgut of Broilers Fed Wheat-based Diets. Poultry Science 84: 875–881

Ward, N.E. (1995). With dietary modifications, wheat can be used for poultry. Feedstuffs 7 Aug, 14-16.

Wyatt, C.L. and T. Goodman. (1993). Utilisation of feed enzymes in laying hen rations. Journal of Applied Poultry Research 2: 68–74.

Yu, B, and T. K. Chung. (2004). Effects of Multiple-Enzyme Mixtures on Growth Performance of Broilers Fed Corn-Soybean Meal Diets. Journal of Applied Poultry Research 13:178–182