THE EFFECTS OF BARLEY ON STARTER- AND FINISHING-PIG PERFORMANCE

by

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GENERAL INTRODUCTION

In a typical swine operation, feed costs represent 60 to 75% of the total cost of production. Therefore, it is important for a producer to formulate diets on a least-cost basis, without jeopardizing production. Swine diets in the U.S. traditionally are made up of corn or sorghum grain and soybean meal. However, there may be limitations on the availability of these ingredients because of geographic location, growing conditions, and market fluctuations. Because any change in availability will be reflected in price, a producer must remain flexible in his feed formulations and be able to incorporate other less expensive feed sources into his operation when necessary. There are also several disadvantages in using alternative feed ingredients that might not make them as economical as expected. These include lower nutrient availability, palatability, unknown composition, and storage problems. All of these factors could contribute to decreased performance of the herd, and eventually lead to higher production costs, rather than short-term savings. Therefore, it is essential for the producer to know the limitations and value of alternative feed sources so he can appropriately incorporate them into his operation without lowering production.

In Kansas, much of the corn produced is grown under irrigation. However, years of continuous irrigation are now leading to a gradual depletion of ground water reserves. This is forcing farmers to drill new wells and to pump water from greater depths. As irrigation costs continue to increase, farmers are turning to dryland crop production. Many of the small grains fit well into this type of system and do extremely well in Kansas soils. Wheat, for example, is one such crop that is well adapted to growing conditions in Kansas. As a result, Kansas produces more wheat than any other state in the country. Unfortunately for the farmer, bumper crops mean low prices and as a result wheat can be an economical alternative feed ingredient for swine diets. Giant surplusses of wheat lead to economic incentives as well as governmental policies for farmers to reduce acerage and limit production. Thus arises the need for a alternative crop that will produce well and be marketable for the Kansas farmer.

Barley (Hordeum vulgare L.) is one such alternative grain crop that will meet these needs. It grows well with the same amount of annual rainfall as wheat, and furthermore, outyields wheat by as much as 25%. Winter barley also matures faster than wheat and can be harvested about two weeks earlier, allowing the producer more flexibility in a double-cropping program. These agronomic factors contribute to barley's profitability, especially if more demand can be generated for it as a feed in the livestock industry.

Present research indicates that barley is equal to 97% the feeding value of corn in cattle rations (Riley, 1985); however, the approximate value for swine is anywhere from 80-90% the feeding value of corn. With more barley being produced because of economical and environmental factors, it is essential to know its exact limitations and advantages in swine diets, so it can be used to its fullest potential by the swine producer.

REVIEW OF LITERATURE

INTRODUCTION

The earliest evidence of domestication of barley stems from the Middle East at approximately 6000 BC. Today, it is the fourth leading crop in world production behind wheat, corn, and rice. Approximately 35% of the barley produced is for human consumption, the vast majority of this is malted. However, over 50% of the barley produced is used for livestock feed. Barley is widely used as a feedstuff in the northern states where corn production is not agronomically feasible, and more extensively throughout Canada, the Soviet Union and northern Europe. Barley's high yield, low moisture requirement, and short growing season make it an ideal grain crop where corn production is limited by these factors. Although barley contains more total protein, lysine, and other essential amino acids than corn or sorghum grain, its use in swine diets is limited because of its high fiber content, which dilutes the amount of energy in the diet and reduces pig performance. These deleterious effects have traditionally limited the use of barley in swine diets.

FEEDING VALUE OF BARLEY VS. OTHER CEREAL GRAINS

Barley has long been compared to corn as an energy substitute in swine diets. The high protein content of barley makes it a potentially valuable substitute. However, the high fiber content dilutes its digestible energy and therefore, is associated with poorer feed efficiency. Because of these characterstics, barley has been limited primarily to growing-finishing diets and is considered to have only 80-90% the feeding value of corn.

In 1940, Morrison, summarized the results of 17 experiments comparing ground barley to corn for growing-finishing pigs. Although the higher protein content of barley reduced the amount of protien supplement required, pigs fed barley had 7% lower average daily gain and were 13% less efficient than corn-fed pigs. Much of the reason behind the inferior performance of pigs fed barley diets is its increased fiber level and low digestible energy. Cornejo et al. (1973) reported the digestible and metabolizable energy values of barley to be 3375 and 3332 kcal/kg respectively. These figures represent 89-90% the digestible energy of corn and wheat.

Lawrence (1970a) compared growing-finishing pigs fed diets composed of either corn, sorghum grain, wheat, or barley. Diets were formulated to contain 85% grain during the grower phase and 90% grain in the finishing phase. All pigs were limit fed a wet mash. During the growing phase and for the overall experiment, pigs fed either wheat or barley diets grew faster ($P<.05$) than those fed corn or sorghum grain. Pigs fed wheat and barley had the same average daily gain (.70 and .70 kg/hd/day), while corn- and sorghum grain-fed pigs averaged .65 and .66 kg/hd/day gain, respectively. Pigs fed barley diets were not significantly different in feed efficiency, but were leaner ($P<.05$) than those fed either corn or sorghum grain. From examining the diets used in this experiment, it is possible that all the diets used were deficient in protein and essential amino acids; however, the wheat and barley diets were only marginally deficient. Therefore, it was the high protein content of the barley and wheat that was responsible for the improved growth.

A similar experiment conducted by Lawrence (1968), evaluated growth and digestibility for pigs fed the four previous diets plus an additional flaked corn diet. Although there was a numerical advantage in average daily gain of pigs fed the corn diet, those fed barley were not statistically different. Feed efficiency was significantly poorer for the barley fed pigs. Barley diets were lower in digestible energy, digestible dry matter, and digestible crude protein. It appeared that increasing digestible energy tended to give higher growth rates, better feed conversion, but results in fatter carcasses.

To study the effects of limit or ad libitum feeding of high or low energy diets, Greer et al. (1965) evaluated growth and carcass characterstics of finishing pigs fed either barley or corn diets. In the first experiment, control pigs were allowed full access to feed for two, 30-minute feeding periods, while the other pigs were fed 85 and 70% of the amount consumed by the control group. Pigs fed corn diets grew faster ($P<.05$) than those fed barley diets. As the level of feed intake decreased, there was a linear decrease in average daily gain. Pigs fed the corn diets required less feed per pound of gain; however, barley-fed pigs had higher ham/loin percentages and were leaner. In a second trial, pigs fed ad libitum grew faster and were more efficient than those that were limit fed. Regardless of the type of feeding program, corn-fed pigs grew significantly faster and were more efficient than the barley-fed pigs.

Hollis and Palmer (1971) compared corn, wheat, and barley in diets balanced on an equal protein basis, and fed to finishing pigs. Pigs fed the corn diets grew faster and were more efficient than pigs fed either wheat or barley diets (.76, .68, and .66 kg/hd/day, respectively) and suggested feeding values of 89 and 87% for wheat and barley compared to corn for supporting growth. However, these diets were formulated on an equal protein basis.

Beams and Sewell (1969) compared barley and sorghum grain diets fed to growing-finishing pigs at four different protein levels. Soybean meal was supplemented in the diet to give crude protein levels of 15.1, 14.0, 12.7, and 11.4%. While there was a decrease ($P<.05$) in average daily gain and feed efficiency as protein level was reduced to 12.7 and 11.4%, there were no differences between grain sources. Further experiments, evaluating three meat and bone meal sources in barley or sorghum grain diets, resulted in no differences in performance between grain sources.

Recently, Libal et al. (1984) compared finishing pigs averaging 64 kg and fed a basal corn-soybean meal diet to pigs fed diets in which barley was substituted on an equal weight basis for corn at levels of 25, 50, 75, and 100% of the diet. There were no differences in average daily gain between treatments; however, feed efficiency tended to increase when barley composed over 75% of the diet.

In a 4x2 factorial experiment, McConnel et al. (1975) evaluated barley, corn, wheat, and milo in diets supplemented with either soybean meal or roasted soybeans for growing-finishing swine. There were no differences in performance among the eight treatments from 21 to 57 kg. However, from 57 to 101 kg, pigs fed barley plus soybean meal grew slower ($P<.05$) than all other treatments. Overall, average daily gain of pigs fed barley plus roasted soybeans was equal to corn-, wheat-, or milo-fed pigs supplemented with either protein source. Average daily gains were significantly lower for pigs fed barley plus soybean meal. Supplementation with roasted soybeans improved feed efficiency of the barley diet to equal both milo diets. Nevertheless, pigs fed barley plus roasted soybeans were still inferior to those fed corn and wheat diets in feed efficiency. The improved response to the barley diet supplemented with roasted soybeans was because of its high energy content supplied by the fat in the roasted soybeans.

Increasing the caloric density of barley-based diets by adding fat is one way of masking the deleterious effects of barley's high fiber content, Heitman (1956) found that 5 and 10% added tallow or lard to significantly improve average daily gains of pigs fed barley-based diets. Similar results were reported by Anglemyer and Oldfield (1957) and Oldfield and Anglemyer (1967), who also found improvement in average daily gain with up to 5.5% added fat in the diet.

While results comparing growing-finishing pigs fed barley to pigs fed other grains are varied, there is less discrepency in results evaluating barley in pig starter diets. Pond and Manner (1984) reviewed several experiments with starter pigs fed barley diets and found little difference in performance because of grain source. The results of the review are similar to the results of Bowland (1974), in which pigs averaging 5.6 to 7.5 kg were used to compare wheat and barley based starter diets. All diets were composed of 83.6% cereal grain and 12.5% soybean meal (48.5% crude protein). Average daily gain, feed intake, and feed efficiency were similar for all diets, and indicate that barley is of equal feeding value to wheat for starter pigs. Results of a digestion trial reported that the barley was lower ($P<.05$) than three varieties of wheat in digestible energy (83.8 vs. 87.3%), metabolizable energy (81.4 vs. 84.5%), and digestible nitrogen (81.5 vs. 85.7%). However, these differences failed to affect pig performance. Results from these studies indicate that the energy content of the cereal grain may not be as limiting or important for starter pigs as high quality and adequate protein levels.

HIGH LYSINE BARLEY AND DIFFERENCES BETWEEN VARIETIES

Common cereal grains fed to livestock are often associated with a specific and narrow range of nutrient composition. However, examining a grain family more carefully, one finds an endless assortment of different varieties and cultivars developed for specific purposes. When the many varieties are combined with the various growing conditions, there exists a potential for a grain to have an extremely wide variation in nutrient composition, not only between, but also among varieties.

The many varieties of barley may be broken down into three subclasses: two-row, six-row, and irregular barley. In the past, two-row barley was a high quality, malting variety, while six-row barley was a high yielding, feed grade barley. However, developments in plant breeding have decreased the nutritional and yield differences between the two.

Castell and Bowren (1980) compared growing-finishing pigs fed two or six-row barley in growth, digestion, and palatability experiments. Although there were no significant differences in performance of pigs because of barley genotype, there were numerical advantages in favor of the two-row in average daily gain, feed intake, and feed efficiency. Two-row barley also tended to be preferred by pigs over the six-row barley, and was higher ($P<.05$) in digestible dry matter, energy, and protein. This improved digestibility may be a reflection of the lower fiber content of the two-row over the six-row barley (5.3 vs. 6.0%).

Other newly developed varieties of barley have received much research attention. These are the high lysine and high amylose varieties of barley. In general, high lysine barley contains up to .72% lysine and 16% crude protein (Misir et al., 1984). However, unlike normal barley, protein content and lysine concentrations of high lysine barley are negatively correlated. This is because during optimum growing conditions or with nitrogen fertilization, the increased protein content is a result of the increased prolamine fraction of the endosperm (McBeath et al., 1960; and Elwinger, 1978). Prolamines, while high in net protein, are low in lysine content. The high lysine content is developed from a redistribution of the grain protein fractions resulting in an increase in the lysine-rich albumins and globulins, at the expense of the prolamines. Therefore, high lysine barley will normally have total protein levels similar to normal cultivars. It would appear from the amino acid profiles of high lysine barley that a vitamin-mineral fortified, high lysine barley diet would meet all the nutrient requirements for finishing pigs (50 to 100 kg).

Misir and Sauer (1982) evaluated several high lysine barley lines for growing rats as well as amino acid digestibility. In comparison to a normal feed cultivar, high lysine barley tended to be lower in digestible dry matter and crude protein, but equal for some essential amino acid digestibilities. In further experiments with growing pigs, Misir et al., (1984) found that high lysine barley could meet all the amino acid requirements for 60 to 100 kg pigs, or replace most of the soybean meal in the diet. Newman et al. (1978) compared pigs fed diets in which soybean meal was replaced by high lysine barley or high lysine barley plus synthetic lysine or methionine. Pigs fed a blend of high lysine barley plus synthetic amino acids grew faster ($P<.05$) in the grower phase and for the overall experiment, but in the finishing phase were equal to the barley-soy control pigs. This was because of the slightly higher protein and lysine content of the blended high lysine-amino acid diets. However, in a second experiment, when the amino acid differences were corrected, there were no differences in average daily gain or feed efficiency. From these results, it would appear that high lysine barley may be blended with normal barley to replace a large part of the soybean meal in the diet. Depending on the variety of high lysine barley, the amount of soybean meal may be reduced at considerable savings to the producer. However, like other high lysine mutants of cereal grains, yields of high lysine barley can be expected to be between 30 to 50% less than those of normal barley.

High amylose barley was developed for use in the malting industry. It differs from the normal isogene not only in amylose but also increased amino acid content. High amylose barley also contains less amylopectin. However, the compositional advantages of high amylose barley appear to be limited for the pig. Newman et al. (1978) compared performance of rats fed normal Glacier and High Amylose Glacier barley and found improved performance for the rats fed the high amylose barley. This was attributed to its improved lysine content. However, in a rat digestion experiment, true protein digestibility was better for the normal isogene (79.4 vs. 72.6%). When pigs were fed the High Amylose Glacier or Glacier barleys (Calvert et al., 1981), there were no differences in average daily gain. However, feed efficiency of the pigs fed the High Amylose Glacier were poorer (P<.05) than those fed the normal Glacier barley. These results suggest a possible decrease in digestibility for high amylose barley diets. This is supported by experiments showing resistance to in vitro amylose digestion of high amylose varieties. This supports the hypothesis that the starch structure of high amylose barley might be more tightly bound than that of normal barley, thus digestible starch for energy may become a limiting factor for growth.

The third major barley genotype is classified as irregular barley, which includes the hulless varieties. The hull portion of barley has long been suspected as the cause of its decreased feeding value. First, the hull which is high in fiber, dilutes available nutrients and can decrease digestibility of these nutrients. Secondly, it has been hypothesized that barley hulls might contain growth inhibitors, which could also limit digestibility and utilization of its nutrients. More recent research has identified B-glucans, a lignin-like carbohydrate, as a possible digestive inhibitor. It should also be noted that hulled barley may be pearled to remove the hull, and that this type of processing might be another alternative in improving the quality of barley.

Newman et al. (1968) compared different varieties of hulled and hulless barley to corn in diets fed to starter pigs, and found mixed results depending on the variety of either barley used. Pigs fed hulless Compana barley performed equally in average daily gain and feed efficiency to those fed the corn diets; however, pigs fed the covered barley grew slower and were less efficient (P<.05). In a second experiment, there were no differences in performance of pigs fed Glacier or hulless Glacier barley. In later studies, Newman et al. (1980) compared two different varieties of covered and hulless barleys in growing-finishing rations supplemented with bacterial diastase. Pigs fed the hulless barley grew faster and were more efficient than those fed the covered barley. However, pigs fed the covered barley supplemented with bacterial diastase were not different in performance to those fed the hulless barley with or without the bacterial diastase. These findings indicate that enzyme supplementation of covered barley might improve nutrient digestibility, therefore, resulting in performance equal to that of pigs fed hulless barley.

Wahlstrom et al. (1977) found hulless barley to be inferior to corn or oat-based diets fed to starter pigs. However, the barley diet used in this experiment was deficient in lysine, thereby making any evaluation of hulless barley impossible.

Digestibility experiments conducted with hulless and covered barleys have resulted in mixed observations. Mitchall et al. (1976) found hulless barley to have higher digestible energy than hulled (77.3 vs. 73.0%), but lower digestible protein (69.6 vs. 73.1%). Bhatty et al. (1970) found similar results in digestible energy in favor of the hulless barley (81.8 vs. 73.6%), as well as higher protein digestibility (66.6 vs. 61.5%). However, there was one six-row, hulled variety that had higher nutrient digestibilities. While differences in the age of pig used in each experiment might account for some of the variability between results, it should be noted, that in each experiment there were significant differences in digestibilities because of the variety of barley used. From these experiments, it would appear that hulless barley, is more digestible than hulled; however, the degree of improvement depends on variety.

Results of experiments feeding hulless barley to chickens are contrary to the findings reported with swine. In experiments with chickens that were fed either corn, barley, or pearled barley, there was no improvement in performance from the pearling process, (Fry et al., 1958), and both types of barley were inferior to corn. These results are in agreement with those found by Jensen et al. (1957). However, addition of 6-8% tallow (Fry et al., 1958) or bacterial diastase (Jensen et al., 1957) to the pearled barley improved its feeding value to a level equal to that of corn as measured by chick performance.

Hesselmann et al. (1981) studied the effects of dry or high moisture barley harvested at two different stages of maturity with B-glucanase supplementation on chick performance. Anaerobic storage of high moisture barley resulted in an increase in the amount of reducing sugars as a result of sucrose and raffinose breakdown, as well as the possible breakdown of B-glucans to glucose. Supplementation of B-glucanase to high moisture barley had an additive effect in improving growth and performance of chicks over those fed dry or unsupplemented diets. The authors concluded that the positive response to B-glucanase supplementation of high moisture barley was a result of the breakdown of the B-glucans.

The level of B-glucans in barley has been determined to affect the feeding value of barley for swine. Honeyfield and Froseth (1983) developed prediction equations from several experiments evaluating pigs fed different varieties of barley, and found B-glucan content to be an important criterion in evaluating the feeding value of a cultivar. Because B-glucans are undigestible to the pig, they increase the viscosity of the digesta, thereby limiting contact with digestive enzymes and decreasing digestibility. As more undigestible nutrients are available, there is an increase in the bacterial population, which also competes for nutrients, further limiting their availability to the pig.

The high fiber content of barley also plays a role in decreasing nutrient absorption. Keys et al. (1971) and Kornegay (1978) found that as dietary fiber levels were increased, digestibility of dry matter, crude protein, and energy decreased. Bell (1983) ground barley and air classified it into hulls, starch, and protein components. They combined these components and simulated barleys of various qualities. Upon feeding the simulated barleys to pigs in a digestion trial, energy digestibility was highly correlated (r=-.90) with percent hulls and crude fiber. Apparent protein digestibility was also decreased ($P<.05$) by increasing fiber levels.

To further investigate the effect of fiber and possible growth inhibitors of barley hulls, Larson and Oldfield (1960) examined the effects of fiber from barley hulls or purified cellulose on pearled barley and corn diets fed to pigs. Pigs fed pearled barley grew faster and were more efficient than those fed corn diets. Addition of 3.3% cellulose failed to depress average daily gain of the corn-fed pigs, where additions of 20% barley hulls decreased average daily gain. It was concluded that barley hulls do more than just dilute available nutrients, and may possibly contain growth inhibitors.

From the literature, it would appear that the hull portion of barley may play a major role in decreasing its feeding value for growing swine. Whether this is because of its high fiber content or unidentified growth inhibitors is unclear. However, it would appear that the structural carbohydrates of barley are not readily digestible by the pig and may hinder other nutrient utilization. Processes that alter chemical composition and improve performance of pigs fed barley, such as anaerobic storage and enzyme supplementation, would tend to support this hypothesis. However, further research into this area is needed for identification and mode of action of these inhibitors.

HIGH MOISTURE BARLEY

High moisture storage of barley may result in advantages by reducing harvesting losses and improving the feeding value of barley. Improvement in feeding value would be a result of a change in chemical composition under anaerobic storage. Harvesting barley at higher moisture levels would also further increase double cropping potential and increase land production. However, there are certain disadvantages in feeding high moisture barley or any other high moisture grain that must be considered. First, there must be adequate facilities for storing high moisture grains, preferably oxygen-limiting structures to reduce spoilage and retain nutrients. Second, a suitable program for feeding must also be set up including how often the material is to be fed and incorporated into the diet. Finally, if formulating a complete diet, it is essential to balance high moisture barley on a dry matter basis.

Cole et al. (1975) fed growing-finishing pigs propionic acid-treated barley at moisture levels of 21 and 22%, and found no differences in performance between pigs fed the high moisture and dry barley diets. Further experiments (Cole et al., 1980), again found no differences in pigs fed acid treated barley at 14, 18, and 24% moisture when balanced on a dry matter basis.

When high moisture barley diets were not adjusted on a dry matter basis, Livingstone and Livingston (1970) found decreases in average daily gain with limit fed pigs. Overall, three other experiments with feeding high moisture barley found decreased growth and efficiency when compared to dried barley. The authors attributed the reduced performance of the high moisture barley to poor feed intake as a result of spoilage.

These findings agree with other data on the use of high moisture grains in that the grain must be free of mold and spoilage and diets must be balanced on a dry matter basis to ensure comparable performance.

AMINO ACID SUPPLEMENTATION

Barley is considerably higher in protein and several essential amino acids than corn or sorghum grain. This could be of great economic advantage in swine diets by reducing the amount of supplemental protein needed to balance the diet. Dinusson et al. (1960a) conducted 15 experiments with growing-finishing pigs fed barley based diets supplemented with blood meal, meat scraps, and soybean meal, either alone or in combination. Pigs fed diets containing soybean meal performed numerically better than pigs receiving any other of the supplemental protein sources. Further experiments showed a response to .4% lysine added to barley-blood meal-meat scrap diets. Further supplementations with lysine and tryptophan improved performance, while methionine additions alone reduced average daily gain. From these experiments, it was concluded that soybean meal appeared to be the least variable protein source and lysine supplementation greatly improved pig performance regardless of protein sources. This research agreed with earlier work (Dinusson et al., 1958) that showed significant improvement in gain and feed efficiency with starter pigs (11 kg) when lysine was supplemented to the basal barley diet.

Reimer and Meade (1964) conducted a series of experiments to evaluate growing-finishing pigs fed barley diets with various protein and lysine levels and sources. No differences were found in performance of pigs fed barley diets supplemented with soybean meal, tankage, or a combination of the two, in either a two phase growing-finishing program (16% followed by 13% crude protein), or a continuous 14% crude protein finishing diet. This is in disagreement with the results of Diunsson et al. (1960a), who evaluated animal protein supplementation of barley-based diets. However, it may be explained by the lysine quantity and availability differenes between the two animal protein sources. The second experiment in the series evaluated effects of lysine and methionine additions on performance and nitrogen retention of growing swine (Soldevila and Meade, 1964). Supplemental lysine and methionine caused no improvement in nitrogen retention in limit-fed pigs. This was thought to be the result of the pigs breaking down amino acids to meet their energy requirements. However, when pigs were allowed to consume more feed, lysine was the only amino acid supplementation that increased nitrogen retention.

Further experimentation with a 14% crude protein, barley based diet with .3% supplemental lysine resulted in improved average daily gains and feed efficiency over those supplemented with .2% methionine alone or in combination with .15% lysine. These results suggest that lysine is the first limiting amino acid and methionine is not limiting in barley-based diets for growing pigs.

In the final paper of the series, Reimer et al. (1964) evaluated pigs fed a pelleted, 14% crude protein diet, which gave no response in gain or carcass leaness to supplemental lysine or methionine additions. While this contradicts previous experiments (Soldevila and Meade, 1964), it was the author's opinion that pelleting allowed the pigs to consume larger quantities of feed than in the previous experiments, thereby allowing the pigs to meet their lysine requirements.

More recently, Wahlstrom et al. (1984a) evaluated growing pigs fed barley-based diets supplemented with .05, .1% L-lysine, or barley-soybean meal diets balanced to equal lysine levels of the synthetically supplemented diets. Increased lysine levels did not improve performance or lower blood urea levels. Pigs fed the basal corn diets grew significantly faster and more efficiently than pigs fed any of the barley diets. However, average daily gain appeared to be related to feed intake, and indicated that the barley was not as palatable or was too bulky for 20 kg pigs to consume adequate amounts to support optimal growth. Similar decreases in average daily gain and poor feed efficiency because of low feed intake in growing pigs fed barley-based diets supplemented with either .05% lysine and/or 2.5% fat were reported by Wahlstrom et al. (1984b). However, in the finishing phase, when feed intake of the barley diets increased, performance was equal to that of corn-fed pigs with the exception of the barley diet without supplemental lysine and fat.

The variable response of pigs fed lysine-supplemented barley diets may be affected by the level of feed intake of the higher fiber barley diets. Therefore, it would appear that lysine supplementation is beneficial when protein quantity is low or borderline (Braude et al., 1972), supplemental protein source is variable, or feed intake is reduced by either palatability or fiber levels.

With lysine clearly established as the first limiting amino acid in barley-based diets, research has focused on finding the second and third limiting amino acids and optimum levels of supplementation. Fuller et al. (1974) fed gilts averaging 33 kg a fortified barley diet supplemented with synthetic amino acids to determine optimal amino acid levels by measuring nitrogen retention. Threonine added at 1.2 g/kg, reduced urinary nitrogen levels with added lysine and was determined to be second limiting. However, attempts to identify the third limiting amino acid were less successful since further addition of isoleucine, methionine, and tryptophan did not reduce urinary nitrogen excretion. However, histidine addition moderately lowered nitrogen excretion, but not significantly enough to support a recommendation. Average daily gain and feed efficiency were maximized when lysine was suplementated at 4.0 g/kg and threonine at 1.9 g/kg of the diet above levels already present in diets (Fuller et al. 1972, 1974).

Aw-Yong and Beams (1975) further demonstrated lysine and threonine to be the first and second limiting amino acids in barley-based diets. Performance of pigs fed the control barley-soybean meal diet were superior to any of the barley-synthetic amino acid diets in the growing phase. However, in the finishing phase, there were no differences in average daily gain between pigs fed either the barley-soy control or barley plus supplemental lysine and threonine at levels of .75 and .45% of the diet, respectively. However, for maximal efficiency, threonine had to be supplemented an additional .15%. These results for optimal lysine supplementation are similar to those found by Chung and Beams (1974), although they found .29% total threonine to be sufficient for adequate performance.

AMINO ACID AVAILABILITY

Although it would appear from the previous experiments that a synthetic amino acid-fortified barley diet would be sufficient for adequate performance, this has not necessarily been true. Several of the differences in suggested amio acid supplementation may be accounted for by discrepencies in amino acid availability. Although NRC (1979) does not make a recommendation for "available" amino acids, most of its recommendations have been based on corn-soybean meal or semi-purified diets, and therefore, it might be possible that use of ingredients other than corn and soybean meal with different availabilities could result in amino acid deficiencies.

Neilson et al. (1963) evaluated L-lysine supplementation of barley and corn-based diets fed to growing-finishing pigs. Lysine supplementation improved average daily gain and feed efficiency of pigs fed sub-optimal protein levels. Although lysine content of the barley-soybean meal diets was higher than that of the corn-soy diets, there was a greater response to added lysine of the pigs fed the barley-based diets. This suggests that the availability of lysine in barley is less than that of corn.

Sauer et al. (1974) compared availability of amino acids from barley, wheat, triticale, and soybean meal. Pigs averaging 10 to 30 kg were fed a protein-free diet to determine endogenous protein excretion, followed by the experimental cereal based diets. True amino acid availability was determined by subtracting fecal and endogenous amino acid excretions from amino acid intake. Although true nitrogen digestibility and amino acid availablity decreased slightly as the pigs became older, there were similar trends for amino acid digestibility for each group. Individual amino acid digestibility was lowest for lysine in all feeds except soybean meal. There were then slight improvements in availability for isoleucine, methionine, threonine, and valine, while availabilities for leucine, arginine, histidine, and phenylalanine were the highest.

As for amino acid availabilities and nitrogen digestibility of the feed ingredients, there was a decrease ($P<.05$) in availability in order of soybean meal, triticale, wheat, and barley. Available lysine decreased from 94.9 to 86.3, 80.8, and 77.1%, while true nitrogen digestibility decreased from 94.7 to 92.0, 90.9, and 85.5%, respectively.

In a second experiment, Sauer et al. (1981) determined availabilities of amino acids from barley and four wheat varieties using ileocecal cannulation. It was felt that apparent ileal digestibilies would be more accurate than fecal determinations because they by-passed microbial degradation in the large intestine. Experimental procedures were similar to those of Sauer et al. (1974) except pigs averaged 45 kg. Average true ileal availability of lysine, methionine, and threonine was 83.5, 85.0, and 85.7%, respectively. From these experiments, it would appear that among soybean meal, triticale, wheat, and barley, barley would contain the least available amino acids. It would also appear that lysine is one of the least available of the individual amino acids. One possible explanation for decreased amino acid availability in barley would be its relative porportions of individual amino acids in the protein fraction of the kernel. Most of the lysine content of a kernel of grain is in the albumin and globulin protein fractions. These proteins make up a substantial part of the aleurone layer of the kernel. The aleurone layer lies on the border between the bran and endosperm and contains a large amount of cellulose, which is undigestible by the pig. Unlike other cereal grains, barley contains a multi-cellular aleurone layer. These two factors contribute to decreasing the breakdown and utilization of lysine and other amino acids within the aleurone, and thus, decrease lysine availability. Moran (1985) reported that feed processing is essential for rupture of the aleurone layer in order to improve digestibility of the amino acids.

Therefore, the decreased availability of the amino acids in barley may be because of the structure of the kernel and the high amount of lysine contained within the aleurone layer.

PROCESSING AND PARTICLE SIZE

Physical form of the diet can play a key role in its nutritional value and subsequent utilization by the pig. Generally, as particle size decreases, surface area increases, thus allowing for more interaction with digestive enzymes and increased digestibility. While generally this improved digestibility will not elicit a response in average daily gain, it normally improves feed efficiency. However, reduced particle size may improve average daily gains if it alters the form of an undigestible component of the diet (i.e., the hull), making it more digestible. Fine grinding also improves performance by incorporating unpalatible ingredients into the diet, thus preventing sorting and settling of the diet (Crampton and Bell, 1946). The effects of particle size are more evident as the age of the pig increases. This is because young pigs masticate their feed better than finishing pigs. However, feedstuffs ground too finely may reduce performance of the pig by reducing feed intake if the diet becomes too dusty. Finely ground diets are also associated with increased incidence of esophageal ulcers.

Mahan et al. (1966) and Maxwell et al. (1966, 1970, and 1972) assessed the correlation between particle size and esophageal ulcers, and concluded ulceration to be a result of lower stomach pH, increased pepsin activity, and increased fluidity of the stomach contents with finely ground diets. The increased fluidity in the stomach leads to pepsin and acid coming into contact with the unprotected esophageal tissues of the stomach, resulting in their ulceration.

Contrary to these findings, Lawrence (1970b), studying the effects of barley particle size, found decreasing particle size to give higher mean stomach pH values. The increased pH was thought to be related to decreased rate of passage with decreasing particle size. Changes in stomach pH were also found to be associated with feeding frequency, in that as feeding frequency increased the stomach pH increased.

Maxwell et al. (1966) found addition of 25% coarsely (9.4 mm screen) ground oat hulls to reduce (P<.05) the number of ulcerations in stomachs of pigs fed basal corn diets ground through the same screen. However, when oat hulls were finely ground, there was no positive effect on reducing the incidence of esophageal ulcers.

PARTICLE SIZE REDUCTION

Lawrence (1970a) evaluated the effects of particle size on growth, feed efficiency, digestibility, and rate of passage of barley diets on growing pigs. Treatments included grinding barley through 1.56, 4.68, 9.36 mm screens, cold rolling and coarse crimping, and whole barley. Whole barley was lower in digestible energy, dry matter, and crude protein than any of the processed diets. Furthermore, pigs fed the whole barley grew slower and had the poorest feed efficiency (P<.05). There were no differences in average daily gain among the processed treatments. However, feed efficiency, tended to become poorer as particle size increased, with the exception of the cold rolled treatment, which had the best feed efficiency. Rate of passage was the longest for the finely ground barley diet, which had almost double the retention time of the whole barley. The results of this experiment indicate the need for some type of processing for optimum utilization of barley diets by swine.

Beams and Ngwira (1978) evaluated whole compared to ground barley for growing pigs averaging 23 kg. Pigs fed whole barley grew slower and less efficiently (P<.05) than those fed ground barley (478 vs. 571 g/d and 4.23 vs. 3.48, respectively). Digestibility of both whole and ground barley was higher in young pigs than older pigs. Grinding improved dry matter digestibility over whole grain 77.6 vs. 67.0% and nitrogen digestibility 76.5 vs. 68.7%. These findings are in agreement with Frape et al. (1968) who also found rolled barley to improve feed efficiency 20% over whole barley and improve nutrient digestibility for growing pigs and sows.

Simonsson (1978a) conducted five feeding trials to determine the effects of barley ground through screens ranging from 1 to 5.25 mm on growing-finishing pig performance. Processing through these screens gave mean particle sizes for the diets ranging from 200 to 700 microns. In evaluating all five experiments, there were no significant differences in average daily gain, feed efficiency, or digestibilities of dry matter, energy, and crude protein. However, there were numerical trends in all of these criteria toward improvements with decreasing particle size of the diet.

Simonsson (1978b) further evaluated pigs fed barley processed with a central or peripheral hammer mill, attrition mill, or a rollermill. These mills gave a range of mean particle sizes from 410 to 1750 microns. In these experiments, there were no differences in performance or digestibility for pigs fed finely ground barley diets processed by either type of hammer mill or rolled diets. However, diets ground through a centrally fed hammer mill equipped with a 4 mm screen or diets ground through an attrition mill resulted in slower gains and poorer feed efficiency ($P<.05$). Geometric mean particle size for the centrally fed hammer mill with a 4 mm screen was 1450 microns while the attrition mill processed diets were 1100 and 1750 microns in diameter. It is interesting to note that with the exception of a rolled diet, which had a geometric mean particle size of 1100 microns, these diets with significantly poorer performance also had the largest particle size. It must be kept in mind that while mean particle size was relatively high on the one rolled diet, rolling produces more uniform particle size and might have reduced the number of whole kernels in the diet compared to the coarsely hammer milled diet.

In experiments with high moisture barley, Livingstone and Livingston (1970) found no differences between pigs fed either roller or hammer mill processed diets. However, Cole et al. (1975) found acid treatment of hammer milled barley diets superior to similar rolled diets, but no differences between processing methods of dry barley. A second experiment (Cole et al., 1970) found a 11% improvement in feed efficiency of pigs fed hammer milled diets over rolled high moisture diets.

From the results of these experiments evaluating barley particle size, it is evident that barley must be processed rather than fed whole for optimum efficiency. However, it is difficult to draw any conclusions on rolled vs. hammer milled diets because of the lack of particle size information, and the lack of specificity on how the diets were processed. However, using the results of Simonsson (1978a, 1978b) as an index, as geometric mean particle size increases, there would tend to be poorer feed efficiency and digestibility. However, hammer milled diets would not begin to show any significant differences in performance until mean particle size approached 1450 microns. In attriton mills, the mean particle size where performance would appear to decline would be approximately 1100 microns. This is lower than the mean size for hammer mills because of the grinding characteristics of an attrition mill. Information on upper mean particle size limits for rolled diets is less specific. Rolled diets with particle sizes up to 1100 microns showed no adverse affects, yet in experiments where rolling reduced average daily gain or feed efficiency there was no report of any particle size. However, an upper limit might be around or slightly above those values for hammer milled diets. Wu (1984) demonstrated that rolled diets with particle sizes equal to coarsely ground diets produced better efficiency because of the reduction of whole kernels in the diet.

The effects of the pelleting barley diets have been evaluated in several experiments. Vanschoubrock et al. (1971) summerized 117 experiments and found pelleting to improve average daily gain by 6.6% and feed efficiency by 7.9%. However, it was noted that as the net energy level of the diet increased, the level of improvement decreased. The beneficial effects of pelleting can be attributed to less feed wastage, decreased bulk density, and increased nutrient digestibility.

Improvement in pig performance by pelleting high fiber diets has been demonstrated by Dinusson et al. (1960b), where growing-finishing pigs were fed barley-based diets supplemented with either 0, 15, or 30% oat hulls. There were no differences in performance between pigs fed pelleted diets regardless of level of oat hull addition. However, pigs fed pelleted diets grew significantly faster and more efficiently than those fed diets in meal form.

Further experiments were designed to study the effects of pigs fed normal or low bushel weight barley diets that were either in pelleted or meal form. There were significant differences in average daily gains and feed efficiency between pigs fed the pelleted or meal diets, but no differences between the barley of different bushel weight. Of the studies conducted by Dinusson et al. (1960b) assessing growing-finishing pigs fed barley diets that were either in pelleted or in meal form, pelleting improved average daily gains 10 to 12% and feed efficiency 12 to 14%. These results are in agreement with those of Larson and Oldfield (1960), who also found pelleting to improve gain and feed efficiency of pigs fed barley diets.

It appears that the improved performance of pigs fed pelleted diets may be due to a change in the bulk density of the diet. This decrease in bulk density of the diet allows the pig to consume enough of a high fiber diet to meet its nutrient requirements. Physical changes of the grain as a result of steam pressure within the pelleting process may also contribute to improving performance. However, Hintz and Garrett (1967) found no improvment in pig performance with steam-pressure processed barley diets, and under high pressure conditions, found adverse affects on pig performance.

Because of the characterstics of the barley kernel, some type of processing is necessary before incorporation into a swine diet. From the literature, it would appear that processing improves the feeding value of barley by making it both more palatable and digestible. Decreasing particle size has been shown to improve digestibility and feed efficiency of pigs fed barley diets, while pelleting decreases bulk density of the diet and improves average daily gain and feed efficiency by masking the deleterious effects of the fiber content.

INTRODUCTION

Barley is the fourth leading crop in world production behind wheat, corn, and rice. Much of the barley is produced in areas where corn production is not agronomically feasible. Barley is well adapted for these areas because of its short growing season and low moisture requirement. Barley also has a competitive advantage over other small grains as a feed source because of its high yields. For these reasons barley is a major feed ingredient in Europe, the Soviet Union, and Canada. However, in the U.S. where swine diets are traditionally balanced around corn, barley is only considered an alternative feed ingriedient when economically favorable.

Barley is limited in its uses for swine diets by its high fiber content. This high dietary fiber level decreases pig performance by the dilution of energy and other nutrients in the diet, thus preventing the pig from consuming adequate amounts for optimal performance. Other factors associated with barley that have been suggested to lower its feeding value are palatability and possible growth inhibitors.

The adverse effects of high dietary fiber are most apparent in experiments evaluating growing-finishing pigs fed barley diets. In general, energy appears to be the first limiting nutrient in these experiments, and as a result, pigs fed barley diets grow at slower rates and are less efficient. These results suggest that barley has only 80 to 90% the feeding value of corn for growing pigs.

However, in experiments evaluating weanling pigs, where protein quality and quantity requirements may slightly overshadow energy requirements, there appear to be no adverse effects of barley level on pig performance.

Barley is receiving renewed attention in Kansas from both agronomic and nutritional points of view. Future barley production will depend on its profitability resulting from its increased use as a feed ingredient in the livestock industry. Therefore, it is essential to know how barley can be used to its fullest potential in swine diets.

The following experiments were undertaken to evaluate the performance of pigs fed barley-based rations and to determine the limitations and most economical formulations for adding barley to swine diets.

EXPERIMENTAL PROCEDURES

A total of 712 crossbred pigs were utilized in five growth trials (two starter and three finishing) and one digestion trial (starter) to evaluate the effects of feeding barley-based diets on pig performance. All trials were conducted at the swine unit, Department of Animal Science and Industry, Kansas State University. Particle size analysis of the diets was conducted at the Pilot Feed Mill of the Department of Grain Science and Industry. All diets used in these experiments were formulated to meet or exceed NRC (1979) recommendations and varied by grain source and/or processing method. The barley used in these experiments was a Kanby variety (table 1) that was locally grown in the 1984-1985 growing season.

MATERIALS AND METHODS

STARTER PIGS

Two-hundred and forty crossbred pigs weaned at approximately 21 days of age were allotted on the basis of ancestry, weight, and sex to one of five dietary treatments using a randomized complete block design. Following weaning, pigs were placed in an environmentally controlled nursery maintained at 32^{o} C for the first week, and temperature was gradually decreased each week as the experiment progressed. Pigs were housed in 1.2 x 1.5 m pens with woven wire flooring over a V-flush gutter. Each pen was equipped with one, four-hole feeder and one nipple waterer. During the first three days on trial, the waterers were blocked open to acclimate the pigs to drinking. Feed and water were provided ad libitum. Pigs were weighed initially and then each week, to determine average daily gain. Feed additions were recorded and feeders weighed weekly to determine average daily feed intake. From these, feed efficiency was calculated. Each trial lasted 35 days.

The basal diet consisted of milo-soybean meal with 1.25% lysine and 20% dried whey. The diet was supplemented with 4% added fat and formulated to contained .8% Ca, .7% P, 250 ppm $CuSO_4$, and .3 ppm Se. Barley was then substituted on an equal weight basis for milo at levels of 10, 20, 30, and 40% of the diet (table 2). Each pen was observed for incidence of scouring and given a daily mean scour score based on the following scale: 1= firm feces, 2= soft feces, 3= loose feces, and 4= watery feces.

DIGESTION TRIAL

Nine barrows weaned at approximately 28 days of age were placed in metabolism cages in an environmentally controlled room maintained at 30^{o} C. Pigs were randomly assigned to one of three dietary treatments. Pigs were allowed to acclimate to their surroundings and diets for seven days prior to a five-day collection period. Pigs were then randomly assigned in a crossover design to a different dietary treatment for a four-day adjustment period followed by a second five-day collection period.

Pigs were fed either the milo diet or the 20 or 40% barley diets. During the collection periods, pigs were fed at a constant level (the maximum amount that could be consumed by all pigs). This was 220 and 600 g for the first and second collection periods, respectively. Pigs were fed in two equal feedings at 0800 and 1700 hours. Water was provided ad libitum. Any feed spillage or wastage was collected, weighed, and recorded daily. Five grams of ferric oxide was mixed into the feed as a marker to signal the start and end of each collection period. Feces were collected daily and stored in a freezer. At the end of the experiment, feces were weighed, dried in a forced air oven at 38^{o} C for six days, then reweighed. Feces were then ground in a Wiley mill equipped with a 1 mm screen. Representative samples were then taken for analysis to determine dry matter, nitrogen, and gross energy.

Urine was collected in 5 L containers and 10 ml, 2N HCL was added to the urine daily. At the end of each collection period, urine volume was determined and a 100 ml sample was taken and frozen until analyzed for percent nitrogen.

FINISHING PIGS

One-hundred and fifty (trial 4) or one-hundred and sixty (trial 5) finishing pigs were allotted by ancestry, weight, and sex to one of either five or eight dietary treatments. Pigs were housed in the K.S.U. finishing barn in 3.7 x 4.6 M pens with half solid and half slotted flooring. Each pen was equipped with one, two hole self-feeder and a nipple waterer.

The basal diet was a 14% crude protein .6% lysine milo-soybean meal finishing diet formulated to contain .7% Ca, .55% P, and .1 ppm Se (table 3). Barley was then substituted for milo at various levels or through different processing methods. Feed and water were provided ad libitum. Pigs were weighed initially then at three week or monthly intervals. Feeders were also weighed at this time and average daily gain, average daily feed intake, and feed efficiency were calculated. On the last day of each trial, pigs were scanned for last rib fat depth with a Scanoray[1] probe.

ANALYSIS

Representative feed samples were analyzed for dry matter, nitrogen, crude fiber, ether extract, Ca, and P according to AOAC (1980). Acid detergent fiber and neutral detergent fiber were determined by the methods described by Goering and Van Soest (1970). Gross energy was determined using an oxygen bomb calorimeter for both feed and fecal samples (Parr Instrument Co., 1970). Fecal samples were analyzed for dry matter and nitrogen, also according to AOAC (1980), wheras urine was analyzed for percent nitrogen.

[1] Scanoprobe, Ithaco Inc., Ithaca, N.Y. 14850.

In experiment 6, two representative ground grain and feed samples were obtained for particle size analysis. Particle size determination was made according to ASAE (1973) standard methods of determining and expressing fineness of ground feed by sieving. A 100 g sample was sifted for 10 minutes with a Ro-Tap sifter. The screens used were Tyler standard 4, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan. From the weight measured over each of the screens, geometric mean particle size and standard deviation were determined, and from these the surface area per gram of ground feed was calculated.

Statistical analysis was made by least squares analysis of variance utilizing General Linear Models of the Statistical Analysis System (SAS 1982), and when treatment mean differences were significant, mean separation was performed by Duncan's new multiple range test. Correlation coeficients and regression analysis of particle size data were calculated using Stepwise procedures of the Statistical Analysis System (SAS 1982). In each experiment, pen was considered the experimental unit with the exception of the digestion trial where individual means were used.

EXPERIMENT 1

One-hundred and forty pigs weaned at approximately 21 (±5) days of age and averaging 6.4 kg were allotted to one of five dietary treatments, with seven pigs per pen and four replications per treatment. The basal diet consisted of milo-soybean meal with 1.25% lysine and 20% dried whey. Barley was substituted for milo on an equal weight basis at various levels of the diet giving the following treatments:

A. Milo-soybean meal control diet.

B. 10% Barley, milo-soybean meal.

C. 20% Barley, milo-soybean meal.

D. 30% Barley, milo-soybean meal.

E. 40% Barley-soybean meal.

Criteria of response were average daily gain, average daily feed intake, feed efficiency, and scour score. Trial duration was 35 days and procedures and analysis were as previously described.

EXPERIMENT 2

One-hundred weanling pigs weaned at approximately 21 (±5) days of age and averaging 6.3 kg were allotted to one of the five dietary treatments used in experiment 1. There were four pigs per pen and five replications per treatment. The trial duration was 35 days. Criteria of response, procedures, and analysis were as described for experiment 1.

DIGESTION TRIAL, EXPERIMENT 3

Nine barrows weaned at approximately 28 days of age and averaging 9.1 kg were utilized to determine the nutrient digestibility of the basal milo, 20, and 40% barley diets. Pigs were placed in metabolism cages allowing for separate collection of feces and urine for two, five-day collection periods preceded by a seven and four-day adjustment period, respectively. Procedures and analysis were as previously described.

EXPERIMENT 4

One-hundred and fifty crossbred finishing pigs were utilized to evaluate the effects of barley-based finishing diets on pig performance. Pigs averaged 53.0 kg and were allotted to one of five dietary treatments, with 10 pigs per pen and three replications per treatment. The control diet consisted of milo-soybean meal with 14% crude protein and .6% lysine, and was formulated to contain .7% Ca and .55% P. Barley was substituted for milo to make up the following treatments:

A. Milo-soybean meal control diet.

B. Barley substituted for milo on an equal weight basis.

C. As B, pelleted.

D. Barley with 5% added fat, isocaloric to A.

E. Barley balanced on an equal lysine basis to A.

The trial was conducted from November 1984 through January 1985 and lasted 68 days. Average final weight was 104.8 kg. Criteria of response measured were average daily gain, average daily feed intake, feed efficiency, and last rib fat depth. Procedures and analysis were as previously described.

EXPERIMENT 5

One-hundred and sixty pigs averaging 46.7 kg were alloted to either one of the five dietary treatments as in finishing experiment 1, or one of three additional treatments.

F. Barley with 5% added molasses.

G. As B, rolled.

H. Barley subsitituted for half of the milo.

There were 10 pigs per pen and two replications per treatment. The trial was conducted from January 1985 through March 1985 and lasted 74 days. Average final weight was 104.3 kg. Criteria of response, procedures, and analysis were as previously described.

EXPERIMENT 6

One-hundred and fifty pigs averaging 46.4 kg were utilized to evaluate the effects of barley with differing geometric mean particle sizes on average daily gain, average daily feed intake, feed efficiency, last rib fat depth, and incidence of gastric ulcers. The basal diet consisted of milo-soybean meal with 14% crude protein and .6% lysine, .7% Ca, and .55% P. Milo was replaced by an equal amount of barley, which had been processed through 3.2, 4.8, or 6.4 mm screens with a Jacobson model 240 B, 25 horsepower, tear drop hammer mill, or rolled with a Wagner, 20 horsepower two high, double rollermill giving the following dietary treatments:

A. Milo-soybean meal control diet ground through a 4.8 mm screen.

B. Barley-soybean meal ground through a 3.2 mm screen.

C. As B, ground through a 4.8 mm screen.

D. As B, ground through a 6.4 mm screen.

E. As B, rolled.

The rollermill rolls were 22.9 cm in diameter and 61.0 cm in length. The top rolls were cut with a LePage corrugation, with 2 corrugations per cm, and running at a 2.5 to 1 differential. The bottom pair were cut with 7 corrugations per cm, a 1.44 mm/cm spiral, and running at a 1 to 1 differential.

Criteria of response were average daily gain, average daily feed intake, feed efficiency, and last rib fat depth. In addition, six barrows from the milo control, 3.2, and 6.4 mm barley treatments were slaughtered at the end of the experiment and stomachs were examined for incidence of esophageal ulcers. Stomachs were evaluated and scored using the following scale: 1= normal stomach, 2= slight cornification, 3= cornified, 4= slight ulceration, and 5= severe ulceration. The trial was conducted from August 1985 through October 1985 and lasted 62 days. Average final weight was 99.0 kg. Procedures, particle size analysis, and diet analysis were as previously described.

Table 1. Composition of Kanby Barley

Item	Percent[a]
Dry matter	88.5
Crude protein	11.5
Crude fiber	7.4
Either extract	1.7
Nitrogen free extract	77.4
Acid detergent fiber	4.5
Neutral detergent fiber	21.7
Ash	3.3
Calcium	.13
Phosphorus	.47
Amino Acids	
Alanine	.40
Valine	.44
Glycine	.41
Isoleucine	.32
Leucine	.60
Proline	.80
Threonine	.33
Serine	.39
Methionine	.11
Phenylalanine	.41
Aspartic acid	.54
Glutamic acid	1.70
Tyrosine	.25
Lysine	.37
Hisidine	.17
Arginine	.34

[a] As fed basis.

Table 2. Composition of Starter Diets, Experiments 1, 2, and 3.

	Treatments[a]				
Ingredients %	Milo	10% Barley	20% Barley	30% Barley	40% Barley
Milo (IFN 4-04-444)	40.10	30.00	20.00	10.00	---
Barley (IFN 4-00-549)	---	10.00	20.00	30.00	40.25
Soybean meal (IFN 5-04-604)	32.00	32.00	32.00	32.00	32.00
Whey (IFN 4-04-182)	20.00	20.00	20.00	20.00	20.00
Soy oil	4.00	4.00	4.00	4.00	4.00
Dical (21% P)	1.90	1.90	1.90	1.90	1.80
Limestone	.80	.80	.80	.80	.80
L-Lysine HCL	.33	.33	.30	.30	.30
Salt	.15	.15	.15	.15	.15
T.M. Premix[b]	.10	.10	.10	.10	.10
Vitamin Premix[c]	.25	.25	.25	.25	.25
Se premix	.15	.15	.15	.15	.15
$CuSO_4$	.10	.10	.10	.10	.10
Antibiotic[d]	.10	.10	.10	.10	.10
Calculated Analysis:					
% Protein	20.40	20.60	20.70	20.90	21.00
% Lysine	1.25	1.27	1.28	1.28	1.25
% Crude fiber	3.16	3.60	4.02	4.45	4.88
% Ca	.81	.82	.82	.81	.79
% P	.70	.72	.73	.75	.74
ME Kcal/kg	3225	3199	3172	3146	3120

[a] Diets A, C, and E were used in the digestion trial, experiment 3.
[b] Containing 5.5% Mn, 10% Fe, 1.1% Cu, 20% Zn, 0.15% I, and 0.1% Co.
[c] Each lb of premix contains the following: vitamin A 400,000 IU, vitamin D 30,000 IU, vitamin E 2,000 IU, riboflavin 450 mg, d-pentothenic acid 1,200 mg, choline 40 g, niacin 2,500 mg, B_{12} 2.2 mg, menadione dymethylpyrimidinol bisulfate 250 mg, ethoxyquin 3,850 mg.
[d] Cloretetracycline 50g/lb.

Table 3. Composition of Finishing Diets, Experiments 4, 5, and 6.

	Treatments[abc]							
Ingredients, %	Milo Basal	Barley Basal	Barley Pellets	Barley +5% Fat	Barley =Lysine	Barley +5% Mol.	Barley Rolled	Barley 50%
Milo (IFN 4-04-444)	81.85	---	---	---	---	---	---	41.05
Barley (IFN 4-00-549)	---	82.05	82.05	77.15	86.30	77.15	82.05	41.05
Soybean meal (IFN 5-04-604)	15.0	15.0	15.0	15.0	10.75	15.0	15.0	15.0
Soy oil	---	---	---	5.00	---	---	---	---
Molasses	---	---	---	---	---	5.00	---	---
Dical (21% P)	1.25	.85	.85	.85	.85	.85	.85	1.05
Limestone	.95	1.15	1.15	1.05	1.15	1.15	1.15	1.05
Salt	.50	.50	.50	.50	.50	.50	.50	.50
T.M. premix	.10	.10	.10	.10	.10	.10	.10	.10
Vitamin premix	.25	.25	.25	.25	.25	.25	.25	.25
Antibiotic	.10	.10	.10	.10	.10	.10	.10	.10
Calculated Analysis:								
% Crude protein	14.0	15.0	15.0	14.5	13.7	14.5	15.0	14.0
% Lysine	.60	.74	.74	.73	.60	.73	.74	.68
% Crude fiber	3.0	7.3	7.3	6.8	7.7	6.8	7.3	5.1
% Ca	.69	.70	.70	.69	.69	.69	.70	.70
% P	.56	.56	.56	.56	.55	.56	.56	.56
ME Kcal/kg	3126	2897	2897	3135	2886	2868	2897	3005

RESULTS AND DISCUSSION

STARTER EXPERIMENTS 1, 2, AND 3.

Results of the starter experiments 1 and 2 are presented in tables 4 and 5, the combined results are presented in table 6. In experiment 1, increasing dietary barley levels up to 40% of the diet had no adverse effect on average daily gain (ADG) or average daily feed intake (ADFI). However, a trend (P<.06) towards poorer feed efficiency (F/G) was observed for pigs fed the 10 and 30% barley diets. Increasing levels of dietary fiber, corresponding with increasing barley levels, had no effect on incidence of scouring, nor was scouring a problem at any time during the experiment.

In experiment 2, increasing dietary barley levels had no effect on pig performance as ADG, ADFI, F/G, and scour scores (SS) were not affected for the overall experiment. However, during the first week of the experiment (d 0 to 7), there was a decrease (P<.01) in ADFI of the pigs fed the 40% barley diet. This resulted in a slight decrease in ADG (P=.14). In the second week of the trial, neither ADFI nor ADG were decreased by dietary barley level, and overall performance was not affected.

When data from both experiments were combined, there were no significant differences in ADG or ADFI between pigs fed the milo or barley-based diets. However, pigs fed the 10 and 30% barley diets tended to be poorer in feed efficiency (P<.06). Feed efficiency would normally be expected to increase with increasing fiber levels in the diet. However, the poorer feed efficiency of the pigs fed the 10 and 30% barley diets would appear to be the result of numerical differences in ADFI and ADG rather than actual treatment differences.

Diets with high fiber levels have been suggested to lower the incidence of scours in weanling pigs. However, increasing fiber levels from dietary barley addition had no improvement on reduction of scours, although scouring was not observed to be a problem during either experiment.

ADFI was decreased (P<.03) during the first week of the experiment (d 0 to 7), resulting in a decrease in ADG (P<.07) of pigs fed the 40% barley diet. This may be a reflection of the normal postweaning inappetence compounded by a slight palatability problem. However, as in experiment 2, ADFI and ADG increased by the second week on trial and overall performance was unaffected. Wahlstrom et al. (1984a, 1984b) found the palatability of barley diets to be a factor in lowering feed intake and subsequent average daily gains of growing pigs. However, it would appear that finishing pigs have less of an acceptance problem with barley-based diets than starter or growing pigs.

Poor palatability and low digestible energy have been cited as the main reasons for the exclusion of barley in starter diets in the past (Garber, 1985). However, addition of more palatable or high energy feed ingredients such as dried whey, sugar, or fat may improve the feeding value of barley-based diets for weanling pigs. Addition of fat and dried whey as in these experiments would ideally complement barley's low energy content and mask any palatability problem. The high protein and amino acid content of the barley diets may offset its low energy level. This may account for the similarities in performance between pigs fed either the milo or barley-based diets, as performance of the young pig may rely more heavily on protein and amino acid requirements rather than energy levels.

These results would indicate that barley may replace all of the milo in a grain-soybean meal, 20% dried whey (1.25% lysine) nursery diet without adversely affecting pig performance.

Results of the digestion trial (experiment 3) evaluating the nutrient digistibility of pigs fed the milo control diet or the 20 and 40% barley diets is presented in table 7. Dry matter digestibility (DMD) and digestible energy (DE) were decreased (P<.01) as level of barley increased. Crude protein digestibility (CPD) was not affected by dietary barley level. Nitrogen retention (NRT) as expressed in grams N retained/d was higher (P<.01) for pigs fed either the 20 or 40% barley diets. Nitrogen retention, expressed as percent of intake (%NRT) numerically increased (P=.13) with increasing NRT for pigs fed either barley diet.

Increasing dietary fiber levels have been associated with lower nutrient digestibility and stimulation of microbial fermentation in the large intestine. These factors would account for the lowered DMD and DE of the 20 and 40% barley diets and are in agreement with other digestion studies with weanling pigs in which DMD and DE were significantly lower for pigs fed a barley-soybean meal starter diet in comparison to a wheat-soybean meal diet (Bowland, 1974). Wu and Ewan (1979) also found DMD and DE to be lowered by increasing levels of barley in a basal diet. In both of these studies, CPD was also lowered for pigs fed barley diets, contradictary to the results of this experiment. These differences may be accounted for by the differences in CPD of the respective grains used in the control diets. Hsu (1983) found protein digestibility to be lower for milo than corn or wheat (70.9 vs. 77.7 vs. 89.5% CPD, respectively). Therefore, the lack of significant difference between CPD of the barley and milo diets in this experiment may be a result of naturally low protein digestibility of milo.

Increases in NRT and %NRT for pigs fed the 20 and 40% barley diets may be a reflection of the higher protein content of these diets combined with the slightly improved CPD of barley over milo. However, these differences were not evident by improved ADG or F/G of pigs fed barley-based diets in the growth trials.

These results are in agreement with Wu and Ewan (1979) who found improved nitrogen balance whether expressed as a percentage of intake or percent nitrogen digested as dietary barley level increased. However, the manner of barley substitution into the diet may have affected nitrogen balance. Bowland (1974) found no significant differences in nitrogen retention when comparing pigs fed either barley- or wheat-based diets, and in this experiment, N retention was quite variable and the author felt that it was not a useful criteria to evaluate.

The results of the digestion trial (experiment 3) indicate that DMD and DE are decreased as dietary barley level is increased, while at the same time CPD is unaffected, and NRT and %NTR are increased. However, these results have no effect on pig performance as demonstrated by the comparable ADG and F/G exihbited by pigs in the growth trials. These differences in digestibility may be attributed to the inherent structural characteristics of barley and milo kernels, although the relatively small amounts of either grain in the diet compared to the amount of dried whey and soybean meal may dilute any major affect they may have on the diet. Therefore, barley may repace all of the milo in a 20% dried whey (1.25% lysine) nursery diet without seriously hindering pig performance.

FINISHING EXPERIMENTS 4, 5, AND 6.

The results of finishing experiment 4 are presented in table 7. Pigs fed the basal barley diet tended (P<.09) to gain slower than those fed the pelleted barley diet. ADG of pigs fed the milo control, added fat, or isolysine barley diets were not statistically different from those pigs fed either the pelleted or basal barley diets. However, pigs fed the isolysine barley diet appeared to be equal in ADG to those fed the barley diet, whereas pigs fed the milo control, added fat, barley diets were equal in ADG to pigs fed the pelleted barley diet. Although not statistically significant, there was a 10% reduction in ADG of pigs fed either the basal or isolysine barley diets compared to those fed either the milo control, added fat, or pelleted barley diets.

There were no significant differences in feed intake among pigs fed any of the dietary treatments. However, pigs fed the added fat barley diet had the lowest ADFI. Calculated metabolizable energy (ME) intake per day was highest for the milo control feed pigs and lowest for those fed the basal barley diet. The equal ME intakes of pigs fed either the isolysine and added fat barley diets reflects the pig's ability to adjust feed intake to meet its energy needs; however, there would appear to be differences in the nutrient utilization of the respective diets.

Feed efficiency was improved (P<.05) by the addition of fat to the diet, since pigs fed the added fat barley diet had the best feed efficiency. Pelleting also improved feed efficiency, as pigs fed the pelleted barley diet were intermediate in F/G between those fed either the added fat barley diet or milo control diet. Feed efficiency was poorer (P<.05) for the basal and lysine balanced barley diets.

From these results, it would appear that energy is a limiting factor in barley diets for finishing pigs. Increasing the caloric density of the diet by adding fat or decreasing the bulk density by pelleting, improved gains and feed efficiency. These processes would tend to mask any detrimental effects of the fiber content of the barley and to improve palatability. Similar results were found by Heitman (1956), Anglemyer and Oldfield (1957), Oldfield and Anglemyer (1967), and McConnel et al (1975), in which addition of tallow or fat improved pig performance on barley-based diets. Conrad (1958) summarized several experiments and found pelleting to improve ADG of pigs fed barley diets by 14.0% and feed efficiency 15.4%. Dinusson et al. (1960b) and Larson and Oldfield (1960) also found pelleting to improve pig performance and speculated that it was a result of the decreased bulk density of the diet or possible changes in the chemical composition from the pelleting process.

In the basal and lysine-balanced barley diets, it would appear that the pigs could not consume enough feed to optimize their growth because of the high fiber and bulkiness of the diet. Reese (1985) reported barley to be considerably bulkier that corn or milo, with bulk densities of 30.9, 48.4, and 42.2 g/cm^3, respectively. This would indicate that pigs may not be able to consume enough feed to meet their energy requirements because of gut fill. The high fiber in the diet may also lower digestibility by increasing rate of passage or encouraging microbial fermentation in the hind gut. The presence of possible growth inhibitors and more recently B-glucans in the hull portion of the kernel may also play a role in decreasing the feeding value of barley. B-glucans may decrease nutrient digestion by increasing viscosity of the digesta, preventing its thorough mixing with digestive enzymes (Honeyfield and Froseth, 1983). Reduced feed intake may also be related to palatability of the barley diets. Wahlstrom et al. (1984a and 1984b) noted performance of pigs fed barley-based diets to be related to feed intake, which was reduced during the grower phase of the experiments. Both the basal and isolysine barley diets were considerably dustier than the other diets, which could also affect feed intake.

The results of this experiment are in agreement with the findings of Morrison (1940), Lawrence (1968), Hollis and Palmer (1971), McConnel et al. (1975), and Wahlstrom et al. (1984b), in which unsupplemented barley diets averaged 90% of the feeding value of corn, wheat, or sorghum grain for finishing pigs. However, this is contrary to the findings of Libal et al. (1984), who found no significant differences between pigs fed either corn or barley.

The equal performance of pigs fed the barley basal and isolysine barley diets suggests that finishing diets may be balanced on a lysine basis. This may be of economic importance to the producer, since it could reduce the amount of soybean meal in the diet by 28%. These results are in agreement with the findings of Libal et al. (1984) and Froseth et al. (1981).

The poorer feed efficiency of pigs fed the barley basal or isolysine barley diets is a result of the high fiber level in the diet, and concurs with a previous reveiw by Young (1985), who found pigs fed barley-based diets to require 10% more feed per unit of gain.

Last rib fat depth was not affected by dietary treatment. This is in agreement with carcass and fat depth measurements by Wahlstrom et al. (1984a), who found pigs fed barley diets to have carcass characteristics equal to those fed corn diets. However, Lawrence (1968) and Wahlstrom et al. (1984b) found pigs fed barley to be leaner than those fed corn, wheat, or sorghum grain. However, this may have been a result of a slower rate of gain, limit feeding level, or dietary deficiencies.

Results of finishing experiment 5 are presented in table 9. Pigs fed the barley diet with added fat gained the fastest, although not statistically different from ADG of pigs fed the milo control or pelleted barley diet. ADG of pigs fed the basal, lysine balanced, or 50% barley diets were not statistically different from those fed the control or pelleted barley diets. However, as in experiment 4, pigs fed these treatments were 10% slower in ADG than pigs fed the milo control, added fat, or pelleted barley diets.

ADG was poorest for pigs fed the 5% added molasses or rolled barley diets, having only 88 to 85%, respectively, the ADG of pigs fed the milo control diet.

These results again suggest energy to be a limiting factor in performance of pigs fed barley diets. As in experiment 4, pigs fed the added fat or pelleted barley diets were equal in performance to those fed the milo control, whereas pigs fed the basal, isolysine, and 50% barley diets gained at 90% the rate of the milo control-fed pigs. The substitution of only 50% of the milo by barley did not improve barley's feeding value over the 90% compared to milo which is contrary to the findings of Libal et al. (1984) who reported pigs fed a 50% barley/corn diet to be numerically superior in ADG over those fed 100% corn or barley diets, or 25/75% mixtures of the two grains.

Addition of molasses to the diet further diluted its caloric density and surpressed ADG. The poor response of the pigs fed the 5% added molasses diet in addition to the lowered energy content, may also be the result of the physical form of the diet. Because of the cold weather at the time of the experiment, the molasses did not blend well into the diet, and formed marble sized aggregates. The high feed intake and poor feed efficiency may indicate that the pigs tried to increase feed intake to meet their energy requirements or sorted out these molasses balls and wasted a large amount of feed.

Average daily gain and feed efficiency were also poorest for the pigs fed the rolled barley diet. It would appear that the pigs were unable to efficiently utilize the rolled barley because of the large amount of whole kernels in the diet. The poor performance of the pigs fed the rolled barley diet may also be a result of the settling out of ingredients in the diet. While several reports have found rolling or crimping to be beneficial in improving the feeding value of barley diets, there is little information on the specifications for rollermilling on particle size. Because of the great variation in rollermills and their operation and specifications, one cannot assume that rollermilling in general will improve the feeding value of a grain. In this experiment, the decreased performance from whole kernels and subsequent lowered digestibility are in agreement with Cole et al. (1970), Simonsson (1978a) and Wu (1984), who found poorer feed efficiency as particle size and presence of whole kernels in the diet increased. In this experiment, however, digestibility was also lowered enough to affect ADG.

ADFI was highest for the pigs fed the milo control and 5% added molasses diets; however, these were not significantly different from the pigs fed the basal barley, pelleted, rolled, and 50% barley diets. Feed intake of the pigs fed the isolysine diet was intermediate between that of pigs on these treatments and the 5% added fat treatment, which was lowest (P<.05), as in experiment 4. However, unlike experiment 1, feed intake was lower for pigs fed the isolysine barley diet. From the calculated ME intakes, it would appear that the pigs tried to maintain a constant energy intake, but were limited by high dietary fiber levels.

Feed efficiency was the best for pigs fed the 5% added fat barley diet; however, not statistically different from pigs fed the isolysine, pelleted, or milo control diets. Feed efficiency of the pigs fed the basal or 50% barley diets were intermediate.

Backfat was lowered (P<.08) for the pigs fed the rolled barley diets, followed by the pigs fed the basal barley diet. The lowered fat thickness may be a result of the pigs' low digestible energy intake or lighter average weight at the conclusion of the trial.

Upon combining the five like treatments of experiments 4 and 5, there was a trial x treatment interaction for F/G (P<.02), with a corresponding trend (P<.08) in ADFI. This interaction is due to the lower feed intake and subsequent improved feed efficiency of the pigs fed the lysine balanced barley diet in experiment 5, over experiment 4. This represents a 12% improvement in feed efficiency from one trial to another. It is difficult to account for this differences between experiments, and it may be due to the low number of replications in experiment 5.

Results of the particle size analysis of the ground milo, barley grain, and diets are presented in tables 10 and 11. Barley ground through a hammer mill equipped with a 3.2 mm screen resulted in the finest particle size; however, it was not statistically different from milo hammer milled with a 4.8 mm screen. Rolled barley had the largest mean geometric particle size ($P<.01$) and the smallest standard deviation. Increasing screen size gave significantly larger mean geometric particle sizes of barley grain. Particle size standard deviation was similar for all hammer milled barley diets, and intermediate between the milo and rolled barley diets. As mean particle size increased, surface area was decreased ($P<.01$).

Results of the particle size analysis of the ground diets closely follow those of the individual grains.

Not only has particle size reduction been shown to affect nutrient digestibility and subsequent pig performance, but Heimann (1985) demonstrated that rollermills require less energy (ranging from 16 to 86%) to produce a specific particle size than a hammer mill. It was also shown that as particle size decreases, energy requirements are increased and mill capacity decreases in hammer mills. Mill capacity was approximately cut in half for processing barley from 5440 kg/h with a 6.4 mm screen to 2834 kg/h for barley with a 3.2 mm screen.

Results of pig performance in finishing experiment 6 are presented in table 12. Pigs fed barley processed through the 3.2 mm screen were not different in ADG from pigs fed the milo control diet ground with a 4.8 mm screen. Pigs fed barley diets processed through either a 4.8 or 6.4 mm screen or rolled grew slower ($P<.01$) than pigs fed either the control or finely ground barley diets. ADG of pigs fed the coarse or rolled barley diets was only 86% that of the pigs fed the milo control diet.

Feed intakes of the pigs fed any of the barley diets were not different from each other and all were lower ($P<.01$) than pigs fed the milo control diet. Again it would appear that the high fiber of the barley diets may have limited intake because of gut fill. However, at equal feed and ME intakes, ADG may have been improved by the increased digestibility of the finely ground barley diet.

Therefore, it would appear that the feeding value of barley is greatly improved when it is finely ground. Upon visual observation of the feed, grinding with a 3.2 mm screen ground virtually the hull portion of the barley kernel, whereas rolling or coarse grinding left virtually all intact hulls. Medium grinding with the 4.8 mm screen only ground a portion of the barley hulls. Although not significantly improving nutrient content, fine grinding of the hull portion of the kernel, along with the increased surface area of the grain, which may improve digestibility and nutrient utilization, thereby improving ADG and F/G.

Feed efficiency was improved for the pigs fed the finely ground barley diets, although it was not statistically different from that of pigs fed the milo control diet. Pigs fed the medium, coarse, or rolled barley diets were not different from each other in feed efficiency; yet, all were poorer ($P<.01$) than pigs fed the milo or finely ground barley diets. Feed efficiency tended to worsen as particle size increased and surface area decreased.

Regression analysis performed on the relationship between particle surface area and its effect on feed efficiency is presented in figure 1 . There was a quadratic relationship between surface area on feed efficiency ($P<.01$) of pigs fed barley finishing diets expressed by the model $Y = .01109(X_1) -.00018(X_1^2) + 3.550$, where Y= F/G and X_1= surface area. Other variables were tested but did not contribute to lowering the variance of the model (R^2= 83%).

The relationship between feed efficiency and surface area reflects the increased nutrient availability from increased surface area, allowing for more interaction of the feedstuff with digestive enzymes, and is in agreement with the findings of Cole et al. (1970), Simonsson (1978a, 1978b), and Wu (1984).

Last rib fat depth was lower for pigs fed the barley diets regardless of particle size ($P<.09$). This is in agreement with other studies (Lawrence, 1968), in which finishing pigs fed barley diets were leaner than those fed corn, wheat, or sorghum diets. However, in this experiment the differences in leanness were not necessarily a result of slower growth, as evidenced by the ADG performance of the pigs fed the finely ground barley diet.

At the conclusion of the experiment, six pigs from the milo control and 3.2 and 6.4 mm ground barley diets were slaughtered and their stomachs were evaluated for incidence of gastric ulcers. Results of the stomach evaluation are presented in table 14. Ulceration did not appear to be a problem during the trial since all pigs appeared healthy, nor were there any severe ulcers found after stomach evaluation. Previous research (Maxwell et al., 1966 and Wu, 1984) would indicate that much smaller particle sizes are needed to increase the incidence of ulceration, and that high fiber diets may mitigate the incidence of esophegeal ulcers.

The results of this experiment indicate that processing may play a key role in the utilization of barley in swine diets. Reduction of particle size and disintegration of the hull portion of the kernel improved ADG and F/G of pigs fed barley diets. It also appears that particle surface area of the diet play a direct role in nutrient digestibility as shown by the quadratic relationship with feed efficiency. Although mill capacity decreases and energy consumption increases with fine grinding, this may be the producer's most economical method of incorporating barley into swine diets.

Table 4. Effect of Barley in Starter Diets, Experiment 1.[a]

Item	Barley: / Milo:	-- / 40%	10% / 30%	20% / 20%	30% / 10%	40% / --	SE
				Treatments			
Avg. daily gain, kg							
0 to 7 d		.11	.13	.13	.12	.11	.03
0 to 35 d		.40	.38	.39	.38	.39	.03
Ave. daily feed, kg							
0 to 7 d		.15	.17	.18	.18	.17	.03
0 to 35 d		.63	.64	.59	.61	.62	.07
Feed/gain							
0 to 7 d		1.40	1.42	1.39	1.47	1.57	.13
0 to 35 d		1.56[b]	1.68[c]	1.52[b]	1.61[bc]	1 .59[b]	.03
Scour score[d]		1.57	1.57	1.42	1.58	1.40	.09

[a] Total of 140 pigs (7 pigs/pen with 4 pens/treatment), average initial wt. 6.4 kg and trial duration was 5 weeks.

[bc] Means on the line with different superscripts differ (P<.06).

[d] Average daily pen scour score based on 1= firm feces, 2= soft feces, 3= loose feces, and 4= watery feces.

Table 5. Effect of Barley in Starter Diets, Experiment 2.[a]

Item	Barley: / Milo:	-- / 40%	10% / 30%	20% / 20%	30% / 10%	40% / --	SE
Avg. daily gain, kg							
0 to 7 d		.22[b]	.21[b]	.22[b]	.23[b]	.16[c]	.04
0 to 35 d		.44	.45	.45	.46	.44	.03
Ave. daily feed, kg							
0 to 7 d		.24[d]	.24[d]	.24[d]	.24[d]	.13[e]	.05
0 to 35 d		.67	.68	.68	.72	.66	.05
Feed/gain							
0 to 7 d		1.14	1.15	1.16	1.04	1.08	.06
0 to 35 d		1.51	1.53	1.52	1.58	1.51	.02
Scour score[f]		1.37	1.23	1.31	1.47	1.24	.10

[a] Total of 100 pigs (4 pigs/pen with 5 pens/treatment), average initial wt. 6.3 kg and trial duration was 5 weeks.
[bc] Means on the same line differ (P=.14).
[de] Means on the same line differ (P<.01).
[f] Average daily pen scour score based on 1= firm feces, 2= soft feces, 3= loose feces, and 4= watery feces.

Table 6. Effect of Barley in Starter Diets, Experiments 1 and 2.[a]

Item	Barley: / Milo:	-- / 40%	10% / 30%	20% / 20%	30% / 10%	40% / --	SE
Avg. daily gain, kg							
0 to 7 d		.17[b]	.17[b]	.18[b]	.18[b]	.14[c]	.03
0 to 35 d		.43	.42	.43	.43	.42	.03
Ave. daily feed, kg							
0 to 7 d		.20[d]	.21[d]	.22[d]	.21[d]	.15[e]	.04
0 to 35 d		.65	.67	.64	.68	.64	.05
Feed/gain							
0 to 7 d		1.37	1.28	1.26	1.23	1.35	.06
0 to 35 d		1.53[fg]	1.60[g]	1.52[f]	1.59[g]	1.55[fg]	.02
Scour score[f]		1.46	1.38	1.36	1.52	1.31	.08

[a] Pooled data from experiments 1 and 2, total of 240 pigs, average initial wt. 6.4 kg and trial duration 35 days.

[bc] Means on the same line differ (P<.07).

[de] Means on the same line differ (P<.03).

[fg] Means on the same line differ (P<.06).

[h] Average daily pen scour score based on 1= firm feces, 2= soft feces, 3= loose feces, and 4= watery feces.

Table 7. Effect of Barley on Nutrient Digestibility, Experiment 3.[a]

		Treatments		
Item	Barley: Milo:	-- 40%	20% 20%	40% --	SE
Dry matter digestibility %		84.5[b]	82.2[bc]	79.8[c]	.92
Crude protein digestibility %		80.7	82.5	83.5	1.22
Digestible energy %		85.3[b]	83.4[bc]	80.8[c]	.90
Nitrogen retention %		59.2	64.7	66.9	2.58
Nitrogen retention g		6.53[b]	8.50[c]	8.52[c]	.42

[a] A total of 9 pigs, (3 pigs/treatment), average initial wt. 9.1 kg.
[bc] Means on the same line differ ($P<.01$).

Table 8. Effect of Barley in Finishing Diets, Experiment 4.[a]

Item	Treatments					
	Milo Basal	Barley Basal	Barley Pellets	Barley +5% fat	Barley =Lysine	SE
Avg. daily gain, kg	.78[bc]	.71[c]	.79[b]	.76[bc]	.72[bc]	.05
Avg. daily feed, kg	2.94	2.83	2.92	2.74	2.99	.17
Feed/gain	3.76[e]	4.00[f]	3.71[de]	3.54[d]	4.15[f]	.07
Backfat, cm[g]	2.06	2.01	1.93	2.06	1.93	.05
ME intake, Kcal/d	9152.0	8216.8	8478.2	8607.9	8648.4	
Final wt, kg	107.2	102.8	106.9	105.0	101.9	

[a] Total of 150 pigs (10 pigs/pen with 3 pens/treatment), average initial wt 53 kg and average final wt 104.8 kg. Trial duration 68 days.
[bc] Means on the same line differ (P<.09).
[def] Means on the same line differ (P<.05).
[g] Last rib fat depth.

Table 9, Effects of Barley in Finishing Diets, Experiment 5.[a]

Item	Treatments								
	Milo Basal	Barley Basal	Barley Pellets	Barley +5% fat	Barley =Lysine	Barley +5% Mol.	Barley Rolled	Barley 50%	SE
Avg. daily gain, kg	$.80^{bc}$	$.75^{cd}$	$.80^{bc}$	$.82^{b}$	$.75^{cd}$	$.70^{de}$	$.68^{e}$	$.76^{c}$	.04
Avg. daily feed, kg	3.12^{b}	2.96^{cd}	3.05^{bc}	2.87^{de}	2.76^{e}	3.12^{b}	2.98^{bcd}	3.02^{bc}	.12
Feed/gain	3.91^{bc}	3.96^{cd}	3.82^{bc}	3.50^{b}	3.69^{bc}	4.40^{e}	4.36^{de}	4.00^{cde}	.09
Backfat, cm^{gj}	1.91^{g}	1.71^{h}	1.87^{g}	1.83^{gh}	1.83^{gh}	1.79^{gh}	1.57^{i}	1.85^{g}	.02
ME intake, Kcal/d	9712.1	8594.3	8855.6	9016.3	7983.2	8948.8	8652.4	9094.8	
Final wt, kg	109.1	102.7	107.0	107.7	103.4	99.6	97.7	102.5	

[a] Total of 160 pigs (10 pigs/pen with 2 pens/treatment), average initial wt 46.7 kg, average final wt 104.3 kg. Trial duration 74 days.
[bcdef] Means on the same line differ (P<.05).
[ghi] Means on the same line differ (P<.08).
[j] Last rib fat depth.

Table 10. Particle Size Analysis of Milo and Barley Grain, Experiment 6.

Item	Grain: Screen mm:	Milo 4.8	Barley 3.2	Barley 4.8	Barley 6.4	Barley Rolled	SE
		Treatments					
Particle size diameter (microns)		759.4[a]	649.8[a]	912.3[b]	1278.5[c]	2894.3[d]	105.1
Geometric standard deviation		2.21[a]	1.97[a]	2.06[a]	2.04[a]	1.44[b]	.08
Surface area (cm^2/g)		82.3[ab]	86.4[a]	63.3[bc]	45.5[c]	16.5[d]	5.8

[abc] Means on the same line differ (P<.01).

Table 11. Particle Size Analysis of Milo and Barley Diets, Experiment 6.

Item	Grain: Screen mm:	Milo 4.8	Barley 3.2	Barley 4.8	Barley 6.4	Barley Rolled	SE
		Treatments					
Particle size diameter (microns)		664.7[a]	710.9[a]	921.1[b]	1159.1[c]	2205.9[d]	41.0
Geometric standard deviation		2.32	1.97	2.02	2.06	1.92	.17
Surface area (cm^2/g)		97.9[a]	79.3[ab]	62.1[abc]	49.9[bc]	24.9[c]	10.1

[abc] Means on the same line differ (P<.01).

Table 12. Effect of Barley Particle Size in Finishing Diets, Experiment 6.[a]

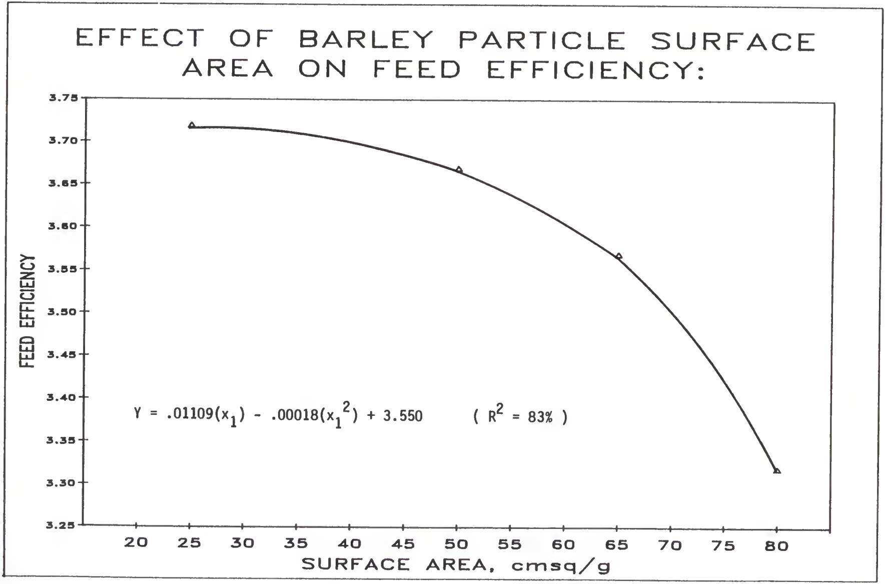
Item	Grain: Screen mm:	Milo 4.8	Barley 3.2	Barley 4.8	Barley 6.4	Barley Rolled	SE
		Treatments					
Avg. daily gain, kg		.93[b]	.89[b]	.82[c]	.80[c]	.79[c]	.05
Avg. daily feed, kg		3.15[b]	2.95[c]	2.82[c]	2.95[c]	2.95[c]	.12
Feed/gain		3.39[b]	3.32[b]	3.58[c]	3.65[c]	3.72[c]	.05
Backfat, cm[df]		1.99[d]	1.87[e]	1.83[e]	1.90[de]	1.84[e]	.02
ME intake, Kcal/d		9805.7	8565.3	8187.8	8586.3	8565.3	
Final wt, kg		104.1	102.1	96.8	96.3	95.3	

[a] Total of 150 pigs (10 pigs/pen with 3 pens/treatment), average initial wt 46.4 kg and average final wt 99.0 kg. Trial duration 62 days.
[bc] Means on the same line differ (P<.02).
[de] Means on the same line differ (P<.09).
[f] Last rib fat depth.

Table 13. Effect of Milo and Barley Particle Size on Incidence of Gastric Lesions, Experiment 6.

Item	Grain: Screen mm:	Milo 4.6	Barley 3.2	Barley 6.4
No. pigs		6	6	6
No. normal stomachs		1	1	4
No. slight cornifications		4	2	1
No. cornifications		1	3	1
No. slight ulcers		0	0	0
No. serious ulcers		0	0	0

Figure 1.


EFFECT OF BARLEY PARTICLE SURFACE AREA ON FEED EFFICIENCY:
FEED EFFICIENCY
3.75
3.70
3.65
3.60
3.55
3.50
3.45
3.40
3.35
3.30
3.25
Y = .01109(x1) - .00018(x1 2) + 3.550
(R2 = 83%)
20 25 30 35 40 45 50 55 60 65 70 75 80
SURFACE AREA, cmsq/g

SUMMARY

Five growth trials (three finishing and two starter) and one digestion trial (starter) were conducted to evaluate the effects of feeding barley-based diets on pig performance. These studies evaluated pigs fed diets with various levels of barley substituted for milo, as well as barley processed by different methods. The barley used in these experiments was a Kanby variety locally grown in the 1984-85 growing season.

Two starter experiments were conducted to evaluate weanling pigs averaging 6.4 kg fed diets in which barley was substituted for milo at levels of 10, 20, 30, and 40% of the diet. During the first week of the experiment, pigs fed the 40% barley diet had lower feed intakes and subsequently lower average daily gains. However, in the second week of the experiment, feed intake increased and overall performance was not different from those fed the milo control diet. Pigs fed the diets containing 10 or 30% barley tended to have poorer feed efficiency. However, these differences appear to be related to numerical differences between fed intake and average daily gain, rather than treatment differences.

Results of the digestion trial evaluating pigs fed the milo control diet or 20 and 40% barley diets indicates decreased dry matter digestibility and digestible energy as level of barley increased. However, crude protein digestibility was similar for pigs fed either grain source. Nitrogen retention was higher for pigs fed the 20 and 40% barley diets, as was percent nitrogen retention, although the latter was not significantly different.

While some differences in digestibility may exist between pigs fed milo or barley nursery diets, these differences were not great enough to affect pig performance, as shown by the results of the growth trials. Therefore, it would appear that barley may replace all of the milo in a 20% dried whey (1.25% lysine) nursery diet, without adversely affecting pig performance.

Results of the three finishing pig experiments evaluating 460 pigs fed either milo or barley-based diets indicates that energy is the first limiting factor in barley diets. The high fiber and bulkiness of barley dilutes the energy content of the diet and subsequently limits feed intake. Increasing the caloric density of the diet by adding fat or decreasing the bulk density by pelleting significantly improved pig performance over unsupplemented barley diets. Pigs fed diets with barley substituted for all or half of the milo, or balanced on a lysine basis, had lowered average daily gains and poorer feed efficiency, suggesting barley to be only 90 to 95% the feeding value of milo for finishing pigs.

Results also indicate that fine grinding of barley has a beneficial effect by improving nutrient digestibility. Pigs fed finely ground barley were equal in average daily gain and feed efficiency to pigs fed the milo control diet, while pigs fed the medium, coarse, or rolled barley diets grew significantly slower and less efficiently. There was a quadratic relationship between particle surface area on feed efficiency. The increased surface area would account for the improved digestibility for pigs fed finely ground barley by providing for greater interaction between the digesta and digestive enzymes.

As to the question whether it is pratical for the producer to grow and/or incorporate barley into his swine diets is dependent on several considerations. Certainly market prices and availability are of first importance, along with guidelines on processing methods, diet formulation, as well as feeding value for each stage of production. But several indirect costs must also be considered, including growing season, irrigation costs, rainfall, double crop potential, and production costs. Consideration of these costs will ultimately determine the feasibility of barley production and will dictate its role in future livestock production.

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THE EFFECTS OF BARLEY ON STARTER- AND FINISHING-PIG PERFORMANCE

by

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ABSTRACT

Five growth trials (three finishing and two starter) and one digestion trial (starter) were conducted to determine the effects of feeding barley-based diets on pig performance and nutrient digestibility.

In two starter trials, 240 weanling pigs averaging 6.4 kg were utilized to evaluate the effects of increasing dietary barley levels on pig performance. The control diet consisted of a milo-soybean meal, 20% dried whey (1.25% lysine) nursery diet. Barley was then substituted on an equal weight basis for milo at levels of 10, 20, 30, and 40% of the diet. Pigs fed the 40% barley diet had lowered average daily feed intake (ADFI: $P<.03$) and subsequently lowered average daily gain (ADG: $P<.07$) during the first week of the experment; however, ADFI and ADG of pigs fed this diet improved in the second week of the experiment and overall performance was not affected by dietary barley level. Pigs fed the 10 and 30% barley diets tended to have the poorest feed efficiency (F/G: $P<.06$). Incidence of scouring was not affected by increasing dietary barley levels.

A digestion trial was conducted to determine the effects of barley on dry matter digestibility (DMD), digestible energy (DE), crude protein digestibility (CPD), and nitrogen retention (NRTg) in the weanling pig. Nine pigs averaging 9.1 kg were fed either the milo control diet, or diets with 20 or 40% added barley. DMD and DE decreased ($P<.01$) as level of barley increased. CPD was not affected by dietary barley level, however, NRTg was improved ($P<.01$) for pigs fed either the 20 or 40% barley diets. Nitrogen retention when expressed as a percent of intake also tended to increase with increasing barley levels ($P=.14$).

The results of these studies indicate that although increasing dietary barley levels may lower DMD and DE of the diet, there is no adverse effect on pig performance as shown by the results of the growth trials, and therefore, barley may successufully replace all of the milo in a 20% dried whey nursery diet.

In three finishing pig growth trials, 460 crossbred pigs averaging 48 kg were utilized to evaluate the effects of feeding barley on pig performance. In trials 1 and 2, pigs were fed: 1) a milo-soybean meal control diet (14% CP. and .6% lysine), 2) basal barley diet (equal substitution of barley for milo), 3) as 2, pelleted, 4) barley with 5% added fat, 5) barley balanced on a isolysine basis for milo. In trial 2, three additional treatments were included: 6) barley with 5% added molasses, 7) as 2, rolled, 8) barley substituted for 50% of the milo.

In trial 1, ADG of pigs fed the basal barley diet tended (P<.09) to be lower than that of pigs fed the pelleted barley diet. In addition, pigs fed the isolysine balanced barley diet also tended to be numerically inferior in ADG to those pigs fed the milo control diet. Pigs fed the basal and isolysine balanced barley diets were poorer in feed efficiency. Pigs fed the pelleted or added fat barley diets were similar in ADG and more efficient compared to those pigs fed the milo control diet. Neither last rib fat depth nor ADFI were affected by dietary treatment.

The results of trial 2 are similar with those of trial 1, with the exception that pigs fed the isolysine balanced barley diet were not statistically different in ADFI or F/G than those fed the added fat barley diet. Pigs fed the basal or 50% barley diets were similar to each other in ADG and F/G. Pigs fed rolled or 5% added molasses barley diets, were poorest in ADG and F/G.

Finishing trial 3 evaluated the effects of barley particle size on pig performance. The five dietary treatments included: 1) milo control, ground through a 4.8 mm screen, 2) barley (equal substitution for milo) ground through a 3.2 mm screen, 3) barley ground through a 4.8 mm screen, 4) barley ground through a 6.4 mm screen, or 5) rolled barley. Pigs fed the finely ground barley were not different in ADG and F/G from those fed the milo control diet. However, pigs fed medium, coarse, or rolled barley diets grew slower and were less efficient (P<.01) than pigs fed either the milo control or finely ground barley diets.

Regression analysis revealed F/G to be a quadratic function of the surface area (SA) of ground barley ($P<.01$), expressed by the equation: $F/G = .01109(SA) -.00018(SA^2) + 3.550$ ($R^2 = 83\%$).

These results indicate that diets in which barley is substituted for all or half of the milo, or balanced on a lysine basis, appear to have 90 to 95% the feeding value of milo for finishing pigs. Furthermore, increasing the caloric density of barley diets by adding fat or decreasing the bulk density by pelleting also improves pig performance, while fine grinding of barley has a beneficial effect on pig growth and feed efficiency by improving nutrient digestibility.