EVALUATION

OF MICRONIZED DEHULLED BARLEY

FOR PIGS AND BROILER CHICKENS

A Thesis

Submitted to The Faculty

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by

Janet Lee Lynn Boychuk

In Partial Fulfillment of the

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree

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DEDICATION

This work is dedicated to my husband, Clarence, who made me laugh when I cried, gave me the strength to endure everything that was thrown at me, and sacrificed many hours and opportunities to stand beside me every step of the way.

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I am especially grateful to my mom and dad, and Randy and Rod who introduced me to the worlds of learning, education and hard work, and have supported and loved me throughout this whole ordeal. You have shown me that anything is possible if you set your mind to it.

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ABSTRACT

The purpose of this study was to evaluate the nutritive value of micronized dehulled barley for pigs and poultry. Bedford barley was mechanically dehulled and micronized prior to mixing in the dietary treatments. The micronized dehulled barley (MB) was evaluated for ileal and total tract starch and apparent amino acid digestibilities in 12 kg bodyweight cannulated pigs. Micronization of dehulled barley (DB) increased the ileal starch digestibility of the DB by 13%. There were relatively no differences in the apparent ileal and total tract amino acid digestibilities of the pigs fed either the DB or MB diets. Two pig feeding trials were conducted using MB included at different levels compared with either wheat (Trial 1) or corn (Trial 2). The trials started at 10 kg bodyweight and ended at market weight (105 kg), with three different phases per trial. In trial 1, 96 pigs (48 gilts and 48 barrows) were randomly assigned to one of four treatments (100% wheat (W), 75%W/25%MB, 50%W/50%MB, 100%MB). In trial 2, 120 pigs (60 gilts and 60 barrows) were randomly assigned to one of three treatments (100% corn (C), 50%C/50%MB, 100%MB). The pigs fed any level of MB in trial 1, from 10 kg to 37 kg bodyweight, and from 10 kg to 20 kg bodyweight in trial 2, showed a decrease in ADFI ($P<0.05$) without changes in the ADG. The feed conversions were improved in the starter ($P>0.05$) and grower phases in trial 1 ($P>0.05$) and the starter phase of trial 2 ($P>0.05$). From these results, it was concluded that partial replacement (50%) for corn or wheat in starter pig diets with micronized dehulled barley improved average daily feed intakes and feed efficiencies. One-hundred and sixty-eight Cotswold pigs were fed one of four dietary treatments. The diets were

hulled barley, corn, MB-enzyme or MB+enzyme. The inclusion of enzymes to the MB diet improved the feed efficiency by 9.1% (P>0.05), however there were no significant differences between the remaining diets for ADFI, ADG or F/G efficiencies. There was a significant difference in the ADG (P<0.01) between the pigs fed either of the MB diets and those fed the corn or barley diets in the grower phase. The overall performance of the pigs fed the MB-enzyme diet throughout the study showed a lower feed efficiency (P<0.01) than those pigs fed the MB+enzyme diet. These results suggest that pigs do not have improved performance by supplementing enzymes to the MB diet. Nineteen hundred and twenty broilers were fed a diet composed of either corn, wheat, barley or MB with or without enzyme supplementation. The broilers fed the MB diets had a lower ADG (P<0.05) and lower ADFI (P<0.05) than the broilers fed the other treatment diets. There was a grain*enzyme interaction (P<0.05) with the F/G efficiency between the two wheat diets and between the two barley diets. There was a significant grain*period interaction (P<0.05) for ADG with the broilers on the barley diets performing better in the grower phase than the starter phase. The birds fed the wheat diets showed a grain *period interaction (P<0.05) for F/G with the birds doing better in the starter phase than the grower phase. The broilers fed enzymes showed an enzyme*period interaction with the birds fed the enzyme diets (P<0.05) in the grower phase having lower feed efficiencies (F/G) than the birds in the starter phase compared to those fed the unsupplemented diets. A grain*enzyme *period interaction (P<0.05) occurred with the broilers fed the wheat+enzyme diet having a higher feed efficiency in the grower phase than those fed the wheat-enzyme diet. The birds fed the MB-enzyme diet had higher viscosity levels than those birds fed the other diets ($p<0.01$). The addition of enzyme to the MB diet caused a decrease in the digesta viscosity ($p<0.01$) by 49.1%. These results indicate that the inclusion of MB in broiler diets decreases the performance of the birds. The addition of enzymes to MB diets for broilers does not appear to increase the availability of the nutrients, and results in poorer performance of the broilers compared with other grain sources.

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LIST OF ABBREVIATIONS

AA	Amino acid
ADE	Apparent digestible energy
ADFI	Average daily feed intake
ADG	Average daily gain
AOAC	Association of Official Analytical Chemists
BV	Biological value
C	Corn
DB	Dehulled barley
DE	Digestible energy
DM	Dry matter
ENZ	Enzyme
F/G	Feed to gain efficiency
GLM	General Linear Modeling
GT	Gelatinization temperature
MB	Micronized dehulled barley

ME	Metabolizable energy
NPU	Net protein utilization
NRC	National Research Council
PUN	Plasma urea nitrogen
SAS	Statistical analysis system
SEM	Standard error of the mean
SNK	Student Neuman Keuls
TME	True metabolizable energy
WT	Weight
Wht	Wheat

INTRODUCTION

Grains commonly used in young pig diets are wheat, corn and hulless oats. Barley is commonly used in hog diets throughout western Canada, as it is readily available at a cost-effective price. The choice of grain is dependent on the geographical location of the producer and the availability and economic advantage of using one grain over another.

Wheat, corn and hulless oats are high energy grains and are beneficial in energy dense diets. Cereals are also useful protein sources since they are included at high levels in swine diets. Corn contains about 8.5% protein, wheat between 12-16% protein and hulless oats between 14-16% protein. The considerable variations in protein and energy levels among the same cereals may be partially attributed to environmental conditions during growth (Zhang et al.1994). The percent fibre in wheat, corn and hulless oats is very low (2.3, 2.6 and 2.5 respectively (NRC, 1988) and allows for easier digestion of other nutrients by the young pig.

Throughout western Canada millions of pigs are raised annually on barley-based diets. The amount of protein and energy in barley available for swine are intermediate to those of wheat and corn. The high crude fibre content (5.1%) of barley is one of the major reasons for its comparably low energy value. Barley, because of its lower energy content, finds only limited use in diets fed to starter pigs. However, when the price of other grains are high, it is possible to include high quality barley in starter pig diets, provided a supplement of liquid fats, or oils are used. Barley can be fed very successfully to growing pigs. High energy cereals such as corn or wheat are often used in combination with barley to maximize growth rate. Recent evidence indicates that pelleting may also improve the digestibility of barley-based diets.

The hull of barley consists of two glumes that completely enclose the seed and has a low digestibility. The concentration of energy in barley should, therefore, be increased when the hull is removed. This should yield a product that is comparable in feeding value to wheat or corn in hog diets.

The processing of barley using dehulling and heating processes should increase the availability of nutrients to the pig and therefore its level of performance. This should be of benefit to hog producers in western Canada. It is hypothesized that the performance of pigs fed this type of processed barley will be better than that of pigs fed wheat or corn. An increased local usage of barley for hog production will result in a reduced export of barley from western Canada, and greater economic returns to both the grain and livestock producer.

The objectives of these studies were:

1. To determine the digestibilities of starch and amino acids (ileal and total tract) of micronized dehulled barley in young pigs.

2. To determine the nutritive and economic value of micronized dehulled barley for starter, grower and finisher pigs.

3. To determine the influence of enzyme supplementation on the utilization of micronized dehulled barley by starter and grower pigs.

4. To determine the nutritive value of micronized dehulled barley in broilers.

CHAPTER ONE

LITERATURE REVIEW

Nutrient Content of Barley

Protein and Amino Acids

Barley may contain 9.5-11.5% protein. Its content of protein may vary with cultivar and growing conditions (Boila et al. 1996).

Lysine is generally the first limiting amino acid in practical swine diets (NRC, 1988). The lysine level of barley (0.40%) is similar to the lysine level of wheat (0.40), higher than that of corn (0.25%), and lower than that of hulless oats (0.53%) (NRC, 1988).

Fibre

Barley contains a higher level of crude fibre (5.0%) than wheat (2.3%), corn (2.3%) or hulless oats (2.5%) (NRC, 1988). This may contribute to the lower performance observed when feeding barley to young pigs. The high fibre content of barley results in lower digestible energy (DE) (13.05 MJ/kg) and metabolizable energy (ME) (12.72 MJ/kg). The removal of the hull, aleurone and outer endosperm of barley by abrasion produces pearled barley grain (Sumner et al. 1985). Pearling for 1.5 minutes removes about 15-16% by weight of the original kernel. This consisted of the hull and some of the other outer layers (Sumner et al. 1985). The protein content of hulled and pearled barley were 10.5% and 10.2%, respectively. The hull fraction that was removed had a protein content of 12.3%. Its high protein content was attributed to the inclusion of protein from the outer layers and the germ. The fiber level decreased from 4.5% in whole barley to 1.5% in dehulled barley. The starch level increased from 68 to 72.4%.

Energy

The true metabolizable energy (TME) value of hulled barley varies inversely with the crude fibre content (Sibbald and Price, 1976). For swine, the ME of barley is 12.72 MJ/kg, and the DE is 13.05 MJ/kg (NRC, 1988). Since the hull fraction accounts for a large percentage of the fibre of the barley kernel (Sumner et al. 1985), removing the hull should proportionally increase the available energy of the dehulled barley. The energy content of barley is also affected by the environmental conditions during growth and the cultivar of barley. (Zhang et al. 1994; Boila et al. 1996).

Minerals

Chemical analyses show that barley is generally a poorer source of minerals than wheat or hulless oats, and a better source than corn. Copper and magnesium levels of barley are higher than wheat or hulless oats (NRC, 1988). The iron level is superior to wheat, and the zinc level in barley is higher than hulless oats.

Vitamins

Barley is not generally considered to be a major source of vitamins for livestock. It has however, higher concentrations of vitamin E (tocopherol) than hulless oats or wheat, of biotin and niacin than hulless oats, wheat or corn, and of choline and pantothenic acid than corn. Excessive heat, grinding, pelleting, long feed storage periods, moisture and mold can lower the concentration of tocopherol in grains (Young et al. 1975).

Factors Affecting the Nutritive Value of Barley

β-Glucans

The major nutrients in barley, starch and protein, are enclosed within endosperm cell walls consisting mainly of non-starch polysaccharides made up of mixed (1-3),(1-4)β-D-glucans and arabinoxylans (Åman and Graham, 1987). Studies with pigs have shown that the level of fibre bound protein in cereals correlates well with their protein/amino acid digestibility (Rybka et al. 1992). The use of appropriate processing methods and/or supplementation with enzymes could allow greater access to the nutrients in barley for the pig's endogenous enzyme secretions to act on. The increased nutrient availability would lead to improved overall digestibility of the nutrients. Investigations in broiler chickens have established that supplementation of barley based diets with β-glucanase preparations can substantially improve their nutritive value (Newman and Newman, 1987; Brenes et al. 1993). This has been attributed mainly to a breakdown of endosperm cell wall components, resulting in a more complete digestion of starch and protein in the small intestine. (Hesselman and Åman, 1986). Heat treatments can increase ileal starch digestibility (Fadel et al. 1988). Graham et al. (1989) concluded that pelleting and β-glucanase supplementation disrupts the endosperm cell walls in barley, with pelleting resulting in solubilization of the mixed-linked β-glucans and the β-glucanase supplementation leading to a greater pre-ileal digestibility of starch in pigs. Graham et al. (1989) reported a greater increase in ileal starch digestibility after pelleting than after enzyme supplementation which they concluded was probably due to a partial gelatinization or disruption of the starch granules during the pelleting.

Hulless barley appears to be more harmful in feeding than hulled barley (Classen et al. 1985). Its poorer nutritive value may be related to its high content of water-soluble β-glucan (Newman and Newman, 1987)resulting in high viscosities (Rotter et al. 1989).

Grain Processing

Structural and Physical Properties of Starch

Starch is a common material of great nutritional and industrial importance. It occurs as minute granules in leaves, stems, roots, fruits and seeds. Starch is considered to be a reserve material that is stored for future use in the plant.

Chemical Structure of Starch

Amylose:

Amylose is a straight chain starch containing only α(1-4) glucose units. Most commercial starches (e.g. potato, corn) contain about 25% amylose, the remainder being amylopectin. (French, 1973) (Figure 1).

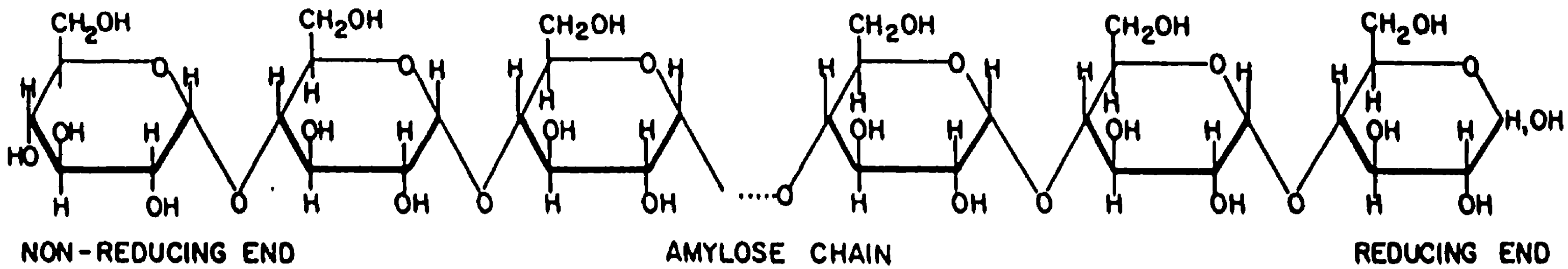

Figure 1. Chemical structure of amylose.

Amylopectin:

Amylopectin is the branched fraction of starch. This chain is branched at approximately 25 monomer intervals by α(1-6) glycosidic linkages. These α(1-6) branch links comprise about 4 to 5 % of the total number of linkages in amylopectin (Figure 2).

Proper processing of grains improves the digestibility of starch by livestock. Gelatinization is associated with the rupture of the secondary hydrogen bonds that hold the polymer chains together in the crystallites and results in complete destruction of the ordered molecular arrangement. Since it is not possible to re-establish the molecular arrangement possessed in the original granule, the process is completely irreversible (French, 1973). Gelatinization temperature (GT) can thus be defined as the temperature of water at which starch granules placed in it lose their property of birefringence. Starches containing relatively large amounts of amylose, such as wrinkled peas and amylomaize, gelatinize at a higher temperature and may even contain some granules that resist gelatinization in boiling water (French, 1973). Gelatinization of grain starch is indicative of animal utilization but the improvement observed may not be due only to the gelatinization of the grain. The protein matrix of the endosperm is disrupted during processing, which allows for easier access to the starch granules by enzymes. Prior to 1960, little progress had been made in grain preparation other than simple grinding or dry rolling (Hale, 1973). There are at least 18 different methods of grain processing. The processed grains that are of possible importance in modern livestock production are ground grains, pressure cooked, dry rolled,

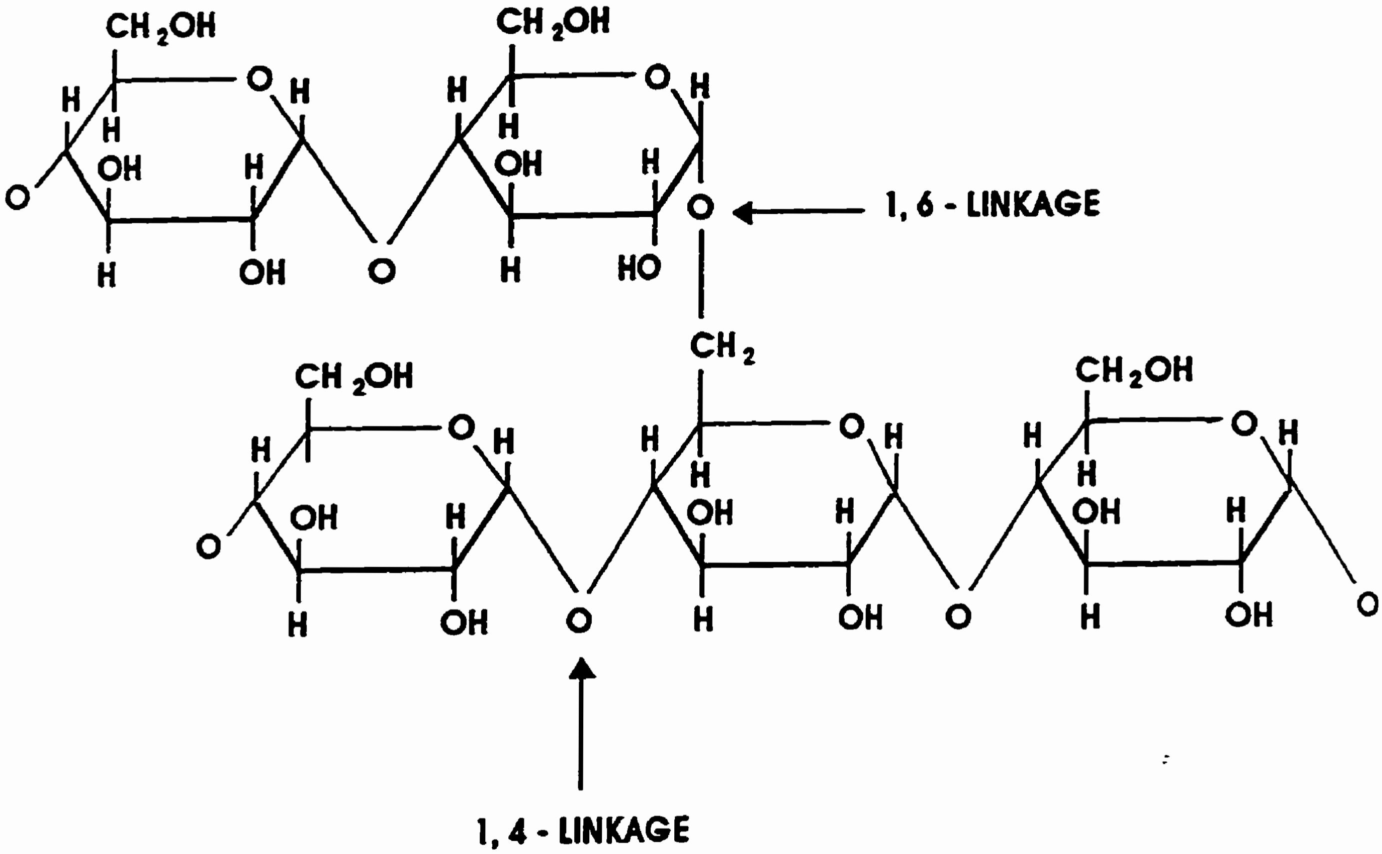

Figure 2. Chemical structure of amylopectin illustrating an alpha 1-6 branch point.

steam flaked, extruded, popped, and micronized cereals, with the exception of grinding are methods that use heat treatment and cause some starch gelatinization.

Grain Processing Methods

1. **Cracked or Ground Cereals.** Grains with initial moisture of 10-12% are ground through a hammer mill (Mercier, 1971). Lawrence (1970) showed that barley diets that were ground were significantly better digested in swine than whole barley diets. Lawrence (1970) also demonstrated that digestibility decreased as the percentage of larger-sized particles increased. Sibbald (1982) found that fine grinding compared to coarse grinding decreased rather that enhanced energy availability, possibly because of heat damage to protein.

2. **Pressure Cooked Cereal.** The process as described by Mercier (1971) involves steaming dried whole cereals for 1.5 minutes under a pressure of 60 psi. The steamed cereal is then passed through a roller. Pressure cooking and flaking sorghum grain increased digestibility of the nitrogen free extract in cattle by 14% when compared to dry rolled sorghum grain (Husted et al.1968). The starch from pressure cooked sorghum was significantly less digestible in the small intestine of the ruminant than that of the starch from steam rolled sorghum (Holmes et al.1970). The differences in digestion of processed compared to raw starch was attributed to a greater degree of amylolysis in the small intestine in the treated sorghum (Hinman and Johnson, 1974).

3. **Dry-rolled Cereal.** In this process, dried whole grains (8-12% moisture) are passed through a roller with no steam (Mercier, 1971). Rolled barley is only slightly, and not

significantly, more efficiently digested and utilized than whole barley in growing pigs (Frape et al. 1968). Lawrence (1970) showed that a cold-rolled diet was significantly better digested by pigs than a whole-barley diet. There was also a tendency for the cold-rolled diet to have the highest digestibility when compared to a ground- and crimped-barley diet (Lawrence, 1970). It was also suggested that the cold-rolled diet produced the best growth rate and food conversion efficiency compared to those obtained with ground-barley, whole-barley or crimped-barley diets (Lawrence, 1970).

4. **Steam-Flaked Cereal.** Mercier (1971) steamed dried whole grains (8-12% moisture) for 3-5 minutes in an atmospheric steam chamber before passing them through a roller. The rollers were set to produce "thin" and "thick" flakes (distance between rollers 0.025 and 2.0 mm). Immediately after rolling, wheat and barley had a moisture content of 16%, corn, 18% and sorghum, 20%. As soon as the grain was rolled, it was dried to 12% moisture (by air ventilation). Zinn (1993) showed that steam processing in addition to rolling will further increase the net energy value for maintenance of barley by 2.8 to 7.0% in steers, depending on the thinness of the flake.

5. **Extruded Cereal with Steam.** Dried whole grains were put through the extruder making "flakes" under 300 psi (Mercier, 1971). Extrusion, which has been shown to thoroughly gelatinize starch even at normal food moisture levels, enhances starch digestibility (Gomez and Aguilera, 1983). Camire et al. (1990) stated that the extrusion-cooking process produces favorable properties for starch digestibility while maintaining availability of other nutrients. The degree of 'cooking' of an extruded cereal-based

product is an important industrial variable because an incomplete 'cook' is believed to be involved with unsatisfactory storage stability, palatability and digestibility of extruded products (Paton, 1981). The degree of 'cook' is associated with the degree of irreversible swelling and eventually the complete rupture of the starch granule.

6. **Popped Cereal.** Dried whole grains, with an initial moisture of 12-14% were dry-steamed, under vacuum, at the temperature of 200-300°C (Mercier, 1971). Dry heat expansion or "popping" of milo was more slowly digested in vitro compared to milo that was steamed at atmospheric pressure and flaked, or pressure cooked and flaked (Walker et al. 1970). Popping slightly increases the amount of water-soluble material, does not decrease the apparent availability of lysine, but lowers the amount of extractable protein. Walker et al. (1970) demonstrated that the performance of ruminants was similar when fed either popped, steamed and rolled, or pressure-cooked and rolled grains. Riggs et al. (1970) reported that the percentage of grain that was actually popped varied from 13 to 45% and appeared to be influenced by moisture content, temperature to which it was exposed and the rate of flow through the machine. The popped sorghum mixture that Riggs et al. (1970) fed to finishing steers had significantly higher digestibilities of all fractions except for ether extract, fiber and protein compared to those obtained with the nonheated grain. Reduced feed intake occurred and was accompanied by increased feed efficiency and a tendency for a decreased rate of gain, dressing percentage, carcass grade and fat thickness (Riggs et al. 1970).

The Need for Grain Processing

Farlin (1974) suggested that processing would improve feed efficiency, improve rate of gain, and increase the moisture level in grain. Feed efficiency and rate of gain are important factors in cost of gain, therefore processing grain to improve the feeding value is one way of attempting to reduce energy costs of the diet.

General reviews on processing have been reported by Mercier (1971), Lawrence (1970), Hale (1973), Theurer (1986), Hinman and Johnson (1974), and Zinn (1993). Mercier (1971) stated that micronizing seemed to be the most efficient processing treatment for barley, but for corn and sorghum, steam flaking offered the most efficient processing technique. Hinman and Johnson (1974) noted that the degree of gelatinization was greatest for micronized and steam flaked sorghum with small differences between dry rolled and ground sorghum. Steam processing and rolling increases the net energy for maintenance value of barley, depending on the thinness of the flake (Zinn, 1993). Hale (1973) recognized that proper processing of grains improves the digestibility of starch by ruminants. He stated that gelatinization of starch in grain is indicative of animal utilization but the improvement may not be entirely due to the gelatinization of the grain. Hale (1973) suggested the protein matrix of the endosperm of the grain is disrupted during processing which permits easier enzymatic access to the starch granules.

The digestive tract of the young pig changes dramatically in the first few weeks of the pig's life. These changes include changes in salivary α-amylase, gastric, pancreatic and small intestine secretions (Hartman et al. 1961; Aumaitre and Corring, 1978; Cranwell, 1995). The absorption capacity of the intestines is relatively low during this period. Lactose in milk is the main source of energy in the young piglet's diet before weaning. Starch is the main energy source in the weaned young piglet's diet and should be easily digested (Cunningham, 1959). However, an excess of indigestible starch such as mono, di- and trisaccharides may result in scouring (Weijer and van de Kamer, 1965).

Digestibility of starch is affected by many factors, such as its amylopectin content, its physical form and the weight of the pig. The presence of inhibitors and the physical distribution of the starch in relation to dietary fibre components are important (Rerat, 1978; Dreher et al. 1984; Bengala et al. 1987). The digestion of raw starch by newborn pigs is restricted by the structure of the starch granule (Cunningham, 1959) and because of insufficient production of enzymes such as amylase, the accessibility of the starch granules by enzymes is reduced. Starch can be modified by different heat treatments which result in changes in its crystallinity and/or gelatinization, and makes it more accessible by enzymes.

Starch Gelatinization

Swelling of starch granules occurs when the starch is exposed to water and is gradually heated. Starch granules swell and take up water up to 50% of their weight, and with increased heat (60° to 80° C) will undergo irreversible swelling, or gelatinization. The starch molecules swell, and release amylose from its crystalline structure. This occurs when energy is applied to break the inter-molecular hydrogen bonds of the crystalline structure (Rooney and Pflugfelder, 1986). The gelatinization process is initiated in the amorphous areas of the granule, but as water and heat are added, they penetrate into the more crystalline regions, however, at a slower rate.

Rooney and Pflugfelder (1986) observed that the presence of free water is critical in the process of starch gelatinization. When water is limiting, a greater amount of heat (mechanical energy) is required to plasticize the amorphous regions and decrease the organization of the crystalline areas.

Mechanical gelatinization involves milling and /or grinding of cereal grains which produces 'damaged' starch (Evers and Stevens, 1985). Some 'damaged' or gelatinized starch is desirable since it is more accessible to amylase. Non-damaged or non-gelatinized starch has lower amylase susceptibility. Grain type, moisture and milling conditions affect this process (Rooney and Pflugfelder, 1986). It is important and critical that adequate uptake of water into the endosperm takes place which allows gelatinization to occur. Enzyme susceptibility analysis which is conducted to determine the extent of gelatinization, assumes that gelatinized starch is rapidly hydrolyzed by enzymes. Thus, the extent of gelatinization is directly related to the amount of sugar produced when the sample is incubated with glucoamylase for a certain time under prescribed conditions (Rooney and Pflugfelder, 1986).

The effect of processing on utilization of starch has been reviewed extensively (Mercier and Feillet, 1975: Hale, 1973; Fadel et al., 1988; Theurer, 1986.). Fadel et al. (1988) noted that klason lignin increased and starch decreased with extrusion of barley, and that extrusion cooking of barley caused a shift of insoluble nonstarch polysaccharides to soluble nonstarch polysaccharides such as galacturonans, arabinogalactans, and β-glucans. Mercier and Feillet (1975) demonstrated that starch from extruded grain was solubilized, without any formation of maltodextrin. The amount of solubilized starch was dependent on temperature of extrusion, moisture content of starch before extrusion, and the amylose-amylopectin ratio of the cereal. Theurer (1986) indicated that starch utilization may be markedly enhanced by proper grain processing; however, the extent of improvement is primarily dependent upon the animal species, grain source, and method of processing.

Processing changes the physical and chemical characteristics of starch resulting in improvements of digestibility by livestock. Physical processes include breaking, cracking, grinding, rolling or pelleting dried grains. Physiochemical processes involve the application of water and heat which act to hydrate and swell the amorphous and crystalline structures of the starch granules. This alteration in structure enhances amylolytic digestion. The degree of moist heat application to grain, in addition to physically reducing the particle size has benefits greater than either process alone (Theurer, 1986), particularly in sorghum and corn. Theurer (1986) reported that steam flaking consistently improves the digestibility of starch by cattle fed corn or sorghum based diets over whole, ground, or dry rolled processes. This improvement in starch utilization appears to be the primary reason for enhanced feed conversion of cattle fed these processed grains.

Dry heat processed cereals are not effectively utilized because of insoluble protein caused by the excessive heat process. In studies where starch is completely gelatinized and ruptured (pressure rolling/flaking) the insoluble protein effect has been indicated to be poorly utilized by monogastrics. Dextrinization (formation of fragments of amylose and amylopectin (dextrins)) occurs as a result of dry heat processing of grains (Rooney and Pflugfelder, 1986). Dextrinized starch is partially soluble in water, tends to be sticky and is actually useful in the formation of adhesives. Also, some enzyme resistant glycosidic bonds are formed during this process. (Rooney and Pflugfelder, 1986).

Factors that affect the utilization of nutrients in monogastrics:

Moran and Summers (1970) discussed protein denaturation, the Maillard reaction and the possible need for excess protein in a diet (processed or containing processed ingredients) to capitalize upon gains in productive energy due to processing. Protein denaturation, according to Moran and Summers (1970), is one of the most obvious of the changes that occurs upon heat processing a feedstuff. Most of the poor digestibility of the protein in some feedstuffs results from the structural stabilization that builds with the accumulation of cystine disulfide linkages, hydrogen bonds and ionic interactions. The secondary and tertiary involvement greatly influences the availability to the animal and dictates the severity of processing conditions necessary to effect a dishevelment of structure. In all cases, moisture must be present if denaturation is to effectively take place. The Maillard or browning reaction, in addition to denaturation, is another alteration in the protein that occurs upon heating a feedstuff with a large amount of carbohydrates. (Moran and Summers, 1970). At high temperatures several of the amino acids may react with carbohydrates to form a complex which renders the amino acids unutililizable by the body although still present as indicated by analysis. Moran and Summers (1970) used pressure cooking of keratin as an example of how temperatures in excess of those utilized in cereal processing, can yield nutritionally valuable meals despite protein denaturation.

Micronization

The micronization process uses a machine called a micronizer to process the grains. The micronizer consists of gas fired infra-red ceramic heaters under which a moving belt carries grains or seeds one layer thick. The infra-red rays excite the molecules in the seeds which vibrate at a frequency of 600-1,200 million megacycles per second resulting in rapid internal heating and a rise in water vapor pressure (Lawrence, 1973a). In effect, the grain is cooked from the inside out and it swells and fractures. The soft, turgid ruptured grain is then rolled and flaked when the starch is gelatinized thus considerably enhancing the grain's digestibility and feeding value, either in direct form or following further processing, such as grinding in the feed mill. The micronizer, compared to other grain processing techniques, has a greater capacity, is much cleaner and simpler to operate and produces a tougher flake which does not go moldy. The aim of hot, wet processing techniques is to make the cereal grains more available for breakdown by livestock (Lawrence, 1973a). The feed carbohydrates are rendered more susceptible to degradation by enzymes in the animal. Gelatinization which increases the susceptibility of cereal starch to enzyme attack is believed to be the key change in the structure of the starch. This will thereby increase the energy content of the cereal. Harbers (1975) demonstrated that micronization alters the starch granules and produces small conglomerates of non-descript starch. Harbers (1975) concluded that processing grain alters starch so it is more susceptible to amylolytic attack.

Micronized Feedstuffs

1. Whole soybeans

The average analysis of raw whole soybeans is 10% moisture, 18.8% oil , 37% protein, 5.2% fibre, and 4.5% minerals. The main advantages of using soybeans in livestock nutrition include its high energy and high digestible oil content (15.17 MJ/kg ME)(NRC, 1988)) and its high protein content. Normally, soybeans are extracted to make use of the oil for human consumption, and the residue, a 44% protein product, is sold for use in animal feeds.

The nutritive value and protein digestibility of soybeans are very poor unless they have been cooked or subjected to a form of heat treatment. This is due to the presence of biologically active antinutritive substances, the most important being the proteases (trypsin inhibitors), and haemagglutinins (lectins). There are also urease, allergenic and flatulus factors, saponins, and goitrogens. Kunitz (1945) demonstrated that a protein isolated from the raw bean was able to combine with the digestive enzyme, trypsin. This formed an inactive complex, called the trypsin-trypsin inhibitor complex. These trypsin inhibitors also cause hypertrophy and hyperplasia of the pancreas which results in excessive loss of protein from the body through the secretion of pancreatic enzymes. The trypsin factor can be inactivated by heat treatment and autoclaving at about 120° C for 15-45 minutes which will improve the availability of the protein. The process of ordinary oil extraction does not involve temperatures of higher than 100° C, so the meal must be further processed to render it safe. If the soybean meal is overcooked, essential amino acids such as lysine and methionine can be destroyed and the nutritive value of the meal will be seriously impaired. The urease test assays for the presence of urease in the meal. There is a reciprocal correlation between the urease activity and trypsin inhibitor level of the meal. The urease activity determines if underheating has occurred during processing. A dye binding test using cresol red as an indicator, indicates whether or not heat-processing has been sufficient to destroy anti-nutritional factors without seriously reducing the protein quality.

The micronization process was developed for the cooking of whole soybeans to keep the high energy highly digestible oil in the finished micronized soya. Hutton and Foxcroft (1975) evaluated micronized flaked soybean processed under different temperatures. They determined that the urease activity, trypsin inhibitor capacity and protein solubility may be reduced to a minimum level without a serious loss in availability of lysine. The results of the cresol red dye absorption test are consistent with these observations, as a value of 3.8-4.3 mg dye absorbed per g of oil-free meal is considered acceptable, and it is concluded that a micronizing temperature of between 200 and 225°C is required for optimal processing of whole soybeans. Hutton and Thompson, (1975) used male rats to determine the apparent digestible energy (ADE), true digestibility of nitrogen, biological value and net protein utilization using different soybean treatments. They determined that increasing processing temperature had no significant effect on ADE. The biological value (BV) of the protein in the diets containing soybean processed at 200° C or above were significantly greater than those of the other diets. The Net Protein Utilization (NPU) values for the diets containing the 200° C processed soybeans were significantly greater than those for the other diets. Parker (1974) performed a trial with 10-day old chicks using soya processed at different temperatures. He demonstrated that the micronizer was able to remove the adverse effects present in raw soya. The results of the birds fed micronized full fat soymeal was equivalent to the results shown using regular processed soymeal and added fat. The micronized full fat soya meal was also superior in physical qualities over regular soymeal.

Heating affects the physical structure of both the protein and carbohydrates while the presence of moisture can increase the effectiveness of the heating process. It partially denatures the protein making its digestion more effective, especially in pigs and poultry, as well as increasing the metabolizable energy content and fat absorption. It also destroys trypsin inhibitors and other enzymes. Overheating of feeds may reduce the nutritional value of the feed, especially for the amino acids that undergo a Maillard reaction. This may result in the formation of lysinoalanine or methionine sulphoxide (Yannai, 1980). Therefore, the feed processor must be aware of the processing temperature.

Micronization is a process which is effective in increasing the dry matter, oil, protein and energy content of the treated feedstuff. The process also reduces the trypsin inhibitor level in soyabeans to less than 10% of that found in the raw bean and improves the nutritional value as measured in terms of protein digestibility, net protein utilization, and biological value.

Evidence has shown that the full fat soya oil meal, due to its high content of C-18 fatty acids (e.g. linoleic acids) has a synergistic effect on the digestibility of tallow type fat in the diet (Sibbald et al. 1962). Thus micronization results in improved performance when it replaces extracted soyabean meal and animal fat in the diet, because of the improved digestibility of the oil in the diet. The oil in micronized whole soya flakes is mostly intracellular and, for a product containing 18% oil, feels very dry and possesses free flowing characteristics. It also avoids problems with soft pellets, by allowing high energy diets to be manufactured, reducing the use of liquid oils or fats.

2. Micronization of Field Beans/ Peas:

McNab and Wilson (1974) stated that the major changes in the composition of field beans (Vicia faba L.) caused by micronizing were that the moisture content was reduced by 4%, the trypsin inhibitor activity was reduced from 2.49 to 0.21 trypsin inhibitor units/mg dry matter and the available carbohydrate content was raised form 40.6 to 50.2%. Growth and food consumption were not affected when micronized beans replaced raw beans in poultry diets. Food conversion efficiency, apparent dry matter digestibility and nitrogen retention were improved and pancreas size significantly reduced when the birds were fed the diet containing the micronized beans. The ME of beans was improved by 10% by micronization from 10.59 to 11.67 MJ/kg dry matter. The improvement in nutritive value is attributed partly to the destruction of the trypsin inhibitor and partly to the increased availability of the carbohydrate fraction of the beans. van Zuilichem and van der Poel (1988) compared the extruder with the micronizer. They investigated two varieties of peas (pisum sativum), with each variety undergoing either extrusion or micronization. Both treatments reduced the concentration of anti-nutritive factors like the trypsin inhibitor and lectins but tannins were only partly degraded. The miconization procedure had better results in terms of lysine availability than the extruder method.

Myer and Froseth, (1983) suggested that extruded small red beans (Phaseolus vulgaris) may require methionine supplementation when fed to young pigs for better feed utilization. Red beans are a good source of lysine, but they are deficient in the sulphur-containing amino acids. Extrusion of the red beans resulted in significantly higher apparent digestibilities of all amino acids except methionine, cystine and alanine than autoclaving.

3.0 Micronization of Corn

Micronization of corn for pigs has been reported by Lawrence (1973a,b; 1975). The micronization process slightly increased the DM content of the corn by 2%, particularly when the micronized cereal was flaked. Micronizing, flaking and grinding reduced the nitrogen content of the grain by 0.8% on a DM basis. The crude fibre content was also slightly reduced by these three treatments while the ether extract content was markedly reduced by the flaking treatment. Starch availability of the ground cereal was increased by 1.8% following the micronizing and grinding treatment and 24.1% when flaking followed the heating of the micronization process. Flaking, compared with micronizing and grinding therefore increased the availability of the starch by 22.3% (Lawrence, 1973a,b).

Lawrence (1973a,b) concluded that micronizing and flaking were the best methods for the processing of corn. The results further suggest that micronization is a more effective method for improving starch availability than steam flaking. The micronization process increased DM, nitrogen and gross energy digestibility but this effect was only statistically significant for the gross energy fraction of the diet. A micronized-corn diet significantly gave better growth rates and DM conversion efficiencies in pigs than a simple ground corn diet (Lawrence 1973b). Diets based on micronized cereals gave significantly higher carcass yield (killing-out percentages) compared to those obtained with diets based on ground cereals. Carcass length was significantly greater in pigs fed the micronized corn diet compared to those fed a ground corn diet. The backfat thickness of the loin and shoulder positions were greater for the ground corn diet compared to the micronized corn diet.

4.0 Micronized Wheat

Lawrence (1973b) saw no response for improved growth rate or improved DM conversion efficiencies when hogs from 17 to 50 kg bodyweight were fed micronized wheat versus those fed ground wheat. Lawrence (1973b) also noted a significant depression in growth rate and DM conversion efficiencies in 50-90 kg pigs fed the micronized wheat.

Lawrence (1975) concluded that the micronization process has little potential as a processing technique for improving the nutritive value of wheat for the growing pig. He suggested that this difference in response compared with barley and maize may be associated with the differences which exist between cereal in starch content, in the make-up of that starch (Greenwood, 1970; Mercier, 1971) and in the make-up of the protein. The high gluten content of wheat may have been responsible for the sticky consistency after micronizing which could explain differences in results obtained between in vivo and in vitro responses. The micronized wheat diets were very sticky and difficult to eat when mixed with water in a wet feeding system (Lawrence, 1975).

5.0 Micronized Barley

Lawrence (1973a) conducted in vitro starch availability tests and observed that the micronization process on barley increased the starch availability, compared with that in the ground un-micronized cereal. The improvements were by 25.7% when grinding followed the process and by 29.0% when the process was subsequently flaked or flaked and ground. The flaking process, therefore, marginally improved starch availability compared with the effect of the micronization and grinding process alone. Lawrence (1973a) showed the DM content of the barley increased after micronization from 2.3 to 2.4% and the nitrogen content decreased from 0.4 to 0.5% on a DM basis. The ether extract and crude fibre contents of the cereals were not affected by the micronization process. The results of digestibility and nitrogen balance studies that Lawrence conducted (1973a) showed a significant improvement in gross energy digestibility of the micronized barley, with a difference of approximately 4.3% occurring between the ground diets and the micronized, flaked and ground diets and an insignificant increase in the DM and nitrogen digestibility.

In vivo experiments conducted by Lawrence (1973b) indicate that for barley the micronization process significantly improved growth rate and the efficiency of conversion of dietary DM. Lawrence (1973b) discovered that the diets based on the barley fed in the micronized form had a significantly higher carcass yield (killing-out percentages) than for pigs which were offered feed in the ground form. These differences were not accompanied by a significantly higher deposition of back fat.

Fernandes et al., (1975) also saw an increase in the DM of the micronized barley, and marked improvement in the in vitro starch availability, but noted that micronization decreased the crude protein content of the grain. This study confirmed Lawrence's (1973 ab) work that the micronization process achieves its major aim of increasing the availability to the animal of the starch in the grain. Fernandes et al. (1975) determined that the improvement should have caused a similar increase in rate of liveweight gain. Its failure to do so may be explained by the lower crude protein content (5%) of the micronized-barley diet compared to the non-micronized diet, or possibly, to an adverse effect of the processing treatment on protein quality.

The use of micronized feedstuffs has had varied results in different livestock species and in the different feedstuffs that are processed through micronization. Improved growth rates and feed conversions in hogs that were fed micronized corn or micronized hulled-barley diets suggest that micronization causes starch gelatinization and thereby increases the availability of the starches to the digestive enzymes.

The micronized barley that has previously been studied has always had the hull on the kernel. The micronization of a mechanically dehulled-barley should produce a nutritious, easily digested feedstuff for young pigs. The starch in micronized dehulled-barley, in theory, should be gelatinized and therefore should be highly digested by young animals. Heat processes may decrease protein quality, and ability of the animal to utilize the protein. The concern of β-glucans in the barley and its influence on young pigs and broilers may require enzyme supplementation to yield the best performance. These thoughts and concerns will provide new information on how micronized dehulled barley will affect the performance of monogastrics. The benefits of the micronization process must offset the increase in cost that micronization incurs on the diet. The cost of micronization is substantially higher than the cost of non-processed grains. The improvements in the livestock production must be large enough to be economically advantageous.

CHAPTER TWO

MANUSCRIPT 1

EFFECT OF MICRONIZATION OF DEHULLED BARLEY ON ILEAL AND FECAL DIGESTIBILITIES OF STARCH AND AMINO ACIDS BY YOUNG PIGS

ABSTRACT. Dehulled and micronized dehulled barley were evaluated for ileal and total tract digestibilities of starch and amino acids by young pigs. Seven Cotswold gilts of 12 kg initial liveweight were used to determine the effect of micronization on the nutritional value of dehulled barley (DB). The animals were surgically fitted with cannulae at the ileo-cecum valve in order to study nutrient digestion in the small intestine. Apparent ileal amino acid digestibility of DB was not affected ($P>0.05$) by micronization. There was an increase in the apparent ileal digestibility of threonine, serine, glycine, tyrosine and histidine ($P<0.05$) of micronized dehulled barley (MB) compared with DB and a decrease ($P<0.01$) in the total tract digestibility of methionine. The MB had improved glutamic acid, glycine, serine and histidine apparent total tract digestibility ($P<0.05$). There was a 13% increase in ileal starch digestibility of MB compared with DB ($P<0.05$), with the MB digestibility being 98.2%. The results suggest there is relatively no change in the apparent amino acid digestibilities of the micronized MB diet. Micronization improves the digestibility of the starch in dehulled barley by 13%.

INTRODUCTION

The major aim of the micronization process is to increase the availability of the starch within the dehulled barley to the animal. Lawrence (1973a) saw an increase in the *in vitro* starch availability by 29.0% when the material was flaked and ground. The *in vivo* digestibility results (Lawrence, 1973a) were very similar to the *in vitro* starch availabilities. Lawrence (1973a) also noticed a change in the proximate analysis of the micronized grains, with a change in the nitrogen (crude protein) content. Lawrence (1973b) saw no change in the crude protein content of grains after micronization.

The aim of this experiment was to examine the effects of the micronization process on the digestibilities of starch and amino acids in the young pig.

MATERIALS AND METHODS

Experimental Diets

Micronized dehulled barley (manufactured by WestCan Micronization) and mechanically dehulled barley were ground. Chromium oxide which was included at 1 g/kg in the diets as the indigestible marker, was finely ground and thoroughly mixed with the diets to ensure an even distribution. Two experimental diets were formulated to determine the influence of micronization on mechanically dehulled barley (Table 1). Mash feed was provided to the animals. Water was available free choice.

Experimental Animals

Seven Cotswold gilts (12 kg liveweight) were fitted with a simple T-cannula, approximately 5-10 cm anterior to the ileo-caecum. The animals were surgically fitted with a steered ileo-caecal valve cannula (SICV), in which an inner ring was placed inside the distal ileum and another outer ring was fixed outside the ileo-caecal junction to prevent the inner ring from sliding into the caecum. A cannula was fitted in the caecum opposite the ileo-caecal valve, and a string connecting the inner ring came through the cannula, out of the abdominal wall. The ileo-caecal valve opened when the string was

TABLE 1. Diet formulation for pig digestibility trial.

	Micronized Dehulled Barley	Dehulled Barley
Ingredients (kg)		
Micronized Dehulled Barley (11.4%)	974.0	--
Pearled Barley (11.3%)	--	974.0
Premix[1]	25.0	25.0
Chromium Oxide	1.0	1.0

[1]Premix provided per kg of diet: 9,000 IU vitamin A, 1,500 IU vitamin D3, 18 mg vitamin E, 1.5 mg vitamin k, 250 mg choline chloride, 30 mg niacin, 27.5 mg calcium pantothenate, 9.4 mg B2, 1 mg B1, 1mg B6, 25 mcg B12, 50 mcg biotin, 0.5 mg folic acid, 5.75 g calcium, 2.6 g phosphate, 3.5 g sodium chloride, 27.5 mg manganese, 105 mg iron, 125 mg copper, 0.6 mg iodine

pulled, allowing quantitative collection of ileal digesta. After collection, the string was released and the valve returned to normal position allowing a normal digesta flow to the large intestine. A detailed procedure is described by Mroz et al. (1996). Pigs were housed in individual metabolism crates and fed a standard diet. The pigs were fed at 4.5% of their live body weight during the experiment, and their daily allowance was divided into two meals fed at 8:00 and 17:00h. The trial consisted of three periods. The first period (8 days) was an adaptation period to the diet, in which the animals received test diets at the same amount as during the collection period. After the adaptation period, two collection periods followed. The first was a 2 day fecal collection from 7:30 to 19:30h, then a third day ileal digesta collection from 8:00 to 23:00h. The samples were stored at -20° C immediately after collection until required for analysis. Room temperature was kept constant at around 20° C and the animals had free access to water. The trial was repeated twice within a cross over design.

Analytical Techniques

For amino acid determination, 100 mg sample was prepared for acid hydrolysis using the method of AOAC (1984) as modified by Mills et al. (1989). This involved digestion in 4ml of 6 N HCL in vacuo for 16h at 121°C, followed by quantification using an LKB 4151 Alpha AA analyzer (LKB Biochrom Ltd. Cambridge, England). Samples for the analysis of methionine and cystine were prepared using formic acid oxidation followed by acid hydrolysis (Hirs, 1967). Non-AA N content was calculated by difference between total N and N measured as AA. The average amino acid digestibility coefficients were derived from four duplicate sample determinations.

Starch content was determined by an enzymatic procedure (Williams, 1968). Ileal digesta and fecal samples were mixed with a solution of amyloglucosidase and hydrolysed. The control sample which was cornstarch was subjected to the same hydrolysis procedure. Glucose was determined by using a modified deproteinized procedure (Sigma Glucose Kit #510). In this procedure, 50-100 μl of deproteinized solution was mixed with 5 ml of the color enzyme reagent.

The Sigma procedure is based upon the following coupled enzymatic reactions:

$$\text{Glucose} + H_2O + O_2 \Rightarrow \text{Gluconic Acid} + H_2O_2 \quad \text{enzyme : Glucose Oxidase}$$

$$H_2O_2 + \text{o-Dianisidine} \Rightarrow \text{Oxidized o-Dianisisdine} \quad \text{enzyme : Peroxidase}$$

(Colorless) (Brown)

Ileal and total tract amino acid digestibilities were calculated using the relative concentrations of chromic oxide in the diets, ileal digesta and feces. The apparent amino acid digestibility coefficient was calculated using the following equation (Angkanaporn et al. 1996):

apparent amino acid coefficient =

$$\frac{\dfrac{\text{concentration of amino acid in feed}}{\text{concentration of chromic oxide in feed}} - \dfrac{\text{concentration of amino acid in sample}}{\text{concentration of chromic oxide in sample}}}{\dfrac{\text{concentration of amino acid in feed}}{\text{concentration of chromic oxide in feed}}}$$

Starch digestibilities were determined by calculating the concentration of starch in the diet, and comparing them to the amount remaining in the ileal digesta and feces.

$$\text{Starch digestibility} = \frac{\text{Glucose concentration of sample}}{\text{Glucose concentration of diet}} \times 100$$

Statistical Analysis

Starch and amino acid digestibilities of digesta and feces were subjected to an analysis of variance using General Linear Modeling (GLM) in the Statistical Analysis System (SAS Institute Inc., 1988).

The model used was $Y_{ijk} = \mu + t_i + p_j + a_k + tp_{ij}$, where Y_{ijk} = the digestibility of the k^{th} pig fed diet i in the j^{th} period, μ= the population mean, t_i = the effect of the i^{th} diet, p_j = the effect of the j^{th} period, a_k = the effect of the k^{th} period, tp_{ij} = the effect of the interaction of the i^{th} diet and the j^{th} period.

RESULTS AND DISCUSSION

Amino Acids

In the digestion trial, the animals consumed all their alloted feed and gained weight. In general, there was a relatively small difference in apparent (Table 2) ileal and total tract (Table 3) digestibilities between pigs fed the dehulled and the micronized dehulled barley diets. A significant improvement was observed ($P<0.05$) in the ileal amino acid digestibility of threonine, histidine, glycine, serine and tyrosine in the MB diet. There was a decrease ($P<0.01$) in the total tract methionine digestibility of the micronized pearled barley, and an increase in the glutamic acid, glycine, serine and histidine digestibility ($P<0.05$). Significant differences were observed for these amino acids but in most comparisons the absolute differences were relatively small.

Starch

There was significant improvement ($P<0.05$) in the digestibility of the starch in the ileum of pigs fed the MB diet compared to those fed the DB diet. (Table 4). The micronized diet was 98.2% digested in the ileum, whereas only 69.7% of the pearled barley diet was digested in the ileum. This 13% improvement in starch digestibility indicates that the micronization process makes the starches more available for the animal. Fadel et al. (1988) saw higher ileal starch digestibility in pigs fed extruded barley diets compared to those fed ground barley diets. The improved digestibility showed the effect of increased upper tract digestibility of starch after extrusion. Douglas and Sullivan (1991)

Table 2. Effect of micronization on apparent ileal amino acid digestibility of dehulled barley.

Diets	Dehulled Barley	MicronizedDehulled Barley	SEM[1]	Sig[2]
Essential AA (%)	70.5	74.0	1.4	NS
Lysine	72.6	76.1	1.4	NS
Methionine	86.7	82.6	1.8	NS
Threonine	60.4	65.5	1.5	**
Histidine	70.6	78.6	1.3	**
Isoleucine	67.8	68	3.7	NS
Leucine	71.9	75.9	1.5	NS
Cystine	61.3	62.7	2.3	NS
Phenylalanine	74.1	77.7	1.4	NS
Valine	64.6	68.1	2.2	NS
Non-Essential AA (%)	66.1	69.4	1.1	
Aspartic Acid	59.4	62.9	1.9	NS
Alanine	68.5	71.2	1.3	NS
Glutamic Acid	77.4	79.5	0.8	NS
Glycine	52.8	56.6	0.9	**
Proline	63.4	62.1	2.2	NS
Serine	64.2	69.5	1.3	**
Tyrosine	66.1	73.7	2.2	**
Arginine	77.0	79.1	1.5	NS

1- SEM = standard error of the means
2** = statistically significant at $p<0.05$; NS = non-significant at $p>0.05$

TABLE 3. Effect of micronization on apparent total tract (fecal) amino acid digestibility of dehulled barley.

Diet	Dehulled Barley	Micronized Dehulled Barley	SEM[1]	Sig[2]
Essential AA (%)	79.9	77.7	0.6	NS
Lysine	79.9	79.9	2.5	NS
Methionine	86.4	78.7	0.9	***
Threonine	72.6	75.4	1.0	NS
Histidine	82.0	85.5	0.9	**
Isoleucine	72.8	76.7	1.6	NS
Leucine	77.4	80.0	0.9	NS
Phenylalanine	78.8	80.8	0.6	NS
Cystine	80.4	78.4	0.7	NS
Valine	75.3	77.7	1.2	NS
Non-Essential AA (%)	79.5	77.3	0.6	NS
Aspartic Acid	70.7	72.7	0.7	NS
Alanine	72.5	74.6	0.8	NS
Glutamic Acid	86.3	87.9	0.4	**
Glycine	76.4	78.5	0.6	**
Proline	84.7	84.9	0.7	NS
Serine	77.1	79.2	0.6	**
Tyrosine	69.6	73.1	1.2	NS
Arginine	83.3	84.4	0.7	NS

1 SEM = standard error of the mean

2 ** - statistical significance at $p<0.05$; ***- statisitcal significance at $p<0.01$; NS = non-significant at $p>0.05$

Table 4. Effect of micronization on ileal and total tract (fecal) digestibility of starch.

	Dehulled Barley	Micronized Dehulled Barley	SEM[1]	Sig[2]
Ileal Digesta (%)	69.7	98.2	3.28	**
Total Tract (%)	98.1	98.1	0.73	NS

[1] standard error of the means
[2] NS = non significant at $P>0.05$; ** = statistically significant at $P<0.05$

and Savage et al. (1980) concluded that micronization increased the in vitro starch digestibility. Pigs fed extruded barley diets had higher energy digestibilities as a result of an increase in ileal starch digestion (Fadel et al. 1988).

The total tract (fecal) starch digestibility was very high, with approximately 98.1% of the starches being digested for both diets before it was excreted (Table 4). This suggests that digestion of starch for the dehulled barley diet was completed in the large intestine. Fadel et al. (1988) concluded that the lack of fecal digestibility differences between extruded and regular barley diets is not an indication of digestibility differences anterior to the colon, but a shift of the location of starch digestion in the gastrointestinal tract.

CHAPTER THREE

MANUSCRIPT 2

EFFECT OF MICRONIZATION OF DEHULLED BARLEY ON STARTER, GROWER AND FINISHER PIGS COMPARED WITH WHEAT

ABSTRACT. Micronized dehulled barley (MB) was compared with wheat to determine the nutritional and economical benefit of MB. Ninety-six Cotswold pigs (forty-eight barrows and forty-eight gilts) were randomly alloted by sex into one of four dietary treatments. MB was included at different levels compared with wheat. The trial started at 10 kg bodyweight and ended at market weight (105 kg), with three different phases in the trial. The dietary treatments were 100% wheat (W), 75%W/25%MB, 50%W/50%MB and 100%MB. The pigs fed any level of MB in this study from 10 kg to 37 kg bodyweight showed a decrease in ADFI ($P>0.05$) without changes in the ADG. The feed conversions were improved in the starter ($P<0.20$) and grower phases ($P<0.28$). The use of MB in the starter diet at an inclusion rate of 25 to 50% replacement with wheat is more economical than the total wheat diet. From these results, it was concluded that partial replacement (50%) for wheat in starter pig diets with micronized dehulled barley improved average daily feed intakes and feed efficiencies.

INTRODUCTION

In the previous digestibility study, the results suggest that micronization of dehulled barley produces a product that is almost entirely digested in the small intestine of the young pig. There was very little change in the amino acid digestibilities of the dehulled barley after the micronization process, which allows us the ability to formulate the treatment diets with the confidence that the pigs will be able to utilize the amino acids in the micronized grain. The methionine digestibility is a factor that needs to be considered since the previous results indicate decreased digestibility after micronization. With this knowledge, it leads to the question as to whether the increased digestibility of the starch will cause increased performance in the growth of pigs. Lawrence (1973b) reported an improvement in the growth rate and feed conversion of pigs fed micronized barley or corn diets. Wheat is commonly fed in hog production units in western Canada. For micronized dehulled barley to be used by the hog industry, it must have an increased performance that offsets the extra cost of micronization. The purpose of this study was to investigate the effects on pig performance of diets that contained high levels of wheat, or various levels of micronized dehulled barley.

MATERIALS AND METHODS

Experimental Diets:

Complex dietary treatments were fed to pigs from 24 days of age to 70 kg live weight. A common finisher diet was fed from 70 to 105 kg bodyweight. Treatment diets differed by the amount of micronized dehulled barley that was included as part of the overall grain portion of the diet (Table 5, 6, 7). The diets contained 0, 25, 50 or 100 percent MB, with the remainder of the grain portion of the ration made up of wheat. The feed was steam-pelleted and available ad libitum from self feeders. All diets were formulated to be iso amino acid and isoenergetic in digestible energy (DE). The pigs were

TABLE 5. Proximate and calculated analysis of starter diets for pigs fed various concentrations of micronized dehulled barley (MB) and wheat.

Wht/MB Ratio	100% Wht	75%Wheat 25% MB	50%Wht 50%MB	100% MB
Level of MB (%)	0	12.25	23.55	47.15
Ingredients (%)				
Wheat (13.2%)	47.30	35.04	23.55	0.00
Micronized barley (11.4%)	0.00	12.25	23.55	47.15
Barley (11.5%)	10.00	10.00	10.00	10.00
Soyabean Meal (44.0%)	16.30	16.00	16.00	15.50
Canola Oil	3.70	4.00	4.20	4.60
Iodized Salt	0.28	0.28	0.28	0.28
Dicalcium Phosphate	1.80	1.80	1.80	1.80
Calcium Carbonate	1.20	1.20	1.20	1.20
Starter Premix[1]	2.00	2.00	2.00	2.00
L-lysine (HCL)	0.25	0.24	0.23	0.25
Methionine	0.08	0.10	0.10	0.12
Threonine	0.19	0.19	0.19	0.20
Milk Products	13.40	13.40	13.40	13.40
Herring Meal	3.50	3.50	3.50	3.50
Chemical Analysis (As Fed Basis)				
Protein (%)	20.42	19.51	19.13	18.4
Dry Matter (%)	10.26	9.54	9.29	9.04
Gross Energy (MJ/kg)	17.60	17.20	17.15	17.50
Ether Extract (%)	7.78	6.90	7.16	9.07
Neutral Det. Fibre (%)	8.73	8.63	7.97	7.51
Amino Acid Composition[2]				
Lysine (%)	1.36	1.34	1.33	1.32
Methionine (%)	0.45	0.46	0.46	0.46
Cystine (%)	0.36	0.36	0.35	0.33
Threonine (%)	0.89	0.89	0.87	0.86

[1]Premix provided the following per kg of diet:130mg zinc, 69mg manganese, 165mg iron, 140mg copper, 1.9mg iodine, .25mg selenium, 280mg choline chloride, 11445iu vitamin A, 1700iu vitaminD3, 100iu vitamin E,2.3mg vitaminK, 6mg riboflavin, 23.5mg niacin, 184mcg biotin, 18mg calcium pantothenate, 46mcg vitamin B12.
[2]Calculated analysis

TABLE 6. Proximate and calculated analysis of grower diets for pigs fed various concentrations of micronized dehulled barley (MB) and wheat.

Wht/MB Ratio	100% Wht	75%Wheat 25% MB	50%Wht 50%MB	100% MB
Level of MB (%)	0	15.5	31	61.9
Ingredients (%)				
Wheat (13.2%)	61.98	46.52	31.00	0.00
Micronized barley (11.4%)	0.00	15.50	31.00	61.90
Barley (11.5%)	10.00	10.00	10.00	10.00
Soybean Meal (44.0%)	15.00	14.60	14.30	13.91
Canola Oil	3.70	4.00	4.30	4.70
Iodized Salt	0.28	0.28	0.28	0.28
Dicalcium Phosphate	1.80	1.80	1.80	1.80
Calcium Carbonate	1.20	1.20	1.20	1.20
Premix[1]	2.00	2.00	2.00	2.00
L-lysine (HCL)	0.26	0.28	0.29	0.32
Methionine	0.08	0.10	0.11	0.15
Threonine	0.20	0.22	0.22	0.24
Herring Meal	3.50	3.50	3.50	3.50
Chemical Analysis (as fed basis)				
Protein (%)	18.49	17.80	17.49	15.67
Dry Matter (%)	11.20	10.79	9.87	9.41
Gross Energy (MJ/kg)	16.97	16.90	17.22	17.10
Neutral Det. Fibre (%)	10.51	8.63	8.99	7.51
Amino Acid Composition[2]				
Lysine (%)	1.20	1.20	1.20	1.20
Methionine (%)	0.47	0.44	0.44	0.43
Cystine (%)	0.32	0.36	0.35	0.36
Threonine (%)	0.80	0.80	0.82	0.81

[1]Premix provided the following per kg of diet:130mg zinc, 69 mg manganese, 165mg iron, 140mg copper, 1.9mg iodine, .25mg selenium, 280mg choline chloride, 11445 iu vitamin A, 1700iu vitaminD3, 100iu vitamin E, 2.3mg vitaminK, 6mg riboflavin, 23.5mg niacin, 184mcg biotin,18mg calcium pantothenate, 46mcg vitamin B12.

[2]Calculated analysis.

TABLE 7. Proximate and calculated analysis of finisher diet of pigs fed various levels concentrations of micronized dehulled barley and wheat.

Ingredients (%)	
Barley (11.5%)	40.00
Wheat (13.7%)	35.00
Soybean Meal (44.0%)	15.39
Calcium	1.30
Phosphate	1.80
Iodized Salt	0.28
Premix[1]	2.00
Lysine	0.11
Threonine	0.13
Tallow (Animal Fat)	4.00
Chemical Analysis (as fed basis)	
Crude Protein (%)	16.45
Dry Matter (%)	88.39
Gross Energy (MJ/kg)	16.66
Neutral Det Fibre (%)	11.38
Amino Acid Composition[2]	
Lysine (%)	0.86
Methionine (%)	0.26
Cystine (%)	0.34
Threonine (%)	0.65

[1]Premix provided the following per kg of diet: 130mg zinc, 69 mg manganese, 165mg iron, 140mg copper, 1.9mg iodine, .25mg selenium, 280mg choline chloride, 11445 iu vitamin A, 1700iu vitaminD3, 100iu vitamin E, 2.3mg vitamin K, 6mg riboflavin, 23.5mg niacin, 184mcg biotin,18mg calcium pantothenate, 46mcg vitamin B12.
[2]Calculated Analysis

fed a starter diet from 10 kg to 37 kg bodyweight, a grower diet from 37 kg to 70 kg bodyweight, and a common finisher diet from 70 kg to market weight. Water was available free-choice for all pigs. All diets met or exceeded the nutrient requirements of the NAS-NRC (1988).

Experimental Animals

Ninety-six Cotswold pigs (48 gilts and 48 barrows) weaned at approximately 24 days of age were randomly alloted by sex into one of four dietary treatments. These experiments were of completely randomized design with an incomplete block arrangement in which the animals were randomly assigned to one of two rooms, and randomly assigned to one of the four test diets. At the end of the starter phase at 37 kg bodyweight, animals were randomly assigned to one of four rooms, with the treatments remaining the same. Two animals (one from the 25% and 100% MB diets) were removed from the trial in the grower phase due to lameness.

Data Collection

Pigs were sexed, weighed and randomly assigned to pens of four with the average pig weight per pen being approximately 10 kg. The pigs were housed in a total confinement heated building. The pigs were weighed individually at weekly intervals, and the feed intake per pen was recorded weekly as well.

Blood Sampling

Ninety-four pigs from the study were prepared for blood analysis. The pigs were fasted overnight, prior to sampling. Feed was removed at 17:00h and sampling started at 7:30h. Blood was collected via the jugular vein at approximately 70 kg bodyweight. The animals were bled the day they were changing from the grower to the finisher diets. Samples were collected in heparinized vacutainer tubes (Becton Dickinson, Rutherford, NJ) and kept on ice during sampling. Within an hour of collecting, tubes were centrifuged and plasma pipetted into vials. These vials were then frozen at -20° C until analyzed for plasma urea nitrogen.

Analytical Analysis

Feed samples were collected at random intervals during the experiment, and stored. Prior to analysis, samples were mixed and ground in a Tecator cyclotec 1093 sample mill (Hoganas, Sweden). Samples were dried in a convection oven at 105° C for 24 hours to determine dry matter content. The percent crude protein, gross energy, dry matter and neutral detergent fibre of the feed were determined according to the Association of Official Analytical Chemists (AOAC, 1990). Gross energy was determined by using an adiabatic oxygen bomb calorimeter (Parr, model 1241). Plasma samples were analyzed for urea nitrogen concentrations using a standard kit (Procedure No. 535) from Sigma Diagnostics (St. Louis, MO).

Statistical Analysis

Average daily gain, average daily feed intake, feed efficiency were analyzed by analysis of variance using General Linear Modeling (GLM) in the Statistical Analysis System (SAS Institute Inc., 1988)

The model used for average daily feed intake and feed efficiency was $Y_{ijk} = \mu + t_i + s_j + r_k + t_{ij} + e_{ijk}$, where, Y_{ijk} = the average daily feed intake and feed efficiency per stage of each pen on the i^{th} diet in the j^{th} sex within the k^{th} room, μ = the overall mean, t_i = the effect of the ith treatment, s_j = the effect of the j^{th} sex, r_k = the effect of the k^{th} room, ts_{ij} = the effect of the interaction of the i^{th} treatment and the j^{th} sex, e_{ijk} = random error.

The model used for average daily gain was $Y_{ijk} = \mu + t_i + s_j + r_k + t_{ij} + e_{ijk}$, where, Y_{ijk} = the average daily gain per pig on the i^{th} diet in the j^{th} sex within the k^{th} room, μ = the overall mean, t_i = the effect of the i^{th} treatment, s_j = the effect of the j^{th} sex, r_k = the effect of the k^{th} room, ts_{ij} = the effect of the interaction of the i^{th} treatment and the j^{th} sex, e_{ijk} = random error.

Differences between means were compared using orthogonal comparisons at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

The addition of micronized dehulled barley (MB) did not significantly improve the ADG of pigs from 10 to 37 kg bodyweight fed different inclusions of MB and wheat (Table 8). However, the inclusion of MB at 25 and 50% of the grain portion of the diet reduced the ADFI by 8.2% ($P<0.06$) and 10.9% for the 100% MB diet when compared with the all wheat diet, with the ADG of the pigs remaining very similar to that of the wheat control diet. Feed efficiency (F/G) for the pigs fed 25, 50 or 100% of MB from 10 to 37 kg bodyweight was improved by 5.5 to 6.8%, although the effect was not significant ($P>0.05$).

The following regression analysis of the results for the starter phase ADFI indicates that each percent inclusion of MB to the diet resulted in a linear ($P<.02$) increase in ADFI:

$$Y_{STRTADFI} = 1.077 - 0.0012\ (\%MB)\quad r = 45.8$$

The pigs fed the grower diet from 37 to 70 kg bodyweight had no improvement in ADG compared with those fed the wheat control diet (Table 8). There was a significant improvement ($P<0.05$) in the ADFI of these pigs with the decrease in food consumption relative to the wheat diet being 7.2% for the 25% MB diet and 12.8% for the 100% MB diet. There was an improvement in the F/G of 5.9% in the pigs fed the 25% MB diet and 7.2% in the 100% MB diet, although the effect was not significant ($P>0.05$). No studies have looked at the effects of micronized dehulled barley compared to wheat, although there have been some researchers that studied micronized hulled barley. Lawrence (1973b)

Table 8. Performance starter and grower pigs fed various concentrations of micronized dehulled barley and wheat.

% Wheat	100	75	50	0		
% Micronized Barley	0	25	50	100	SEM[1]	Sig[2]
Starter Phase (10 to 37 kg)						
Start wt (kg)	9.8	9.9	9.8	10.0		
Finish wt (kg)	36.5	37.6	37.1	37.2		
ADG (g)	678	669	667	640	20	NS
ADFI (g)	1100	1010	1010	980	30	NS
F/G	1.62	1.51	1.51	1.53	0.04	NS
Cost/kg Gain	$0.63	$0.61	$0.62	$0.67		
Grower Phase (37 to 70 kg)						
Start wt (kg)	36.5	37.6	37.1	37.2		
Finish wt (kg)	73.10	74.4	77.3	71.0		
ADG (g)	925	914	930	879	20	NS
ADFI (g)	2179^{a}	2022^{b}	2220^{a}	1900^{b}	50	**
F/G	2.36	2.22	2.39	2.19	0.08	NS
Cost/kg Gain	$0.71	$0.715	$0.81	$0.82		

1** - statistical significance at P<0.01; NS = nonsignificant (P>0.05)
2 pooled standard error of means

reported a 4.0% improved dry matter conversion efficiency of pigs fed micronized hulled barley over pigs fed a wheat diet from 17 to 50 kg bodyweight. Improved average daily gains of 3.5% were also reported by Lawrence (1973b) in pigs fed micronized hulled barley from 22 to 50 kg compared with wheat. The following regression analysis of the results for the grower phase ADFI indicates that each percent inclusion of MB to the diet resulted in a linear ($P<0.01$) and cubic ($P<0.01$) increase in the ADFI:

$$Y_{GROWADFI} = 2.19 - 0.003\ (\%MB) \quad r = 48.2$$

The results of the finisher stage (Table 9) indicate that the animals that were fed MB diets through the starter and grower stages had a poorer F/G efficiency ($P>0.05$) compared to pigs fed wheat throughout the study. The same finisher diet was fed to all the pigs from 70 to 105 kg bodyweight. The pigs fed 100% MB through the starter and grower phases had an improved ADG of 7.2% in the finisher stage ($P>0.05$) compared with pigs fed the wheat control treatment throughout the trial.

There was a sex effect ($P<0.05$) with barrows having a higher ADG than the gilts in all stages in this study and a lower ADFI ($P<0.05$) in the grower and finisher stages (Table 10). There was an improvement in the F/G ($P>0.05$) of the barrows in the grower and finisher phases of both feeding trials, with conversions becoming very similar to that of the gilts in the diets with an inclusion of 50% MB or more.

Plasma urea nitrogen (PUN) is often used to determine the efficiency of nitrogen utilization. A reduction in PUN concentration reflects a decrease in urea synthesis and therefore more efficient utilization of amino acids (Coma et al. 1995) The plasma urea

TABLE 9. Performance of finisher pigs and the overall performance of pigs fed various concentrations of micronized dehulled barley and wheat.

% Wheat	100	75	50	0		
% Micronized Barley	0	25	50	100	SEM[1]	Sig[1]
Finisher Phase (70 to 105 kg)						
Start wt (kg)	72.9	74.1	77.3	70.9		
Finish wt (kg)	104.3	105.3	105.2	105.7		
ADG (g)	991	1023	960	1062	40	NS
ADFI (g)	2289	2721	2438	2804	20	NS
F/G	2.31	2.66	2.54	2.64	0.16	NS
Cost/kg Gain	$0.55	$0.64	$0.61	$0.63		
Overall Performance (10 to 105 kg)						
Start Wt (kg)	9.8	9.9	9.8	10.0		
Finish Wt (kg)	104.3	105.3	105.2	105.7		
ADG (g)	849.9	849.6	839.5	839.2	20	NS
ADFI (g)	1810	1840	1750	1750	60	NS
F/G	2.15	2.24	2.13	2.14	0.1	NS

1** - statistical significance at p<0.01; NS = nonsignificant (p>0.05)
2 pooled standard error of means

Table 10. Performance of male and female starter, grower and finisher pigs fed various concentrations of micronized dehulled barley (MB) and wheat.

% Wheat	100		75		50		0			
% MB	0		25		50		100			
sex	m	f	m	f	m	f	m	f	sem[1]	sig[2]
Start wt (kg)	10.18	9.35	9.32	10.52	9.65	9.88	9.93	10.07		
Finish wt (kg)	37.2	35.7	38.3	37.0	37.3	36.9	37.6	36.8		
ADG (g)	698	658	687	651	705	630	657	623	30	**
ADFI (g)	1062	1131	1038	981	1056	960	1023	936	40	NS
F/G	1.52	1.72	1.51	1.51	1.50	1.52	1.56	1.50	0.06	NS
Start wt (kg)	37.2	35.7	38.3	37	37.3	36.9	37.6	36.8		
Finish wt(kg)	74.6	71.5	76.2	72.5	83.0	71.6	72.3	69.6		
ADG (g)	956	893	957	870	992	867	934	824	40	***
ADFI (g)	2297	2062	2176	1868	2365	2075	2028	1779	80	***
F/G	2.41	2.31	2.27	2.16	2.38	2.40	2.18	2.18	0.13	NS
Start wt (kg)	74.6	71.5	76.2	72.5	83.0	71.6	72.3	69.6		
Finish wt(kg)	104.8	103.8	105.6	104.9	106.2	104.3	105.8	105.6		
ADG (g)	1057	925	1083	963	1040	881	1113	1010	70	***
ADFI (g)	2790	1831	3032	2427	2725	2167	3061	2545	490	***
F/G	2.64	1.98	2.80	2.52	2.62	2.46	2.75	2.52	0.23	NS

[1] pooled standard error of means
[2] for sex effect :**-statistical significance at P<0.05; *** = statistical significance at P<0.01; NS = nonsignificant (P>.0.05)

nitrogen (PUN) levels (Table 11) of the pigs at 80 kg body indicate that pigs fed MB in the diet through the starter and grower phases had lower PUN concentrations (P<0.01) compared to those fed the all wheat diet. There appeared to be a reciprocal relationship between the inclusion levels of MB in the diet and the corresponding PUN concentration. This suggests that the protein in the MB may be more available to the pigs than the protein in the wheat. The females had lower PUN values than the males (Table 12), which indicates the females utilize protein more efficiently than the males (P<0.05). The higher protein efficiency of the females is possible, which would explain the better feed conversion efficiencies shown by the females.

The diets were priced out at current prices (Table 13, 14, 15) , and the cost per kg gain was calculated. The cost per kg of gain is $0.02 lower in pigs that were fed the diet with 25% MB in the starter phase compared with those fed the total wheat diet. Even the addition of 50% MB shows a cost advantage of $0.01 per kg of gain over the wheat control. This shows there is an advantage in both performance and economics to the hog industry when up to 50% MB is used to replace wheat in the starter diet. There were no cost savings in the other stages by the addition of MB to the diets.

TABLE 11. Plasma urea nitrogen (PUN) levels (mg/dL) of pigs fed diferent concentrations of micronized dehulled barley and wheat.

%Wheat	100	75	50	0		
% Micronized Barley	0	25	50	100	SEM[1]	Sig[2]
Plasma Urea Nitrogen	24.42^{a}	19.79^{a}	19.89^{a}	15.15^{b}	1.53	***

[1]SEM = pooled standard error of the means

[2] *** = statistically significant at $P<0.01$

TABLE 12. Plasma urea nitrogen (PUN) levels (mg/dL) of male and female pigs fed different concentrations of micronized dehulled barley and wheat.

% Wheat	100		75		50		0			
% Micronized Barley	0		25		50		100			
sex	m	f	m	f	m	f	m	f	SEM[1]	sig[2]
Plasma Urea Nitrogen	26.42	22.41	21.17	18.42	19.94	19.83	18.04	12.27	2.19	**

[1]SEM = pooled standard error of the means

[2] ** = statistically significant at $P<0.05$for sex effect

TABLE 13. Cost for starter diet of pigs fed various concnetrations of micronized dehulled barley and wheat.

Ingredient	Cost/MT	100%Wht	Extended Cost	75% Wht 25% MB	Extended Cost	50% Wht 50% MB	Extended Cost	100% MB	Extended Cost
Wheat	$ 160.00	473.00	$ 75.68	350.40	$ 56.06	235.50	$37.68	0.00	$0.00
MB	$ 250.00	0.00	$ 0.00	122.50	$ 30.63	235.50	$58.88	471.50	$117.88
Barley	$ 120.00	100.00	$ 12.00	100.00	$ 12.00	100.00	$12.00	100.00	$12.00
Soybean Meal	$ 365.00	163.00	$ 59.50	160.00	$ 58.40	160.00	$58.40	155.00	$56.58
Herring Meal	$ 1,200.00	35.00	$ 42.00	35.00	$ 42.00	35.00	$42.00	35.00	$42.00
Milk Products	$ 800.00	134.00	$ 107.20	134.00	$ 107.20	134.00	$107.20	134.00	$107.20
Iodized Salt	$ 85.00	2.80	$ 0.24	2.80	$ 0.24	2.80	$0.24	2.80	$0.24
Dicalcium phosphate	$ 445.00	18.00	$ 8.01	18.00	$ 8.01	18.00	$8.01	18.00	$8.01
Calcium carbonate	$ 60.00	12.00	$ 0.72	12.00	$ 0.72	12.00	$0.72	12.00	$0.72
L-lysine	$ 6,500.00	2.50	$ 16.25	2.40	$ 15.60	2.30	$14.95	2.50	$16.25
Methionine	$ 5,100.00	0.80	$ 4.08	1.00	$ 5.10	1.00	$5.10	1.20	$6.12
Threonine	$ 9,800.00	1.90	$ 18.62	1.90	$ 18.62	1.90	$18.62	2.00	$19.60
Starter Premix	$ 600.00	20.00	$ 12.00	20.00	$ 12.00	20.00	$12.00	20.00	$12.00
Canola Oil	$ 900.00	37.00	$ 33.30	40.00	$ 36.00	42.00	$37.80	46.00	$41.40
Total		1000.00	$ 389.59	1000.00	$ 402.58	1000.00	$413.59	1000.00	$439.99

TABLE 14. Cost of grower diet for pigs fed various concentrations of micronized dehulled barley and wheat

Ingredient	Cost/MT	100%Wht	Extended Cost	75% Wht 25% MB	Extended Cost	50% Wht 50% MB	Extended Cost	100% MB	Extended Cost
Wheat	$160.00	619.80	$99.17	465.20	$74.43	310.00	$49.60	0.00	$0.00
MB	$250.00	0.00	$0.00	155.00	$38.75	310.00	$77.50	619.00	$154.75
Barley	$120.00	100.00	$12.00	100.00	$12.00	100.00	$12.00	100.00	$12.00
Soybean Meal	$365.00	150.00	$54.75	146.00	$53.29	143.00	$52.20	139.10	$50.77
Herring Meal	$1,200.00	35.00	$42.00	35.00	$42.00	35.00	$42.00	35.00	$42.00
Iodized Salt	$85.00	2.80	$0.24	2.80	$0.24	2.80	$0.24	2.80	$0.24
Dicalcium phosphate	$445.00	18.00	$8.01	18.00	$8.01	18.00	$8.01	18.00	$8.01
Calcium carbonate	$60.00	12.00	$0.72	12.00	$0.72	12.00	$0.72	12.00	$0.72
L-lysine	$6,500.00	2.60	$16.90	2.80	$18.20	2.90	$18.85	3.20	$20.80
Methionine	$5,100.00	0.80	$4.08	1.00	$5.10	1.10	$5.61	1.50	$7.65
Threonine	$9,800.00	2.00	$19.60	2.20	$21.56	2.20	$21.56	2.40	$23.52
Starter Premix	$600.00	20.00	$12.00	20.00	$12.00	20.00	$12.00	20.00	$12.00
Canola Oil	$900.00	37.00	$33.30	40.00	$36.00	43.00	$38.70	47.00	$42.30
Total		1000.00	$302.77	1000.00	$322.30	1000.00	$338.98	1000.00	$374.76

TABLE 15. Cost of finisher diet for pigs fed micronized dehulled barley and various concentrations of wheat.

Ingredients	Cost/MT	Quantity	Extended Cost
Wheat	$ 160.00	350.00	$ 56.00
Barley	$ 120.00	400.00	$ 48.00
Soybean Meal	$ 465.00	153.80	$ 71.52
Iodized Salt	$ 85.00	2.80	$ 0.24
Dicalcium phosphate	$ 445.00	18.00	$ 8.01
Calcium carbonate	$ 60.00	13.00	$ 0.78
Premix	$ 700.00	20.00	$ 14.00
Lysine	$ 6,500.00	1.10	$ 7.15
Methionine	$ 5,100.00	1.30	$ 6.63
Tallow (Animal Fat)	$ 690.00	40.00	$ 27.60
Total		1000.00	$ 239.93

CHAPTER FOUR

MANUSCRIPT 3

EFFECT OF MICRONIZATION OF DEHULLED BARLEY ON STARTER, GROWER AND FINISHER PIGS COMPARED WITH CORN

ABSTRACT. Micronized dehulled barley (MB) was compared with corn to determine the nutritional and economical benefit of MB in pigs. The trial started at 10 kg bodyweight and ended at market weight (105 kg), with three different phases in the trial. One hundred and twenty Cotswold pigs (sixty gilts and sixty barrows) were randomly assigned to one of three dietary treatments (100% corn (C), 50%C/50%MB, 100%MB). The pigs fed any level of MB from 10 to 20 kg bodyweight showed a decrease in ADFI ($P<0.05$) without changes in the ADG. The feed conversions were improved in the starter phase ($P>0.05$). There were no differences in carcass quality ($P>0.05$) or organ size ($P>0.05$) among the pigs in the different treatments. From these results, it was concluded that partial replacement (50%) for corn or wheat in starter pig diets with micronized dehulled barley improved average daily feed intakes and feed efficiencies. From these results, it was concluded that partial replacement (50%) for wheat in starter pig diets with micronized dehulled barley improved average daily feed intakes and feed efficiencies.

INTRODUCTION

The results from the digestibility study suggest that micronized dehulled barley produces a product that is almost entirely digested in the small intestine of the young pig. The previous feeding study, with micronized dehulled barley showed that animals on the micronized diets consumed less feed but had very similar weight gains compared to those fed an all wheat diet. This resulted in improved feed conversion for pigs fed micronized barley. Corn is a grain that is commonly fed to hogs in Eastern Canada and the United States. The lower digestible methionine levels of micronized dehulled barley that were determined in the previous digestibility study may play a factor in a comparison with corn since corn has a high digestible methionine value. Micronized dehulled barley, to be used by the American and eastern Canadian markets, must have a level of performance that offsets the extra cost of micronization. The purpose of this study was to investigate the effects on pig performance of feeding diets that contained high levels of corn and various levels of micronized dehulled barley.

MATERIALS AND METHODS

Experimental Diets

Complex treatment diets were fed to pigs from approximately 28 days of age to a live market weight of 105 kg. Treatment diets differed by the amount of micronized dehulled barley that was included as part of the overall grain portion of the diet (Table 16, 17, 18). The diet contained 0, 50 or 100 percent of the grain as micronized dehulled barley, with the remainder being corn. The feed was steam pelleted and available ad libitum from self feeders. All diets were formulated to be isoamino acid and in terms of digestible energy (DE) to be isoenergetic. The pigs were fed a starter diet from 10 - 20 kg bodyweight, a grower diet from 20-38 kg and a finisher diet from 38 kg bodyweight to market weight of 105 kg. Water was available free-choice for all pigs. All diets met or exceeded the nutrient requirements of the NAS-NRC (1988).

TABLE 16. Proximate and calculated analysis for starter diets of pigs fed various concentrations of micronized dehulled barley (MB) and corn.

Corn/MB Ratio	100% Corn	50%Corn 50%MB	100% MB
Level of MB(%)	0	25.8	51.8
Ingredients (%)			
Corn (8.6%)	53.26	25.80	0.00
MB (11.5%)	0.00	25.80	51.80
Soybean Meal (44%)	22.50	22.26	21.38
Canola Oil	1.85	3.50	4.20
Dicalcium phosphate	1.80	1.80	1.80
Iodized Salt	0.28	0.28	0.28
Calcium Carbonate	1.20	1.20	1.20
Premix[1]	2.00	2.00	2.00
Lysine	0.09	0.17	0.15
Methionine	0.07	0.13	0.09
Threonine	0.00	0.11	0.15
Milk Products	13.45	13.45	13.45
Herring Meal	3.50	3.50	3.50
Chemical Analysis (as fed basis)			
Crude Protein (%)	19.83	21.31	21.18
Dry Matter (%)	91.50	91.65	91.58
Gross Energy(MJ/kg)	17.60	17.50	17.70
Amino Acids Composition[2]			
Lysine (%)	1.33	1.35	1.36
Methinine (%)	0.41	0.50	0.46
Cystine (%)	0.31	0.33	0.36
Threonine (%)	0.88	0.89	0.89

[1]Premix provided the following per kg of diet: 130mg zinc, 68 mg manganese, 165mg iron, 140mg copper, 1.9mg iodine, .25mg selenium, 280mg choline chloride, 11445iu vitamin A, 1700iu vitamin D3, 100iu vitamin E, 2.3mg vitamin K, 6mg riboflavin, 23.5mg niacin, 185mcg biotin, 18mg calcium pantothenate, 46mcg vitamin B12.
[2] Calculated analysis.

Table 17. Proximate and calculated analysis for grower diet of pigs fed various concentrations of micronized dehulled barley (MB) and corn.

Corn/MB Ratio	100% Corn	50%Corn 50%MB	100% MB
Level of MB(%)	0	33.34	66.7
Ingredients (%)			
Corn (8.6%)	66.71	33.34	0.00
MB (11.3%)	0.00	33.34	66.70
Soyabean Meal (44%)	22.50	21.70	20.70
Canola Oil	1.85	2.70	3.65
Dicalcium phosphate	1.80	1.80	1.80
Iodized Salt	0.28	0.28	0.28
Calcium Carbonate	1.20	1.20	1.20
Grower Premix[1]	2.00	2.00	2.00
Lysine	0.09	0.09	0.09
Methionine	0.07	0.02	0.00
Threonine	0.00	0.03	0.08
Herring Meal	3.50	3.50	3.50
Chemical Analysis (as fed basis)			
Crude Protein (%)	18.22	18.59	18.64
Dry Matter (%)	89.56	90.21	91.13
Gross Energy (MJ/kg)	16.30	16.80	16.60
Amino Acid Composition[2]			
Lysine (%)	1.10	1.12	1.14
Methionine (%)	0.41	0.37	0.35
Cystine (%)	0.26	0.31	0.36
Threonine (%)	0.75	0.74	0.74

[1]Premix provided the following per kg of diet: 130mg zinc, 68 mg manganese, 165mg iron, 140mg copper, 1.9mg iodine, .25mg selenium, 280mg choline chloride, 11445iu vitamin A, 1700iu vitamin D3, 100iu vitamin E, 2.3mg vitamin K, 6mg riboflavin, 23.5mg niacin, 185mcg biotin, 18mg calcium pantothenate,46mcg vitamin B12.
[2] Calculated analysis

Table 18. Proximate and calculated analysis for finisher diets of pigs fed various concentrations of micronized dehulled barley (MB) and corn.

Corn/MB Ratio	100% Corn	50%Corn 50%MB	100% MB
Level of MB (%)	0	34.07	69.85
Ingredients (%)			
Corn (8.6%)	68.00	34.07	0.00
Micronized barley (11.4%)	0.00	34.07	69.85
Soyabean Meal (44.0%)	22.68	21.59	19.00
Canola Oil	1.85	2.80	3.65
Iodized Salt	0.28	0.28	0.28
Dicalcium phosphate	1.80	1.80	1.80
Calcium carbonate	1.20	1.20	1.20
Premix[1]	2.00	2.00	2.00
Lysine	0.09	0.09	0.09
Methionine	0.10	0.06	0.03
Threonine	0.00	0.04	0.10
Herring Meal	2.00	2.00	2.00
Chemical Analysis (as fed basis)			
Protein (%)	18.49	17.49	15.67
Dry Matter (%)	11.20	9.87	9.41
Gross Energy (MJ/kg)	16.97	17.22	17.10
NDF (%)	10.51	8.99	8.87
Amino Acid Composition[2]			
Lysine (%)	1.01	1.03	1.00
Methionine (%)	0.41	0.37	0.34
Cystine (%)	0.26	0.30	0.34
Threonine (%)	0.72	0.71	0.70

[1]Premix provided the following per kg of diet:130mg zinc, 68 mg manganese, 165mg iron,140mg copper, 1.9mg iodine, .25mg selenium, 280mg choline chloride, 11445iu vitamin A, 1700iu vitamin D3, 100iu vitamin E, 2.3mg vitamin K, 6mg riboflavin, 23.5mg niacin, 185mcg biotin, 18mg calcium pantothenate,46mcg vitamin B12.
[2] Calculated analysis.

Experimental Animals

One-hundred and twenty Cotswold pigs (sixty barrows and sixty gilts) weaned at approximately twenty-eight days of age were randomly alloted by sex into one of three treatments. These experiments were of a completely randomized design, with a complete block arrangement in which animals were randomly assigned to one of the three test diets. One pig from the 100% MB diet, two pigs from the 50% MB diet and one pig from the corn control diet died from illness at the start of the trial. The remaining one-hundred and sixteen pigs were fed for the remainder of the trial.

Data Collection

Pigs were sexed, weighed and randomly assigned to pens containing ten pigs per pen with the average pig weight per pen being approximately 10 kg. The pigs were housed in a total confinement heated building with straw bedding. The pigs were weighed individually every two weeks, and the feed intake per pen was recorded bi-weekly as well. At 80 kg bodyweight, blood samples were taken from all pigs.

Blood Sampling

One-hundred and sixteen pigs from the corn study were prepared for blood analysis. Feed was removed at 17:00h the evening prior to the blood collection. Sampling started at 8:00 the following morning. Blood was collected via the jugular vein at approximately 80 kg bodyweight. Samples were collected in heparinized vacutainer tubes (Becton Dickinson, Rutherford, NJ) and kept on ice during sampling. Within an hour of collecting, tubes were centrifuged and plasma pipetted into vials. These vials were then frozen at -20° C until analyzed for plasma urea nitrogen.

Carcass Evaluation

Twelve pigs, four from each treatment were randomly selected for carcass evaluation at market. After slaughter, a half carcass of each pig was cut into the different meat cuts, and weighed. This was conducted by a butcher, with each carcass being divided into the separate cuts by the same individual.

Organ Size Evaluation

Twenty-two pigs, six from the 100% corn diet, nine form the 50% MB diet, and seven from the 100% MB diet were selected for organ evaluation at market. The organs were removed at the slaughter plant, and weighed. The intestinal contents were in the intestines at the time of weighing. The stomach had the contents removed prior to weighing.

Analytical Analysis

Feed samples were collected at random intervals during the experiment, and stored. Prior to analysis, samples were mixed and ground in a Tecator cyclotec 1093 sample mill (Hoganas, Sweden). Samples were dried in a convection oven at 105° C for 24 hours to determine dry matter content. Dry matter, crude protein, and the neutral detergent fibre were determined according to the Association of Official Analytical Chemists (AOAC, 1990). Gross energy was determined by using an adiabatic oxygen bomb calorimeter (Parr, model 1241). Plasma samples were analyzed for urea nitrogen concentrations using a standard kit (Procedure No. 535) from Sigma Diagnostics (St. Louis, MO).

Statistical Analysis

Average daily gain, average daily feed intake, and feed efficiency were analyzed by analysis of variance using General Linear Modeling (GLM) in the Statistical Analysis System (SAS Institute Inc., 1988).

The model used for average daily feed intake and feed efficiency was $Y_{ijk} = \mu + t_i + s_j + ts_{ij} + e_{ijk}$, where Y_{ijk} = the average daily feed intake and feed efficiency per stage of each pen on the i^{th} treatment on the j^{th} sex within the k^{th} room, where μ = the overall mean, t_i = the effect of the i^{th} treatment, s_j = the effect of the j^{th} sex, ts_{ij} = the effect of the interaction of the i^{th} treatment and the j^{th} sex, e_{ijk} = random error.

The model used for average daily gain was $Y_{ijk} = \mu + t_i + s_j + ts_{ij} + e_{ijk}$, where Y_{ijk} = the average daily gain per pig in the i^{th} treatment of the j^{th} sex within the k^{th} room, where μ = the overall mean, t_i = the effect of the i^{th} treatment, s_j = the effect of the j^{th} sex, ts_{ij} = the effect of the interaction of the i^{th} treatment and the j^{th} sex, e_{ijk} = random error.

Differences between means were compared using orthogonal comparisons at a significance level of $P<0.05$.

RESULTS AND DISCUSSION

The dietary inclusion of 50% micronized dehulled barley (MB) significantly ($P<0.01$) improved the ADG of pigs when compared to a diet of 100% corn from 10 to 20 kg bodyweight (Table 19). The following regression analysis of the results for the starter phase ADG indicates that each percent inclusion of MB to the diet resulted in a linear ($P<.0015$) and quadratic response ($P<.0297$) increase in ADG.

$$Y_{(STRTADG)} = 0.412 +.0008\ (\%MB) \quad r = 28.3$$

Previous studies have looked at the effects of micronized hulled barley compared to corn, however none have been done with barley that has been dehulled and micronized. Lawrence (1973b) reported an improved average daily gain of 3.5% of pigs fed micronized hulled barley compared with corn from 17 kg to 50 kg bodyweight. The F/G for the pigs fed 50% or 100% MB from 10 to 20 kg bodyweight compared with corn had an improvement of 5.6% to 14.7% ($P>0.05$).

The ADG of pigs fed the MB diets compared to corn from 20 to 38 kg bodyweight was decreased by 5.1% to 6.8% ($P>0.05$). The ADFI and F/G for the pigs fed the corn control ration in the grower phase were better than that of the diets with MB included, however, these results are insignificant ($P>0.05$). The digestibility of methionine in the MB diets in the grower phase may have been lower than the corn diet, which may have caused an amino acid imbalance, and subsequently hindered the growth of the pigs on the MB diets. Improved dry matter conversion

Table 19. Performance of starter and grower pigs fed various concentrations of micronized dehulled barley and corn.

% Corn	100	50	0		
% Micronized Barley	0	50	100	SEM[1]	Sig[2]
Starter Phase (10-20 kg)					
Start wt (kg)	9.5	9.5	9.6		
Finish wt (kg)	21.6	24.1	24.0		
ADG (g)	398^{a}	481^{b}	474^{b}	20	***
ADFI (g)	570	584	639	50	NS
F/G	1.43	1.22	1.35	0.08	NS
Cost/kg Gain	$0.55	$0.535	$0.62		
Grower Phase (20-38 kg)					
Start wt (kg)	21.6	24.1	24.0		
Finish wt (kg)	38.6	38.1	38.7		
ADG(g)	962	897	913	80	NS
ADFI(g)	1250	1320	1350	140	NS
F/G	1.30	1.51	1.5	0.11	NS
Cost/kg Gain	$0.38	$0.50	$0.55		

1) sem= pooled standard error of the mean
2)*** = statistically significant at P<0.01; NS=- nonsignificant at P>0.05

efficiencies were reported by Lawrence (1973b) in pigs fed corn over pigs fed micronized hulled barley. Our results are very similar to those seen by Lawrence (1973b).

The addition of MB in the finisher phase of pigs from 38 to 106 kg (Table 20) compared to a corn control diet did not significantly improve the ADG, ADFI or F/G. Plasma urea nitrogen (PUN) is often used to determine the efficiency of nitrogen utilization. A reduction in PUN concentration reflects a decrease in urea synthesis and therefore more efficient utilization of amino acids (Coma et al. 1995). The PUN of the pigs at 80 kg bodyweight reflect a tendency for those pigs with higher levels of micronized dehulled barley in the diet, to have higher PUN levels (Table 21, 22). This suggests that the protein in the MB may not be as available to the animals as that from the corn. Lawrence (1973a) reported a reduced N content in micronized hulled barley and attributed it to a physical limitation of the flaking process. However, when cereals were micronized at a later date in better controlled conditions, crude protein content remained unchanged in the barley (Lawrence, 1973b).

The overall ADFI of the pigs fed 100% MB from 10 kg bodyweight to market (Table 20) has a tendency to be higher than that of the corn control or the 50% MB diets ($P<0.07$). The following regression analysis of the overall results indicated that each percent of MB to the diet resulted in a linear ($P<.003$) and quadratic ($P<.01$) increase in the total feed efficiency (F/G).

$$Y_{(TotalF/G)} = 2.462 + .002\ (\%MB) \quad r = 63.0$$

TABLE 20. Performance of finisher pigs and the overall performance of pigs fed various concentrations of micronized dehulled barley and corn.

% Corn	100	50	0		
% Micronized Barley	0	50	100	SEM[1]	Sig[2]
Finisher Phase (38 to 106 kg)					
Start Wt (kg)	38.6	38.1	38.7		
Finish Wt (kg)	106.2	107.6	109.1		
ADG (g)	1020	1021	1020	20	NS
ADFI (g)	3093	3092	3310	180	NS
F/G	2.94	3.03	3.13	0.11	NS
Cost/kg Gain	$0.83	$0.97	$1.10		
Overall Performance					
Start Wt (kg)	9.43	9.37	9.59		
Finish Wt (kg)	106.2	107.6	109.1		
ADG (g)	845	858	859	10	NS
ADFI (g)	2115	2123	2286	50	NS
F/G	2.50^a	2.47^a	2.66^b	0.06	***

1) sem= pooled standard error of the mean
2)*** = statistically significant at P<0.01; NS=- nonsignificant at P>0.05

TABLE 21. Plasma urea nitrogen (PUN) levels (mg/dL) of pigs fed different concentrations of micronized dehulled barley and corn.

% Corn	100	50	0		
% Micronized Barley	0	50	100	SEM[1]	Sig[2]
Plasma Urea Nitrogen	16.2	15.9	17.4	0.49	NS

[1] Pooled standard error of the means
[2] NS = non significant at P>0.05

TABLE 22. Plasma urea nitrogen (PUN) levels (mg/dL) of male and female pigs fed different concentrations of micronized dehulled barley and corn.

% Corn	100		50		0			
% Micronized Barley	0		50		100			
sex	m	f	m	f	m	f	SEM[1]	sig[2]
Plasma Urea Nitrogen	16.55	15.77	17.00	14.85	18.72	16.09	0.69	NS

[1] Pooled standard error fo the means
[2] NS = non significant at P<0.05

There was a sex effect (P<0.05) with barrows having a higher ADG than the gilts in the starter, grower and finisher stage (Table 23, 24). There was an improvement in the F/G of the barrows in the finisher phase of this study, with conversions becoming very similar to that of the gilts in the diets with an inclusion of 50% MB or more.

There were sex*treatment interactions for the ADG in the grower phase (P<0.01).There was a tendency for there to be a sex*treatment interaction in the ADG of the starter phase and in the ADFI of the overall trial (P<0.12). The overall F/G efficiency showed a significant interaction between sex and treatment (P<0.03).

The slaughter evaluation of different meat cuts illustrated that no significant differences in cut quality was determined by feeding MB when compared with corn (Table 25). Fernandes et al. (1975) reported that micronization of hulled barley did not significantly influence the carcass characteristics of growing pigs. There was an increase in the stomach weight (11%) of the pigs fed 100% MB when compared to the corn diet, although this increase was not significant (Table 26).

The diets were priced out at current prices (Table 27, 28, 29), and the cost per kg of gain of pork was calculated using these prices (Table 19, 20). The cost per kg of gain was $0.015/kg lower when the pigs were fed the diet with 50% MB in the starter phase compared to those fed the all corn diet. This shows there is an advantage, both in performance and economics to the hog industry, to feed an inclusion of 50% MB in the starter ration. It was not economically advantageous to add MB into the diets of grower or finisher pigs.

Table 23. Performance of male and female starter, grower and finsher pigs fed various concentrations of micronized dehulled barley (MB) and corn .

% Corn	100		50		0			
% MB	0		50		100			
sex	m	f	m	f	m	f	sem[1]	sig[2]
Start wt (kg)	9.45	9.48	9.50	9.48	9.70	9.49		
Finish wt(kg)	22.5	20.7	25.2	22.9	23.9	24.1		
ADG (g)	428	369	517	444	465	482	30	**
ADFI (g)	627	513	582	587	655	623	70	NS
F/G	1.46	1.39	1.13	1.32	1.41	1.30	0.12	NS
Start wt (kg)	22.5	20.7	25.2	22.9	23.9	24.1		
Finish wt(kg)	41.7	36.1	40.4	40.1	41.2	39.7		
ADG (g)	1067	856	844	950	960	865	110	***
ADFI (g)	1379	1180	1319	1320	1306	1391	20	NS
F/G	1.30	1.30	1.61	1.40	1.37	1.62	0.16	NS
Start wt (kg)	41.7	36.1	40.4	40.1	41.2	39.7		
Finish wt(kg)	108.1	105.0	107.9	107.4	109.5	108.9		
ADG (g)	1066	974	1054	989	1065	976	10	***
ADFI (g)	3426	2761	3208	2976	3442	3178	250	NS
F/G	3.18	2.83	3.01	2.98	3.20	3.24	0.15	NS

[1] pooled standard error of means
[2]for sex effect : **-statistical significance at P<0.05; *** = statistical significance at P<0.01; NS = nonsignificant (P>.0.05)

TABLE 24. Overall performance of male and female pigs fed various concentrations of micronized dehulled barley and corn (10 kg-105 kg).

% Corn	100		50		0			
% MB	0		50		100			
sex	m	f	m	f	m	f	sem[1]	sig[2]
Start wt (kg)	9.5	9.48	9.5	9.48	9.70	9.49		
Finish wt(kg)	108.1	105.0	107.9	107.4	109.5	108.9		
ADG (g)	889	800	875	840	885	832	20	***
ADFI (g)	2301	1929	2166	2079	2326	2246	70	**
F/G	2.58	2.41	2.47	2.47	2.62	2.70	0.09	NS

[1] pooled standard error of means

[2] for sex effect : **-statistical significance at $P<0.05$; *** = statistical significance at $P<0.01$; NS = nonsignificant ($P>.0.05$)

TABLE 25. Slaughter evaluation of finisher pigs (105 kg) fed various concentrations of micronized dehulled barley and corn.

% Corn	100	50	0	SEM[1]	Sig[2]
% Micronized Barley	0	50	100		
Weights (kg)					
Half Carcass	42.7	43.0	43.1	0.75	NS
Head	3.4	3.4	3.2	0.16	NS
Loin+Belly	11.7	11.9	12.3	0.26	NS
Leg	9.9	11.2	9.4	0.83	NS
Shoulder	11.6	11.4	11.7	0.56	NS
Picnic	4.0	3.6	3.4	0.23	NS
Butt	4.1	3.9	4.2	0.25	NS
Hock	1.5	1.4	1.4	0.11	NS
Belly	2.9	2.9	3.2	0.26	NS
Trim	1.0	1.3	1.3	0.32	NS
Fat Trimmings	3.9	3.3	4.1	0.56	NS
Spareribs	1.2	1.3	1.3	0.08	NS
Leg	9.0	8.4	8.2	0.35	NS
Riblets	1.0	0.8	1.2	0.18	NS
Back Fat1[3]	2.1	2.5	2.2	0.31	NS
Back Fat2	2.3	1.9	2.5	0.44	NS
Back Fat 3	1.6	1.9	2.4	0.38	NS
Back Fat4	1.7	1.5	2.7	0.41	NS

1 - SEM= pooled standard error of the means
2 - NS = non significant at $p<0.05$
3- Four backfat measurements were taken per carcass at four different locations on the back

Table 26. Organ evaluation of pigs fed various concentrations of micronized dehulled barley and corn.

Treatment (% MB)	0	n[1]	50	n	100	n	MSE[2]	sig[3]
Slaughter wt (kg)	89.0	6	87.1	9	86.1	3	3.54	NS
Liver wt (kg)	1.54	6	1.58	9	1.55	7	0.19	NS
Total Intestinewt (kg)	7.91	6	7.44	9	7.78	7	0.95	NS
Small Intestine wt (kg)	2.73	4	2.54	7	2.51	6	0.45	NS
Large Intestine wt (kg)	2.71	4	2.47	7	2.56	6	0.56	NS
Stomach wt (kg)	0.56	4	0.53	7	0.63	6	0.09	NS

[1] n = number of observations
[2] mean square errors
[3] NS = non significant at P>0.05

TABLE 27. Cost of starter diet for pigs fed various concentrations of micronized dehulled barley and corn

Ingredients	Cost/MT	100% Corn 0% MB	Extended Cost	50% Corn 50% MB	Extended Cost	100% MB 0% Corn	Extended Cost
Corn	$150.00	532.60	$79.89	258.00	$38.70	0.00	$0.00
Micronized Bly	$250.00	0.00	$0.00	258.00	$64.50	518.00	$129.50
Soybean Meal	$465.00	225.00	$104.63	222.60	$103.51	213.80	$99.42
Iodized Salt	$85.00	2.80	$0.24	2.80	$0.24	2.80	$0.24
Dicalcium phosphate	$445.00	18.00	$8.01	18.00	$8.01	18.00	$8.01
Calcium carbonate	$60.00	12.00	$0.72	12.00	$0.72	12.00	$0.72
Milk Products	$800.00	134.50	$107.60	134.50	$107.60	134.50	$107.60
Herring Meal	$1,200.00	35.00	$42.00	35.00	$42.00	35.00	$42.00
Lysine	$6,500.00	0.90	$5.85	1.70	$11.05	1.50	$9.75
Methionine	$5,100.00	0.70	$3.57	1.30	$6.63	0.90	$4.59
Threonine	$9,800.00	0.00	$0.00	1.10	$10.78	1.50	$14.70
Grower Premix	$700.00	20.00	$14.00	20.00	$14.00	20.00	$14.00
Canola Oil	$900.00	18.50	$16.65	35.00	$31.50	42.00	$29.40
Total		1000.00	$383.15	1000.00	$439.24	1000.00	$459.93

TABLE 28. Cost of grower diets for pigs fed various concentrations of micronized dehulled barley and corn.

Ingredients	Cost/MT	100% Corn 0% MB	Extended Cost	50% Corn 50% MB	Extended Cost	100% MB 0% Corn	Extended Cost
Corn	$150.00	667.10	$100.07	333.40	$50.01	0.00	$0.00
Micronized Bly	$250.00	0.00	$0.00	333.40	$83.35	667.00	$166.75
Soybean Meal	$465.00	225.00	$104.63	217.00	$100.91	207.00	$96.26
Iodized Salt	$85.00	2.80	$0.24	2.80	$0.24	2.80	$0.24
Dicalcium phosphate	$445.00	18.00	$8.01	18.00	$8.01	18.00	$8.01
Calcium carbonate	$60.00	12.00	$0.72	12.00	$0.72	12.00	$0.72
Herring Meal	$1,200.00	35.00	$42.00	35.00	$42.00	35.00	$42.00
Lysine	$6,500.00	0.90	$5.85	0.90	$5.85	0.90	$5.85
Methionine	$5,100.00	0.70	$3.57	0.20	$1.02	0.00	$0.00
Threonine	$9,800.00	0.00	$0.00	0.30	$2.94	0.80	$7.84
Grower Premix	$700.00	20.00	$14.00	20.00	$14.00	20.00	$14.00
Canola Oil	$900.00	18.50	$16.65	27.00	$24.30	36.50	$25.55
Total		1000.00	$295.73	1000.00	$333.34	1000.00	$367.21

TABLE 29. Cost of finisher diets for pigs fed various concentrations of micronized dehulled barley and corn.

Ingredients	Cost/MT	100% Corn 0% MB	Extended Cost	50% Corn 50% MB	Extended Cost	100% MB 0% Corn	Extended Cost
Corn	$150.00	680.00	$102.00	340.70	$51.11	0.00	$0.00
Micronized Bly	$250.00	0.00	$0.00	340.70	$85.18	698.50	$174.63
Soybean Meal	$465.00	226.80	$105.46	215.90	$100.39	190.00	$88.35
Iodized Salt	$85.00	2.80	$0.24	2.80	$0.24	2.80	$0.24
Dicalcium phosphate	$445.00	18.00	$8.01	18.00	$8.01	18.00	$8.01
Calcium carbonate	$60.00	12.00	$0.72	12.00	$0.72	12.00	$0.72
Herring Meal	$1,200.00	20.00	$24.00	20.00	$24.00	20.00	$24.00
Lysine	$6,500.00	0.90	$5.85	0.90	$5.85	0.90	$5.85
Methionine	$5,100.00	1.00	$5.10	0.60	$3.06	0.30	$1.53
Threonine	$9,800.00	0.00	$0.00	0.40	$3.92	1.00	$9.80
Grower Premix	$700.00	20.00	$14.00	20.00	$14.00	20.00	$14.00
Canola Oil	$900.00	18.50	$16.65	28.00	$25.20	36.50	$25.55
Total		1000.00	$282.03	1000.00	$321.67	1000.00	$352.67

CHAPTER FIVE

MANUSCRIPT 4

EFFECT OF β-GLUCANASE SUPPLEMENTATION OF MICRONIZED DEHULLED BARLEY DIETS ON THE PERFORMANCE OF STARTER AND GROWER PIGS

ABSTRACT. This study was conducted to determine the effect of β-glucanase supplementation of micronized dehulled barley diets on the performance of starter and grower pigs. One hundred and sixty-eight Cotswold pigs were fed diets containing either corn, barley, micronized dehulled barley (MB) or MB with β-glucanase supplementation. Two growth phases were fed, the first from 10 to 20 kg bodyweight and the second from 20 to 35 kg bodyweight. Enzyme supplementation of the MB did not improve the ADG, ADFI or the F/G ($P>0.05$) of the starter pigs compared with the other diets. The grower pigs fed either of the MB diets had lower ADG ($P<0.01$) than those pigs fed the corn or barley diets. There was no difference in the ADFI or F/G conversions ($P>0.05$) among the different diets in the grower stage (20-35 kg), however the MB diet with enzyme was 15.4% higher in the F/G efficiency than the unsupplemented MB diet. The overall performance of the pigs (10-35 kg) indicate that the MB diet-enzyme has a lower F/G than the pigs fed the MB+enzyme, corn, or barley diets. These results indicate that β-glucanase supplementation does not appear to be useful in improving the performance of pigs fed MB diets from 10 to 35 kg bodyweight.

INTRODUCTION

Cereal grains are major energy contributors in livestock diets. The amount of energy that is available to the animal from the cereal is influenced by the fibre content and the amount and type of cell wall polysaccharides. Mixed-linked β-glucans are the predominant non-starch polysaccharides in barley. Hulless barley appears more harmful than hulled barley (Classen et al. 1985). Its poorer nutritive value may be related to its high content of water-soluble β-glucans (Newman and Newman, 1987) and high viscosities compared with hulled barley (Rotter et al. 1989).

The anti-nutritive properties of barley can be overcome by the addition of β-glucanase enzymes in the diet of chicks (Hesselman and Åman, 1986). β-Glucanase supplementation disrupts the endosperm cell walls in barley which leads to a greater pre-ileal digestibility of this component in pigs (Graham et al. 1989). β-Glucanase supplementation of barley-based diets also can lead to an improvement in feed conversion efficiency (Newman et al. 1983). The objective of this study was to determine if β-glucanase would improve the nutritive value of micronized dehulled barley for starter and grower pigs.

MATERIALS AND METHODS

Experimental Diets:

Pigs from approximately twenty-four days of age to 35 kg bodyweight were fed diets containing corn, barley, micronized dehulled barley (MB) or micronized dehulled barley with enzyme supplementation (Table 30, 31). The feed was in a crumbled form and available ad libitum from self feeders. All diets were formulated to be isonitrogenous and in terms of digestible energy (DE) to be isoenergetic. The pigs were fed a starter diet from 10 to 20 kg bodyweight, and a grower diet from 20 to 40 kg bodyweight. Water was available free-choice for all pigs. All diets met or exceeded the nutrient requirements of the NAS-NRC (1988).

TABLE 30. Proximate and calculated analysis of starter diets for pigs fed corn or barley and micronized dehulled barley with and without enzmye supplementation (10-20kg)

	100% Corn	100% Barley	100%MBly	100%MBly + Enzyme
Percent of MB	0	0	72.92	72.82
Ingredients (%)				
Barley (12.0%)	0.00	71.47	0.00	0.00
MB (11.4%)	0.00	0.00	72.92	72.82
Corn (86%)	70.84	0.00	0.00	0.00
Soybean Meal (47%)	22.50	17.80	18.00	18.00
FishMeal	3.50	3.50	3.50	3.50
Canola Oil	0.50	4.60	2.40	2.40
Premix[1]	2.50	2.50	2.50	2.50
Lysine	0.10	0.03	0.23	0.23
Methionine	0.06	0.04	0.04	0.04
Threonine	0.00	0.07	0.16	0.16
Porzyme 8100	0.00	0.00	0.00	0.10
Chemical Analysis (as fed basis)				
Dry Matter (%)	92.10	92.13	92.50	92.02
Crude Protein (%)	20.83	19.46	21.08	20.33
Gross Energy (MJ/kg)	16.59	16.80	16.55	16.47
Calcium	1.36	1.38	1.74	1.73
Phosphorus	0.85	0.97	1.04	1.07
Amino Acid Composition[2]				
Lysine (%)	1.31	1.33	1.41	1.4
Methinone (%)	0.51	0.47	0.43	0.42
Cystine (%)	0.28	0.33	0.36	0.36
Threonine (%)	0.86	0.87	0.92	0.91

[1]Premix provided the following per kg of diet: 9,000 IUVitamin A, 1,500 IU Vitamin D3, 18 mg vitamin E, 1.5 mg vitamin K, 250 mg choline chloride, 30 mg niacin, 27.5 mg calcium pantothenate, 9.4 mg vitamin B2, 1 mg vitamin B1, 1 mg vitamin B6, 25 mcg vitamin B12, 50 mcg biotin, 0.5 mg folic acid, 5.75 g calcium, 2.6 g phosphate, 3.5 g sodium chloride, 27.5 mg manganese, 105 mg iron, 105 mg zinc, 125 mg copper, 0.6 mg iodine.
[2]Calculated analysis.

TABLE 31. Proximate and calculated analysis for grower diets of pigs fed corn or barley and micronized dehulled barley with and without enzyme supplementation (20-35kg).

	100% Corn	100% Barley	100%MBly	100%MBly + Enzyme
Level of MB	0	0	74.41	74.41
Ingredients (%)				
Barley (12.0%)	0.00	74.09	0.00	0.00
MB (11.4%)	0.00	0.00	74.41	74.41
Corn (8.6%)	70.13	0.00	0.00	0.00
Soyabean Meal (47%)	22.50	18.50	19.00	19.00
FishMeal	2.00	2.00	2.00	2.00
Vegetable Oil	2.60	2.70	1.80	1.80
Premix[1]	2.50	2.50	2.50	2.50
Lysine	0.12	0.06	0.14	0.14
Methionine	0.08	0.08	0.08	0.08
Threonine	0.07	0.07	0.07	0.07
Porzyme 8100	0.00	0.00	0.00	0.10
Chemical Analysis (as fed basis)				
Dry Matter (%)	91.20	91.90	91.87	92.61
Protein (%)	19.00	18.78	19.10	19.77
Gross Energy (MJ/kg)	17.91	17.88	16.79	17.20
Calcium	0.94	0.86	1.08	0.99
Phosphorus	0.82	0.71	0.80	0.74
Amino Acid Composition (%)[2]				
Lysine	1.10	1.11	1.20	1.20
Methionine	0.40	0.35	0.38	0.38
Cystine	0.27	0.32	0.35	0.34
Threonine	0.76	0.72	0.78	0.77

[1]Premix provided the following per kg of diet: 9,000 IUVitamin A, 1,500 IU Vitamin D3, 18 mg vitamin E, 1.5 mg vitamin K, 250 mg choline chloride, 30 mg niacin, 27.5 mg calcium pantothenate, 9.4 mg vitamin B2, 1 mg vitamin B1, 1 mg vitamin B6, 25 mcg vitamin B12, 50 mcg biotin, 0.5 mg folic acid, 5.75 g calcium, 2.6 g phosphate, 3.5 g sodium chloride, 27.5 mg manganese, 105 mg iron, 105 mg zinc, 125 mg copper, 0.6 mg iodine.
[2]Calculated analysis.

Experimental Animals

One hundred and sixty-eight (Cotswold) pigs, weaned at approximately twenty-four days of age were randomly allotted to one of four dietary treatments (Table 30, 31). These experiments were of completely randomized design, with a complete block arrangement in which animals were randomly assigned to one of twelve pens. Fourteen pigs (seven barrows and seven gilts) were assigned to each pen.

Data Collection

Pigs were weighed and randomly assigned to pens with fourteen pigs per pen with the average pig weight per pen being approximately 10 kg. The pigs were weighed individually each week, and the feed intake was recorded weekly for each pen.

Analytical Analysis

Feed samples were collected at random intervals during the experiment, and stored. Prior to analysis, samples were mixed and ground in a Tecator cyclotec 1093 sample mill (Hoganas, Sweden). Samples were dried in a convection oven at 105° C for 24 hours to determine dry matter content. Dry matter, crude protein, and the neutral detergent fibre were determined according to the Association of Official Analytical

Chemists (AOAC, 1990). Gross energy was determined by using an adiabatic oxygen bomb calorimeter (Parr, model 1241).

Statistical Analysis

Average daily gain, average daily feed intake and feed efficiency were analyzed by analysis of variance using General Linear Modeling (GLM) in the Statistical Analysis System (SAS Institute Inc., 1988).

The model used was $Y_{ij} = \mu + t_i + e_{ij}$, where Y_{ij} = the average daily feed intake and feed efficiency per stage of the j^{th} pen of the i^{th} treatment, μ = the overall mean, t_i = the effect of the i^{th} treatment, e_{ij} = random error.

The model used for average daily gain $Y_{ij} = \mu + t_i + e_{ij}$, where Y_{ij} = the average daily gain of the j^{th} pig in the i^{th} treatment, μ = the overall mean, t_i = the effect of the i_{th} treatment, e_{ij} = random error.

Differences between means were compared using SNK at a significance level of $P<0.05$ (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

The supplementation of the micronized dehulled barley diet (MB) with β-glucanase did not significantly ($P>0.05$) improve the ADG of the starter pigs from 10 to 20 kg bodyweight compared with the other diets (Table 32). There was not a significant

Table 32. Performance of starter and grower pigsand the overall performance of pigs fed micronized dehulled barley with and without enzyme and corn orbarley.

	Corn	Barley	Mbarley(-)	Mbarley(+)	SEM[1]	Sig[2]
Starter Phase (10-20 kg)						
Start wt (kg)	10.8	10.7	10.5	10.5		
Finish wt (kg)	20.3	20.3	19.5	20.4		
ADG (g)	426	428	394	420	20	NS
ADFI (g)	570	582	565	551	30	NS
F/G	1.34	1.36	1.44	1.32	0.07	NS
Grower Phase (20-35 kg)						
Start wt (kg)	20.4	20.5	20.4	20.6		
Finish wt (kg)	38.9	37.3	32.1	34.6		
ADG (g)	694[a]	663[ab]	621[bc]	594[c]	20	***
ADFI (g)	1290	1230	1090	1130	60	NS
F/G	1.86	1.87	1.75	2.02	0.13	NS
Overall Performance (10-35 kg)						
Start wt (kg)	10.8	10.7	10.5	10.5		
Finish wt (kg)	39.1	37.5	33.6	35.4		
ADG (g)	570[a]	555[b]	528[c]	509[d]	10	***
ADFI (g)	971	956	874	899	30	NS
F/G	1.69[b]	1.7[b]	1.66[b]	1.77[a]	0.02	***

1. sem= pooled standard error of the means
2. ** * = statistical significance at P<0.01; NS = nonsignificant at P>0.05

improvement in the ADFI or the F/G (P>0.05) in the starter phase, although the F/G of the pigs on the MB+enzyme diet had an improvement of 8.3% compared to the MB-enzyme diet. This agrees with the findings of Newman et al. (1983) who reported β-glucanase supplementation of barley-based diets will improve the feed conversion efficiency of pigs. These results were not consistent with the previous corn study where the addition of MB improved the ADG (P<0.01) and the F/G (P>0.05) in pigs from 10 to 20 kg bodyweight.

The grower phase from 20 to 35 kg bodyweight had a decrease in the ADG (P>0.05) for the pigs fed the MB+enzyme diet compared to the MB diet without enzyme. The F/G efficiency was 15.4% higher in the enzyme supplemented diet than the control MB diet (P>0.05). There was a significant difference (P<0.05) between the ADG of pigs from 20 to 35 kg bodyweight fed the MB+enzyme diet or MB-enzyme diet and those fed the corn diet. There was a difference of 4.5% in the ADG (P>0.05) between the pigs on the MB+enzyme diet and those without enzyme supplementation. The grower pigs fed the MB diet without enzyme supplementation appeared to do better than those fed the MB diet with the enzymes, although not as good as the corn or barley diets. The gross energy levels of the MB diets were lower than the barley or corn diets. The pigs on the lower energy diets would have consumed more feed to compensate for the lower energy density. However, the MB-enzyme had a lower feed conversion (P>0.05) than the corn or barley diet. This may suggest that because the animal is able to utilize more of the starch in the micronized diet, it has a better DE value from its diet than is assumed. This does not explain why the pigs fed enzymes had such a poor performance.

The overall performance (10 to 35 kg bodyweight) of the pigs fed the MB-enzyme diet had a higher ADG ($P<0.05$), and lower ADFI ($P>0.05$) and F/G efficiency ($P<0.05$) than the enzyme supplemented treatment. The MB+enzyme diet had a significantly poorer ADG ($P<0.01$) than the corn diet. The overall feed conversion was significantly higher ($P<0.05$) for the MB+enzyme diet than the MB-enzyme diet. The MB-enzyme diet had a slightly better F/G ($P>0.05$) than the barley treatment, however, the barley treatment had a better ADG through the overall trial ($P<0.05$). The overall performance of the pigs fed MB diets are not comparable to the performance in the previous corn study. This may be due to the lower energy levels fed in the MB diets in the grower phase.

CHAPTER SIX

MANUSCRIPT 5

EFFECT OF ENZYME SUPPLEMENTATION ON THE PERFORMANCE OF BROILERS FED CORN, WHEAT, BARLEY OR MICRONIZED DEHULLED BARLEY DIETS

ABSTRACT. This study was conducted to study the effects of enzyme preparations on the performance and carcass characteristics of broilers fed corn, wheat, barley or micronized dehulled barley (MB) diets. The barley variety used in this experiment was bedford barley. Avizyme 1500 was used in the corn diet, Avizyme 1300 in the wheat diet and Avizyme 1100 in the hulled barley and MB diets. Nineteen hundred and twenty broilers were fed a diet composed of either corn, wheat, barley or MB with or without enzyme supplementation. The broilers fed the MB diets had a lower ADG ($P<0.05$) and lower ADFI ($P<0.05$) than the broilers fed the other treatment diets. There was no difference in the overall F/G efficiency of any of the treatments. There was a grain*enzyme interaction ($P<0.05$) between the two wheat diets with the birds fed the wheat+enzyme diet having a F/G efficiency that was 2.8% higher than those fed the wheat-enzyme. There was an interaction between the two barley diets. The birds fed the barley+enzyme diet had an improved feed efficiency of 3.5% compared with those fed the barley-enzyme diet. There was a significant period*grain interaction ($P<0.05$) for ADG with the broilers on the barley diets performing better in the grower phase than the starter phase. The birds fed the wheat diets showed a grain *period interaction ($P<0.05$)for feed efficiency with the birds doing better in the starter phase than the grower phase. The broilers fed enzymes showed an enzyme*period interaction with the feed efficiencies of those birds fed the enzyme diets ($P<0.05$) in the grower phase doing better than in the starter phase compared to those fed the unsupplemented diets. A grain*enzyme *period interaction ($P<0.05$) occurred with the broilers fed the wheat+enzyme diet having a higher feed efficiency in the grower phase than those fed the wheat-enzyme diet. The birds fed the hulled barley or MB diets had

higher viscosity levels than those birds fed the corn or wheat diets ($p<0.01$).The birds fed the hulled barley diets had lower digesta viscosity levels than those fed the MB diets ($P<0.01$). The addition of enzyme to the MB diet caused a decrease in the digesta viscosity ($p<0.05$) by 49.1%. These results indicate that the inclusion of MB in broiler diets will decrease the performance of the birds. The addition of enzymes to MB diets for broilers did not appear to increase the availability of the nutrients, and resulted in poorer performance of the broilers compared with other grain sources.

INTRODUCTION

Cereal grains are major energy contributors in livestock diets. The amount of energy that is available to the animal from the cereal is influenced by the fibre content and the amount and type of cell wall polysaccharides. Mixed-linked β-glucans are the predominant non-starch polysaccharides in barley. This carbohydrate creates a viscous environment in the intestinal tract of a broiler, and results in a reduced nutrient utilization. Hulless barley appears more harmful than hulled barley (Classen et al. 1985). Its poorer nutritive value may be related to its high content of water-soluble β-glucans (Newman and Newman, 1987) and high viscosities compared with hulled barley (Rotter et al. 1989).

The anti-nutritive properties of barley can be overcome by the addition of β-glucanase enzymes in the diet (Hesselman and Åman, 1986). The objective of this study was to determine if a β-glucanase enzyme would improve the nutritive value of micronized dehulled barley for broilers.

MATERIALS AND METHODS

Experimental Diets

Complex treatment diets were fed to broiler chicks from one day of age to 40 days. Dietary treatments differed by the grain type used, and each grain was fed with or without enzyme supplementation (Table 33, 34). The grains used were corn, wheat, hulled barley and micronized dehulled barley (MB). The feed was fed in a crumbled form and available ad libitum from self feeders. All diets were formulated to be isonitrogenous and isoenergenic in terms of metabolizable energy (ME). Diets containing 23% crude protein (CP) were fed for 20 days and diets containing 20% CP were fed for the last 20 days. Water was available free-choice for all birds. All diets met or exceeded the nutrient requirements of the NAS-NRC (1994) for poultry.

Experimental Animals

One thousand nine hundred and twenty day-old commercial male broiler chicks were randomly assigned to eight dietary treatments (Table 33,34). Sixty birds were randomly assigned to one of thirty-two pens, with four pens per treatment.

Data Collection

Viscosity measurements were taken at 20 days of age on five randomly selected birds per pen. The contents of the duodenum of each selected bird was collected and centrifuged. The supernatant was pipeted off, and the viscosity measurement was taken twice for each sample using a Brookfield digital plate viscometer (Model DV-II)

Table 33. Formula and analysis for the starter diets of broilers fed corn, wheat, barley or micronized dehulled barley with or without enzyme supplementation

	Corn		Wheat		Barley		Micronized Dehulled Barley	
	+Enz	-Enz	+Enz	-Enz	+Enz	-Enz	+Enz	-Enz
Wheat	0.00	0.00	59.16	59.21	0.00	0.00	0.00	0.00
Corn	53.25	53.27	0.00	0.00	0.00	0.00	0.00	0.00
Micronized Bly	0.00	0.00	0.00	0.00	0.00	0.00	54.08	54.13
Barley	0.00	0.00	0.00	0.00	50.64	50.69	0.00	0.00
Soybean Meal	35.00	35.00	27.70	27.70	32.00	32.00	31.50	31.50
Meat Meal	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68
Iodized Salt	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Calcium	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Phospahte	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Premix[1]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Canola Oil	2.90	2.90	4.30	4.30	8.50	8.50	5.40	5.40
Lysine	0.000	0.000	0.013	0.013	0.000	0.000	0.110	0.110
Methionine	0.225	0.225	0.135	0.135	0.200	0.200	0.200	0.200
Threonine	0.00	0.00	0.03	0.03	0.00	0.00	0.05	0.05
Enzyme	0.05	0.00	0.05	0.00	0.05	0.00	0.05	0.00
Chemical Analysis (as fed basis)								
Crude Protein(%)	23.63	22.40	23.01	22.79	22.37	22.04	23.44	22.69
Dry Matter(%)	90.50	90.70	91.30	91.30	91.85	91.40	93.25	92.35
Energy(MJ/kg)	16.90	15.40	16.10	16.80	16.40	18.10	18.40	17.20
Calcium (%)	1.27	1.34	1.23	1.43	1.27	1.17	1.31	1.34
Phosphorus (%)	0.71	0.54	0.96	0.84	0.69	0.62	0.91	0.98

[1]Premix provides per kg of complete feed: 50mg manganese, 27mg zinc, 80mg iron, 80mg copper, 1mg iodine, .1mg selenium, 12400iu vitaminA, 2700iu vitaminD3, 20mg vitaminE, 3.25mg thiamine, 4.5mg riboflavin, 14mg niacin, 9mg calcium pantothenate, 315mg choline, 2mg pyrodoxine, 1.2mg folic acid, 150mcg biotin, 15mcg vitamin B12.

Table 34. Formula and analysis for the grower diets of broilers fed corn, wheat, barley, or micronized dehulled barley with or without enzyme supplementation.

	Corn		Wheat		Barley		Micronized Dehulled Barley	
	+Enz	-Enz	+Enz	-Enz	+Enz	-Enz	+Enz	-Enz
Wheat	0.00	0.00	69.88	69.93	0.00	0.00	0.00	0.00
Corn	62.89	62.94	0.00	0.00	0.00	0.00	0.00	0.00
Micronized Bly	0.00	0.00	0.00	0.00	0.00	0.00	61.21	61.26
Barley	0.00	0.00	0.00	0.00	60.75	60.80	0.00	0.00
Meat Meal	5.67	5.67	5.67	5.67	5.67	5.67	5.67	5.67
Soyabean Meal	26.75	26.75	18.00	18.00	22.73	22.73	23.25	23.25
Calcium	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Phosphate	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Iodized Salt	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Premix[1]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Canola Oil	1.70	1.70	3.35	3.35	7.75	7.75	6.75	6.75
Lysine	0.00	0.00	0.025	0.03	0.00	0.00	0.05	0.05
Methionine	0.00	0.00	0.00	0.00	0.08	0.08	0.03	0.03
Threonine	0.00	0.00	0.09	0.09	0.03	0.03	0.05	0.05
Enzyme	0.05	0.00	0.05	0.00	0.05	0.00	0.05	0.00
Chemical Analysis (as fed basis)								
Crude Protein (%)	22.18	22.68	22.53	21.84	19.21	19.02	19.06	18.55
Dry Matter (%)	90.30	90.60	90.45	90.30	91.90	92.50	92.40	93.15
Energy (MJ/kg)	16.70	17.00	17.00	16.80	18.20	18.10	16.70	18.10
Calcium (%)	1.24	1.12	1.45	1.06	1.27	1.38	1.11	1.23
Phosphorus (%)	0.79	0.85	0.88	0.90	0.95	0.86	0.88	0.70

[1]Premix provides per kg of complete feed: 50mg manganese, 27mg zinc, 80mg iron, 80mg copper, 1mg iodine, .1mg selenium, 12400iu vitaminA, 2700iu vitaminD3, 20mg vitaminE, 3.25mg thiamine, 4.5mg riboflavin, 14mg niacin, 9mg calcium pantothenate, 315mg choline, 2mg pyrodoxine, 1.2mg folic acid, 150mcg biotin, 15mcg vitamin B12.

(Veldman and Vahl, 1994). Random selection of birds for carcass evaluation occurred at 40 days of age. Fourteen birds per treatment were selected for the carcass evaluation.

Analytical Analysis

Feed samples were ground in a Tecator cyclotec 1093 sample mill (Hoganas, Sweden). Samples were dried in a convection oven at 105°C for 24 hours to determine dry matter content. Dry matter, crude protein, calcium and phosphorus were determined according to the Association of Official Analytical Chemist (AOAC, 1990). Gross energy was determined by using an adiabatic oxygen bomb calorimeter (Parr, model 1241).

Statistical Analysis

Average daily gain, average daily feed intake, and feed efficiency were analyzed by analysis of variance using General Linear Modeling (GLM) in the Statistical Analysis System (SAS Institute Inc., 1988). This experiment was a completely randomized design, with a 4 x 2 factorial arrangement of treatments in which animals were randomly assigned to one of the four grains, and with or without enzyme supplementation. This was further split by period.

The model used was $Y_{ijkl} = \mu + g_i + z_j + gz_{ij} + p_k + pg_{ik} + pz_{jk} + pgz_{ijk} + e_{ijkl}$, where Y_{ijkl} = the average daily feed intake, average daily gain, and feed efficiency per stage of each pen on the j^{th} enzyme within the i^{th} grain within the k^{th} period, μ = the overall mean, g_i = the effect of the i^{th} grain, z_j = the effect of the j^{th} enzyme, gz_{ij} = the effect of the interaction of the g^{th} grain and the z^{th} enzyme, p_k = the effect of the k^{th} period, pg_{ik} = the effect of the interaction of the g^{th} grain and the k^{th} period, pz_{ik} = the interaction of the k^{th} period and the z^{th} enzyme, pgz_{ijk} = the effect of the interaction of the i^{th} grain and the z^{th} enzyme and the k^{th} period, e_{ijk}= the random error.

Differences between means were compared using the Student-Neuman-Keuls (SNK) method at a significance level of P<0.05 (Steel and Torrie).

RESULTS AND DISCUSSION

Overall Performance (Table 35)

The broilers fed the MB diets had a lower ADG (P<0.05) and ADFI (P<0.05) than the broilers fed the corn, wheat or barley diets. This may be due to the increased viscosity that occurs due to the gelatinized starches produced by micronization. There were no differences in the overall feed efficiencies (F/G) of any of the grain diets (P>0.05). There were no significant enzyme effects (P>0.05) in the overall performance of the broilers. There was a significant grain*enzyme interaction between the wheat+enzyme and wheat-enzyme diets, and also the MB-enzyme and MB+enzyme diets (P<0.05). The feed efficiency of the MB+enzyme diet was 3.5% lower than the MB-enzyme diet. The broilers fed the wheat+enzyme diet had a F/G efficiency that was 2.8% higher than the wheat-enzyme diet. The other diets, corn and barley, with enzyme supplementation had slightly higher F/G compared to the reciprocating diet without enzyme supplementation. The broilers fed the wheat-enzyme, corn-enzyme or barley-enzyme diets had higher ADG of

TABLE 35. The overall performance of broilers as affected by the feeding of corn, wheat, barley or micronized dehulled barley (MB) with or without enzyme supplementaion (1-40 days).

		Start Wt (g)	Finish Wt (g)	ADG (g)	SEM[1]	Sig[2]	ADFI (g)	SEM[1]	Sig[2]	F/G	SEM[1]	Sig[2]
Grain												
	Corn	43.2	2381.8	58.4^{b}	0.41	**	105.3^{a}	0.72	**	1.87	0.02	NS
	Wheat	43.2	2361.3	58.2^{b}			105.1^{a}			1.91		
	Barley	43.2	2361.3	57.8^{b}			103.9^{a}			1.86		
	MB	43.2	2274.6	55.7^{a}			100.6^{b}			1.87		
Enzyme												
	with Enz	43.2	2353.6	57.9	0.30	NS	104.1	0.58	NS	1.88	0.01	NS
	w/out Enz	43.2	2335.8	57.1			103.3			1.87		
Grain*Enz												
	Corn +	43.1	2392.8	58.8	0.51	NS	105.7	1.02	NS	1.87	0.02	**
	Corn -	43.2	2370.7	58.0			104.8			1.86		
	Wheat +	43.2	2364.2	58.6			106.1			1.94		
	Wheat -	43.2	2358.3	57.8			104.2			1.88		
	Barley +	43.2	2375.5	58.3			105.0			1.88		
	Barley -	43.2	2347.0	57.3			102.7			1.84		
	MB +	43.3	2282.0	56.1			99.5			1.84		
	MB -	43.2	2267.2	55.3			101.7			1.9		

[1] SEM = pooled standard error of the means
[2] ** = statistically significant at $P<0.05$; NS= non significant at $P>0.05$

4.8, 4.5 and 3.6% respectively (P>0.05), compared to those fed the MB-enzyme diet. The broilers fed MB-enzyme had a 3.5% decrease in the ADG compared to those fed the barley-enzyme diet. This is similar to the 3..5% difference of the overall grain effect with the ADG between the broilers fed MB or barley diets.

Effect x Period Interactions (Tables 36)

There was a significant period*grain interaction for ADG (P<0.05) with the broilers on the barley diets performing relatively better in the grower phase than in the starter phase. There was a significant grain*period interaction (P<0.05) for F/G with the performance of those birds fed the wheat diets in the grower period being poorer than in the starter phase. There was an enzyme*period interaction (P<0.05), with the broilers fed enzymes doing better in the grower phase than in the starter phase compared to those broilers fed the non-supplemented diets. A grain*enzyme*period interaction (P<0.05) occurs with the broilers fed the wheat+enzyme diet having a higher feed efficiency (F/G) in the grower phase than those fed the wheat-enzyme diet. This is very different than the performance of these broilers in the starter phase. The broilers fed the barley+enzyme diet in the grower phase have different F/G conversion efficiencies than the broilers fed the barley-enzyme diet. The performance of the birds on the enzyme diet do not have the same response to the enzyme that they did in the starter phase. In the starter phase, the addition of enzyme to the barley diet improved the F/G conversion efficiency by 4.7%. The low productive value of unsupplemented barley when fed to broiler chickens has been attributed to β-glucans which causes highly viscous conditions in the small intestine and

Table 36. The performance of broilers as affected by the feeding of corn, wheat, barley and micronized dehulled barley (MB) with and without enzyme supplementation. (Values are lsmeans ± SEM for effect * period interaction)

1-20 days		Start wt (g)	Finish wt (g)	ADG (g)	SEM[1]	Sig[2]	F/G	SEM[1]	Sig[2]
Grain									
	Corn	43.2	714.8	33.9	0.57	**	1.44	0.02	**
	Wheat	43.2	712.2	33.8			1.45		
	Barley	43.2	651.8	30.6			1.46		
	MB	43.2	631.3	29.6			1.47		
Enzyme									
	with Enz	43.2	680.7	32.2	0.40	NS	1.44	0.02	**
	w/out Enz	43.2	674.4	31.8			1.47		
Grain*Enz									
	Corn +	43.1	717.3	34.1	0.81	NS	1.45	0.03	**
	Corn -	43.2	712.3	33.7			1.43		
	Wheat +	43.2	709.0	33.7			1.45		
	Wheat -	43.2	715.3	33.9			1.46		
	Barley +	43.2	671.4	31.6			1.42		
	Barley -	43.2	632.3	29.7			1.49		
	MB +	43.3	625.1	29.3			1.45		
	MB -	43.2	637.5	29.8			1.50		

[1] SEM = pooled standard error of the means

[2] for period interaction ** = statistically significant at P<0.05; NS = non significant at P>0.05

Table 36 (continued). The performance of broilers as affected by the feeding of corn, wheat, barley and micronized dehulled barley (MB) with and without enzyme supplementation. (Values are lsmeans ± SEM for effect * period interaction)

(20-40 days)		Start wt (g)	Finish wt (g)	ADG (g)	SEM[1]	Sig[2]	F/G	SEM[1]	Sig[2]
Grain									
	Corn	714.8	2381.8	83.0	0.57	**	2.05	0.02	**
	Wheat	712.2	2361.3	82.6			2.11		
	Barley	651.8	2361.3	84.9			2.01		
	MB	631.3	2274.6	81.8			2.02		
Enzyme									
	with Enz	680.7	2353.6	84.2	0.4	NS	2.06	0.02	**
	w/out Enz	674.4	2335.8	83.0			2.03		
Grain*Enz									
	Corn +	717.3	2392.8	84.7	0.81	NS	2.05	0.03	**
	Corn -	712.3	2370.7	84.1			2.04		
	Wheat +	709.0	2364.2	83.5			2.16		
	Wheat -	715.3	2358.3	81.3			2.06		
	Barley +	671.4	2375.5	84.9			2.06		
	Barley -	632.3	2347.0	85.3			1.97		
	MB +	625.1	2282.0	83.7			1.98		
	MB -	637.5	2267.2	81.3			2.06		

[1] SEM = pooled standard error of the means
[2] for period interaction ** = statistically significant at P<0.05; NS = non significant at p>0..05

interferes with the nutrient absorption (Burnett, 1966). The F/G efficiency of the broilers fed MB+enzyme diet is 3.4% lower in the starter phase and 4.0% lower in the grower phase compared with the broilers fed the MB-enzyme diet. Brenes et al. (1993) reported a marked improvement (P>0.05) in feed consumption, weight gain and feed conversion in birds fed barley-based diets with enzymes. There were no period interactions in the ADFI for any of the effects (P>0.05).

Carcass Evaluation

A significant difference (P<0.05) was seen in the liveweight analysis of the broilers, with the hulled barley diets and the MB-enzyme diet having lower liveweights than the wheat treatments (Table 37). The birds fed the MB+enzyme diet were 3.7% heavier than those fed the MB diet without enzyme supplementation (P>0.05). There was also a decrease of 4.4% in the dress weight of the birds fed the MB-enzyme compared to those fed the MB+enzyme diet. There was a significant decrease in the dress weight (P<0.05) of birds fed the barley+enzyme or the MB-enzyme diets compared with the broilers fed the wheat+enzyme diet. The lower dress weight is expected on the broilers fed the MB-enzyme diet since those broilers had poorer ADG throughout the study. The breast weight for the birds fed the MB+enzyme diet was 6.0% higher than those fed the MB-enzyme diet (P>0.05).

Table 37. Carcass evaluation of broilers fed wheat, barley or micronized barley with and without Enzyme supplementation.

Treatment	Wheat			Barley			Micronized Barley				
Enzyme	+ Enz	- Enz	% Response	+ Enz	- Enz	% Respnse	+ Enz	- Enz	% Response	SEM[1]	sig
Livewt (g)	2725	2657	2.6%	2556	2582.4	-1.0%	2640	2545	3.7%	44.5	**
Dresswt (g)	1905^{a}	1869.5^{ab}	1.9%	1768^{b}	1808^{ab}	-2.2%	1837^{ab}	1760^{a}	4.4%	34.2	**
Abdominal Fat (g)	66.7	62.6	6.6%	65	63.9	1.7%	71.2	68	4.7%	3.88	NS
Cold wt (g)	1825	1937	-5.8%	1824	1878	-2.9%	1774	1808	-1.9%	78.8	NS
Breast wt[3] (g)	441.6	434.9	1.5%	411	424.5	-3.2%	426.8	402.7	6.0%	10.96	NS
Dressing (%)	69.9	70.3	-0.6%	69.1	70	-1.3%	69.6	69.1	0.7%	0.36	NS
Cold Dressing (%)	67.4	72.9	-7.5%	71.3	72.75	-2.0%	67.1	71	-5.5%	2.77	NS

1 - Number of birds per treatment = 14
2 - ** - statistical significance at $p<0.05$; NS = non significant at $p>0.05$
3 - Breast wt = weight of deboned breast filet

Viscosity Measurements

The results of the viscosity measurements (Table 38) show there was a difference in the viscosities of the digesta of the birds fed the various diets ($P<0.01$). The digesta from broilers fed the hulled barley and the MB diets had higher viscosity levels than those fed the corn or wheat diets. Barley β-glucans increase the digesta viscosity and thereby decrease the absorption of nitrogen and carbohydrate (Hasselman and Åman, 1986). The birds fed the hulled barley-enzyme diet had lower digesta viscosity levels than those fed the MB diets. The viscosity of the MB diet without enzymes is very high, which may be explained by the changes the starches undergo during starch gelatinization. The viscosity of the digesta of the birds fed the MB+enzyme remains higher than those fed the barley diet without enzyme. This would explain the poorer performance of the birds on the MB diets. It appears the mechanical dehulling and further processing by micronization increases the β-glucan content, and therefore the digesta viscosity. This high viscosity product becomes poorly absorbed in the gastrointestinal tract, and the poor performance of the birds reflects this inability to utilize the diet.

Table 38. Digesta viscosity measurements of broilers fed corn, wheat, barley and micronized dehulled barley with and without enzyme supplementation.

Grain	Corn		Wheat		Barley		Micronized Barley		SEM[1]	Sig[2]
Treatment	+ Enz	- Enz	+ Enz	-Enz	+ Enz	-Enz	+ Enz	-Enz		
Viscosity	2.85[b]	2.42[b]	3.29[b]	3.98[b]	5.1[b]	4.79[b]	4.91[b]	7.32[a]	0.635	**

[1] pooled standard error of the means
[2] ** - statistical significance at $p<0.01$

CHAPTER SEVEN

GENERAL DISCUSSION

The aim of micronization is to make the cereal grains more available for breakdown by the digestive enzymes of the animal. Starch gelatinization is believed to be a key part in changing the structure of the starch granule to a form that is more susceptible to enzyme attack. Barley contains approximately 65% starch (Mercier, 1971) with 22% of the starch being amylose (Greenwood, 1970). Greenwood (1970) suggested that the gelatinization temperature range for barley should be between 59 and 64° C. Mercier (1971) studied the effects of various processing treatments on barley and suggested from in vitro studies that micronization is a more efficient method than steam-flaking for improving starch availability.

The data from the in vivo starch digestibility study suggests that the starch of the micronized pearled barley is almost 100 percent digested in the small intestine of the pig. This was 13% greater than the digestibility obtained with the non-micronized product. This information indicates the micronization process definitely makes the starches more available to the animal. With this improvement in digestibility, the digestible energy (DE) content of the micronized grain should be higher than that of the unprocessed grain. Lawrence (1973a) reported an increase in the DE contents of micronized maize and barley over the non-processed grains. The apparent ileal and total tract digestibility of most of the amino acids were not affected by micronization of the pearled barley. The decrease in the apparent total tract digestibility of methionine in pigs fed the MB diet may suggest that the sulfide-bonds may be forming indigestible complexes through the micronization process. This decrease in methionine availability may cause problems in achieving maximum growth potential, as amino acid imbalances may result in the pig.

The substitution of MB for wheat and corn in the starter phase improved the feed conversion efficiencies. The ADFI in these studies were reduced by these substitutions while ADG was not affected. The results of the corn study from 20 to 37 kg bodyweight were not the same as the results to 37 kg in the wheat study. The poorer performance of the pigs fed MB compared to those fed corn in the corn comparison study may be related to the lower methionine digestibility in the MB. Corn has a high methionine digestibility, and it may be possible that the pigs on the MB treatments had an amino acid imbalance which affected performance. The use of MB instead of corn in the starter stage up to 20 kg resulted in improved ADFI and feed conversions. The addition of 50% micronized dehulled barley is more cost effective when used in the starter stage compared to the use of diets containing all corn or wheat.

The barrows consistently had higher ADG's than the gilts in both these studies. In both trials, the barrows had feed conversions that improved as more MB was introduced to the diet. The inclusion of 50% MB or more appeared to improve the feed conversions in the finisher stage (40 kg to 105 kg bodyweight) in the corn study, and the grower stage (40 kg to 70 kg bodyweight) in the wheat study. The finishers in the wheat study were all fed the same control diet, so it is not possible to see the effects of added MB in those finisher pigs. These results suggest that the addition of MB in barrows may improve their utilization of feed.

The addition of enzymes to the MB diet improved the ADG, but not the ADFI compared to the MB-enzyme treatment in the starter phase of the pig enzyme study. This resulted in an improved feed conversion. Both of the MB treatments did not perform as well as the corn or the hulled barley treatments. These results are not consistent with the previous corn study where the addition of MB improved ADG and the F/G in the starter phase from 10 to 20 kg body weight. Even the addition of a β-glucanase enzyme did not significantly improve the ADG or F/G over that of the corn control. The addition of enzyme to the MB diet in the grower phase actually decreased the ADG and decreased the F/G. There were differences in the gross energy levels of the treatment diets, with the barley and corn grower diets being much higher than the MB diets. This may explain the differences which were seen in the performance of the pigs fed the MB diets. It is possible that the micronized dehulled barley used in the diets was over-heated or micronized at a lower moisture content. This may decrease the amount of starch gelatinization that would have occurred, and subsequently decreased the availability of the starches to the animal's digestive enzymes. It is possible that a Maillard reaction may have occurred with lysine and starch forming unavailable complexes. This may also explain the poorer performances of the pigs fed the MB diets.

The addition of MB into broiler feeds reduced the performance of the birds. The addition of β-glucanase did not improve the performance (ADG, ADFI) of the birds fed the MB diet compared to those fed no enzyme. The broilers fed the MB+enzyme diet did have an improved feed efficiency compared with the birds fed the MB-enzyme diet. The performance of broilers (ADG, ADFI) fed either MB diet was poorer than those birds fed the other grain diets. This observation could be due to the high digesta viscosity values with the MB diets without enzyme supplementation. The bird is unable to digest water soluble non-starch polysaccharides which could have been increased by the micronization process.

The comparison of the broiler study to the pig studies indicates that viscosity and enzyme-supplementation are not as important to the weaned pig. The young pig has better abilities to digest the viscous product than the young broiler. The addition of enzymes to the MB diets fed to the young pigs did not significantly improve their growth or feed utilization.

CHAPTER EIGHT

SUMMARY AND CONCLUSIONS

An ileal and total tract digestibility study was conducted to determine the apparent amino acid digestibilities and the starch digestibility of micronized dehulled barley. Three pig feeding studies were conducted to determine the nutritive and economic advantages of feeding MB to pigs. A broiler study was conducted to determine the nutritive value of MB for broilers, and the possible advantages of β-glucanase supplementation to the MB diets for broilers.

The improved feed intake and feed conversions of the pigs fed micronized dehulled barley suggests the hog industry can benefit from its use in starter feeds. The high ileal starch digestibility of the micronized grain suggests it may be very beneficial in pre-weaned and early weaned pig diets. The decreased methionine digestibility in the total tract may cause decreased or inconsistent growth performance of pigs. This inconsistent growth, however, could be solved with the addition of synthetic methionine to the diet.

The addition of enzymes to the MB pig diet did not improve performance, which suggests it does not increase the availability of the nutrients in the MB. The poorer performance of broilers fed MB, with or without enzyme supplementation indicates that MB is not suitable for broiler production.

There are some areas of further study that should be considered. The use of oat groats are commonplace in segregated early weaning diets, and it would be interesting to compare the micronized dehulled barley with oat groats in the early weaned diet. The high digestibility of the micronized dehulled barley should produce an excellent grain source for young pig diets. The replacement of lactose with micronized dehulled barley in young pig diets is another area that should be studied in the future. The high digestibility of the micronized product may be a very good partial replacement for lactose as well. The effects of micronization on methionine digestibility should be further studied to better understand the causes of the decreased digestibility.

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