

THE UNIVERSITY OF MANITOBA

EFFECTS OF ENZYME SUPPLEMENTATION ON THE
NUTRITIONAL VALUE OF BARLEY IN CHICKEN DIETS

BY

MICHAEL FRANK NESKAR

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MICHAEL FRANK NESKAR

A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
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DEDICATED TO MY PARENTS

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ABSTRACT

Barley in some cases has a low nutritive value when fed to chickens, which in part may be attributed to its content of B-glucans. A series of experiments were conducted with broiler and Single Comb White Leghorn (SCWL) chicks to (1.) compare the effects on growth performance and nutrient retentions in SCWL chicks fed three enzyme preparations (Pectinex, Celluclast, T.v. Cellulase) when added at three concentrations to a barley-based diet, (2.) compare the response in growth and nutrient retentions in broiler and Leghorn chicks fed hullless barley (Scout) supplemented with Celluclast, (3.) determine the effects of enzyme supplementation on the nutritional value of two cultivars of barley (Scout and Minerva) that contain a high content of total and soluble B-glucans, and (4.) determine if the degree of response of broilers to enzyme supplementation of a barley-based diet (Bedford) was influenced by the duration of the feeding period.

In Experiment one, weight gains and feed consumption were improved ($P < 0.05$) to a greater degree with Celluclast while both Celluclast and T.v. Cellulase effectively improved ($P < 0.05$) the efficiency of feed utilization. Dry matter, fat, and protein retentions were improved ($P < 0.05$) in the presence of all three enzymes, with the effect being greater with Pectinex and T.v. Cellulase compared to Celluclast. The degree of response was the same ($P > 0.05$) for all concentrations of enzymes.

In Experiment two weight gains and efficiency of feed utilization of broilers and Leghorns were affected in a similar ($P > 0.05$) manner by

enzyme treatment during the first and second week of the study. The nutrient retentions, however, were affected to a greater degree ($P < 0.05$) in broilers than Leghorns.

The results from Experiment three showed that the addition of enzymes (Celluclast and SP-249) to barley-based diets at all three concentrations (0.05, 0.10, 0.20%) improved ($P < 0.05$) weight gain, feed to gain ratios and dry matter retentions to a considerable degree, with the effect being greater with Minerva as compared to Scout barley. Enzyme type (Celluclast vs. SP-249) and concentration had no effect ($P > 0.05$) on performance values.

In Experiment four, broiler chickens fed a barley-based diet that had a low content of B-glucan over a six week period did not respond to enzyme supplementation. It was therefore not possible to determine if the response of broilers to enzyme treatment, was influenced by the duration of the feeding period.

In most of the above studies growth improvements in chicks fed the enzyme supplemented diets were equal or superior ($P < 0.05$) to that obtained with the wheat control diets.

The results show that enzyme supplementation of barley-based diets with a high content of soluble B-glucans, significantly ($P < 0.05$) improved growth and nutrient retentions in both broiler and Leghorn chicks. Growth and nutrient retention improvements in some cases even exceeded that of birds fed wheat based diets. Growth improvements were dependent on; type of barley and enzyme used, while enzyme concentrations and bird-type had no effect. Nutrient retentions on the other hand were dependent on; bird-type, enzyme and barley-type. These

same performance values were generally not affected by enzyme concentration. It may be concluded that the nutritive value of certain barley-types may be improved by enzyme supplementation.

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LIST OF ABBREVIATIONS

B	beta
α	alpha
h	hour
kcal	Kilocalorie(s)
kg	Kilogram(s)
<	less than
>	greater than
g	gram(s)
$^{\circ}\text{C}$	degree Celcius
%	percent
SE	standard error
IU	international units
ml	millilitre
S.S.	Sum of Squares
anova	analysis of variance

INTRODUCTION

Historically dietary fibre has been generally defined as being the residue of plant cell walls not digested by the alimentary enzymes of man. Theander and Aman (1979) have also proposed that dietary fibres include all non-starch polysaccharides plus lignin. Mixed linked B-(1- \rightarrow 3),(1- \rightarrow 4)-D glucans, also referred to as B-glucans, are non-starchy polysaccharides which are mainly present in cereals (Hesselman and Aman, 1985). In barley and oats, the endosperm cell walls contain large amounts of B-glucans which greatly influences the physical and nutritional properties of these grains (Wood, 1983).

In recent years there has been interest in increasing the consumption of cereals in human food in developed countries. This is related to their low fat and high starch and fibre contents of cereals (Cummings, 1978). Some positive effects of dietary fibre in human nutrition include a reduction in serum cholesterol and fat, which could aid in possibly reducing antherosclerosis and heart disease (Burkitt, 1976). Some health professionals believe that dietary fibre may provide protection from cancer of the colon and rectum (Spiller and Sorenson, 1976).

The general trend in human nutrition has been to increase the consumption of certain cereals due to the benefits associated with the dietary fibre that is present in these cereals. Animal nutritionists, in contrast have been reluctant to use these cereals as they tend to have a negative effect on nutrient utilization. A concern in the poultry industry is the deleterious effects on weight gains and

efficiency of feed utilization when cereals such as barley are used as the principal ingredient in poultry diets (Campbell et al, 1986). Removal of the hull from barley which is high in fibre through the development of hullless cultivars or by mechanical treatments does not eliminate the problem (Anderson et al 1961; Coon et al, 1979). The reduced feeding value of barley would have to be attributed to other factors, such as, B-glucans (Burnett, 1966) and tannins (Gohl and Thomke, 1976).

It has been proposed that B-glucans reduce growth and efficiency of feed utilization in poultry by increasing the viscosity of the intestinal fluids, thereby impairing nutrient digestion and absorption (White et al, 1983). B-glucans have been known to reduce the digestion and absorption of nutrients such as starch, fats, proteins, and minerals (Classen et al, 1985). Commercial enzyme preparations from *Bacillus subtilis*, *Aspergillus niger*, *Trichoderma viride*, *Trichoderma reesei*, and other sources have been employed to improve the nutritional quality of barley used for poultry feeds (Mannion, 1981; White et al, 1981; Hesselman et al, 1982; White et al, 1983). These enzymes contain high B-glucanase activities which can reduce the viscous components of barley (B-glucans). As a result, efficiency of feed utilization and weight gains are improved (Campbell et al, 1986).

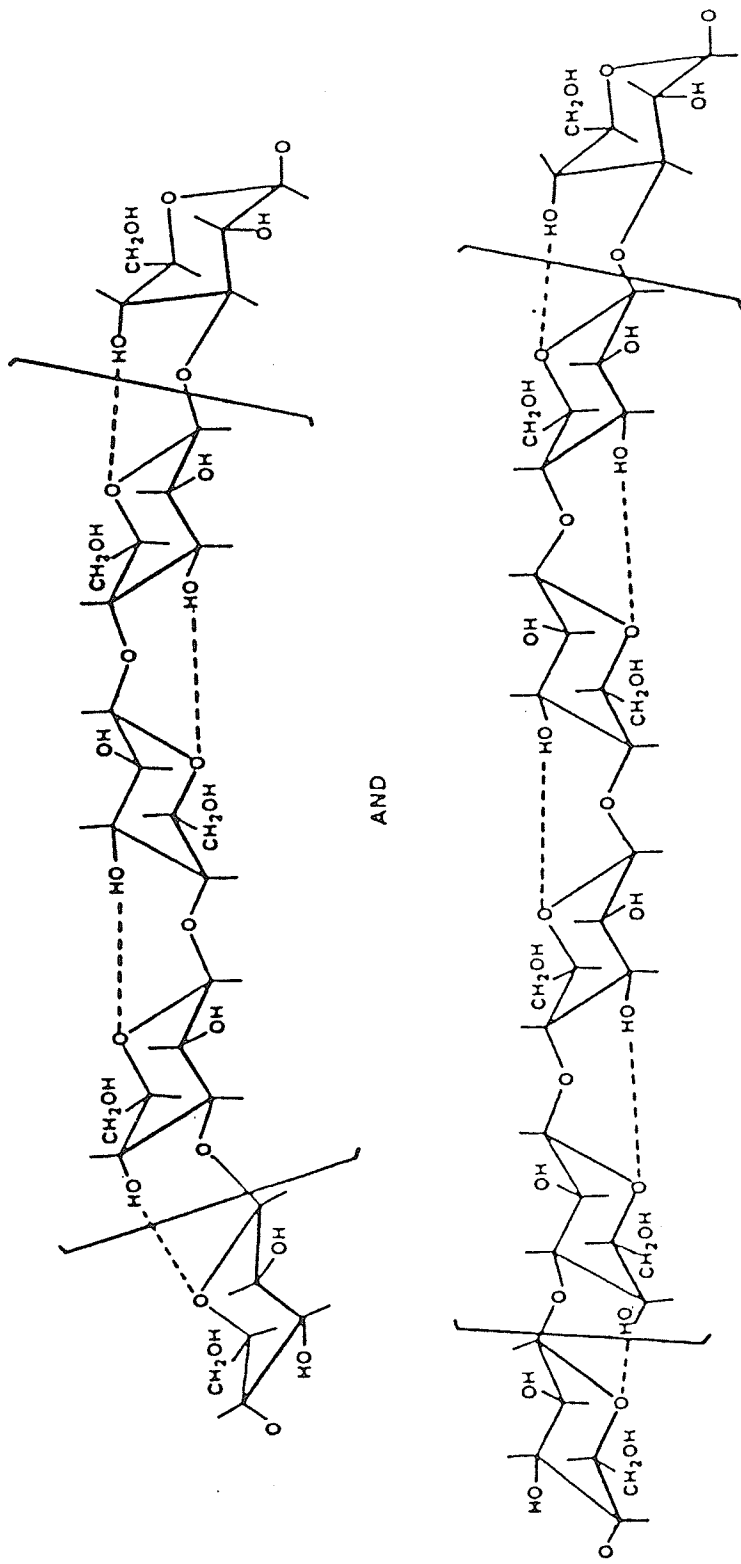
LITERATURE REVIEW

A. Structure of B-glucans in Cereal Grains

Barley and oat B-glucan molecules are unbranched polysaccharides which contain B-(1→3) and (1→4) linked glucopyranosyl units in the ratio of 2 and 3 to 1 (Figure 1; Wood, 1983). Despite the overall structural similarity of cereal B-glucans, there may be quite distinctive differences in physical properties, such as viscosity and solubility due to variations in molecular weights, protein content and sequence of linkages (Wood, 1983). The presence of B-(1→3)-linkages in the B-glucan chain results in irregularities in the molecular shape, which renders the B-glucans more susceptible to hydrolysis compared to the intransient cellulose, which is built up only of B-(1→4)-linkages (Bamforth, 1982).

Recent studies on the fine structure of B-glucans have revealed that about 90% of water-soluble B-glucan from barley endosperm was comprised of randomly arranged cellootriosyl and cellotetraosyl units, separated by single B-(1→3)-linkages (Figure 2; Staudte et al, 1983). The remaining 10.0% consisted of blocks of up to ten or more adjacent B-(1→4)-linkages (Fleming and Kawakami, 1977). In addition it has been reported that this polysaccharide contains sequences of two, three, or four continuous B-(1→3)-linkages, blocks of more than four B-(1→4)-linkages and regions having alternating B-(1→3) and B-(1→4)-linkages (Fleming and Kawakami, 1977).

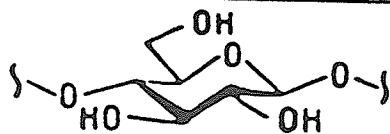
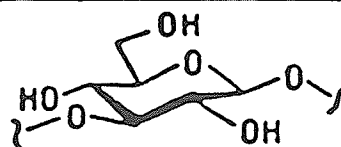
B-glucans in barley and oats are found primarily in endosperm cell walls (Basic and Stone, 1981). In barley they constitute about 70% of



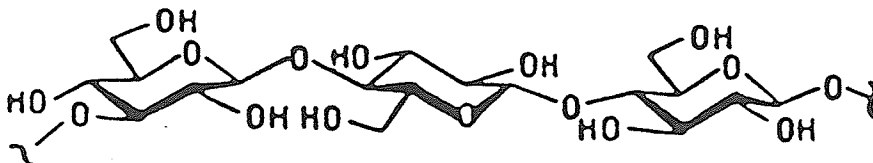
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Fig. 1. Structure of cereal β -glucan

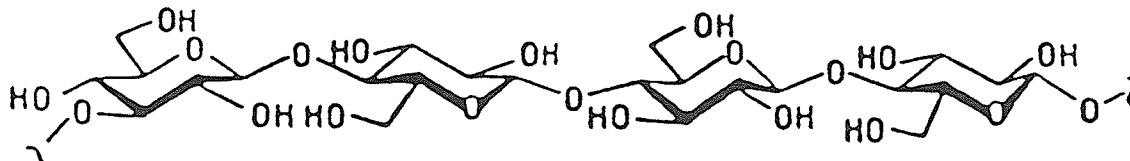
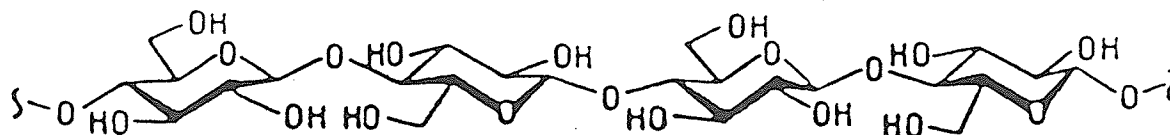
Adapted from Wood, 1983

β -(1 \rightarrow 4)-GLUCOPYRANOSYL β -(1 \rightarrow 3)-GLUCOPYRANOSYLMIXED-LINKED β -GLUCANS

Celotriosyl



Cellotetraosyl

CELLULOSEFig. 2. Conformation Formulas of β -glucan Residues

Conformation formulas of β -(1 \rightarrow 3)-linked glucopyranosyl residue, β -(- \rightarrow 4)-linked glucopyranosyl residue, mixed-linked β -(1 \rightarrow 3), (1 \rightarrow 4)-glucans, including the celotriosyl and cellotetraosyl residues, separated by single β -(1 \rightarrow 3)-linkages and comprising about 90 % of the polysaccharides, and cellulose.

Adapted from Staudte et al, 1983

the starchy endosperm cell walls, the remainder being mainly arabinoxylans (25%), mannose containing polymers, protein and phenolic constituents (Basic and Stone, 1981). Significant differences in the thickness of endosperm cell walls of barley have been reported (Aastrup and Munck, 1985). For example, the cultivar Minerva has starchy endosperm cell walls more than twice as thick as its low B-glucan mutant, M737. Correspondingly, Campbell et al (1986) showed that the extract viscosity's of Minerva was over twice that of M737.

B. B-glucan Content and Occurance in Cereal Grains

The range of total B-glucan concentrations within cereal grains can vary from 2-10%, expressed on a dry weight basis (Wood, 1983). The contents of B-glucans in cereals is influenced by type of cereal, variety differences within cereals, differences in geographical locations, agronomic practices, and methods used for B-glucan determinations (Anderson et al, 1978).

Variations in total B-glucan content from cereal to cereal is evident when barley B-glucan (3-10%) is compared with wheat B-glucan (0.5-1.0%) (Table 1). It should be noted that B-glucan content measurements in this table were taken on different cultivars of barley. Anderson et al (1978) reported wheat, rice, and triticale had very low concentrations of total and soluble B-glucans, while barley and rye comparatively had high concentrations. The low metabolizable energy of barley for poultry, relative to other cereals, i.e. wheat, has been attributed to the suppression of nutrient digestion by the B-glucan component (Rickes et al, 1962; Potter et al, 1965; White et al, 1981). Thus higher concentrations of B-glucan seen in barley and rye as

Table 1 Recent Estimates of B-glucan Content in Barley, Oats, and Wheat by Various Methods

Cereal	Method ¹	B-glucan Content
Barley	a	6.20 - 7.24
Barley	b	3.64 - 6.44
Barley	b	3.16 - 5.78
Barley	b	2.00 - 6.36
Barley	b	1.93 - 6.81
Barley	c	4.5 - 8.2
Barley	d	5.43 - 8.62
Barley	d	4.85 - 8.62
Barley	d	6.13 - 10.7
Barley	e	2.7 - 4.4
Barley	e	2.73 - 5.18
Barley	e	2.53 - 4.47
Oats (whole grain)	b	2.50
Oats (whole grain)	c	4.8 - 6.6
Oats (dehulled)	a	4.6
Wheat	a	1.4
Wheat	b	0.52 - 1.00

¹a, total glucan-starch; b, *B. subtilis* (1→3) (1→4)-B-D-glucan 4-glucanohydrolase; c, cellulase method of Prentice et al (1980); d, cellulase method of Martin and Bamforth (1981); e, cellulase method of Martin and Bamforth (1981) modified to inactivate residual amyloglucosidase.

Adapted from Wood, (1983).

compared to wheat may be responsible for poor growth performance when fed to poultry.

Different varieties of each cereal have been shown to affect the total content of B-glucan in cereals. Table 2 shows that total B-glucan content can differ by as much as 30% among varieties of barley that have been grown under the same conditions.

Differences in geographical locations, with consequential differences in temperature and rainfall can also have an effect on the B-glucan content of cereals (Table 2). These environmental conditions affect B-glucan concentrations in cereals during the latter periods of plant growth (Aastrup, 1979b). In particular, drought conditions tend to elevate both soluble and total B-glucan deposition (Aastrup, 1979b; Hesselman et al, 1982). This may account for the regional differences in the apparent nutritional value of barley as a poultry feed. American barleys from western regions have long been considered inferior to those from more eastern regions, which is thought to reflect climatic influences on B-glucan concentration (Campbell et al, 1986). Lethbridge, Alberta which is comparatively drier than Winnipeg produced barley that has a much higher concentration of B-glucan than that produced in Winnipeg (Bendelow, 1975). The yearly rainfall averages for Lethbridge and Winnipeg are 269.2 mm and 411.0 mm, respectively. Aastrup (1979a) found that hot and dry growing conditions leading to an early harvest of barley resulted in an increased viscosity of acid extracts. Aastrup (1979b) also conducted a series of experiments to determine if rain treated plants had different extract viscosities and B-glucan contents from those of control plants. The results from the

Table 2 Total and 65°C Water-Insoluble B-glucan Content of Canadian Barley Cultivars Grown at Different Locations

Cultivar and Location	Total	65°C Water-Insoluble	65°C Water Soluble (by difference)
'Klages'			
Winnipeg	5.62 ± 0.02	2.46 ± 0.08	3.16
Lethbridge	5.16 ± 0.01	1.85 ± 0.03	3.31
'Betzes'			
Winnipeg	5.29 ± 0.10	2.54 ± 0.11	2.75
Lethbridge	5.46 ± 0.11	2.08 ± 0.06	3.38
'TR 904'			
Winnipeg	4.33 ± 0.03	2.23 ± 0.02	2.10
Lethbridge	3.77 ± 0.10	1.79 ± 0.02	1.98
'TR 406'			
Winnipeg	5.31 ± 0.04	2.15 ± 0.06	3.16
Lethbridge	5.11 ± 0.05	1.78 ± 0.02	3.33

Adapted from Anderson et al, (1978).

experiments showed that during the yellow and full ripeness stages, extract viscosities from all rain treated plants were significantly less ($P < 0.05$) than the control plants. During these stages of plant growth, the differences in the extract viscosities were paralleled by differences in soluble, insoluble, and total B-glucan contents (Aastrup, 1979b). These differences may best be explained on the basis of a lower rate of synthesis of B-glucans during the yellow and full stage ripeness in the rain treated plants as compared to the control plants. Coles (1979) found when the moisture contents of the seed declined by 40-50%, the accumulation rate of mixed linked B-glucans increased sharply in Lami and Triumph barley. The author stated that this result may have occurred as a result of the lack of starch accumulation in the barley grain.

Harvest conditions can also have an effect on extract viscosities on B-glucan contents. Aastrup (1979a) showed that a wet harvest results in barley flour being characterized by having a low extract viscosity and B-glucan content, while a dry harvest yields grains whose flour has a high extract viscosity and B-glucan content. In addition, Gohl et al (1978) found the viscosity of barley extracts were highest in grains harvested at yellow ripeness (Hesselman et al, 1981). Aastrup (1979a) reported a subsequent decline in barley extract viscosity from yellow to full ripeness. This reduction in barley extract viscosity is paralleled by a significant decline in the amount of soluble B-glucans but not in the insoluble B-glucans (Gohl et al, 1978). The structural nature of the soluble B-glucans in barley grains from yellow to full ripeness was similar (Aastrup, 1979a). Therefore, the reduction in

extract viscosity may have resulted from a lower percentage of soluble B-glucans being extracted in the acid flour extract and may have not been due to degradation of the soluble component. Some possible explanations for the reductions in soluble B-glucans from yellow to full stage ripenesses are (Aastrup, 1979a):

1. Continued synthesis of non-B-glucans which would reduce the relative concentration of B-glucan.
2. The soluble B-glucans may become insoluble.
3. The structure of B-glucans may be modified so that the resulting polymers are inaccessible to B-glucanases used for glucan determination.

Agronomic practices can also influence extract viscosity and B-glucan content of barley. Campbell et al (1986) observed an effect of seeding date (May 21 or June 14), fertilizer level, and location on extract viscosity. Prolonging the seeding date reduced extract viscosities of barley, presumably by delaying ripening into the cooler season (Campbell et al, 1986). Similarly, higher fertilization rates tended to reduce extract viscosities and B-glucan contents, which may also be explained on the basis of delayed harvest.

C. B-glucan Assays

Differences in B-glucan contents may also be derived from the wide ranges of methods used for the extractions and the determinations of B-glucans (Jorgensen and Aastrup, 1987).

1. Methods Based on Extraction

A majority of methods published for B-glucan analysis involve solubilization of the B-glucan polymer either in the native or degraded form (Jorgenson and Aastrup, 1987).

a) Viscosity Methods

Determining B-glucans by viscosity measurements of barley extracts is a simple method, and has been used as a screening technique in barley breeding programs (Greenberg and Whitmore, 1974; Bendelow, 1975; Morgan and Gothard, 1977; Aastrup, 1979b).

The final results of such methods may differ depending on the molecular weights of the extracted B-glucan and the co-extraction of other components which also may increase the viscosity (e.g. pentosans, starch). Variations in B-glucan content and extract viscosity may also be attributed to differences in the proportion of soluble and insoluble B-glucans (Wood, 1983). Possible actions of B-glucanases present in the barley during extraction, may also cause the content to be underestimated (Jorgensen and Aastrup, 1987).

b) Difference Methods

These methods are based upon the assumption that the only glucose polymers present in the extracts are derived from B-glucan or starch (Jorgensen and Aastrup, 1987). An estimate of the B-glucan content can be achieved by measuring the total carbohydrate content as glucose in an extract and subtracting that derived from the degradation of starch with amyloglucosidase. This method is considered accurate only if the extraction method employed does not extract too much of the starch

(Jorgensen and Aastrup, 1987). Wood (1983) has shown that some of the B-glucan which is present in the aleurone and sub-aleurone layer may still remain, even after repeated extractions.

2. Non-extraction Methods

a) Near Infrared Reflectance

Near infrared reflectance (NIR) is a well known non-destructive technique commonly used for determining B-glucans in the food and feed industry (McDonald, 1986). NIR analysis is based on the observation that major constituents within the cereal have a spectrum that is specific for the component to be investigated (B-glucan). A computer model can be used to eliminate the effects of interfering substances (Jorgensen and Aastrup, 1987).

b) Calcofluor Staining Used in Flour Suspensions

The fluorochrome, calcofluor, specifically stains B-glucans containing 1,4 linkages. The method involves staining intact cell walls of halved grains and visual inspection in UV light (Jorgensen and Aastrup, 1987). In a technique described by Jensen and Aastrup (1981), fine flour is stained by calcofluor suspended in glycerol and the fluorescence intensity is measured in a spectrofluorometer. A good correlation was found between the fluorescence intensity obtained from the flour suspensions and the total B-glucan content determined by the enzymatic method. Errors from this method may result from not all of the B-glucan cell walls being equally accessible to staining and therefore not stained uniformly (Jorgensen and Aastrup, 1987).

3. Enzymatic Methods

In recent years, it has been possible to analyze for B-glucans using specific B-glucanases. One method utilizes (1->3)(1->4)-B-D glucan 4-glucanohydrolase which is produced by *Bacillus subtilis* (Anderson et al, 1978; Henry, 1984; McCleary and Glennie-Holmes, 1985). This enzyme cleaves the (1->4)-B-linkages of 3-substituted-D-glucopyranosyl residues and is very specific for B-glucan. This B-glucanase is obtained as a contaminant of bacterial amylase (1000 S or 240 L from NOVO Industries, Denmark), and must be purified before use (Jorgensen and Aastrup, 1987). The presence of starch degrading enzymes in the preparation may lead to an overestimation of the B-glucan content. Other errors may be attributed to the B-glucan remaining physically inaccessible to the B-glucanase due to substitution (e.g. with protein) or to covalent cross-linking (Anderson et al, 1978).

D. Influence of B-glucans on Viscosity

The poor nutritive value of barley has been partially attributed to the glucan and B-glucan components (Burnett, 1966). These components give rise to fairly stable and highly viscous solutions in the small intestine (Burnett, 1966) and can be considered to be the main cause of poor animal performance on nutrient utilization (White et al, 1983).

The term viscosity can be defined as the resistance to flow or alteration of shape, by any substance as a result of molecular cohesion or shearing force (Stedman Medical Dictionary, 1976). Certain polysaccharides, i.e. B-glucans, have the ability to attract water and form gel like structures, and as a result increase the viscosity of aqueous solutions (Eastwood, 1973). Water is first tightly bound

through hydrogen bonds and this structure becomes surrounded by loosely-bound water held by dipole attraction and adhesion (Eastwood, 1973). Kay and Strasberg (1978) believed that the hydration capacity of the polysaccharides depended on the orientation and availability of polar groups (carboxyl, hydroxyl, etc.). These polar groups have the ability to bind water and form semi-rigid, jelly-like structures with concomitant swelling and an increase in viscosity. Barley B-glucan must be a soluble component in order for it to effect viscosity (White et al, 1981). Rotter (Personal Communication, 1987. U. of M., Wpg., Man., Canada) demonstrated a close association between the soluble B-glucan content of barley and its corresponding viscosity (Table 3). Similarly Aastrup (1979a) demonstrated that the acid-extract viscosity was closely related to the amount of soluble B-glucans, $R^2 = 0.99$. The solubility and the resulting viscosity are directly related to the molecular weight of the components present. Forrest and Wainwright (1977) showed that B-glucan extracted from barley endosperm cell walls had a high intrinsic viscosity ($15-19 \text{ dl g}^{-1}$), corresponding to a molecular weight of 4×10^7 . The smaller molecular weight B-glucan obtained after rupture of peptidolytic linkages showed an intrinsic viscosity of only $3-5 \text{ dl g}^{-1}$. Preece and MacKenzie (1952) found that individual gum components of many cereals did not markedly differ in the proportions of individual sugar units present, but did differ in molecular conformations, aiding in explaining differences in viscosities. Smith et al (1980) showed that soluble B-glucans were responsible for over 80% of the high molecular weight carbohydrates.

White et al, (1981) conducted experiments to determine how barley

Table 3 Total and Soluble B-glucan Contents and Viscosity Measurements of Hulled and Hullless Barley Used in the Current Studies¹

Cereal	Total B-glucan ² content (%)	Soluble B-glucan ² content (%)	Viscosity ³ (Cps)
Tupper barley (Hullless)	4.39	1.81	1.92
Bedford barley (Hulled)	3.76	2.0	1.87
Scout barley (Hullless)	4.32	2.17	2.83
Minerva barley (Hulled)	5.62	3.12	4.80

¹Rotter, 1987, Personal Communication, Dept. of Animal Sci., U. of M., Wpg., Man.

²Total and soluble B-glucans determined by the method of McCleary and Glennie-Holmes (1985).

³Viscosity determined by the modified method of Greenberg and Whitmore (1974).

B-glucan affected the digestibility of nutrients in broiler chickens. These researchers added barley-B-glucan to a corn based diet (10 g kg^{-1}) and found that it raised the viscosity of the intestinal contents threefold compared to the control diet. They hypothesized that the high viscosity of B-glucans was responsible for reduced nutrient digestibilities, resulting in poor animal performance.

E. Influence of Viscosity of the Diet on Nutrient Absorption and Digestion

B-glucans in barley and oats increase the viscosity of the intestinal contents and either directly or indirectly reduce the absorption of nutrients from the gut (Campbell et al, 1986). Solubilized gums are believed to act as a barrier to the diffusion of nutrients within the gut lumen, which further limits the rate and extent of nutrient absorption (Campbell et al, 1983b). Eastwood (1973) found when a gel forms, a gel filtration system develops, producing a molecular exclusion capacity. The size of the pores dictates the permeability of the surrounding molecules (biological sieving). Another postulated mechanism is based on the ability of gums to interact with cross-linked polysaccharides protruding from the absorptive cells lining the small intestine (Johnson and Gee, 1981). This action may thicken the unstirred water layer immediately adjacent to the enterocyte, and hinder nutrient absorption (Campbell et al, 1986). Hydration capacity of polysaccharides depends on the orientation and availability of polar groups (carboxyl, hydroxyl etc.), which has the ability to bind water and form a semi-rigid, jelly-like structure with concomitant swelling and increase of viscosity (Antoniou, 1986). This phenomenon prevents

the absorption of nutrients by the gut because of dilution and a decreased rate of diffusion of nutrients towards the intestinal mucosa (Kay and Strasberg, 1978). Gohl et al (1978) has reported that B-glucans can reduce the flow rate of intestinal contents of rats. This could further depress performance by reducing nutrients assimilated over a given period of time. These postulated mechanisms are in no way mutually exclusive (Campbell et al, 1986).

Soluble polysaccharides by virtue of their strong affinity for water, compete with proteins and amino acids for available water (Lewis, 1978). This competition for solvent depresses the solubility of proteins which may affect their rate of digestion, but probably have little other consequence (Lewis, 1978). A second interaction with soluble polysaccharides and proteins is a structure-specific physical association which drastically alters the physiochemical and biological properties of proteins (Lewis, 1978). Changing these physiochemical properties would undoubtedly effect protein absorption. Soluble fibre may also interfere with the normal digestive and absorptive pathways of protein (Cummings, 1978). It has been reported that in vitro activity of trypsin and chymotrypsin can be inhibited by various plant fibres (Schneeman, 1977).

Soluble gums such as B-glucans can also reduce the amount of fat absorbed from the small intestine (Campbell et al, 1983a). Malabsorption in the case of fat can be very severe, which may relate to particle size and restraints upon free diffusion imposed by the solubilized gums (Campbell et al, 1986). Thus fat, which exists in the gut lumen as micelles, can form a large conglomerate. These constraints

on diffusion are correspondingly greater than for free sugars, oligosaccharides, amino acids, or peptides (Campbell et al, 1986). One consequence of fat malabsorption may be related to inadequate bone mineralization and leg problems, which may be derived from interference with the absorption of fat soluble vitamin D₃ (Campbell et al, 1983b). The presence of unabsorbed free fatty acids may also compound the problem by complexing dietary calcium and further reduce its availability for bone deposition (Campbell et al, 1983b). Classen et al, (1985) postulated that the reduced tibia ash in chicks fed hullless barley may reflect inadequate vitamin D₃ absorption due to inadequate micelle formation and/or excessive calcium loss via soap formation from undigested fat.

A reduction in fat absorption may also be caused from solubilized gums binding to bile acids and/or cholesterol. One of the main functions of bile salts is to emulsify fats so they in turn can be attacked by lipases (Maynard et al, 1979). When bile acids are bound by fibre, it may decrease their return to the enterohepatic circulation, which indirectly causes a cessation in fat digestion (Burzak and Kellog, 1979). Although it was once thought that bile acids were only bound by lignin (Eastwood and Hamilton, 1968), other researches have found bile acids may also be bound to pectin (Leveille and Sauberlich, 1966; Normand et al, 1979), rice pentosans (Normand et al, 1979), cellulose, hemicellulose and possibly B-glucans (Story and Kritchevsky, 1976; Classen et al, 1985). Normand et al (1979) found that gum polysaccharides had a high binding capacity to deoxycholate and chenodeoxycholate bile acids. Apparently the deconjugation and

dehydroxyl action of bile acids by the thriving intestinal micro-flora promotes their binding to dietary fibre (Antoniou, 1980). Kritchevsky and Story (1974) demonstrated in vitro that bile acid binding is not always hydrophobic as originally suggested but varies with the type of polysaccharide. Non-cellulosic polysaccharides, especially the mucilaginous and gel forming materials are much more effective bile acid adsorbents than cellulose (Kay and Strasberg, 1978).

Cholesterol can also have an effect on fat absorption and metabolism, since it serves as a precursor for bile acids, and it is an essential component of lipid-carrying moieties of the blood (Maynard et al, 1979). Fahrenbach et al (1966) demonstrated the hypocholesterolemic effect of 16 mucilaginous polysaccharides fed to Leghorn Cockerels, using a 3% casein-sucrose based diet containing 3% cholesterol. Oat fractions rich in soluble fibres (B-glucans) have been shown to lower serum total and low-density lipoprotein cholesterol while increasing high density lipoprotein cholesterol in humans and rats (Kirby et al. 1981; Anderson et al. 1984). This cholesterol lowering effect may be related to the increased fecal loss of fat, including bile salts and dietary cholesterol. Pectin and scleroglucan (B1->3 glucans) have been shown to reduce weight gains and blood cholesterol levels in chicks with concomittant increases of fecal lipid and sterol output (Griminger and Fisher, 1966). The chemical dissimilarities of these two carbohydrates suggests their physical properties rather than their chemical properties are responsible for this effect (Griminger and Fisher, 1966). Qureshi et al. (1980) found that soluble polysaccharides in barley can suppress the activity of B-hydroxy-B-methylglutaryl-CoA reductase (the rate

limiting enzyme in the biosynthesis of cholesterol) in chicken liver and reduce the concentration of cholesterol in liver and blood plasma.

In addition to direct effects of B-glucan gums on nutrient digestion, there appear to be secondary effects attributable to higher levels of microbial activity (Campbell et al, 1986). This likely arises as a consequence of slowed passage, which further impairs the ability to translocate endogenous bacteria down the digestive tract, resulting in intestinal overgrowth (Campbell et al, 1983b). It has been established that chicks fed barley or rye give a greater response to antibiotics than those fed wheat or corn (Classen et al, 1985). Microbial activity has been found to be affected by very small changes in the carbohydrate fraction of the diet (Szyliit and Charlet, 1981). Moran and McGinnis (1965, 1966) showed that turkey poults improved growth and feed efficiencies when fed barley-based diets, supplemented with oleandomycin, bacitracin, or streptomycin. Vanhouny (1982) also demonstrated that antibiotics increased fat absorption when chicks were fed diets containing hullless barley, providing further evidence on the role of intestinal micro-flora in contributing to poor chick performance. The positive response to antibiotic supplementation maybe caused by altering the composition of the intestinal micro-flora by means of suppressing the growth of deleterious bacteria. This would result in less competition between the host animal and the bacteria for available nutrients (Marquardt et al, 1979).

Streptococcus faecum has been reported to have the capability of adhering to the gut wall, permitting a proliferation in the upper regions of the digestive tract (Campbell et al, 1983a). This capacity

as well as the reported ability to deconjugate bile salts (Coates et al, 1981) would enable Streptococci organisms to adversely affect digestive processes, since free bile acids do not participate optimally in micelle formation (Hoffman and Small, 1967). This would account for fat malabsorption as well as the rachitic response since cholicalciferol, being fat soluble, would tend to associate with the fat fraction of the diet (MacAuliffe et al, 1976). Campbell et al (1983a) established that *S. faecum* has the ability to degrade sodium taurocholate. They also found significant improvements in fat retention and tibia ash in broiler chicks when sodium taurocholate was added to rye diets. Undigested fat, as a result of microbial overgrowth may also affect amino acid retentions by indirectly reducing the susceptibility of other dietary components to enzymatic attack (Campbell et al, 1983b). The proliferation of bacteria as a result of gum polysaccharides invariably increases the microbial nitrogen requirements (Haurmuth-Hoene and Schwerdtfeger, 1979). As a result the animal nitrogen requirements (protein) would have to be increased.

B-glucan can also have deleterious effects on starch digestion in poultry. B-glucans in the cell walls of the endosperm and aleurone encapsulate easily available nutrients, such as starch, intracellular protein and fat, and act as a physical hinderance to nutrient hydrolysis and absorption within the small intestine (Campbell et al, 1986; Classen et al, 1985). Classen et al (1985) showed that starch absorption was lower in the small intestine of broilers when hullless barley was substituted for wheat. Marquardt et al. (1979) postulated that gum polysaccharides absorb and retain large volumes of water, which induces

swelling, causing a premature satiety feeling in the birds.

Insoluble B-glucans and other insoluble polysaccharides can also affect mineral metabolism by acting as cation exchangers (Antoniou, 1980). Pectins and a number of hemicelluloses (glucans included with glucuronic acids) can show weak ion-exchange capacities for positively charged minerals such as dietary calcium, zinc and magnesium (Kratzer et al, 1967). This would directly affect bone formation and enzyme metabolism. The cation exchange properties of gum polysaccharides are related to the free carboxyl groups in pectin and to a lesser extent in the hemicelluloses (Antoniou, 1980). In addition, insoluble B-glucans as well as other degradation products may bind or interact with toxins, minerals or microbes in the upper part of the gastrointestinal tract. This effect would be reduced in the large intestine where B-glucans can be rapidly fermented by the microbes.

F. B-Glucanase Supplementation for Broilers

It is well known that barley generally has a low nutritive value when fed to broiler chickens. This in part may be attributed to its content of B-glucans and their contribution to high viscosities (Hesselman and Aman, 1985, 1986). In addition feed barley may also cause reduced fecal dry matter contents and sticky feces (Gohl et al, 1978; Wood, 1983). A considerable reduction in the frequency of sticky droppings as well as improvements in feed intake, growth rate, and feed efficiency, has been obtained by adding exogenous enzymes to the diet (Hesselman et al, 1982; Campbell et al, 1986; Hesselman and Aman, 1986). These enzymes are capable of degrading B-glucan components (Wood, 1983). Hydrolysis of the glycosidic bonds of B-glucans can be carried out by

two B-gluconases; exogluconases and endogluconases. The former successively removes single glucose units from the non-reducing ends of the B-glucon chain, while the latter randomly hydrolyses the interior gluconosidic bonds of the B-glucons, liberating oligomers of lower molecular weight.

Research in the area of enzyme supplementation began as early as 1959, when researchers experimented with the use of α -amylases in broiler breeder chicken diets (Willingham et al, 1959). They found several preparations of crystalline α -amylases to be ineffective in improving the growth of chicks fed diets containing barley. They also found that adjusting the pH had no effect on chick growth and α -amylase content of crude enzyme preparations. The researchers concluded that normal intestinal conditions did not deactivate the enzyme preparation. Therefore further work will be needed to determine if other enzyme preparations can improve chick growth.

Positive growth responses in chicks fed barley with B-gluconase supplementation was first demonstrated by Rickes et al, (1962). In more recent studies (Mannion, 1981; Hesselman et al, 1981, 1982; White et al, 1981; Reese et al, 1983; Campbell et al, 1986; Hesselman and Aman, 1986) the uses of commercial B-gluconases in barley-based diets for broilers has been investigated in detail. Hesselman et al (1981) conducted experiments to evaluate the effects of various levels of B-gluconase inclusion on the productive value of broiler chicken diets containing barley harvested at two stages of ripeness. Live weight gains were improved at all levels of B-gluconase inclusion. Maximum gains were predicted to occur at an enzyme concentration of 0.25% of the diet,

giving a 20% predicted improvement over the control at 14 days and a 22% predicted improvement at 21 days. Feed consumption and feed to gain ratios were affected in a manner similar to that of weight gains. Dry matter contents of the excreta were also increased by enzyme supplementation (Hesselman et al, 1981, 1982). Hesselman et al (1981) also reported that early yellow ripeness (EYR) barley not only had a higher acid extract viscosity than combine ripeness (CR) barley, but also depressed chick performance to a greater degree. Aastrup (1979b) found a decreased solubility of B-glucans with maturity, with a subsequent reduction in extract viscosity. These improvements in growth are in agreement with results obtained by Mannion (1981). He found improvements in body weight gains, feed intake and feed to gain ratio when broilers were fed barley based diets supplemented with crude α -amylases from either bacterial or fungal origin, containing endoglucanase activity. When 0.30% of α -amylase was added to the diets, broiler feed consumption was improved by 7.0% and feed efficiency by 15%. There were no differences in broiler growth performance when the enzyme concentration was 0.15% vs. 0.30% ($P > 0.01$) and also no differences in response between enzymes of bacterial and fungal origin ($P > 0.01$). The concentration of excreta sugar, starch, and pentosan were all reduced when enzymes were incorporated into the diet, aiding in the explanation for improved growth. Metabolizable energy contents of the diets were significantly improved by both bacterial and fungal amylases, and could probably account for the improvement in nutrients retained within the bird.

White et al (1981, 1983) conducted research on the effect of

B-glucans on intestinal viscosities and the corresponding effects of B-glucanase supplementation. As with previous research, White et al (1981) showed that weight gains and feed to gain ratios in broilers was improved by 18% and 9.5%, respectively, when 400 mg kg⁻¹ of B-glucanase derived from *T. viride* was added to barley based diets. These researchers added barley B-glucan to a corn based diet (10 g kg⁻¹) to evaluate the effect of B-glucanase on the viscosity of B-glucans in the intestinal contents of the chick. The barley B-glucan increased the viscosity of the chick intestinal contents three fold and the B-glucanase preparation reduced the viscosity of the same diet to near control levels. This work is in agreement with subsequent studies by the same researchers (White et al, 1983), where they showed a 6.7 fold increase in intestinal viscosities with the addition of 2.0% hydroxyethyl cellulose, and a subsequent reduction in viscosities to near control levels when B-glucanase from *T. reesei* was added to corn-based broiler diets. Hydroxyethyl cellulose has physical properties similar to barley B-glucan (White et al, 1983). Along with a reduction in intestinal viscosities White et al (1983) further noted improved body weight gains and feed efficiencies when B-glucanase from *T. reesei* was added to a corn-based diet containing hydroxyethyl cellulose. This improved growth is probably a manifestation of reduced intrinsic intestinal viscosities (White et al, 1981). The enzymes derived from *T. reesei* and *T. viride* contain high activities of both exoglucanases and endoglucanases (NOVO Laboratories, 1984).

Hesselman and Aman (1986) reported that body weight gains, feed consumption and feed to gain ratios were all improved in broiler

chickens when supplemented with B-glucanase (0.5 g kg^{-1} GV-P, Grindsted Products, Denmark). Starch digestion was also improved throughout the total length of the small intestine in the presence of B-glucanase. The improvements in starch digestibility over the control was far greater with the high viscosity barley compared to low viscosity barley, when B-glucanase was supplemented to the diet. Nitrogen digestibility was improved upon B-glucanase supplementation in the latter two-thirds of the small intestine as well as in the colon. B-glucanases also improved B-glucan degradation in the small intestine as well as the ceca.

Campbell et al (1986) determined the effect of enzyme supplementation on broiler chick performance when fed different cultivars of barley that were obtained from different localities of Saskatchewan. The improvements in body weight gains following enzyme supplementation for the 12 cultivars of barley ranged from 2 to 25% over the control for the first three weeks. Corresponding improvements in feed to gain ratio ranged from 0% to 11.0%. Enzyme addition also had a very pronounced effect on reducing the variability in body weight gains and feed to gain among broilers fed the different cultivars of barley. Body weights in birds fed the unsupplemented diets ranged from 345-467 g which was much greater than that obtained when birds were fed diets containing enzyme (455-496 g). Likewise variations in feed conversions were less in the enzyme supplemented chicks (1.62-1.71) as compared to their unsupplemented counterparts (1.63-1.88) (Campbell et al, 1986). The variation in chick performance fed the different barley cultivars may be attributed to variations in their contents of B-glucan and its associated effects on the viscosity of the digesta. Campbell et al,

(1986) also found that when broilers were fed unsupplemented barley, days to market were prolonged by 4-5 days, compared to those fed a corn-wheat based diet. This difference was subsequently reduced to 1.5 days, when birds were fed enzyme supplemented barley. The reduction in days to market reduces the hours of labour per broiler produced, and may also give producers extra time for maintenance and may enable him to increase the number of cycles per year.

B-glucanase supplementation may not be needed throughout the total lifetime of a broiler, since the magnitude of response declines with age (Malic, 1965; Reese et al, 1983; Campbell et al, 1986). The actual age of broilers when enzyme supplementation may be withdrawn has yet to be determined. Rotter et al (1987) conducted an experiment to determine if the degree of growth response to enzyme supplementation of a barley (Scout) based diet was influenced by the duration of the feeding period. Enzyme treatment of the barley based diet produced dramatic improvements in broiler weight gains and feed efficiencies, and this affect was extended through the entire 6 week test period. Growth responses, however, during the 0-4 week period appeared to be greater than the 4-6 week period. Average relative improvements in broiler weight gains and feed to gain for the six week period were 11.2 and 8.5%, respectively.

Classen et al (1985) conducted a series of experiments to test the feeding value of hullless barley and also hullless barley supplemented with B-glucanases fed to broilers. These researchers reported a linear depression in broiler growth performance when hullless barley replaced hulled barley or wheat in the diet. The reduction in performance of broilers fed hullless barley versus hulled barley may be related to

differences in their content of B-glucans (Wong, 1978). Supplementation of the hulless barley diets with enzymes improved weight gains and feed to gain ratios in broilers by 9.2% and 4.2% respectively (Classen et al, 1985). Correspondingly, fat and starch absorption were increased by 15.3% and 5.3%, respectively. The improvements in fat and starch absorption helps explain the positive growth responses when broilers are fed hulless barley, supplemented with B-glucanase. Lincomycin did not significantly affect fat and starch absorption in broilers, when added to hulless barley diets and comparing it to enzyme supplemented hulless barley.

In summary, B-glucanase supplementation of barley-based diets promotes positive improvements in weight gains, feed consumption and feed to gain ratios of broilers during the early stages of growth (Malic, 1965; Campbell et al, 1986). The improvements in growth may be explained by an increase in fat absorption, starch and nitrogen digestion, as well as B-glucan degradation (Classen et al, 1985; Hesselman and Aman, 1986). B-glucanase supplementation of barley-based diets, may improve broiler growth and nutrient digestibility by reducing the water binding capacity of the B-glucans. This change would promote an increased rate of passage of digesta, which would enable broilers to increase feed intake and thereby increase rate of growth. Enzyme supplementation may also improve nutrient digestibilities by increasing their availabilities to enzyme hydrolysis and absorption (Hesselman et al, 1982). The lack of supplemental B-glucanase to barley-based diets allows the organization of B-glucans within the aleurone region of the cell walls to act as a physical hinderance for nutrient hydrolysis and

absorption (Hesselman and Aman, 1986): Enzyme when added to barley based diets will degrade B-glucans, causing a reduction in molecular weights (DeSilva et al, 1983). This reduction in molecular weights will cause a decline in intestinal viscosities, which enhances nutrient absorption (Burnett, 1966). A substantial reduction of intestinal viscosities has been known to improve the dry matter contents of the digesta, when broilers are fed enzyme supplemented barley (Hesselman and Aman, 1986). Enzyme supplementation may also stimulate broiler growth by decreasing excessive populations of deleterious intestinal microbes. These intestinal microflora can compete with the host animal for available nutrients and thereby reduce broiler growth (Marquardt et al, 1979).

G. B-Glucanase Supplementation for Laying Hens

Since broiler experiments with the supplementation of B-glucanases to barley-based diets indicate that younger birds seem to be more sensitive to the effects of enzyme, it is not surprising that their effect on laying hen production be only minimal (Campbell et al, 1986). In fact, laying hens fed barley alone generally give results no different from that obtained with wheat or corn diets (Campbell et al, 1986). Thus if there is no problem to correct, it is not likely that any substantial benefit will ensue from enzyme addition. Campbell et al (1986) reported that laying hens fed hulless or hulled barley had egg production levels which were slightly higher, but not significantly different from hens fed a wheat-based diet. When B-glucanases were added to hulless barley, egg production increased only slightly (2.0%) over the control. This work is in agreement with Berg (1961), who also

found no improvements in egg production when layers were fed barley supplemented with B-glucanases. Berg (1961), however, reported that body weight gains were significantly improved ($P < 0.05$, 10%) over the control up to eight weeks of age, when pullets were fed this same enzyme supplemented diet. Again, enzyme supplementation of barley-based diets may only be beneficial for young birds, in a manner similar to that obtained with broilers. Therefore, the only benefit of feeding laying hens enzyme-supplemented barley-based diets, may lie in the fact that cages and birds would be cleaner, due to an improvement in the dry matter of the feces (Gohl et al, 1978). The effects of B-glucanase, however, are not to be completely ruled out as the above authors did not establish the level of B-glucans in the different barley-based diets nor did they relate viscosity of the diet to performance values.

H. B-Glucanase Supplementation for Turkeys

Campbell et al (1986) reported that enzyme supplementation of barley-based diets improved turkey performance in a manner similar to that obtained with broiler chicks, although the response was less dramatic. As with broilers, the benefits in turkeys was most evident during the first 3-4 weeks of life, with less benefits occurring in older birds (Campbell et al, 1986). When diets containing a conventional hulled barley was supplemented with B-glucanase derived from *B. subtilis*, broiler turkey weight gains and feed to gain ratios were improved 8.8% and 7.0% over the control, respectively. During weeks 4 to 10, turkey growth was not affected by enzyme supplementation of hulled barley diets. Moran and McGinnis (1965) also demonstrated positive growth responses up to four weeks of age, when turkeys were fed

enzyme-supplemented barley. The relative improvements in weight gain and feed to gain ratios of turkeys fed enzyme-supplemented barley up to four weeks of age were 12.0% and 4.0%, respectively. However, in contrast to Campbell et al, (1986), Moran and McGinnis (1965) obtained significant improvements in weight gain (13.0%) and feed to gain (3.2%) over the control, when turkeys were fed enzyme supplemented barley between 4 and 7 weeks of age. The concentrations of enzymes used by Campbell et al, (1986) were not disclosed, while Moran and McGinnis (1965) used 110 mg kg^{-1} of enzyme in the starter diets (0-4 weeks) and 220 mg kg^{-1} in the grower diets (4-7 weeks). Thus increasing concentrations of enzymes in the grower diet compared to the starter diet may have had a beneficial effect.

These observations suggest that growing turkey poults can be also adversely affected by B-glucans present in barley-based rations. Reductions in weight gains and feed efficiencies may be attributed to increased intestinal viscosities, with a subsequent reduction in nutrient absorption (Campbell et al, 1986). Poults growth and presumably nutrient absorption can be substantially enhanced when B-glucanases are supplemented to barley based rations.

I. Objectives of the Current Study

The existing studies demonstrated that the nutritive value of barley can be effectively improved with the supplementation of enzyme preparations. Previous research, however has not examined a variety of commercially available enzyme preparations and their effectiveness when used in poultry diets. The objectives of the experiments described herein were designed to examine the following questions, namely to:

1. Identify the most effective enzyme preparation for the enhancement of the nutritive value of barley. Several enzyme preparations of fungal origin were to be compared.
2. Establish the relative sensitivity of broiler and Leghorn chicks to the effects of selected B-glucanases when added to barley based diets.
3. Establish the effects of enzyme supplementation when added to barley-based diets that have different concentrations of B-glucans and different intrinsic viscosities.
4. Establish if the degree of growth response to enzyme supplementation of a barley-based diets for broilers was influenced by the duration of the feeding period.

MATERIAL AND METHODS

A. Formulation of Diets and General Procedures

Diets for the Single Comb White Leghorn (SCWL) cockerels were formulated to meet the minimum requirements in Scott et al (1982), while broiler diets were formulated to meet the minimum NRC (1984) requirements. When broilers and SCWL were used in the same experiment, diets were formulated to meet the minimum NRC (1984) requirements for broiler chicks.

All diets were fed in mash form, and contained the same vitamin and mineral premixes, added at 1.00% and 0.35% of the diets, respectively (Tables 4 and 5). Feed and water were available ad libitum. Chromic oxide was added to all vitamin and mineral premixes (3 g kg^{-1}) in all short term studies.

Feed consumption, weight gain and feed gain⁻¹ data given in this thesis are reported on a per bird basis and were calculated in the following manner:

$$\text{weight gain per bird} = \frac{\text{final pen weight}}{\text{number of birds alive in pen}} - \frac{\text{initial pen weights}}{\text{number of birds in pen}}$$

$$\text{feed consumption per bird} = \frac{\text{initial feed plus feed added} - \text{feed remaining plus feed spilled}}{\text{number of birds per pen (six)}}$$

Feed to gain ratio per pen was calculated by dividing feed intake per bird by bird weight gain.

If a mortality occurred early in a given time period, the dead bird was assumed not to have consumed any feed. If the mortality occurred after the second day of the experiment, the following correction method according to Rotter et al (1985) was applied for the feed consumption data: 1.) The number of days between feed weighings was determined and

Table 4 Standard Vitamin Premix

Ingredients	g kg ⁻¹ Premix
Vitamin A (500,000 IU g ⁻¹)	1.65
Vitamin D (40.9 million IU kg ⁻¹)	0.50
Vitamin E (40,000 IU kg ⁻¹)	27.25
Vitamin B ₁₂ (1.0 g kg ⁻¹)	1.15
Vitamin B ₅₈ (2-4-6-100) ¹	125.0
Menadione Sodium-Bisulfate (50%)	0.22
Niacin 98%	3.75
Choline Chloride 60% (521 g choline kg ⁻¹)	150.0
Folic Acid Pure	0.075
Biotin (20 g kg ⁻¹)	1.25
Delaquin 66.6% ²	18.75
Methionine - D.L. (99%)	50.0
Strep-Pen 100 (Pen. - 55 g kg ⁻¹ ; Strep. 165 g kg ⁻¹)	10.0
Amprol	50.0
Vegetable Oil	10.0
Wheat Middlings	550.405

¹Vitamin B₅₈ contains per kg:
 Riboflavin, 4.49 g
 Ca-Pantothenate, 8.8 g
 Niacin, 13.2 g
 Choline chloride, 220 g

²Delaquin (ethoxyquin) is an antioxidant which supplies hydrogen to the first free radical formed.

Table 5 Standard Mineral Premix

Ingredients	g kg ⁻¹ Premix
Manganese oxide (Mn, 60% Mn)	26.2
Zinc oxide (ZnO, 72% Zn)	19.85
Ferrous Sulfate (FeSO ₄ · H ₂ O, 31% Fe)	73.75
Copper Sulfate (CuSO ₄ · 5 H ₂ O, 25.2% Cu)	5.65
Sodium Selenite (0.02% · Se)	142.5
Iodized Salt (NaCl · KI, .007% I)	732.05

divided into the total feed consumed during that time period in that particular pen. This calculation would give an estimate of how much feed was consumed by the whole pen per day during that period. 2.) The number of days the dead bird was alive during that period was then determined. For this number of days minus two days, the feed per day for the pen was summed and divided by the number of birds alive prior to death. This procedure gives a feed per bird value for the time before the mortality. 3.) The pen consumption data for the days following death was then divided by the number of remaining birds to give a feed per bird per day value for the days following the mortality. 4.) The values of the feed per bird per day before and after death were then added to give an estimate of the feed consumed per bird during that time period. 5.) The amount of feed consumed per pen for a one week period could then be multiplied by seven days. This procedure was applied in experiment one and two.

All fecal material collected for the retention studies were collected three days before the last day of test. During this time fecal collection trays were lined with black plastic garbage bags, for ease of collection. This procedure was used in experiments one, two and three.

B. Chicks and Management: Short Term Studies (Experiments 1-3)

One-day old chicks were purchased from a commercial hatchery and housed in electrically heated, thermostatically controlled Jamesway batteries with raised wire floors and provided with continuous lighting for the first seven days. The room and battery temperatures were 21°C and 32°C, respectively. All chicks were fed commercial chick starter

crumbles containing a minimum of 21% protein for the first seven days of life. SCWL chicks were used in the first three experiments. Broiler chicks were used in Experiment two.

All short term experiments were completely randomized in design. At seven days of age, immediately prior to the start of the experiment, chicks were starved for a four h period to decrease gastro-intestinal tract fill. Also two h prior to randomization, fluorescent lights were shut off to help calm the birds. Birds were then individually weighed and placed into several weight range groups. Birds were randomly selected from the median weight range groups in such a manner that the initial pen weights were the same and so that weight variation among birds was minimal. In experiment three, initial pen weights with SCWL differed from broilers, but within each strain, weights were the same. The number of treatments varied between experiments and will be discussed separately.

Birds on test were housed in Petersime battery brooders with continuous light and heat. The battery and room temperatures during the 14 day experimental period were 32°C and 21°C, respectively. During and at the end of an experiment, prior to pen weights being taken, the birds were starved for a four h period.

C. Chicks and Management: Long Term Broiler Study (Experiment 4)

Day old, vaccinated (Mareck's) male broiler chicks of a commercial (Cobb and Arbor Acre) parentage were used in Experiment 4. Management procedures were as described in Mollison (1983). The birds were raised from day old in 1.54 x 4.31 m floor pens with a stocking rate of 9 birds m^{-1} (0.11 m^2 per bird) 60 birds pen^{-1} . All pens were located in an

environmentally controlled barn that provided continuous (24 h) lighting at an intensity of about five lux at the level of the feeder. The temperature was regulated so that birds were exposed to 35°C for the first week, using small canopy brooders with heat lamps. Thereafter, temperatures were lowered approximately 3°C per week by raising the brooder, removing one or two of the bulbs and eventually removing the brooder when the desired temperature was reached (21°C). For the first four days, each pen was provided with a floor-type trough feeder. From four days of age until the end of the trial, feed was available from tube-type feeders (2 per pen, 40 cm diameter). Water was available from a 15 cm diameter cup waterer.

Daily management procedures included stirring and inspecting litter, shaking down feeders, dusting equipment and culling birds. Mortality occurring during the first three days of the experiment were replaced by spare birds. Subsequent mortalities were recorded by pen number, treatment number, wingband number and dead weights and submitted for necropsy. Weight gains and the feed gain⁻¹ ratio were corrected for mortalities.

D. Source and Description of Feed Ingredients

The enzymes used in this study were T.v. Cellulase, Pectinex, Celluclast, and SP-249. All enzymes used in this thesis contain activities as described by the suppliers. Cellulase T.v. concentrate (Miles Laboratories, Inc. Elkhart, IN), was obtained by the controlled fermentation of *T. viride* and has enzyme activity that specifically hydrolyzes the B-1-4 glucosidic bonds of cellulose, its oligomers and derivatives. This enzyme is added as an amorphous dry powder. Pectinex

(NOVO A/S, Denmark), is a partially purified enzyme preparation produced from a selected strain of *A. niger*. Pectinex contains pectin-transesterase, polygalacturonase, pectinesterase and hemicellulases which are capable of breaking down pectic substances in plant material. Pectinex which has a density of 1.2 g ml^{-1} , was added in liquid form. Cellulast (NOVO A/S, Denmark), is a cellulase preparation derived from the fermentation of selected strains of the fungus *T. reesei*. Cellulast may be characterized by its content of exo-activities (cellobiohydrolase, and exo-1,4-beta D-glucosidase) as well as an endo-activity (endo-1,4-beta D-glucanase). This enzyme was obtained in the liquid form and has a density of 1.2 g ml^{-1} . SP-249 (NOVO A/S, Denmark), is an enzyme preparation from a selected strain of *A. niger*. Besides containing high activities of B-glucanases, this preparation also contains proteolytic, hemicellulolytic, and pectolytic activities. SP-249 attacks most vegetable tissues by endo- and exo-hydrolysis of the glucosidic bonds of cellulose, hemicellulose, and branched pectic substances. Low molecular carbohydrates are produced by this action. This enzyme is also in liquid form and has a density of 1.2 g ml^{-1} .

The four cultivars of barley used in these studies were; Minerva (hulled), Scout (hulless), Tupper (hulless) and Bedford (hulled). Minerva, Scout, and Tupper were chosen for use due to their high but variable content of soluble B-glucan (Table 3). Bedford barley was chosen for the long-term broiler study, because of its availability. Tupper barley was also used in the preliminary experiments where 15 enzyme preparations were tested.

The barley used for this research was obtained from the following regions; Minerva barley - grown under dry land conditions near Bozeman, Montana USA, courtesy Dr. C.W. Neuman; Scout barley - mid-eastern Saskatchewan; Tupper barley - Brandon, Manitoba; Bedford barley - Glenlea, Manitoba.

E. Analysis

Fat concentrations in the diet and excreta were determined by the method of Marchello et al. (1971). Chromic oxide was determined following the procedure of Williams et al. (1962). Dry matter and crude protein (N x 6.25) were determined as described in AOAC (1984). The AOAC procedure numbers for dry matter and crude protein were, 7.003 and 7.015, respectively. Energies were determined using adiabatic oxygen bomb calorimetry. Nutrient retention was calculated as described by Marquardt et al. (1979). Chemicals used in the lab analysis were from Fisher Scientific, Winnipeg.

Analysis of variance was conducted for all data using the general linear models procedure (GLM) of the Statistical Analysis System (SAS Institute, Inc., 1985). Tukey's tests and selected linear contrasts were used for multiple comparison of means.

Effects of Feeding Three Enzyme Preparations on the Performance of Leghorn Chicks Fed a Hulless Barley.

Experiment 1 was designed to compare effects of three enzyme preparations at three concentrations, on feed consumption, body weight gains, feed to gain ratio and the retentions of dry matter, fat, and protein in Leghorn chicks when fed hulless barley (Tupper). The three enzyme preparations used were Celluclast, T.v. Cellulase, and Pectinex. Concentrations used were, 0.0%, 0.05%, 0.10%, and 0.2% of the hulless barley inclusion. Celluclast and Pectinex were added in liquid form and corrected for density, while T.v. cellulase was added in powder form.

Three hundred and ninety-six SCWL male chicks were randomly distributed among eleven treatments. There were six birds per replicate and six replicates per treatment. The 11 treatments were as follows: (1.) wheat control (Table 6), (2.) (Tupper) hulless barley control, (3.) barley plus 0.05% T.v. Cellulase, (4.) barley plus 0.10% T.v. Cellulase, (5.) barley plus 0.20% T.v. Cellulase, (6.) barley plus 0.05% Celluclast, (7.) barley plus 0.10% Celluclast, (8.) barley plus 0.20% Celluclast, (9.) barley plus 0.05% Pectinex, (10.) barley plus 0.10% Pectinex, and (11.) barley plus 0.20% Pectinex. The wheat and barley control diets were outlined in Table 6. Birds were on test for 14 days and body weight gains and feed consumption values were determined on days 7 and 14 of the experiment. Dry matter, protein, and fat retentions were also determined.

The data was compared using linear contrast comparisons.

Table 6 SCWL Diets (Experiment 1)

Ingredients	Diet 1 Control, wheat- soybean diet (g kg ⁻¹)	Diet 2 Control, barley- soybean diet (g kg ⁻¹)
Tupper barley (hulless, 12.5%) ¹	-	640.0
Wheat (16.3%) ¹	640.0	-
Soybean meal (46.0%) ¹	201.0	225.0
Soybean concentrate (84.1%) ¹	-	26.0
Tallow	63.0	67.0
Vitamin premix	10.0	10.0
Mineral premix	3.5	3.5
Calcium carbonate	13.0	13.5
Calcium phosphate	13.5	12.0
Wheat middlings	53.0	-
Chromic oxide	3.0	3.0
Calculated Analysis		
ME ² (kcal/kg)	2849	2832
Protein, N x 6.25 (%)	20.5	20.5
Calcium (%)	.815	.808
Phosphorous (%)	.413	.416
Methionine (%)	.276	.291
Lysine (%)	.931	1.114
Methionine and Cystine (%)	.606	.583

¹Percent protein (N x 6.25)

²Metabolizable energy

EXPERIMENT 2

Effects of Three Levels of Enzyme Supplement in Broiler and Leghorn Chicks Fed Hulless Barley Diets.

This experiment was designed to compare the relative response in growth and nutrient retention in broilers and Leghorns when fed hulless barley (Scout) supplemented with Celluclast. Weight gain and feed consumption values were obtained after the chicks had been on test for one and two weeks. Energy and dry matter retentions were also determined. Celluclast at a concentration of 0, 0.10 and 0.20% was used, as this appeared on the basis of the previous study, to be the most effective concentration and the most effective enzyme among those compared.

One hundred and forty-four male SCWL and one hundred and forty four Cobb-Arbor Acre broiler chicks were separated and randomly distributed among four treatments, using six birds per replicate and six replicates per treatment for each strain. The four treatments were as follows: (1.) wheat control, (2.) barley control, (3.) barley plus 0.10% Celluclast, (4.) barley plus 0.20% Celluclast. The composition of the wheat and barley control diets are outlined in Table 7.

A split plot analyses was used to determine if there were any significant treatment differences between broiler and Leghorn growth performances between weeks one and two. Energy and dry matter retentions were also analyzed by a two and one way fixed affects annova.

Table 7 SCWL and Broiler Diets (Experiment 2)

Ingredients	Diet 1 Control, wheat- soybean diet (g kg ⁻¹)	Diet 2 Control, barley- soybean diet (g kg ⁻¹)
Scout barley (hulless, 14.6% ¹)	-	629.7
Wheat (13.6%) ¹	630.2	-
Soybean meal (44.3%) ¹	264.0	240.0
Soybean concentrate (84.1%) ¹	21.5	26.0
Tallow	37.0	58.0
Vitamin premix	10.0	10.0
Mineral premix	3.5	3.5
Calcium carbonate	14.9	15.4
Calcium phosphate	14.9	13.4
D.L. Methionine	1.0	1.0
Chromic oxide	3.0	3.0
Calculated Analysis		
ME ² (kcal/kg)	2950	2938
Protein, N x 6.25 (%)	22.03	22.03
Calcium (%)	0.90	0.90
Phosphorous (%)	0.45	0.456
Methionine (%)	0.43	0.40
Lysine (%)	1.21	1.15
Methionine and Cystine (%)	0.80	0.88

¹Percent protein (N x 6.25)

²Metabolizable energy

EXPERIMENT 3

Comparative Response Among Leghorn Chicks Fed Hulless and Hulled Barleys Supplemented with Enzyme.

This experiment was designed to determine the effects on SCWL performance when 1.) Celluclast is incorporated into diets containing hulless (Scout) or hulled (Minerva) barley. 2.) SP-249 is incorporated into diets containing hulless (Scout) barley. The enzyme concentrations used were 0.0%, 0.05%, 0.10%, and 0.20%. Parameters examined were weight gains, feed consumption, and feed to gain ratios during a 7 and a 14 day feeding trial. Dry matter retention were also determined.

Four hundred and thirty-two SCWL male chicks were randomly distributed among 12 treatments. There were six birds per replicate and 6 replicates per treatment. The 12 treatments were as follows:

(1.) wheat control, (2.) Scout control, (3.) Minerva control, (4.) Scout plus 0.05% Celluclast, (5.) Scout plus 0.10% Celluclast, (6.) Scout plus 0.20% Celluclast, (7.) Minerva plus 0.05% Celluclast, (8.) Minerva plus 0.10% Celluclast, (9.) Minerva plus 0.20% Celluclast, (10.) Scout plus 0.05% SP-249, (11.) Scout plus 0.10% SP-259, and (12.) Scout plus 0.20% SP-249. The wheat and barley control diets are presented in table 8.

All data in this experiment was analysed using linear contrast comparisons.

Table 8 SCWL Diets (Experiment 3)

Ingredients	Diet 1			Diet 2		Diet 3	
	Control, wheat- soybean diet (g kg ⁻¹)	Control, wheat- soybean diet (g kg ⁻¹)	Control, wheat- soybean diet (g kg ⁻¹)	Control, Scout- soybean diet (g kg ⁻¹)	Scout- soybean diet (g kg ⁻¹)	Control Minerva soybean diet (g kg ⁻¹)	Control Minerva soybean diet (g kg ⁻¹)
Wheat (12.84% ¹)	569.2	-	-	-	-	-	-
Scout barley (hulless, 14.2% ¹)	-	-	627.8	-	-	-	-
Minerva barley (hulled, 14.6% ¹)	-	-	-	-	-	624.4	-
Soybean meal (43.0% ¹)	329.2	-	240.0	240.0	-	222.8	-
Soybean concentrate (84.1% ¹)	-	-	15.0	15.0	-	24.0	-
Bran (15.8% ¹)	-	-	-	15.0	-	-	-
Corn Starch	-	-	-	-	-	27.0	-
Tallow	60.0	-	60.0	60.0	-	60.0	-
Vitamin premix	10.0	-	10.0	10.0	-	10.0	-
Mineral premix	3.5	-	3.5	3.5	-	3.5	-
Calcium carbonate	12.4	-	12.4	13.6	-	11.9	-
Calcium phosphate	12.7	-	12.7	11.6	-	12.9	-
Methionine	-	-	-	0.50	-	0.50	-
Chromic oxide	3.0	-	3.0	3.0	-	3.0	-
Calculated Analysis							
ME ² (kcal/kg)	3065		2946	2946		2934	
Protein, N x 6.25 (%)	21.45		20.77	20.76		20.76	
Calcium (%)	0.80		0.80	0.80		0.80	
Phosphorous (%)	0.40		0.40	0.40		0.40	
Methionine (%)	0.31		0.31	0.331		0.33	
Lysine (%)	0.958		0.958	1.039		1.078	
Methionine and Cystine (%)	0.620		0.612	0.612		0.60	

¹Percent protein (N x 6.25)

²Metabolizable energy

Effects of Feeding Bedford Barley Supplemented with Enzyme on Growth Performances of Broilers.

This experiment was designed to determine if the degree of response to enzyme supplementation of a barley-based (Bedford) diet for broilers was influenced by the duration of the feeding period.

Cobb-Arbor Acre male, broiler chicks (1800) were randomly distributed among five treatments. There were 60 birds per pen, and six pens per treatment and assigned to 30 floor pens. The five treatment groups were fed the following diets: (1.) wheat control, (2.) barley control, (3.) barley plus 0.10% Celluclast for the first two weeks, and then the barley control (diet 2) for four weeks. This is referred to as the two week enzyme treatment period. (4.) barley plus 0.10% celluclast for four weeks followed by the barley control diet for two weeks (four week enzyme treatment period). (5.) barley plus 0.10% Celluclast for six weeks (six week enzyme treatment period). Starter and finisher diets are given in Table 9 and Table 10, respectively. Starter diets were fed from 0-4 weeks of age and finisher diets from 4-6 weeks of age.

The birds were on test for six weeks and body weights and feed consumption values were determined after two, four and six weeks on test.

A split plot analysis was used to determine if there were any significant differences in broiler growth performance during the six week experiment period. Relative broiler body weight gains, relative feed consumption and feed to gain ratios were analysed using a one way fixed effects anova.

Table 9 Broiler Starter Rations (0-4 weeks) (Experiment 4)

Ingredients	Diet 1 Control, wheat- soybean diet (g kg ⁻¹)	Diet 2 Control, barley- soybean diet (g kg ⁻¹)
Wheat (13.6%) ¹	530.0	-
Bedford barley (hulled, 11.56% ¹)	-	536.6
Soybean meal (44.03%) ¹	333.7	327.6
Fish meal (71.5%) ¹	22.0	22.0
Tallow	70.0	70.0
Vitamin premix	10.0	10.0
Mineral premix	3.5	3.5
Calcium carbonate	16.2	16.9
Calcium phosphate	13.6	12.4
D.L. Methionine	1.0	1.0

Calculated Analysis

ME ² (kcal/kg)	3064	2905
Protein, N x 6.25 (%)	23.46	22.29
Calcium (%)	1.0	1.0
Phosphorous (%)	0.45	0.45
Methionine (%)	0.51	0.50
Lysine (%)	1.36	1.30
Methionine and Cystine (%)	0.85	0.88

Actual Analysis

Protein, (N x 6.25)	24.94	23.01
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¹Percent protein (N x 6.25)

²Metabolizable energy

Table 10 Broiler Finisher Rations (4-6 weeks) (Experiment 4)

Ingredients	Diet 1 Control, wheat- soybean diet (g kg ⁻¹)	Diet 2 Control, barley- soybean diet (g kg ⁻¹)
Wheat (13.6%) ¹	639.5	-
Bedford barley (barley, 11.56% ¹)	-	642.7
Soybean meal (44.03%) ¹	248.0	245.0
Tallow	70.0	70.0
Vitamin premix	10.0	10.0
Mineral premix	3.5	3.5
Calcium carbonate	16.2	16.0
Calcium phosphate	11.8	11.8
D.L. Methionine	1.0	1.0
Calculated Analysis		
ME ² (kcal/kg)	3126	2930
Protein, N x 6.25 (%)	19.52	18.3
Calcium (%)	0.90	0.90
Phosphorous (%)	0.40	0.40
Methionine (%)	0.425	0.425
Lysine (%)	1.00	0.97
Methionine and Cystine (%)	0.72	0.70
Actual Analysis		
Protein, (N x 6.25)	20.75	19.7

¹Percent protein (N x 6.25)

²Metabolizable energy

RESULTS

Experiment 1

The first experiment was designed to compare the effects on chick performance and nutrient retentions of three enzyme preparations when added at three concentrations to a barley (Tupper) based diet. Individual values are presented in Table 11 and linear contrast comparisons of interest are given in Table 12. In general, enzyme concentrations (.05, 0.10 or 0.2%) did not affect ($P > 0.05$) weight gains, feed consumption or feed to gain ratios except for those few comparisons shown in the footnote of Table 12. Also no consistent patterns were established in the comparisons that were different ($P < 0.05$).

All three enzymes, when added to barley, decreased ($P < 0.05$) feed to gain ratios, with the most dramatic effect being obtained with Celluclast and T.v. Cellulase (Tables 11 and 12) compared to those fed the barley control.

Celluclast, however, was the only enzyme that significantly ($P < 0.05$) improved feed consumption (5.1%) and weight gains (11.5%). Also, among enzymes Celluclast improved ($P < 0.05$) weight gains and feed consumption to a greater degree than the other two enzymes while Celluclast and T.v. Cellulase most effectively improved the efficiency of feed utilization. Weight gain, feed consumption and efficiency of feed utilization of chicks fed barley diets treated with Celluclast were superior to those obtained with chicks fed the wheat-based diet. In addition, when chicks were fed barley-based diets, supplemented with

Table 11 Performance and Retention of Nutrients of Leghorn Chicks when Fed Barley-Based (Tupper) Diets Containing Three Concentrations of Three Different Crude Enzyme Preparations (Experiment 1)

Cereal	Enzyme	Conc. (%)	14 Day Period			Retention of Nutrients		
			Weight Gain (g)	Feed Consumption (g)	Feed to Gain Ratio	Dry Matter (%)	Fat (%)	Protein (%)
1	Wheat (Control)	0	118.0	239.0	2.02	71.5	87.2	85.1
2	Barley (Control)	0	115.0	238.0	2.07	68.3	85.0	81.3
3	Barley	Cellulase T.V.	122.0	239.0	1.96	72.3	89.3	83.7
4	Barley	Cellulase T.V.	122.0	241.0	1.97	72.4	88.7	84.0
5	Barley	Cellulase T.V.	120.0	234.0	1.96	72.1	88.1	84.8
6	Barley	Cellulclast	126.0	245.0	1.95	69.4	86.2	88.2
7	Barley	Cellulclast	134.0	255.0	1.91	70.8	86.9	86.5
8	Barley	Cellulclast	127.0	251.0	1.98	70.0	88.1	83.6
9	Barley	Pectinex	119.0	248.0	2.08	71.8	86.7	81.6
10	Barley	Pectinex	120.0	241.0	2.02	73.8	88.4	86.9
11	Barley	Pectinex	122.0	239.0	1.96	73.4	89.6	83.3
SE			2.3	4.4	0.02	0.3	0.3	0.9

Table 12 Selected Linear Contrasts for Growth Performance and Nutrient Retention of Leghorn Chicks Fed Barley Based Diets Supplemented with Enzymes (Experiment 1)

Contrast ¹	Percent Increase or Decrease Relative to Second Comparison									
	14 Day Period					Nutrient Retention				
	Weight Gain	Feed Consumption	Feed to Gain Ratio	Gain Ratio	Dry Matter	Fat	Protein	Dry Matter	Fat	Protein
BTV-B	4.9**	0.2*	-4.9**	6.8**	4.3**	3.5**	6.8**	4.3**	3.5**	3.5**
BCELL-B	11.5**	5.1	-5.8	2.6**	2.3**	5.9**	2.6**	2.3**	5.9**	5.9**
BPEC-B	3.9	1.7	-2.1	6.8**	3.7**	3.2**	6.8**	3.7**	3.2**	3.2**
W-B	2.4	0.4	-2.3*	4.7**	2.5**	4.7	4.7**	2.5**	4.7	4.7
BTV-W	2.5**	-0.3*	-2.7**	1.9**	1.7	-1.1	1.9**	1.7	-1.1	-1.1
BCELL-W	8.9	4.8	-3.7	-2.0**	.2*	1.2	-2.0**	.2*	1.2	1.2
BPEC-W	1.4**	1.5**	0.1	2.0**	1.2**	-1.4*	2.0**	1.2**	-1.4*	-1.4*
BTV-BCELL	-5.9	-5.2	1.0**	4.0	1.9	-2.3	4.0	1.9	-2.3	-2.3
BPEC-BTV	-1.0	1.9*	2.9**	-.1**	-0.5**	0.3**	-.1**	-0.5**	0.3**	0.3**
BPEC-BCELL	-6.8	-3.2*	4.0	4.0	1.4	-2.5	4.0	1.4	-2.5	-2.5

* P<0.05

** P<0.01

¹B = barley; W = wheat; BTV = barley (T.v. cellulase); BCELL = barley (cellulase); BPEC = barley (Pectinex). Contrasts of enzyme concentrations that were significantly different are: BCELL (0.10%) - BCELL (0.05%), 6.3% (P < 0.0298) for weight gain; BCELL (0.20%) - BCELL (0.10%), 3.7% (P < 0.0315) and BPEC (0.20%) - BPEC (0.05%), 5.8% (P < 0.0004) for feed to gain. All other Contrasts of enzyme concentrations for growth performance were not significant (P > 0.05).

T.v. Cellulase, feed to gain ratios were superior ($P < 0.05$) to those obtained when chicks were fed a wheat-based diet. Other comparisons of performance data between wheat and enzyme treated barley diets were not significantly different ($P > 0.05$). Dry matter, fat, and protein retention values were improved ($P < 0.05$) in the presence of all three enzymes with degree of improvement ranging from 2.3 to 6.8%. Among enzymes, T.v. Cellulase and Pectinex yielded similar retention values ($P > 0.05$) whereas Celluclast was generally less ($P < 0.05$) effective.

The retention of all nutrients in wheat fed birds was superior ($P < 0.05$) to that of barley-fed birds (Tables 11 and 12), whereas similar comparisons between diets yielded no significant differences ($P > 0.05$) in the three performance values. Enzyme additions to the barley-based diets, yielded dry matter retention values that were superior ($P < 0.01$) to the wheat-fed birds for all T.v. Cellulase and Pectinex. Leghorns fed Celluclast plus barley, in contrast, had lower ($P < 0.05$) dry matter retentions than those fed the wheat diet. Fat retentions was also greater ($P < 0.05$) in birds fed the barley based-diets containing either T.v. Cellulase or Pectinex, compared to those fed the wheat-based diet. Similar comparisons for protein retention were not significantly different ($P > 0.05$).

RESULTS

Experiment 2

The objectives of experiment two was to compare the response in growth and nutrient retentions in broiler and Leghorn chicks fed barley supplemented with Celluclast. The hullless barley, Scout, was chosen, as it has a higher content of soluble B-glucan than Tupper (Table 3) and therefore should respond to enzyme treatment to a greater degree.

Analysis of variance of the barley data (Table 13) demonstrated several main effects for bird-type and diet and one two-way interaction; week x bird-type interaction for feed to gain. A summary of the significant data is presented in Table 14.

Relative weight gain was not affected by bird-type ($P > 0.05$), but was affected by diet (Table 14). The addition of Celluclast to the barley-based diet improved the average relative weight gains of Leghorn and broiler chicks by 11.0% ($P < 0.05$). The concentration of Celluclast (0.10 or 0.20%) did not affect growth performance ($P > 0.05$). Barley plus Celluclast also yielded broiler and Leghorn weight gains that were superior (10.0%) to those fed the wheat control.

The main effects for feed consumption demonstrated that broiler chicks consumed relatively less feed ($P < 0.05$) than Leghorn chicks (Table 14), while diet had no effect on feed consumption ($P > 0.05$).

The main effect for feed to gain indicates that both bird type and diet affected the feed to gain ratio (Table 14). With regards to diet, Celluclast improved the utilization of the barley diet by 7.0% (1.84 vs. average of 1.69 plus 1.72, Table 14). This value was also 8.0% better

Table 13 Analysis of Variance of Relative Performance Data of Broilers and Leghorn Chicks Fed Diets Containing Hulless Barley (Scout) Supplemented with Celluciast (Experiment 2)

Source of Variation	Relative Weight Gain			Relative Feed Consumption			Relative Feed/gain			
	df	MS	P>F	df	MS	P>F	df	MS	P>F	
			% of total			% of total			% of total	
			S.S.			S.S.			S.S.	
<u>Main Plot Comparisons</u>										
Bird-type	1	0.0024	0.42	1.2	0.020	0.005	44.4	2.3644	0.0001	83.8
Diet	2	0.0966	0.0001	95.2	0.006	0.071	28.6	0.1533	0.0001	10.9
Diet x Bird-type	2	0.0006	0.84	0.6	0.005	0.12	22.7	0.0032	0.529	0.2
Pen (Diet x Bird-type)	30	0.0037			0.002			0.0049		
<u>Sub Plot Comparisons</u>										
Week	1	0.0003	0.68	0.2	0.0011	0.26	2.4	0.0006	0.69	0.02
Week x Bird-type	1	0.00005	0.87	0.02	0.00005	0.80	0.1	0.1272	.0001	4.5
Diet x Week	2	0.0025	0.29	2.5	0.0003	0.67	1.5	0.0059	0.16	0.4
Diet x Week x Bird-type	2	0.0002	0.88	0.2	0.00005	0.95	0.2	0.0021	0.51	0.1
Pen (Diet x Week x Bird-type)	30	0.0019						0.0030		

Table 14 Comparative performances of Broilers and Leghorn Chicks Fed Hulless Barley (Scout), Supplemented with Celluclast (Experiment 2)

<u>Source of Variation</u> ¹	<u>Relative Weight Gain</u> ²	<u>Relative Feed Consumption</u> ²	<u>Absolute Feed to Gain</u>
<u>Bird Type</u>			
Leghorns	1.08 ^a	1.03 ^a	1.93 ^a
Broilers	1.07 ^a	1.00 ^b	1.57 ^b
SE	0.01	0.01	0.01
<u>Diet</u>			
Wheat	1.01	1.01	1.85
Barley	1.00 ^b	1.00 ^a	1.84 ^a
Barley Plus 0.10% Celluclast	1.11 ^a	1.02 ^a	1.69 ^b
Barley Plus 0.20% Celluclast	1.11 ^a	1.03 ^a	1.72 ^b
SE	0.01	0.01	0.02

¹There was a week x bird-type interaction for feed to gain (P < .0001). The individual values for week x bird-type were; 1.97 for Leghorns - WEEK 1, 1.89 for Leghorns - WEEK 2, 1.52 for broilers - WEEK 1, 1.61 for broilers - WEEK 2.

²All weight gain and feed consumption values in this table are reported relative to the barley control (1.00). The absolute overall weight gains for chicks fed the control barley diets were 125.2 g for Leghorns and 347.3 g for broilers. Corresponding feed consumption values were 250.6 g and 588.7 g and feed to gain ratios of 2.00 and 1.68.

^{ab}Means in the same column with different superscripts are significantly different (P < .05).

than that obtained with the wheat diet. Broiler chicks were considerably more efficient (23%, $P < 0.0001$) at utilizing the diets than Leghorn chicks.

There was a week x bird type interaction for the feed to gain ratio. This interaction was considered biologically insignificant as it accounted for only 4.5% of the total sum of squares (S.S) (Table 13), whereas bird type accounted for 83.8% of the total S.S.

Analysis of variance (Table 15) demonstrates that both dry matter and energy retention values are affected by bird type ($P < 0.0001$), diet ($P < 0.0001$), and a bird type x diet interaction ($P < 0.0001$ and $P < 0.001$), respectively. Most of the total S.S. for dry matter and energy retention can be attributed to the diet effect (63.0 and 73.0%; respectively) and a smaller but equal variations for bird-type and diet x bird-type interactions. A summary of the data is presented in Table 16. The interaction between bird-type x diet may be attributed to greater improvement in the retention of nutrients in broilers as compared to Leghorns when barley-based diets were treated with enzyme. For example, the addition of 0.2% Celluclast to the barley-based diets improved dry matter and energy retention values by 5.9 and 11.8%, respectively in broilers, while corresponding values for Leghorn chicks were 4.3 and 6.3%. The retention values for barley plus 0.2% Celluclast were either the same or higher than the corresponding wheat diet. One Leghorn chick died during this study.

Table 15 Analysis of Variance of Nutrient Retention in Broilers and Leghorns Fed Hulless Barley (Scout) Supplemented with Celluclast (Experiment 2)

Source of Variation	Dry Matter		Retention		Energy		Retention	
	df	MS	P>F	% of total S.S.	MS	P>F	% of total S.S.	
Bird-type	1	16.5	.0001	18.0	26.8	.0001	16.0	
Diet	3	18.6	.0001	63.0	40.8	.0001	73.0	
Diet x Bird-type	3	5.5	.0001	19.0	5.8	.0013	11.0	
Pen (Diet x Bird-type)	24	0.4			0.7			

Table 16 Retention of Nutrients of Leghorn and Broiler Chicks when Fed a Barley-Based (Scout) Diet Supplemented with Celluclast (Experiment 2)

Cereal	Enzyme	Conc. (%)	Dry Matter Retention (%)		Energy Retention (%)	
			Broilers	Leghorns	Broilers	Leghorns
Wheat (Control)	-	0	67.7 ^b	68.5 ^b	71.0 ^b	72.6 ^{cb}
Barley (Control)	-	0	64.5 ^c	67.7 ^b	65.9 ^c	70.9 ^c
Barley	Celluclast	0.10	69.4 ^a	68.9 ^b	72.8 ^{ab}	73.1 ^b
Barley	Celluclast	0.20	68.3 ^{ab}	70.6 ^a	73.7 ^a	75.4 ^a
	SE		0.36	0.28	0.39	0.47

^{abc} Means in the same column with different superscripts are significantly different (P < 0.05).

RESULTS

Experiment 3

The objectives of this study were to determine the effects of enzyme supplementation on the nutritional value of two cultivars of barley (Scout and Minerva) that contain a high content of total and soluble B-glucans. Individual values are presented in Table 17 and linear contrast comparisons of interest are given in Table 18. When comparing Scout, Minerva, and wheat with respect to growth performances, SCWL fed wheat-based diets produced significantly higher ($P < 0.01$) weight gains and lower ($P < 0.01$) feed to gain ratios than those fed Scout or Minerva (Table 18). Leghorns fed the wheat-based diet also produced significantly ($P < 0.01$) higher feed consumption values than those fed Minerva. SCWL fed Minerva showed significantly lower ($P < 0.01$) weight gains and a reduced efficiency of feed utilization ($P < 0.01$) than those fed Scout. When comparing Scout, Minerva and wheat with respect to dry matter retentions, SCWL fed Minerva produced dry matter retention values which were lower ($P < 0.01$) than those fed Scout or wheat. There were no differences ($P > 0.05$) in dry matter retentions between SCWL fed Scout or wheat.

Enzyme concentrations (0.05, 0.10, and 0.20%) did not effect weight gains, feed consumption, feed to gain ratios and dry matter retentions ($P > .05$), except for one comparison shown in the footnote of Table 18. Enzyme type had similar effects on chick performances (SCE11 - SSP, Table 18). However the addition of enzymes to the barley based diet at all three concentrations (averaged) improved ($P > 0.01$) weight gain, feed

Table 17 Performance and Retention of Nutrients of Leghorn Chicks when Fed Barley Based Diets Containing Three Concentrations of Two Different Crude Enzyme Preparations (Experiment 3)

Treatments		14 Day Period				
Cereal	Enzyme	(%) Conc.	Weight Gain (g)	Feed Consumption (g)	Feed/gain Ratio	Dry Matter Retention (%)
1	Wheat (Control)	0	128.0	267.0	2.08	69.0
2	Scout Barley (Control)	0	118.0	258.0	2.19	67.7
3	Minerva Barley (Control)	0	87.0	245.0	2.82	61.4
4	Scout Barley	0.05	130.0	261.0	2.01	71.3
5	Scout Barley	0.10	138.0	269.0	1.95	73.2
6	Scout Barley	0.20	138.0	269.0	1.95	-
7	Minerva Barley	0.05	123.0	265.0	2.16	68.5
8	Minerva Barley	0.10	124.0	263.0	2.12	69.6
9	Minerva Barley	0.20	126.0	271.0	2.14	-
10	Scout Barley	0.05	135.0	266.0	1.97	71.4
11	Scout Barley	0.10	135.0	265.0	1.96	71.6
12	Scout Barley	0.20	136.0	277.0	1.96	-
	SE		2.4	5.2	0.03	0.5

Table 18 Selected Linear Contrasts for Growth and Nutrient Retention of Leghorn Chicks Fed Barley Based Diets Containing Three Concentrations of Two Different Crude Enzyme Preparations (Experiment 3)

<u>Percent Increase or Decrease Relative to Second Comparison</u>				
Contrast ¹	Weight Gain	Feed Consumption	Feed to Gain	Dry Matter Retention
M - S	-26.3 **	-5.0	28.7 **	- 9.3 **
W - S	8.5 **	3.7	-5.5 **	1.8
W - M	47.2 **	9.0 **	-26.6 **	12.2 **
[(S+M) CELL] (0.2-0.05)	1.8	0.5	1.1	-
S (SP, 0.2 - SP, 0.05)	0.7	4.3	3.1	-
SSP - SCELL	-0.2	1.1	1.0	1.0
S (CELL + SP) - S	14.5 **	4.5	-9.9 **	6.1 **
MCELL - M	43.0 **	8.6 **	-24.5 **	12.3 **
MCELL - SCELL	-8.1 **	0.1	8.6 **	-4.4 **
W - S (CELL + SP)	-5.2 **	0.3	5.1 **	-4.0 **
W - MCELL	2.4	-0.3	-2.9	0.1

* P < .05

** P < .01

¹Contrasts: M = Minerva; S = Scout; W = Wheat; SCELL = Scout (Celluclast); MCELL = Minerva (Celluclast); SSP = Scout (SP-249); [S + M) CELL] (0.2 - 0.05) = Scout Plus Minerva (for 0.20% Celluclast) vs. Scout plus Minerva (for 0.05% Celluclast); S (SP, 0.20 - SP, 0.05) = Scout plus SP-249 at 0.20% Celluclast vs. Scout plus SP-249 at 0.05% Celluclast.

Contrasts of enzyme concentrations that were significantly different for dry matter retention are S (cell, 0.10%) - S (cell, 0.05), 2.6 (P < 0.03). Other comparisons among 0.05, 0.10, and 0.20% enzyme treatments were not significantly different (P > 0.05).

to gain ratios and dry matter retentions to a considerable degree, with the effect being greater ($P < 0.01$) with Minerva as compared to Scout barley. Feed consumption was not affected by enzyme treatment ($P > 0.05$) except in the case where Minerva was treated with Celluclast, the improvement being 8.6% ($P < 0.01$). All four performance values were similar to those obtained with the wheat-based diet when enzymes were added to Minerva barley. Additions of enzymes to Scout barley yielded SCWL weight gains, feed to gain ratios and dry matter retention values that were superior ($P < 0.01$) to those of wheat. Leghorn fed Scout treated with Celluclast showed superior final weight gains, efficiency of feed utilization and dry matter retention values than those fed Minerva treated with Celluclast. No mortalities occurred during this experiment.

RESULTS

Experiment 4

The objectives of this experiment was to determine if the degree of response to enzyme supplementation of a barley-based (Bedford) diet for broilers was influenced by the duration of the feeding period. When the data were analyzed using a split plot design, all diet x week interactions were non significant ($P > 0.05$), except for the feed to gain ratio ($P < 0.04$). This value only accounted for 1.3% of the total S.S. and was considered to be biologically insignificant (Table 19). These results show that enzyme supplementation of barley based diets did not have a differential effect over time on broiler growth performance.

A one-way fixed effects anova of the data over the six week period demonstrated that enzyme supplementation of the barley-based diet had no effect on relative weight gains, relative feed consumption and feed to gain ratios ($P > 0.05$, Table 20).

However, broilers fed the wheat diet had relative feed consumption and feed to gain values which were significantly lower ($P < 0.05$) than the barley control. Weight gains were not significantly different ($P > 0.05$).

There were a total of 100 mortalities throughout the experiment, with the mortalities being 21 (5.8%) for treatment 1, 18 (5.0%) for treatment 2, 15 (4.1%) for treatment 3, 23 (6.4%) for treatment 4, and 23 (6.4%) for treatment 5.

Table 19 Analysis of Variance of Relative Performance Data when Broilers Were Fed Enzyme Supplemented Barley (Bedford) (Experiment 4)

Source of Variation	Relative Weight Gain			Relative Feed Consumption			Relative Feed/gain				
	df	MS	P>F	MS	P>F	% of total S.S.	MS	P>F	MS	P>F	% of total S.S.
<u>Main Plot Comparisons</u>											
Diet	3	12.1	0.39	17.6	15.9	0.59	23.4	0.004	0.2024	0.004	0.4
Pen (diet)	20	11.5	-	-	14.8	-	-	0.0023	-	-	-
<u>Sub Plot Comparisons</u>											
Week	2	56.3	0.0005	54.5	28.2	0.046	27.6	1.338	0.0001	0.0001	98.3
Diet x Week	6	9.6	.1845	27.9	16.7	0.094	49.0	0.006	0.0383	0.006	1.3
Week x Pen (diet)	40	6.2	-	-	8.5	-	-	0.0023	-	-	-

Table 20 Growth Performance of Broilers Fed Barley (Bedford)
Supplemented with Enzyme (Experiment 4)

Cereal	Enzyme Treatment Period (weeks)	Overall Results		
		Weight Gain (%)	Relative Feed Consumption (%)	Feed to Gain Ratio
Wheat (Control)	-	99.6 ^a	93.8 ^b	1.78 ^b
Barley (Control)	-	100.0 ^a (1825 g) ¹	100.0 ^a (3596 g) ¹	1.90 ^a
Barley (Celluclast)	2	99.3 ^a	101.2 ^a	1.92 ^a
Barley (Celluclast)	4	101.3 ^a	102.2 ^a	1.92 ^a
Barley (Celluclast)	6	100.5 ^a	100.7 ^a	1.90 ^a
SE		.80	1.17	0.01

^{ab}Means in the same column with different superscripts are significantly different (P < 0.05).

¹Absolute overall values bracketed.

DISCUSSION

Enzymes containing high B-glucanase activities when added to barley containing diets enhanced the nutritive value of barley. Preliminary studies with 14 different enzyme preparations of mammalian, fungal and bacterial origin demonstrated that the most effective enzymes on the basis of improved growth performance were T.v. Cellulase (an extract of *T. viride*), Celluclast (an extract of *T. reesei*), and Pectinex (an extract of *A. niger*). (Rotter, 1987, Personal Communication, U. of M., Wpg., Man., Canada). In general, the mammalian enzymes were not as effective at improving Leghorn growth performances as those of bacterial and fungal origin. The three enzyme preparations of fungal origin used in these studies (T.v. Cellulase, Celluclast and Pectinex) not only improved weight gains and efficiency of feed utilization but also increased the retention of dry matter, fat, and protein. Celluclast additions to barley based-diets had the most dramatic effects on chick growth, while T.v. Cellulase and Pectinex most effectively improved the retention of nutrients, which included dry matter, protein and fat. Improvements in nutrient retentions which corresponded to improvements in growth parameters were also demonstrated in Experiments 2 (dry matter and energy) and Experiment 3 (dry matter), when either broilers or Leghorns were fed enzyme supplemented barley. The enhanced retention of nutrients concurrent with enzyme treatment suggests that enzymes have a direct effect on the nutritive value of barley which in turn results in an improved efficiency of feed utilization and rate of growth. Other researchers have reported improvements in nutrient retentions when

poultry were fed barley supplemented with B-glucanases (Hesselman and Aman, 1986; Gohl, 1978; DeSilva, 1983). Hesselman and Aman (1986) also found improvements in weight gains, feed to gain ratios, dry matter retention, and starch and nitrogen digestibilities, when Leghorns were fed high viscosity barley supplemented with B-glucanases. In addition, Gohl et al (1978) demonstrated that barley supplemented with B-glucanases increased fecal dry matter contents and reduced the incidence of sticky feces. The improved nutrient retention in the current studies may be explained on the basis of the ability of the B-glucanases to alter the cellular structure of barley (Hesselman and Aman, 1985) and physical characteristics such as solubility and molecular weight of the mixed linked B-glucans (DeSilva et al, 1983). DeSilva et al (1983) hypothesized that enzyme-induced disruption of the cell walls directly improved nutrient retentions.

Improvements in fat retentions in the current studies may be a direct result of the B-glucanases disrupting the B-glucan structure (Classen et al, 1985). In addition, B-glucanases dramatically improved protein retention in Leghorns (Experiment 1). Lewis (1978) found that soluble polysaccharides (B-glucans) may effect protein absorption and digestion by depressing the solubility of proteins and/or changing the physiochemical and biological properties of protein. B-glucanase supplementation in the current studies may have reduced the ability of the B-glucans to affect the solubility of proteins and also reduce their ability to change the biological properties of protein, thus enhancing protein retentions.

Improvements in energy retentions as a result of enzyme

supplementation (Experiment 2), may be a result of B-glucanases reducing the deleterious effects of B-glucans on starch and fat utilization. Potter et al (1965) also reported improved ME values of barley fed to broilers, following B-glucanase supplementation. When B-glucanases hydrolyze the B-glucans in aleurone cell walls of starchy endosperm, they cannot encapsulate available nutrients such as starch and other intracellular carbohydrates. This may account for the improvements in growth performance of birds fed enzyme supplemented barley (Hessleman and Aman, 1986).

The apparent superiority of Celluclast for improving growth performances, compared to Pectinex and T.v. Cellulase may be a function of its stability as influenced by pH. Celluclast is relatively stable between 3 and 7.5, whereas Pectinex and T.v. Cellulase are stable between pH 2.5 and 5, and 3 and 6.5, respectively (NOVO A/S, Denmark). The wider pH stability range associated with Celluclast, may therefore allow it to catalyze the hydrolysis of B-glucans more effectively than other enzymes when exposed to the variable pH conditions of the intestine. Sturke (1986) reported that the pH of the digestive tract of chickens varied from 4.7 in the muscular stomach to 7.2 in the lower ileum. While it is apparent that Celluclast would operate very effectively within these intestinal pH ranges, Celluclasts superiority may also be attributed to its high B-glucanase activity under the pH conditions of the gastrointestinal tract, compared to the other enzymes that were tested. The enzyme, SP-249 from NOVO A/S, Denmark, had a similar effect on chick performance to that of Leghorns fed barley supplemented with Celluclast.

Enzyme treatment affected barley in a differential manner. They essentially had no effect on the nutritive value of Bedford barley, a small effect on Tupper, a much greater effect with Scout, and a very dramatic effect with the hulled barley Minerva. When Leghorns were fed Minerva supplemented with Celluclast, growth and dry matter improvements were far greater than those fed Scout supplemented with Celluclast or SP-249. Also, when leghorns were fed Minerva, their rate of growth and dry matter retentions were considerably lower than for chicks fed Scout. Minerva's inferior nutritional quality, compared to other barleys used in the current study may be associated with the relatively high content of highly viscous B-glucans (Table 3). High B-glucan contents are known to give rise to highly viscous conditions in the small intestines of poultry, which can adversely affect nutrient utilization and weight gains (Burnett, 1966; White et al, 1983). Although improvements in chick performance was greater when chicks were fed enzyme supplemented diets containing Minerva (a hulled barley) as compared to Scout (a hulless barley), the final weight gains and efficiency of feed utilization were less with Minerva as compared to Scout. These differences may be related to the deleterious effects of the fibrous hull of Minerva. Rossnagel et al (1984) reported that the barley hull can account for 12-14% of the weight of the grain. Fibrous barley hull contains a large proportion of pentosan and lignified tissue and is not readily attacked and hydrolyzed by B-glucanases. The net effect of the hull is to reduce the metabolizable energy value of the cereal, and therefore its nutritional value (Anderson et al, 1961).

Concentrations of enzymes (0.05, 0.10 and 0.20%) affected leghorn

and broiler performances to the same degree, suggesting that possibly an excess of the enzyme preparations were used and that a similar degree of improvement may have been obtained at lower concentrations. White et al (1981) used five concentrations of crude enzyme from *T. viride* and observed no further improvements in the rate of growth of broilers beyond the initial enzyme level (0.005%). In a recent study, Rotter, 1987 (Personal Communication, U. of M., Wpg., Man., Canada) demonstrated a dose response effect at a much lower enzyme concentration.

When broiler and Leghorn chicks were fed barley supplemented with B-glucanases, both responded with similar improvements in relative growth during both week 1 and 2 of the experiment. Although relative growth improvements of broilers and leghorns were similar during the first and second week period, the degree of improvement in nutrient retentions were different. Broilers fed enzyme supplemented barley responded with greater improvements in dry matter and energy retentions compared with that of Leghorns. These results would suggest that the efficiency of nutrient digestion is affected by anti-nutrients to a greater degree in broilers than in Leghorns, perhaps because of the much greater feed intake relative to size in broilers. It would seem that the ability of broilers to digest nutrients approaches an upper limit, compared to Leghorns. Therefore factors that interfere with this process would cause a greater degree of inhibition of digestion than would be observed in Leghorns, as their digestive system may not be subjected to the same limitations. Based on the similar relative growth improvements of Leghorns and broilers over 1 versus 2 weeks, it may be more convenient to use Leghorns over a one week period for the growth

trials. Leghorn chicks would need less feed and water during this time period, and thus would be less labour intensive. Also they are considerably less expensive than broiler chicks. However, for nutrient retention studies broilers would be a more suitable choice.

Generally, enzyme supplementation of barley-based diets showed a trend towards improved feed consumption for both Leghorns and broilers. The degree of improvements seemed to be dependent on either the type of enzyme, or barley used. The highest feed consumption values were obtained when Minerva was supplemented with Celluclast. The high content of anti-nutrients (B-glucans) associated with Minerva, would depress poultry feed consumption to a greater degree than other barley used. Therefore, when enzymes are added to Minerva, they would produce a much larger improvement in feed consumption than other enzyme supplemented barleys. Aastrup (1979a) concluded that B-glucanases can reduce the viscous properties of B-glucans by reducing their hygroscopic nature, causing an improved rate of passage of digesta and correspondingly improved feed intake values. Hesselman et al (1981) also demonstrated that enzyme supplementation of barley-based diets improved feed intake.

It is not surprising that chicks fed untreated barley gave growth performance values that were generally inferior to those fed wheat. However, in Experiment 1, chicks fed Tupper barley (hulless) had weight gains, feed consumption, and feed to gain values that were similar to those fed wheat. In Experiment 4, final weight gains of birds fed Bedford barley (hulled) were also the same as those obtained with wheat. The low soluble, B-glucan contents as well as the low viscosity values

of Tupper and Bedford barley may have contributed to the lack of differences between these cereals (Table 3). In Experiment 3, when Scout and Minerva were fed to Leghorn chicks, growth and nutrient retention values were all inferior to those fed the wheat diet. The relatively low total B-glucan contents associated with wheat (0.5 - 1.0%, Table 1), compared to higher B-glucan contents (total and soluble) and viscosity values (Table 3) of Scout and Minerva probably contributed to these differences. However when Scout and Minerva were treated with B-glucanases, the nutritive value of these barleys were the same or better than wheat. Whereas in the case of Bedford barley treated with enzyme, there was no effect of enzyme on its nutritive value, and only a slight improvement with Tupper. These results would suggest that different barleys vary considerably in nutritive value which in part is attributable to their content of water soluble B-glucans and in part to the content of the fibrous hull. Enzyme treatment may be an effective means of reducing variability among cultivars for barleys grown in different locations. The use of dehulled barleys or hullless barleys would also improve their nutritive value. These results would also suggest that enzyme treated barley or low B-glucan containing barleys can both be effectively used for poultry diets.

Results from Experiment 4 were disappointing in that no growth response was obtained when broilers were fed enzyme supplemented barley (Bedford). Therefore it was not possible to determine if the response to enzyme treatment was influenced by the length of exposure to enzyme. The failure to obtain a growth response when birds were fed enzyme supplemented barley, may have been attributed to the lack of

anti-nutritional substances within the barley. Even though this barley (Bedford) had a relatively high content of total B-glucans, its content of soluble B-glucan and viscosity values were relatively low (Table 3). In fact, this particular cultivar of barley yielded final broiler weight gains that were the same as those fed the wheat control diet. Efficiency of feed utilization of broilers fed wheat, however was somewhat higher. Campbell et al (1986) also found no growth improvements when broilers were fed enzyme supplemented barley (Bedford). In contrast, Rotter et al (1987a) found that the degree of broiler growth response to enzyme supplementation of a barley-based (Scout) diet was influenced by the length of exposure to enzyme. The higher contents of soluble B-glucan, as well as its higher viscosity (Table 3), may have contributed to the positive results obtained with enzyme supplementation in their studies in contrast to the lack of response in the current study.

The results of these studies demonstrate that the four enzymes vary somewhat in their ability to improve performances in chicks, when fed a barley-based diet. The degree of improvement was not affected by concentration of enzyme but was influenced by the cultivar of barley. Both Leghorn and broiler chicks responded to enzyme treatment in a similar manner, but not an identical manner.

SUMMARY AND CONCLUSIONS

- 1) Enzyme supplementation of barley-based diets with a high content of total and soluble B-glucans significantly improved growth and nutrient retentions in both broiler and leghorn chicks. In fact, in some cases, growth rates in chicks fed the enzyme-supplemented barley diets exceeded that of birds fed wheat-based diets. The relative economics of using B-glucanase in poultry diets would be influenced by ingredient cost (i.e. wheat vs. barley), enzyme cost, and biological performance.
- 2) Growth and nutrient retentions of leghorn chicks appeared to be influenced by the B-glucan contents of barley. Greater improvements in growth and nutrient retention were obtained upon enzyme supplementation of a diet that contained a high as compared to a low content of soluble B-glucans.
- 3) Growth improvements of Leghorn and broiler chicks fed barley supplemented with enzyme will result in the improvements in fat, dry matter, protein and energy retention within the bird.
- 4) Enzyme treatment of barley improved nutrient retentions to a greater degree in broilers as compared to Leghorn chicks. In contrast growth performances of both types of birds were affected in a similar manner with enzyme treatment during the first week of the study and over a two week period.
- 5) Feed consumption values were either not affected by enzyme treatment or were increased. The improvement may be a result of B-glucanases reducing the viscous properties of the B-glucans.
- 6) Broiler chickens when fed a barley that had a low content of

B-glucans over a six week period did not respond to enzyme supplementation. It was therefore not possible to determine if the response of broilers to enzyme treatment was influenced by the length of exposure to enzyme. The minimum concentrations of total and/or soluble B-glucans in barley, in order to obtain a growth response from enzyme supplementation will have to be determined.

7) Broiler and leghorn growth improvements were not affected by using different enzyme concentrations. Further research will be needed to establish a dose response effect.

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