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Title EFFECT OF BARLEY PRETREATMENT ON FEEDING BEHAVIOR, RATE AND EFFICIENCY OF GAINS FOR SWINE

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A series of four animal experiments utilizing 129 pigs and associated laboratory studies was conducted to study the causes of the lowered performance on high barley rations fed to swine. Previous work at this Station has shown barley to have a value of 80-85 percent of corn for swine, and demonstrated that barley hull is responsible for the major part of the growth depression when it is present in swine rations.

Numerous trials have been conducted at this Station to overcome the limitation imposed by hull material in high barley swine rations. Outside of pearling, which was completely successful in overcoming the depressive effect of barley; soaking, enzyme treatment, pelleting, and the addition of fat have been used with varying degrees of success. Pelleting has been the most successful of the latter four treatments, yet its beneficial effect is lost upon regrinding of the pellets. Recent work has indicated that soaking

high barley swine feeds may be beneficial. The recent finding that antibiotics interfere with nutritional improvement of barley for poultry during water treatment suggested that a part of the benefit of soaking had been lost due to the presence of antibiotics in the swine rations. Addition of enzymes specific for cellulose, the major structural component of barley hull, has not been demonstrated to be of any advantage, yet conditions have not been optimum in terms of the enzyme's potential activity. These findings were considered in the objectives and design of the experiments described herein.

Ground and whole barley were soaked for 24 hours at 30 C. before being mixed with the protein supplement just prior to feeding. Pigs receiving ground, soaked barley grew 4.2 percent faster on 3.2 percent less feed compared to the same ration fed dry but these differences were not significant. Pigs receiving soaked whole barley grew 12.2 percent slower and required 17.0 percent more feed than those which received the ground soaked barley ration. These differences were significant ($P < .01$). Pigs receiving whole barley soaked with constant aeration and with added cellulase 4000 enzyme did not differ significantly in growth rate nor feed efficiency from a lot which received whole, soaked barley. There was a six percent reduction in the cellulose content of barley treated with the enzyme preparation.

The addition of five percent fat to a high barley ration improved feed efficiency but not rate of gain. The production of a pellet containing five percent added fat with the same density as the pelleted control ration, through use of a specially-constructed die, resulted in increases in both rate and efficiency of gain. Fatness as measured by back fat thickness was significantly increased by the fat-containing pellet.

Feed waste and its causes were studied. Waste varied from 3 to 25 percent with group-fed pigs depending upon the form of the ration and the type of feeder used. Individually-fed pigs wasted from 7 to 36 percent of the feed when fed alike indicating that waste varies greatly from one pig to another. Pelleting of a meal ration reduced the amount of feed wasted from an average of 12.18 to 3.08 percent. Pigs consume more pellets than meal of similar composition even though the apparent disappearance from the feeder of the two forms is similar.

Electronic measurement of feeding time showed that pigs spent 16.74 percent of the day consuming meal and only 7.34 percent of the day eating pellets of the same composition. A photographic study and close observation showed that pigs fed meal spend considerable time sorting out barley hull. Chemical analysis of the material wasted out of the feeders had a fiber content 2.5 times as high as the original ration.

The studies reconfirm the conclusion that hull is primarily responsible for the lowered performance of barley rations. Barley hull splinters which result from grinding the grain apparently reduce the amount of feed the animal will consume while increasing feeding time and feed waste. Pelleting enables the animal to consume more of the ration in less time with less waste. The limitation imposed by barley hull upon swine performance appears to be associated with the prehension of feed rather than exclusively with mechanical interference in digestion and absorption of nutrients as previously believed.

EFFECT OF BARLEY PRETREATMENT ON FEEDING BEHAVIOR, RATE AND EFFICIENCY OF GAINS FOR SWINE

by

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INTRODUCTION

The concept of improving the efficiency of use of livestock rations through chemical and mechanical modifications of the feed ingredients has received relatively little exploration. During the late 1920's and early 1930's electrical energy became available to American farms and ranches. This progress led to experimentation into the value of grinding and rolling of feed grains for livestock feeding.

Interest in the relative merits of changing the physical character of feeds was again rekindled with the widespread introduction of pelleting machines following World War II. These subsequent investigations were largely limited to testing the comparative feed values of pelleted rations and their non-pelleted counterparts.

Morrison (33, p. 448) states (and this is widely accepted) that when the cost of grinding is considered, barley has a feeding value of only 81-85 percent of that of corn in swine rations. Vast regions of the Western United States are suitable for growing barley while being either too dry or otherwise unsuitable for corn production. Today the production of barley plays an important role in the economy of the western states.

Future feed grain production is closely tied to its efficient conversion into saleable animal products. Since American agricultural production is being achieved on a rapidly shrinking profit margin it has become more difficult for swine producers in the West to compete with producers in corn-growing areas of the Midwest.

The Department of Animal Science at Oregon State University has a continuing project designed to improve the efficiency of barley in swine rations. Barley contains gross calories per pound equal to or greater than those of corn according to the National Research Council (34, p. 6–10). The protein quality of barley is superior to that of corn based on biological value determinations made by Block and Mitchell (3, p. 163). Feeding trials conducted by Gill (16) using rats indicated that the protein quality is quite high.

The work completed at Oregon State University has shown the almost complete inadequacy of existing in vitro methods for evaluating feedstuffs to detect differences brought about by feed processing. It is apparent that pelleting of a feed does not change its chemical composition, yet feeding trials have shown that pelleting barley-containing swine rations increases both the rate and efficiency of gains.

This thesis is a continuation of work carried out by Larsen (28, p. 1-79), Chapin (5, p. 1-88), and Wilson (45, p. 1-75) at this Station. It can be divided into two main areas. The first deals with the effect of soaking, germination, and enzyme treatment of barley. The second delves into the effect of supplementation of exogenous energy to pelleted and non-pelleted barley rations.

Methods were developed to bring about conditions under which barley could be soaked in a manner well controlled in terms of time and temperature. Previous work (45, p. 61) had shown a trend toward improvement of gains and feed efficiency due to soaking a barley ration 8 to 14 hours prior to feeding; however, the data were variable for a number of reasons, including the lack of control of temperature during the soaking process.

Larsen (28, p. 30-36) at this Station, has shown that the hull portion of barley is closely involved with the poor performance of barley rations compared with corn. The addition of barley hulls to a corn ration had reduced the performance of the ration to a greater degree than did equal amounts of pure cellulose from wood pulp when the two fiber sources were used as diluents at the same levels.

Work in the area outlined thus far is greatly complicated by the almost complete inadequacy of chemical techniques to evaluate modifications in the composition of barley brought about by treatment and to relate these changes to predicted animal performance. Differences between rations, while of great economic importance and of tremendous impact on the livestock industry, are difficult to demonstrate experimentally due to inherent variables which are found in all feeding trials. Experimental feeding trials need constant refinements to enable the scientist to make inferences which are of practical importance to the livestock industry while using a minimum of experimental animals and facilities.

Minor modifications in feedstuffs can be presumed to bring about differences in palatability detectable only by the animals to which they are fed. It has been observed that the wastage of feeds has not been constant between treatments when using different rations. This variable was studied extensively and the inferences drawn may be of more practical significance than the other work.

The difference between the actual performance of barley and corn rations has been visualized as a deficiency of available energy in the case of barley. The addition of stabilized animal fats to barley rations as a source of supplemental energy has been shown to improve their performance (5, p. 73; 11, p. 8-9; 43, p. 955).

Wilson (45, p. 38-39) and Chapin (5, p. 73) pointed out the desirability of testing to see if an additive effect could be attained due to pelleting and fat addition to a barley ration. Previously the addition of fat to swine rations to be pelleted resulted in a soft, crumbly pellet which had not given the anticipated additive effect. Through the courtesy of Mr. Ross Chapin of the Elliott Feed and Seed Company (Perrydale, Oregon) it was possible to obtain access to a special mill die to facilitate this investigation. The die was thicker than usual and the holes were tapered thus causing a much greater pressure which resulted in a durable fat-containing pellet. The production of this type pellet made it possible to test the hypothesis put forward by Chapin and Wilson.

Studies were made to isolate those factors in barley that reduce its efficiency in swine rations. Mechanical and chemical modification of the feed were tested in attempts to reduce or eliminate the interference caused by the factors which appear to reduce the feeding value of Western barleys.

REVIEW OF LITERATURE

In recent years there has been considerable research conducted toward improving the feeding value of barley for poultry. At the same time research on improving the utilization of barley in swine rations has had little success in terms of a breakthrough which could be easily and economically applied on a commercial scale. It is probable that the short time involved and the limited scale on which the research has been conducted are responsible for the lack of progress. Research efforts with swine might well be modeled after the extensive studies on barley utilization with poultry that have been carried out at Washington State University.

The Improvement of the Nutritive Value of Barley in Relation to Corn in Swine and Poultry Rations

Larsen (27, p. 46) has shown that barley has 86 percent of the value of corn in swine rations. Leong (32, p. 36-39) found that in poultry rations, barley has a metabolizable energy value of 1410 Calories per pound while corn had a value within the range of 1760 to 1980 Calories per pound.

Poultry nutritionists have been successful in improving the feeding value of western-grown barleys in chick- and poult-growing rations in relation to corn. They have accomplished this improvement through two approaches. The first method involved the addition of crude enzyme preparations to the dry poultry rations and the second, the soaking of barley for about eight hours followed by drying at less than 70° C until the moisture content was reduced to less than ten percent. Following drying, the barleys were ground and formulated into rations in the normal manner.

Enzyme Treatment of Barley in Poultry Rations

Willingham (44, p. 539-544) has shown that the growth-depressing effect of barley as compared with corn in chick rations can be overcome by the use of crude enzyme preparations from either fungal or malt origin. He has shown that fungal amylase, bacterial amylase and barley malt amylase have been able to improve the nutritional value of barley. Crystalline bacterial amylase failed to give any improvement in the feeding value of barley. With the exception of the latter, the other preparations used are crude mixtures of amylolytic, proteolytic and cellulolytic properties apparently having their greatest degree of activity on starch.

More recently, Jensen (23, p. 13) has stated that the specific enzyme necessary for improving barley and oats for poultry appears to be β-glucanase, which is specific for a polysaccharide found in barley and oats called β-glucan. β-glucan is a carbohydrate consisting of long chains of glucose molecules attached together by β1-4 and β1-3 linkages. Gascoigne (15, p. 243-244) states that there are two β-glucanases, an endo-β-glucanase and an exo-β-glucanase. Studies have shown that these enzymes have different properties other than their pattern of attack on the β-glucan molecule.

Water Treatment of Barley in Poultry Rations

Leong (32, p. 36-39), Arscott (1, p. 268-270), and Thomas (42, p. 1209-1213) have shown that water treatment of barley is able to improve its feeding value in poultry rations to equal that of corn. Leong has shown that some barleys actually give a superior growth response to corn after water treatment. In his experiments, he found that barley was improved in feeding value for chicks from 1410 Calories per pound to 1869 Calories per pound of metabolizable energy. Fraps (14, p. 37) reported that untreated barley has only 70 percent of the "productive energy" of corn for poultry.

The mechanism involved in the improvement of barley for poultry during water treatment was reported by Thomas (42, p. 1209-1213). His group found that autoclaved barley was significantly improved by subsequent water treatment, thus implying that enzymes endogenous to barley are not necessary for improvement by this means. They also reported that the physical effect from water treatment was not a factor in barley improvement. Special reference will be made to this point in the subsequent results and discussion of this thesis. Thomas reported that the drying temperature of barley during water treatment was most favorable for microbial growth during the first seven hours of drying, due to evaporation. Air in the feed preparation rooms contained sufficient bacteria to recontaminate autoclaved barley during the subsequent soaking and drying process. He concluded that the enzymes or other factors produced by microorganisms on the barley bring about nutritional improvement during water treatment.

It is significant that when barley was maintained under sterile conditions no nutritional improvement was found following the water treatment.

Enzyme Treatment of Barley for Swine

Both water treatment and the addition of crude enzyme preparations to the barley portion of poultry rations have been successfully used to improve the feeding value of these rations. On the other hand, the application of these techniques to attempt improvement of the feeding value in swine rations has not been successful. Neither Chapin (5, p. 73), nor Wilson (45, p. 38-39) were able to demonstrate consistent improvement in the feeding value of barley by the use of enzyme supplementation. The literature concerning the value of adding enzyme preparations to swine rations can best be summarized by stating that these additions appear to give a slight, but non-significant, increase in efficiency of utilization.

Oldfield (35, p. 78-80), in a review article, pointed out that the difference in the anatomy and physiology of the digestive systems of swine and fowl may explain the failure of swine to respond to enzyme supplementation. Similarly, Gill (16, p. 1-7) stated that the pig has no comparable site to the crop of fowl where time, moisture conditions, and pH might be suitable to afford an enzyme preparation an opportunity to act on the ration.

Crude enzyme preparations, when added to dry swine rations, do not have an opportunity to react to any extent with the feed prior to its wetting in the mouth of the animal. While these products are sold to the livestock industry as enzymes, the Federal Food and Drug Administration (40) has pointed out to the manufacturers that on the basis of their reviews these agents should be described as agents for "increasing the palatability of animal rations."

The conclusion reached by the Food and Drug Administration seem reasonable since little or no change in the composition of the feedstuff could be accomplished prior to the ingestion of the ration by the animal. Following ingestion, it is probable that any enzymatic activity in the feed would be destroyed by the strongly acid gastric juices before it could reach the small intestine where pH and moisture conditions would be optimum. As mentioned previously, poultry may afford these enzyme preparations an opportunity to react in the crop prior to their eventual deactivation by the gastric juices. It should be pointed out that even though a positive growth response has been obtained due to enzyme treatment in poultry rations, the evidence does not rule out the possibility of effects as flavoring agents or other non-enzymatic activities (i.e. antibiotic effect).

It is difficult to conceive of any way that the addition of an enzyme preparation could cause a desirable modification of the components of a dry swine ration in normal feed handling and feeding practices.

Yet the desirability of enzymatic degradation of the more difficultly-digestible portions of feedstuffs prior to feeding is apparent.

Water Treatment and Soaking of Barley for Swine

Swine have not responded to the water treatment of barley as have chicks and poults. Larsen (29, p. 601-606) soaked and dried barley prior to its subsequent grinding and incorporation into swine rations. He found no advantage to this laborious and expensive procedure in terms of growth rates or feed efficiency. In this case the barley was soaked for eight hours and then dried for eight to twelve hours at 110°F. to 140°F., the same conditions as have been used to produce the positive response in poultry work.

He found that the addition of 2.5 percent barley malt during soaking increased rate of gain slightly but ten percent malt reduced gains and feed consumption. The addition of a cellulolytic enzyme preparation during soaking was found to have no advantage.

The soaking of barley with an enzyme preparation specific for the fibrous portion of the feed may be desirable, especially if it were possible to bring about an improvement in the feeding value of a ration under economically feasible conditions. The soaking or wetting of swine feeds prior to feeding in the wet state may afford an opportunity for improvement of these feeds.

The practice of soaking swine feeds is not new. In 1909 a Kansas Agricultural Bulletin (22, p. 382-390) stated that as much pork can be produced from a given amount of feed either in wet or dry form provided an abundance of drinking water is available. Wet feeding today may be desirable under certain types of management systems especially where dust may aggravate disease conditions.

The wetting or soaking of barley may afford an opportunity for both the endogenous enzymes of barley and/or the addition of crude enzyme preparations to modify the structural compositions of the poorly digestible portions of the grain. Wilson (45, p. 42-44) soaked a complete swine ration containing 86.6 percent barley and fed it wet. This treatment increased average daily gains and feed consumption but lowered feed efficiency. Seerley (38, p. 1-3), at South Dakota, found that pigs self-fed a wet corn-soy-tankage ration gained 5.5 percent faster than pigs fed the dry ration. In a second trial the pigs fed the wet ration were less efficient. Becker et al. (2, p. 1-6), at Illinois, found that pigs fed a wet corn-soy ration had a feed conversion of 2.96 as compared with 3.36 for the dry control rations.

Thomas (41, p. 1204-1208) has reported that the incorporation of oxytetracycline and certain other antibiotics into wet barley rations interfered with nutritional improvement during subsequent water treatment for chicks. This finding leads to reconsideration of the interpretation placed upon the findings where barley-containing rations were soaked for swine. Wilson's swine rations had oxytetracycline formulated into the rations prior to soaking. The use of antibiotics in swine rations is widely accepted and generally practiced. Thomas's finding may explain the failure of many swine rations to respond to the soaking process.

The Effect of Barley Hulls on the Efficiency of Utilization of Barley by Swine

Larsen (28, p. 26-42) has demonstrated the growth depressing effect of barley hulls in swine rations. He fed a pearled barley ration and compared it to the same ration diluted with barley hulls and wood cellulose. Rate of gain was depressed from 1.73 pounds a day to 1.60 pounds a day when the same barley was fed without pearling. The addition of a comparable level of wood cellulose to the pearled barley ration caused a growth rate intermediate between that of the pearled and whole barley at 1.67 pounds a day.

Feed efficiency was reduced to a greater extent by the addition of barley hulls than by a comparable level of wood cellulose. When barley hulls or wood cellulose were added to a corn ration, the barley hulls had a greater growth depressing effect than did the cellulose.

Larsen concluded that barley hulls contain a growth-depressing substance other than pure cellulose. He suggested that the lignification of the hull and other non-characterized factors appear to be responsible for the growth depression in swine rations.

The feeding of pearled barley to poultry has not been shown to be of any advantage over regular barley. Leong (31, p. 615-619) states that water treatment of pearled barley results in the same marked improvement for poults as does that of the regular barley. He also has shown in this work that fiber *per se* is not the component that determines whether or not a diet will be improved by enzyme supplements. Fiber tended to be detrimental for chick growth, perhaps because of lowered nutrient intake.

At this point the evidence leads to the conclusion that the poor performance of barley in relation to corn in swine rations is associated with the hull or fibrous portions of the kernel. Tables

1 and 2 give the chemical composition of the common cereals and of barley and malt in more detail.

The implication of the barley hull with the growth depressing factor in barley rations for swine calls for a brief review of the types of barley produced. Not all barleys have hulls. The common barleys available as feed grains in the Northwest, are almost always the hulled varieties. It is these hulled varieties with which this thesis is concerned.

The hulless or naked barleys, while being less common, by their nature of having less fiber have a higher feeding value for swine. Joseph (25, p. 18) found that pigs grew as well on a hulless variety of barley as they did on corn. The distinguishing feature of the two types of barley is the behavior of the lemma and pale in relation to the caryopsis (kernel) at maturity. In the common feed barleys the caryopsis fuses with the lemma and pale as maturity approaches so that the hull does not separate at threshing. They can be separated only with considerable difficulty in a process called pearling. These structures do not fuse in the hulless varieties and the hull is easily removed at threshing time. Carlson (4, p. 117) points out that in Japan, where barley is grown as a staple food, over half of the varieties grown are hulless. Archaeological studies in England indicate that naked barley was predominant in the early years of the Christian era. It should be emphasized that today many

Table 1. The chemical composition of cereals. Results expressed as percent air dry weight (8, p.435).

Grain	Dry Matter	Cellulose	Starch and Other Carbohydrates	Protein	Other Non-Nitrogenous Matter	Ash
Barley	85	4.8	60	10.0	3.4	2.6
Wheat	86	2.5	65	12.5	2.4	1.9
Rye	85	2.0	63	11.5	4.9	2.0
Oats	87	10.8	53	11.7	2.1	3.0
Maize	86	3.6	60	10.0	6.5	1.0
Rice	86	2.0	70	7.7	-*	0.3

* Value not available.

Table 2. Overall analyses of barley and malt (6, p. 435).

Substance Analyzed	Content(Percent Dry Weight) Barley	Malt
Starch	63-65	58-60
Sucrose	1-2	3-5
Reducing sugars	0.1-0.2	3-4
Other sugars	1	2
Soluble gums	1-1.5	2-4
Hemicellulose	8-10	6-8
Cellulose	4-5	5
Lipids	2-3	2-3
"Proteins" (N x 6.25)	8-11	8-11
Mineral matter	2	2.2
Other materials	5-6	6.7

varieties of barley would fall somewhere in between the hulled and naked varieties in the firmness of attachment to the hull.

The Chemical Structure of Barley Hull

Pollock (36, p. 352) states that about one-twentieth of the weight of barley is cellulose and most of it is derived from the hull. Harris (21, p. 470) states that hemicelluloses, which make up between 10-11 percent of the weight of barley, are concentrated throughout the hull and endosperm. It has been shown that 75 percent of the hemicelluloses remain unchanged during malting, emphasizing either their resistance to the intrinsic barley enzymes or the lack of specific enzymes for hemicellulose. The hemicellulose of the hull chemically resembles the hemicellulose from cereal straws. They are not modified to any extent during germination. The hemicellulose and gums of the endosperm differ in structure from those of the hull and undergo extensive modification during the germination process. The presence of cellulases in germinating barley has been demonstrated by their degradation of cotton cellulose. The tables have shown that barley does not have appreciably more cellulose than corn. Likewise, the starch levels of barley and corn are comparable.

The crude fiber portion of barley has been implicated frequently with the poor performance of this grain in swine rations. Swine nutritionists in this country tend to hold to the position that crude fiber in swine rations is detrimental. In Europe it is believed that the ideal swine ration has an optimum fiber level. The fact that it has been shown that pelleting increases the feeding value of high fiber swine rations may indicate that fiber in the ration acts by diluting the ration or more probably by reducing the animal's nutrient intake.

The Effect of Pelleting Barley Rations for Swine

Dinusson (9, p. 1256), at North Dakota, has shown that pelleting of barley rations for swine gave a 12 to 15 percent increase in daily gains and a 14 to 20 percent increase in feed efficiency over similar rations in meal form. Barley made up 95.1 percent of these rations. When rations were formulated and pelleted to compare "plump" (47 pounds per bushel) and "thin" (37 pounds per bushel) barley to an unpelleted meal ration of the same formulation, the "plump" barley supported gains 12.6 percent faster and on 30.8 percent less feed when pelleted. The "thin" barley gave gains 18.5 percent faster and on 21.3 percent less feed. When 30 percent oat hulls were added to the barley diet, however, pelleting improved the utilization of this ration so that pigs gained more rapidly and economically than with a meal ration diluted with 15 percent oat hulls. Table 3 shows the results of this phase of the work.

Table 3. The effect of addition of oat hulls and pelleting on the performance of a swine ration (9, p. 1256).

Ration Form	Oats Hulls (percent)	Fiber Content (percent)	Daily Gain (pounds)	Feed Per Pound Gain (pounds)
Meal	15	11.9	1.34	5.21
Pellet	30	14.4	1.50	4.66

Wilson (45, p. 37-39) found that pelleting increased the efficiency of utilization of a high barley ration at this Station. On the otherhand, Larsen (28, p. 22) could not improve the feeding value of a high corn ration by pelleting. He did, in the same series of tests, find a considerable advantage to pelleting a high barley ration. When he fed reground barley pellets the advantage due to pelleting was lost.

The apparent advantage to pelleting a barley ration must not be in any changes brought about in the pelleting process if the response is lost upon regrinding. It should be pointed out that in these previously described experiments the apparent feed efficiencies would include feed wasted, and in this connection, Larsen noted that the apparent advantage to pelleting may be due to a reduction in the amount of feed wasted. He observed that waste appears to be greater on a meal ration than on a pelleted ration but no actual measurements were made.

It has been demonstrated that pigs have a definite preference for certain forms of the same ration. Koch (26, p. 840) fed pigs sorghum grain prepared by different processing methods. Pigs had access to six feeders containing sorghum grain from the same source but processed differently. Their preferences were as follows: whole, 20.4 pounds per day; rolled and pelleted, 19.8 pounds per day; steam rolled, 9.3 pounds per day; dry rolled, 3.3 pounds per day; and fine ground, 0.2 pounds per day. In a subsequent test using sorghum from one source but processed differently, feed required for 100 pounds of gain was as follows: whole, 393 + 48; rolled and pelleted, 293 + 56; steam rolled, 247 + 63; steam conditioned rolled, 371 + 55; and dry rolled, 339 + 55. The second figure in each case is the pounds of 40 percent protein supplement consumed free choice along with the sorghum grain. The difference in rates of gain in the test were non-significant.

It is significant that the animals chose the whole sorghum over the ground sorghum even though they gained more economically on the rolled and pelleted grain. Sorghum more closely resembles corn than barley in its composition and it has been shown that there is little advantage to grinding corn for larger pigs (33, p. 57-59). Morrison (33, p. 57-59) states that it has been shown that it is advantageous to grind barley and oats when fed to swine.

It is probable that a ration must be in a form most acceptable to the animals to reach maximum rates of gain and feed efficiency. The high cost of maintenance in terms of percent of total energy intake in relation to the remaining productive energy of the ration would result in a slight reduction of feed intake causing a substantial decrease in rate of gain and feed efficiency.

Supplementation of Energy in High Barley Swine Rations

Regardless of the cause of the poor performance of barley rations in comparison to corn rations for swine feeding the end result can be visualized as a deficiency of metabolizable energy in the case of barley.

Chapin (5, p. 67) found that the rate and efficiency of gains can be increased by the addition of five percent fat to the barley ration when the ration was fed in the meal form. In an attempt to obtain an additional beneficial effect Chapin pelleted the fat-containing barley ration but failed to detect any increase in the performance on the ration. He stated that this was probably due to the fat which caused very soft and crumbly pellets thus reducing their consistency to resemble reground pellets by the time they were handled and reached the feeder.

The addition of supplemental fat to high barley rations affords an improvement of performance which can be used to economic advantage by commercial swine growers when fat can be purchased at a price commensurate with its advantage. At present no advantage has been demonstrated for pelleting these rations containing additional fat.

EXPERIMENTAL PROCEDURE AND RESULTS

Experiment I: Barley Soaking Experiment

Experimental Procedure

Since Wilson (45, p. 38-39), at this Station, and Seerley (38, p. 1-3) at South Dakota, have provided some evidence for improved swine performance on soaked barley rations, the following experiment was devised to allow water treatment of grain under controlled conditions.

Better control of the soaking process than has been previously reported was brought about in the following manner: soaking vats were constructed using 55 gallon drums with the tops removed. These drums were insulated with a layer of wood shavings about six inches thick on all sides with the top being exposed. Immersion heaters[1] of 1150 watt capacity were suspended near the bottom of the barrels which were filled 3/4 of the way full with water. Immersion-type thermostatic controls[2] controlled the heating elements. Thermostats were set at 30° C. and were of sufficient accuracy to

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[1] Safe-Hete, model 1150, Electra, Inc., 809 W. Waveland Avenue, Chicago 13, Illinois.

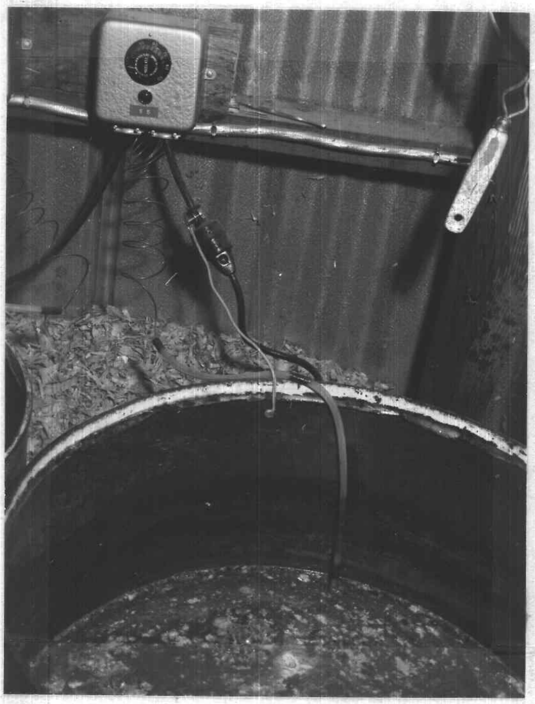
[2] Model 453, 115-230 volt 22 amp, manufactured by Cox and Company, Inc., New York 10, New York.

maintain the water temperature within ±0.5° C. at all times. The soaking barrels are pictured in Figure 1.

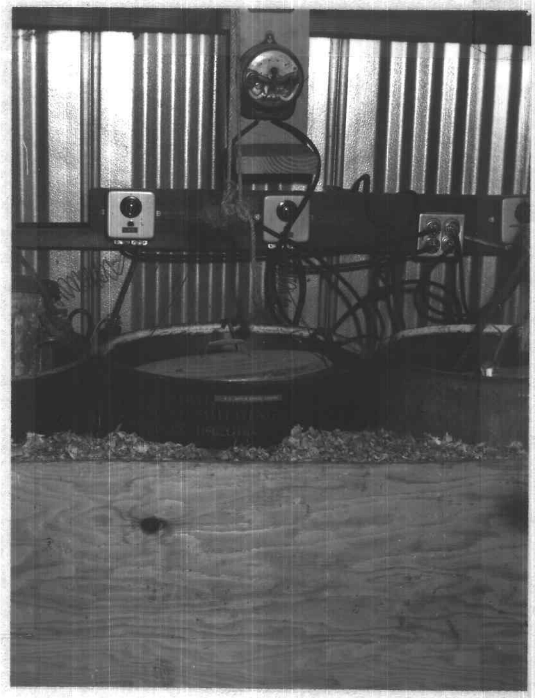
Twenty-five gallon galvanized containers held the barley in the soaking barrels. The bottoms of these containers had about 100 3/16 inch holes drilled in them and then two layers of fine mesh screen were secured to the bottoms. After barley was weighed into the containers they were placed into the barrels and allowed to sink leaving about two inches of the container above the water level as pictured in Figure 1.

Pilot studies were conducted to test the soaking process in small scale under laboratory conditions prior to the construction of the previously described apparatus. These studies showed that when barley was soaked anaerobically at 30° C. the pH dropped rapdily and that within two hours had dropped to pH 5.5. The bubbling of a small amount of air through the soaking mixture maintained pH at near neutral. The experimental design shown in Table 4 was selected following the pilot work.

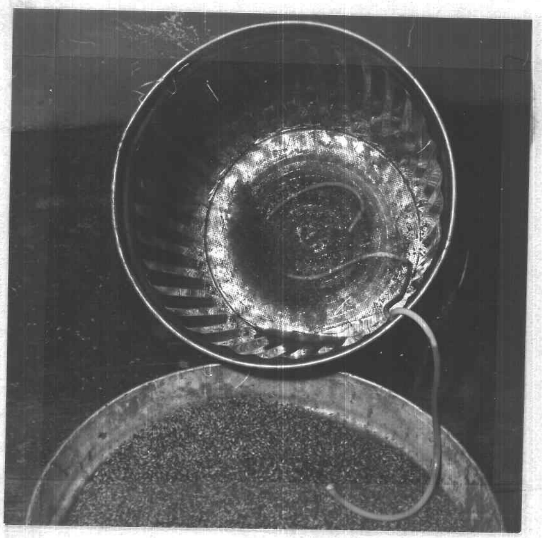
The design of the experiment necessitated the following modifications in the previously-described equipment. Treatments I-4 and I-5 had three feet of coiled 3/8 inch internal diameter neoprene tubing perforated with many small holes coiled under the fine mesh screens in the soaking containers. These coils were wired in place and connected through a "T" coupling to an air pump.



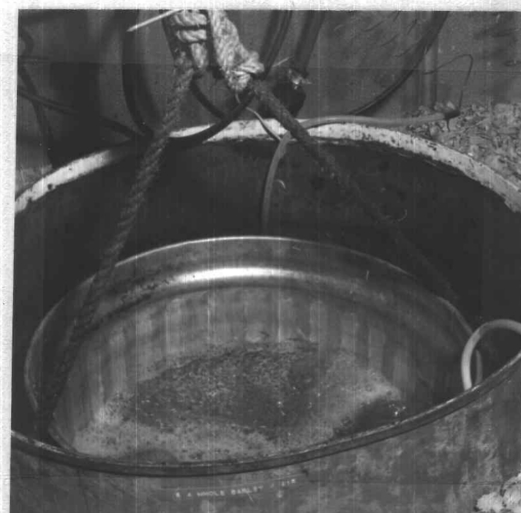
Soaking barrel showing thermostat with immersion bulb.



Soaking barrels showing meter used to measure electrical energy consumed.



Soaking container showing tubing which carried air for constant aeration. Whole barley after soaking is shown in the tub.



Barley being soaked with aeration.

Figure 1. Soaking barrels, containers and electric controls used to soak barley in Experiment I. Water temperature was maintained at 30° C.

Table 4. Design of experiment to test various treatments during the soaking of barley.

Treatment Designation	Form	Treatment	No. of Animals
I-1	Ground barley	Fed dry	9
I-2	Ground barley	Soaked 24 hours	9
I-3	Whole barley	Soaked 24 hours	9
I-4	Whole barley	Soaked 24 hours + aeration	9
I-5	Whole barley	Soaked 24 hours + aeration + cellulase 4000[1]	9

[1]Added to the whole barley just prior to soaking at a rate of 0.543 grams per pound of barley soaked. Cellulase 4000 is a product of Miles Chemical Co., Elkhart, Indiana.

The containers were continuously aerated. Because the soaked ground barley for treatment I-1 dissolved to some extent in the water, the soaking container did not have holes in the bottom and pre-warmed water was added to the barley at a rate of two parts water to one part barley by weight. The container was then placed in the temperature-controlled barrel.

The barley was soaked for 24 hours under the conditions described. In contrast to Wilson's (45, p. 29) work, only the barley portion of the ration was soaked. Thomas (41, p. 1402-1408) has shown that oxytetracycline and other antibiotics interfered with the nutritional improvement of barley brought about by water treatment in chick work. This experiment therefore was designed to allow the barley to be soaked for 24 hours without possible interactions by the antibiotics which were incorporated in the protein supplement. The protein supplement was added to the barley just prior to feeding at a rate of 0.176 pound for each pound of barley (air-dry weight basis) that was soaked. On an air-dry basis, the rations thus were made up of 85 percent barley and 15 percent protein supplement. The composition of the protein supplement is shown in Table 5.

Table 5. Composition of concentrate used in the soaking experiment.

	(percent)
Herring fish meal	40.66
Soybean oil meal (44 percent CP)	46.66
Bonemeal, steamed	8.66
Iodized salt	3.33
Premix*	0.66

* The premix was formulated to the following levels per pound of complete ration:

Vitamin A	500 units
Vitamin D	100 units
Pantothenic acid	2.40 mg
Riboflavin	0.10 mg
Terramycin	5.00 mg

Barley was accurately weighed into the soaking containers and the weight recorded. Twenty-four hours later the barley was removed from the soaking containers, mixed with the concentrate, weighed again, and divided according to the appetite of individual pigs. From these weights the actual consumption in terms of air-dry barley (just prior to being soaked) and concentrate were calculated.

The animals were individually housed at the Experiment

Station Swine Nutrition barn in 4 x 6 pens each having its own self-feeder and waterer as previously described by Wilson (45, p. 31-33).

Crossbred barrows averaging 41 pounds were obtained from the Oregon State University herd. These 45 pigs were selected for uniformity in terms of age, size and genetic origin. They were then randomly allocated into five lots of nine on each treatment and the animals were positioned within the barn in a repeating sequence of five through three rows of pens.

Pigs were weighed weekly and were removed from test when the average of their lot equalled or exceeded 190 pounds.

Results and Discussion

The soaking of a feed such as barley prior to feeding to swine may afford an opportunity for enzymatic degradation of the more difficultly-digestible portions of the cereal. The treatment designated as I-2 afforded an opportunity to measure pig growth response as a result of soaking ground barley for 24 hours at 30° C. just before feeding.

Treatment I-3 allowed a comparison of whole barley under the same conditions as described for treatment I-2. Hale (19, p. 837) has found that ensiling of milo grain under anaerobic conditions improved its utilization by beef cattle; however, if the milo was ground prior to ensiling no improvement was noted. He concluded that the grain had to be intact for this improvement to take place. As stated previously, the literature shows a considerable advantage to grinding barley for hogs if the grain is fed in the dry state. This test allowed a comparison of the ground versus the whole barley when fed wet. If there were no advantage to grinding barley which was to be soaked, this saving in cost might offset the cost of soaking.

Treatment I-4 was included to test whether it is possible to bring about an improvement in the feed value of barley through the activity of intrinsic barley enzymes. The enzyme, β-glucanase, is present in barley during the early stages of germination. Harris (31, p. 479) states that there is a rapid breakdown of β-glucan during germination. This treatment was designed to give as rapid germination as possible within a reasonable time period (i. e. 24 hours at 30° C. with constant aeration) recognizing that losses do occur due to accelerated respiration during germination. The germination process results in some breakdown of the structural carbohydrates of barley in the early stages. Later there is resynthesis of structural carbohydrates as the process continues and rootlets form. Chemical tests show a rather substantial reduction of crude fiber resulted when barley was treated in this manner. The crude fiber content of barley dropped from 8.36 percent to 5.32 percent after soaking for 24 hours at 30° C. with aeration in a laboratory test conducted by the author. There was no detectable reduction of crude fiber when aeration was not used.

Treatment I-5 was the same as the previous treatment with the exception that cellulase 4000 enzyme preparation[1] was added to the barley just prior to soaking at a rate of two pounds per ton of final ration (including the protein supplement which was to be added). Conditions, with the exception of the slightly lower temperature, might duplicate those in the crop of poultry.

Changes were expected to take place during the soaking process. Table 6 shows how pH and loss of dry matter were affected.

Table 6. Loss of dry matter and final pH after 24 hours of soaking

Treatment	Loss of Dry Matter	Final pH
I-1	----	----
I-2	None detectable	5.12
I-3	1.829 percent	5.50
I-4	1.959 percent	7.55
I-5	2.327 percent	7.45

The effect of these treatments upon the rate of growth and feed efficiency of pigs is shown in Table 7. The average daily

[1] The term cellulase in this thesis is a general term applied to impure enzymes catalyzing not only the hydrolysis of cellulose, but also the hydrolysis of other β-glycosides and active also in transglycosylation reactions. The above definition does not exclude that the cellulases described in this thesis may or may not have considerable activity on substrate other than the mentioned carbohydrates.

Table 7. Summary of results for Experiment I testing the value of soaking barley rations for swine.

	I-1	I-2	I-3	I-4	I-5
	Dry Ration	Soaked Ground Barley	Soaked Whole Barley	Soaked Whole Barley + Aeration	Soaked Whole Barley + Aeration + Enzyme
Number of pigs	9	9	9	9	9
Average initial weight (pounds)	40.44	40.78	42.89	41.33	40.44
Average daily gain (pounds)[1]	1.80	1.88	1.65	1.58	1.55
	a	ab	c	cd	cde
Average daily feed intake[2] (pounds)	6.33	6.42	6.79	6.43	6.40
Feed conversion (pounds per pound gain)[1, 2]	3.52	3.41	4.11	4.07	4.13
	a	ab	c	cd	cde

[1] Values with the same letters within a column do not differ significantly ($P < .05$) according to Duncan's (12, p. 1-42) New Multiple Range Test.

[2] Corrected for feed wastage.

feed intake and feed conversion are corrected for feed wasted by the animals. Uncorrected data are presented in Appendix A.

It is apparent that grinding of barley is essential for economical gains and rapid growth even if barley is soaked. Treatments I-1 and I-2 showed significantly ($P < .05$) more rapid gains and feed required per pound of gain was significantly ($P < .05$)

reduced compared with the treatments in which whole barley was fed.

As in Wilson's experiment (45, p. 61), the soaking of a ground barley ration (I-2) showed a trend toward supporting increased growth rate when compared with I-1 but the difference was not significant. In contrast to Wilson's work, but agreeing with that of Becker et al. (2, p. 6), feed conversion showed a trend toward improvement but only approached significance at the $(P < .05)$ level.

Interpretation of these findings is complicated by the fact that measured feed wastage in this test was 7.85 percent for the dry feed (I-1) and 11.11 percent for the soaked feed (I-2). However, in a second test designed to measure feed wastage, the pigs on dry feed wasted 24.94 percent while those on wet feed wasted 10.24 percent.

In both tests the data probably reflected accurately the loss in the test being conducted. Data collected during the first test indicate that feed wastage is an individual characteristic of the animals and probably explain the difference in the results of the two experiments. Further reference to this subject will be made later.

There was a very apparent difference in changes taking place in the barrels during the soaking process between treatments I-3 and I-4. The barley in I-3 (24 hours at 30° C. under anaerobic conditions) had a very sour smell and taste as it came out of the soaking container. The odor was characteristic of butyric acid. The pigs apparently liked this feed as their average daily intake was the highest of all the treatments. Gains and feed efficiency were significantly less than when ground barley was fed.

The barley in treatments I-4 and I-5 had little or no odor when removed from the soaking barrels. This was probably because volatile fatty acids, if formed, were driven off by the constant aeration. Rates of gain and feed efficiency were poor. There was no apparent benefit derived from adding the cellulase 4000 preparation in treatment I-5. Laboratory studies to measure the cellulolytic activity of the enzyme during this treatment are reported later.

Experiment II. The Effect of Addition of Fat and Pelleting on the Utilization of High Barley Rations for Swine

Experimental Procedure

Forty cross-bred barrows from the Oregon State University swine herd averaging 51 pounds were randomly divided into four lots and put on test December 3, 1963. Ten pigs were placed in each of four large pens and raised as groups. These pens were partly covered and had wooden pallets in lieu of bedding placed over part of the concrete floor. Each pen was equipped with an automatic waterer and a self-feeder from which the pigs were fed *ad libitum*. These self-feeders were not equipped with weather covers over the feeding chambers.

The experimental design is shown in Table 8.

Table 8. Design of experiment to test the effect of pelleting and of addition of fat to barley rations for swine.

Treatment Designation	Composition of Rations: Barley (percent)	Protein Supplement[1] (percent)	Fat[2] (percent)	Form of Ration
II-1	85	15	0	Meal
II-2	85	15	0	Pellet
II-3	80	15	5	Meal
II-4	80	15	5	Pellet

1 Composition of this concentrate is given in Table 5.

2 Stabilized beef tallow.

Proximate analyses of these rations are given in Table 9.

Table 9. Composition of rations used in Experiment II.

Treatment	H_2O (percent)	Crude Protein (percent)	Ether Extract (percent)	Crude Fiber (percent)	Ash (percent)
II-1	8.04	14.16	1.72	4.06	4.62
II-2	8.03	14.91	1.83	3.28	4.08
II-3	8.05	13.71	5.53	3.69	4.43
II-4	8.09	13.51	5.18	3.59	4.65

These rations are generally similar to those used in the soaking experiment; however, in rations II-3 and II-4 five percent barley was replaced with five percent stabilized beef tallow. Rations were mixed commercially for this experiment. The rations for lots II-2 and II-4 were pelleted through a 3/16 inch die, while the other two rations were fed in the meal form. The pellet for lot II-4 was pelleted through a special die which was thicker in the body and which had a greater taper in the holes, as described earlier in this thesis. The result was a pellet containing five percent fat which had about the same degree of hardness and durability as those for lot II-2 which did not contain added fat, but were pelleted through a conventional die.

Relative density of the rations was determined by filling a cylinder having one liter capacity to the top without compression and wiping off the excess with a straight edge. Weight of the cylinder was recorded before and after filling and density is expressed as percent increase or decrease over Ration II-1.

Animals were weighed individually each week during the test. They were marketed when they reached about 225 pounds. The pigs were slaughtered commercially and back fat measurements were taken 24 hours after slaughter.

Results and Discussion

Chapin (5, p. 67-68) found that addition of five percent stabilized beef tallow to a high-barley swine ration improved both rate of gain and feed efficiency. Pelleting a high-barley ration without addition of fat increased the efficiency of its utilization. Chapin tried unsuccessfully to get a second additive effect through the pelleting of a ration containing supplemental fat, and he noted that the pellets containing five percent added fat were very soft and crumbled in the sacks and feeders. Since the value of pelleting is lost when the ration is returned to meal form (10, p. 28-30; 28, p. 61; 35, p. 78-80) the addition of fat to the pellet in Chapin's work in essence reduced the pellets' consistency to that of meal.

Following Chapin's work a special pellet die[1] was made available for experimental work at this Department. When feeds containing additional fat are pelleted through conventional dies, the fat appears to have a lubricative effect on the die. This is evidenced by the fact that the addition of five percent stabilized beef tallow to a high barley ration will increase the output of the mill 10 to 15 percent with no increase in power. The result is that the fat-containing pellet is probably subjected to much less pressure in the pelleting process which probably leads to easy crumbling.

Chapin (5, p. 45) had reported that pellets containing five percent added fat were 12 percent bulkier than pelleted rations without added fat. Through the use of the special die a ration containing five percent fat was obtained which had essentially the same density

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[1] Die made available through the courtesy of Ross Chapin at the Elliott Feed and Seed Company, Perrydale, Oregon.

as did the standard ration pelleted through a conventional die. The relative densities of the feeds used in the trial were as follows: Ration II-2 was 11.92 percent and Ration II-4 was 13.08 percent denser than Ration II-1. Ration II-3 was 2.20 percent less dense than Ration II-1.

The goal of this phase of the experimental work was to find out whether there was an advantage in terms of increased feed efficiency and/or rates of gain due to pelleting diets containing supplemental fats. The results of this trial are shown in Table 10.

The data show that the pelleting of a fat-containing barley ration (II-4) through a special die increased the feeding value of the feed. The improvement in feed efficiency over the other ration is apparent.

Feed efficiency data were not subjected to statistical analysis since the pigs were fed as groups and feed consumption data on individual pigs were not available. These pigs were significantly fatter (as determined by back fat probe) ($P < .05$) than those which received the barley pellet without fat (II-2). The difference between II-4 and II-3 approached significance ($P < .05$) but was not significant. The pigs fed the fat-containing pellet utilized feed more efficiently but did not grow at a different rate than the other lots ($P < .05$).

The ration for II-3 created special problems in feeding. It had a tendency to stick together in the self-feeder and to

Table 10. The effect of addition of fat and pelleting of high fat diets on rates of gain, feed efficiency and back fat of market hogs.

Treatment	Ration	Avg. Initial Weight (pounds)	Avg. Final Weight (pounds)	Avg. Daily Gain (pounds)	Avg. Daily Feed Intake (pounds)	Feed Per Pounds Gain (pounds)	Back Fat (inches)
II-1	Ground barley meal	51.1	221.1	1.89	7.07	3.74	1.90
II-2	Ground barley pellet	51.9	217.9	1.84	6.43	3.48	1.78
II-3	Ground barley meal + five percent fat	51.1	221.1	1.89	6.61	3.50	1.93
II-4	Ground barley + five percent fat (pelleted)	51.3	227.5	1.96	6.39	3.27	2.05

remedy the situation the metal slides which are normally adjusted to regulate feed flow from the reservoir into the feeding chamber were removed. This action probably contributed to a higher feed waste. However, feed waste on this feed probably did not exceed that which occurred on Ration II-1 based upon daily observations.

Calculated average daily feed intake was higher for the two rations fed in the meal form than for the pellets. This may be due to a higher feed waste of the meal rations. The possibility exists, as later evidence will support, that the pigs consuming meal may have actually had a lower feed intake than those pigs consuming pellets. Theoretical calculations will be derived to support this hypothesis.

Experiments III and IV: Feeding Behavior of Pigs Resulting in Feed Waste and the Effect of Different Ration Forms and Feeders upon Rate of Waste

Experimental Procedure - Experiment III

Larsen (28, p. 24) stated that it was difficult to correlate feed intake and ration density because of feed wastage that took place within individual pens. When feed is wasted in experimental work the major purpose of the tests being conducted is often defeated. Gill and Egan (17) measured feed wastage on a group of 113 White Leghorn layers housed in individual cages at 33.3 percent of the feed. These birds were fed according to the accepted practices and even with this large wastage produced eggs within the commonly accepted feed-to-egg ratios.

Data are not available pertaining to the amount of feed wasted by swine. Frequent mention of wastage problems is made but actual measurements are not given. It must be recognized that feed wastage will vary with different feeds, management systems, feeder designs and methods of feeding. Precise measurements of feed waste were essential for proper interpretation of the previous experiments and to study the causes of feed waste. There is some evidence that certain constituents of the rations fed my be in part responsible for some feed waste.

Due to the different forms of rations used in this thesis (i. e. dry ground, wet ground, wet unground, and pelleted) it was imperative that wastage be measured and appropriate corrections made to establish actual feed intake. Measurements of feed wastage were made during two separate tests.

Part I. The first measurements were made during Experiment I described on page 26. During this experiment the pens were cleaned daily. Twenty-four hours after feeding all feed that was found on the floor or in the gutter was collected and weighed. Due to the labor involved, this task could not be performed every day so at random times during the experiment ten collections and weigh-backs were made for all 45 of the animals on test. Four of the five treatment groups were fed soaked feed which made it necessary to correct weighed-back feed to its original air-dry weight. The assumption was made that this feed did not pick up or lose appreciable moisture in the time between feeding and collection.

Part 2. A separate study of feed wastage designated as Experiment III was made following the first experiment. To accomplish even greater accuracy in measuring feed wastage on different forms of the same ration, modifications to the feeders were made as follows:

Feeders were raised four inches above the concrete floor and expanded metal screens were placed under and around them so that wasted feed could fall into a collection chamber. These modifications prevented wasted feed from being tracked or otherwise moved away from the feeders and mixed with fecal material, dirt and dust.

Six pigs were assigned to each of six lots on the basis of size. The feeding regimes are described in Table 11. Feeders for lots 1 to 4 were troughs 18 inches wide overall, 8 inches deep and 48 inches in length with a 2 x 4 inch guard over the top to prevent pigs from getting into the feeder. They are pictured in Figure 2. Lots 5 and 6 were fed out of Oaks two hole self feeders. The feeders and waste trap are pictured in Figure 3.

The ration had the same composition as II-1 in the previous

Table 11. Feeding regimes used to measure the extent of feed wastage as affected by form of ration, feeder design, and method of feeding.

Lot No.	Ration Description	Feeder Type	Times Fed, Daily
III-1	Ground barley ration	Trough	1
III-2	Soaked ground barley ration	Trough	1
III-3	Ground barley ration	Trough	2
III-4	Soaked ground barley ration	Trough	2
III-5	Pelleted barley ration	Self	_ad lib._
III-6	Ground barley ration	Self	_ad lib._

experiment, the composition for which is shown in Table 8. Lot 5 received this ration in the pellet form. It was identical to II-2 described in Table 8.

Experimental Procedure - Experiment IV

Feed wastage and apparent advantage from pelleting barley rations might be related to the eating habits of swine. Hafez (18, p. 339-341) states that the apparent advantage of pellets may be due to the fact that pigs cannot sort out the less palatable components. Feed wastage may be the result of excessive sorting of some types of rations. Jensen (24, p. 1414-1419) has observed that

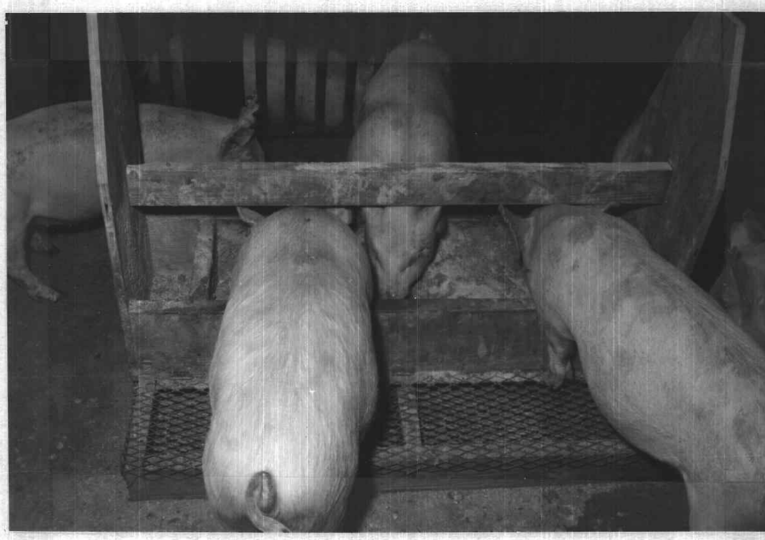

Figure 2. Feeders used in Experiment III for lots 1-4 to measure feed waste as affected either by wet or dry meal fed once or twice daily.

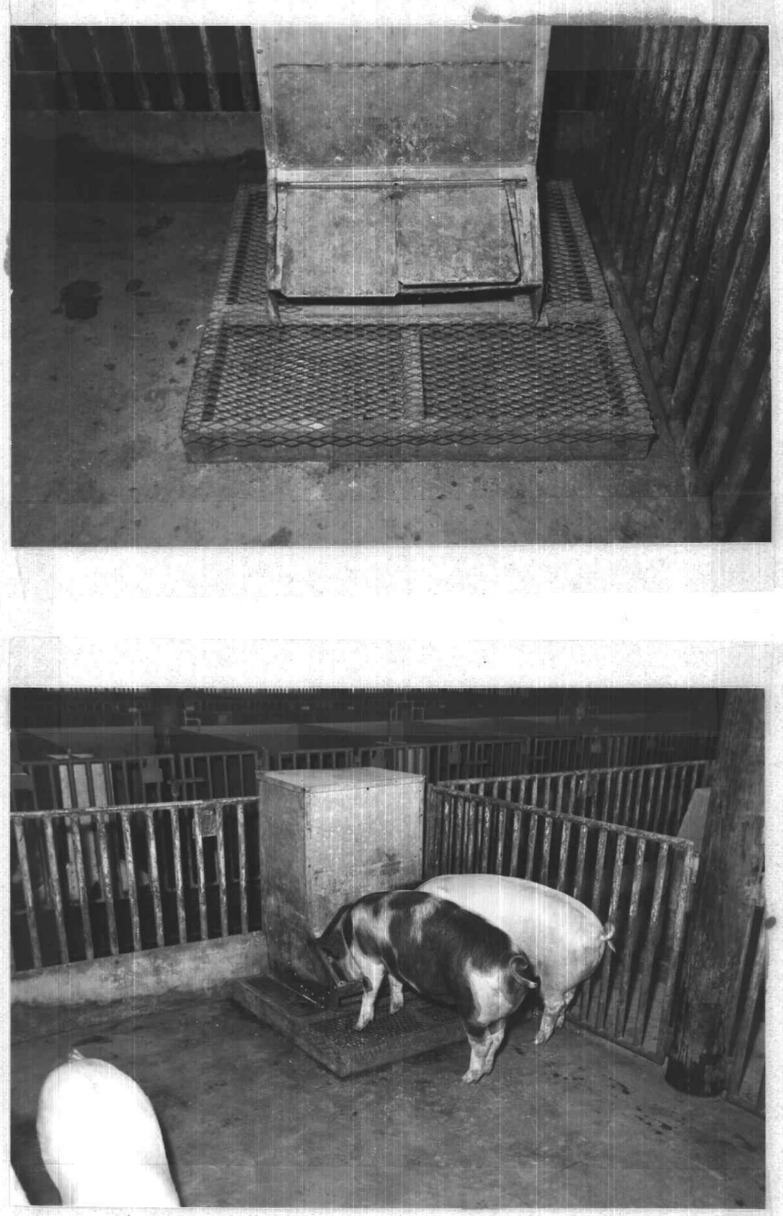

Figure 3. Self-feeders used in Experiment III for lots 5 and 6 with special base to trap wasted feed.

poults fed mash used 18.8 percent of a 12 hour day eating while those fed the same ration pelleted used only 2.2 percent of the day. Data collected on turkeys are hardly applicable to swine work; however, Siegl (39, p. 3375) found that pigs spent considerably less time consuming a soaked swine ration than the same ration in the dry form. The pigs when given free choice of wet and dry feed preferred the wet ration and their daily intake was made up of 32.5 percent dry and 67.5 percent wet feed.

Facto (13, p. 1488) has used time lapse cinematography to study animal behavior and ration preferences. He noted that the presence of personnel around the feeding area disrupted the normal feeding habits.

A fourth experiment was conducted to measure feeding times of pigs eating the same ration in meal and pelleted form.

In Experiment IV a photoelectronic relay[1] was selected to measure the feeding time. This device was selected because it was capable of making accurate measurements in this type of research, and because it was more economical than other methods considered. The photo cell was placed opposite a shielded light source on one side of the feeder and connected to an electric clock

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[1] Photoelectronic Relay Kit 83 Y 702-D from Allied Radio, 100 North Western Avenue, Chicago 80, Illinois.

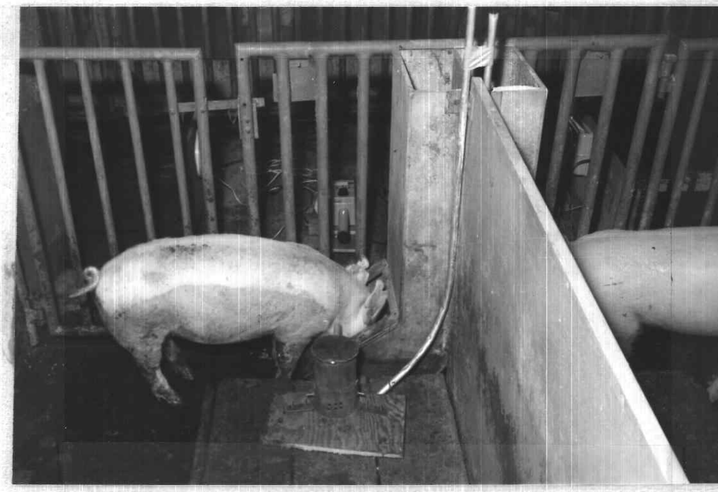
which ran whenever a pig placed its head in the feeder. The installation is depicted in Figure 4.

Two of these relays were obtained. Eight pigs averaging 50 pounds were individually placed in 4 x 6 foot pens and were fed from self-feeders. The eight pigs were divided into two treatments with one treatment receiving the ground barley ration (composition same as II-1 in Table 8) and the other the same ration pelleted. Time spent feeding was recorded in two consecutive 24-hour periods on each pig. Following the completion of the recordings, the feeds were reversed and a second series of recordings were made. Feed consumption was recorded in both tests.

Experiment III: Results of Feed Wastage Measurements

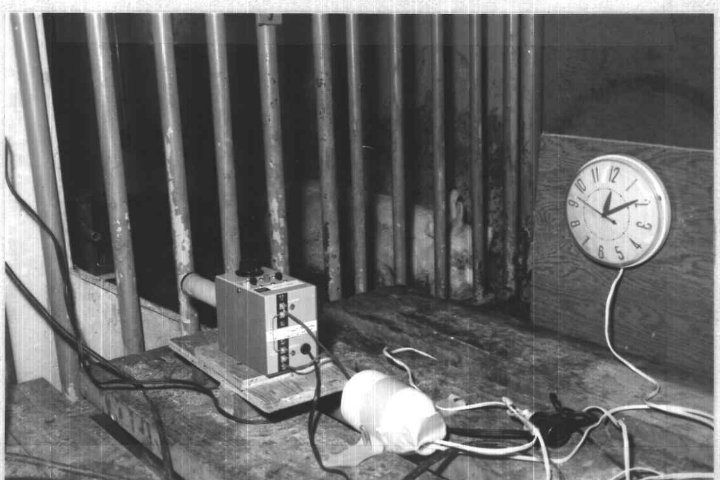
Results and Discussion

Part I. Feed Wastage among pigs individually fed during Experiment I was excessive. Average feed waste data are given in Table 12. Data are presented on feed wasted by individual pigs in Appendix A. These data show that feed wastage was a trait that varied greatly among individual pigs. When the data were corrected for wastage, the feed efficiency figures become more homogenous among the treatments. The inference might be drawn that less-efficient-appearing pigs may be simply greater wasters of feed.



Light source is shown in the lower center of picture.

White plastic bottles to the rear of the photoelectric relay contained a 110 volt switching relay which controlled the clocks.



Experiment in operation with clock not running.

Figure 4. Electronic equipment used to measure feeding time in Experiment IV.

Table 12. Average feed waste of pigs during Experiment I.

Treatment Number	Ration	Percent of Feed Wasted
I-1	Dry barley + concentrate	7.85
I-2	Soaked ground barley + concentrate	11.11
I-3	Whole soaked barley + concentrate	14.71
I-4	Aerated, whole soaked barley + concentrate	14.10
I-5	Aerated, enzyme-treated whole soaked barley + concentrate	14.00

The economic impact on efficient pork production of feed wastage is apparent from Table 12. While the feed wastage among treatments I-3, I-4, and I-5 was obvious to the swine herdsman and others visiting the facility, the extent of feed waste in treatments I-1 and I-2 was not evident. The unground barley in treatments I-3, I-4, I-5 was very apparent when seen on the floor due to its physical nature, and it should be noted that the whole barley used in the test was plump grain having a test weight of 50 pounds per bushel. After soaking, it had expanded to about one and a half times its original size and thus it was very apparent on the floor around the feeders.

The increased volume of the soaked feeds probably contributed to the higher wastage of these feeds. The larger volume necessitated that the feeders be more completely filled and spillage was quite common. Gill and Egan (17) found that if the level of feed in feeders was kept very low, necessitating frequent feedings, loss of feed by White Leghorn chickens could be cut from 33.3 percent to 2.1 percent using the same feeders. This was accomplished by changing from feeding every three days to twice daily. This change in feeding regime also increased feed consumption 15 percent and brought about a subsequent increase in egg production.

Part 2. Feed wastage was measured again in Experiment III to evaluate the effect of different types of feeders on the three ration forms previously fed. Dry meal, soaked meal, and pellets were used. The dry meal and soaked meal were fed in troughs either once or twice daily, while pellets and dry meal were also fed *ad lib.* using a self-feeder. The data collected are presented in Table 13.

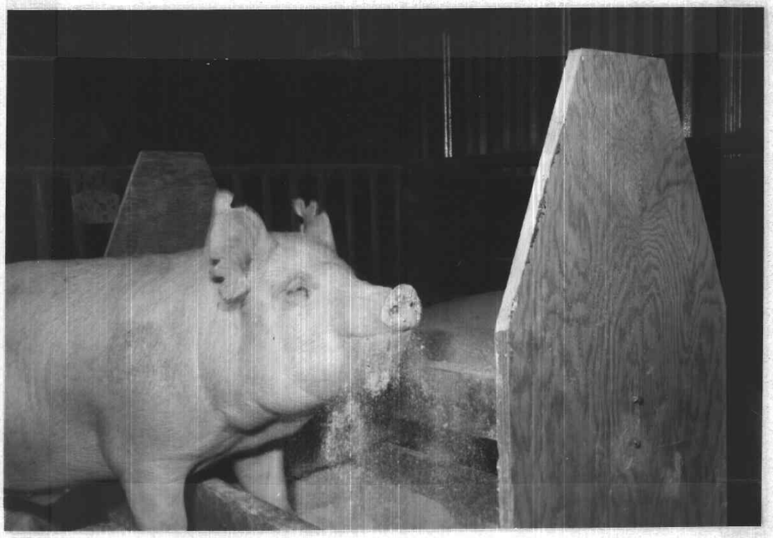
Feeding the dry meal once daily in a trough to Lot 1 resulted in an excessive rate of feed waste (24.94 percent). Feeding the same feed either wet or dry twice daily reduced feed waste by over half (ten percent) in lots 2 and 3. Offering the same ration *ad lib.* from a self-feeder reduced waste to about four percent. The reason for the marked reduction of waste in the latter was apparently not associated with *ad lib.* feeding since the other lots were fed slightly more than they would consume, but rather the feeder design. The difference is attributed to the rain covers (see Figure 3) which the pig had to lift to obtain access to the feed. Once the pig had lifted the cover

Table 13. Effect of ration form and method of feeding upon feed waste and efficiency of gains during Experiment III.

Lot	Treatment	Times Fed Per Day	Fed (pounds)	Waste (pounds)	Waste (percent)	Consumed (pounds)	Feed/Pound Gain (pounds)	Actual Feed/Pound Gain (pounds)	Gain (pounds)	Average Daily Gain (pounds)
1	Dry	1	1069	266.6	24.94	802.4	4.29	3.22	249	1.97
2	Wet	1	998	102.2	10.24	845.8	3.35	3.01	298	2.37
3	Dry	2	1008	101.9	10.11	906.1	3.55	3.19	284	2.25
4	Wet	2	857.5	79.6	9.28	777.9	3.50	3.18	245	1.94
5	Pellet	*ad lib.*	826.7	25.5	3.08	801.2	2.98	2.89	277	2.20
6	Meal	*ad lib.*	863.0	34.0	3.94	829.0	3.42	3.29	252	2.00

it would keep its head down in the feeder until it moved away. It was observed that only rarely would a pig eating from these feeders allow the lid to close and then reopen the feeder. The rate of feed waste by pigs eating out of self-feeders without trap doors was observed to be about the same as was recorded using troughs in lots 1 and 3. Depending on the adjustment of the flow rate of the feeder the level of feed in the feeder will range between that observed between the once and twice daily feeding using troughs.

Pigs fed from the trough would raise their heads out of the feeder as if to gulp every mouthful down. Figure 5 illustrates this behavior. The wetting of the feed prior to feeding (lots 2 and 4) reduced feed waste compared to the once daily dry feeding. Twice daily feeding has the advantage of keeping the feed low in the feeder which reduces the amount of feed that the pigs root out. This makes the pigs reach further into the feeder because of the lower level, and causes more of the feed which spills out of the pig's mouth to return to the feeder rather than fall onto the floor. There appears to be little advantage to feeding the wet feed twice daily. Very little feed was wasted when the ration was pelleted.



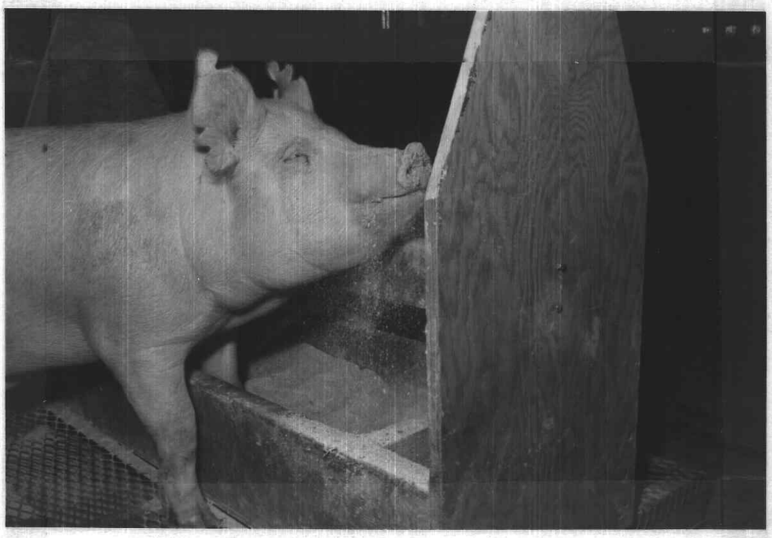


Figure 5. Pigs eating and wasting feed during Experiment III.

Experiment IV: Feeding Behavior of Swine Fed High Barley Rations in the Meal vs. Pellet Form

Results and Discussion

Electronic measurement of the time spent feeding by pigs on meal and pellet forms of the same barley ration indicated a very clear-cut difference in the feeding habits of the animals. Pigs fed pellets spent 7.34 percent of the day (24 hours) consuming feed while those fed meal spent 16.74 percent of the day at the feeder. Table 14 shows that in no case did a pig fed pellets use more than 127 minutes out of the day feeding while the least time one of the meal fed pigs spent eating was 180 minutes. Statistical analyses of these data show, as expected, that the differences shown in the table are highly significant.

The average daily feed intake was 4.76 pounds for pigs eating the meal and 5.02 pounds for the pigs eating the same ration in the pellet form. These values did not differ significantly ($P < .05$) undoubtedly because of the small number of animals on test.

Pelleting of a swine ration clearly reduced the time that pigs spent at the feeder. This observation is in accord with that of Siegl (39, p. 302-321) who showed that pigs spent a much greater portion of a 12 hour day eating a meal rather than a soaked ration. Close observation and a photographic study showed that the pigs fed

Table 14. Feeding time (minutes per 24 hour day) as electronically measured on pigs self fed the same ration in either meal or pellet form.

	PELLETS Feeding Time in Minutes			MEAL Feeding Time in Minutes		
Pig Number	First Reading	Average	Second Reading	First Reading	Average	Second Reading
1	105	116	127	200	197	195
2	83	92	102	218	219	220
3	120	111	103	240	220	201
4	121	110	100	230	205	180
5	108	116	125	311	324	337
6	93	97	102	233	268	304
7	96	98	101	210	228	246
8	107	102	97	286	265	245

meal were doing an appreciable amount of sorting of the meal feed. Feed material collected on the floor close to the feeders about two hours after feeding showed a high concentration of barley hulls. This material contained 2.5 times as much crude fiber as the original feed.

Based on the chemical analyses of the recovered feed and confirmed by observation it appears that pigs are quite adept at sorting out the fibrous hull of the barley. It was necessary to ascertain that the fibrous material found on the floor was not due to wind sorting of the feed in the feeder. Crude fiber content of residue found near the feeders in pens where the pigs were fed the soaked barley ration did not differ from that from the pens where the pigs were fed the dry meal. This would tend to rule out the possibility of wind sorting as would the observation that the concentration of fiber on the floor was evident on wind-free days.

The rations in question were tested in the laboratory for wind sorting using an electric fan. When the air stream was of sufficient force to blow feed the most finely ground portion of the grain blew away first, leaving behind unground pieces of barley and the coarsest of the barley hulls. The finely ground hull material or chaff follows the finely ground "starchy" portion of the ration. It would appear that wind sorting, while it could reduce the value of the ration, would not be responsible for the rather large pieces of barley hull which are found on the floor by the feeders. This fibrous material was completely absent around the feeders where pellets were fed.

These data add strength to Larsen's (30, p. 440-444) conclusions that the hull of the barley is inhibitory to rapid gains and feed efficiency. It is possible that the effect of the hull is due to inhibition of the pigs feed intake rather than to any toxic or absorption-inhibiting mechanism. The clear cut improvement in the feeding value of these rations by pelleting would indicate that barley hull reduces feed intake of meal rations, but does not interfere with the utilization of other nutrients once ingested by the animal to the extent previously believed.

Seerley (37, p. 834-837) reported that when a ration is pelleted that the retention time in the digestive tract is reduced. His rations were made up essentially of corn, oats and soybean meal. Average retention times for pellets and meal were 30. 7 and 36. 3 hours, respectively when given in equal amounts and 26. 3 and 43. 5 hours when fed to appetite.

Based on the findings in these experiments, the theory that barley hull reduced the utilization of the ration by mechanically interfering with absorption in the digestive tract would not be valid. It is probable that the animals consuming pellets had a higher intake of fiber than those consuming meal if sorting had taken place.

Jensen (24, p. 1418-1419) reported that passage time in the gut of poults and chicks was not altered by offering pellets or meal form of the same ration. Considerable difficulty was encountered in making these measurements since the marker, chromic oxide, was first excreted one hour after feeding it to the birds. The digestive tract of the bird makes it much more to difficult to measure rate of food passage than does that of the pig. In either case the assumption must be made that the indicator will pass at the same rate as the feed, and this assumption is open for valid criticism. Jensen found that poults fed mash required 18. 8 percent of a 12 hour day eating while those fed pellets required only 2.2 percent, and he advanced the opinion that the basis for the growth response with pellets may be related to the large differences in time needed for prehension of food. He further stated that it is possible that the birds fed pellets grow faster because they spend less energy in the prehension of feed and, therefore, have more energy available for growth.

Laboratory Studies to Measure the Effect of a Cellulase Enzyme Preparation on Barley and Solka Floc

The hull of barley has been shown to reduce the efficiency of utilization of swine rations. Two mechanical processes have been shown to reduce the adverse effect of barley hull in these rations, thus pelleting and the complete removal of the barley hull by pearling have been successfully used at this Station. Both of these processes are expensive and for this reason considerable experimentation has been conducted using enzymes to attempt to bring about a reduction of the hull of this cereal.

The cellulose content of hull portion removed by hand from the Hannchen barley used in the previous experiments was determined using the method of Crampton and Maynard (7, p. 390-392). It contained 40.69 percent cellulose. The whole grain had a cellulose content of 5.83 percent confirming as stated earlier that most of the cellulose in barley is in the hull. The remainder of the hull is made up primarily of hemicellulose, lignin, and gums. The cellulase enzyme used in these tests was Takamine's cellulase 4000 which is derived from Aspergillus niger. It contains beside its cellulolytic properties appreciable pectinase and hemicellulase activities. Theoretically, under ideal conditions, this enzyme preparation would be capable of catalyzing the breakdown of an estimated 50 to 70 percent of the barley hull; however, rather extensive pretreatment would be required to open up the structure of the hull for attack. Cotton linters must be soaked for two hours in cold H_3PO_4 before any appreciable breakdown can be accomplished by the cellulase enzyme.

Laboratory tests were conducted to measure the extent of degradation brought about by enzyme treatment during soaking of either ground barley or solka floc under the conditions imposed in Experiment I. The barley was ground through a 60 mesh screen prior to treatment. The cellulose content of the soaked barley was reduced 6. 13 percent by the enzyme treatment. The cellulose content of solka floc was reduced 2. 11 percent under the same conditions. The rate of breakdown of barley cellulose did not differ between samples which were soaked under anaerobic conditions at pH 5. 50-5. 12 and under aerobic conditions at pH 7. 45-7. 55. The optimum pH of the enzyme preparation was 4. 5, with a wide range of activity from about pH 1-10. The addition of as much as 100 times the usual amount of enzyme had no effect on the final amount of cellulose decomposed at the end of 24 hours. The addition of glucose to the soaking media at a rate of up to 14. 1 mg per ml. did not inhibit the reaction.

The obtained reaction rates were very slow but compare closely with reported values using similar substrates under like conditions. Halliwell (20, p. 605-610) reported that 11 percent of the cellulose in cellulose powder (Whatman) was solubilized in 45 hours at 37°C. Gascoigne (15, p. 175) reports that cellulase from _Aspergillus niger_ catalyzed a 6. 68 percent decomposition of purified cotton linters in 144 hours. A two-hour pretreatment with H_3PO_4 allowed the enzyme to convert 79. 3 percent of the cellulose in the same time.

It appears that the enzyme cannot penetrate into the hull of barley to achieve a rapid rate of reaction under the conditions imposed in Experiment I. Barley hull from some barleys creates a problem in malting which emphasizes its resistance to the penetration of liquids. These barley hulls are so impervious to liquid that the barley must be soaked in alkali in order to allow water to penetrate the grain for germination (35, p. 312).

It is not known to what extend degradation must proceed to bring about an improvement in the feeding value of barley. The results of Experiment I show that the degree of breakdown which had occurred in the soaking barrel did not result in any significant benefit in terms of a growth response by the pigs.

GENERAL DISCUSSION

Hulled barley is the major constituent of swine rations in the North Western part of the United States. The improvement of these rations is imperative if the swine industry in this area is to survive competition from the corn growing areas and to grow to meet the increasing market demands of a growing population. The investigations carried out in this thesis work have yielded information which gives the research worker an insight into some of the reasons for the poorer performance of high barley rations.

The data collected in Experiments III and IV show that pigs do not consume high barley rations in the meal form as readily as they do in the pelleted form. Experiment IV showed that pigs eating meal spend more than twice the time at the feeders consuming slightly less feed than do pigs consuming the same ration in the pelleted form. Data collected in Experiment III show that at least part of this increased time at the feeder may result from time spent sorting the fibrous portion of the ration from the feed and discarding it. The increase in both growth rate and feed efficiency of pigs fed pelleted rations would indicate that the fiber in these rations once assimilated is not the major cause of the poor performance of the animals. The result of this barley hull in meal ration is an increase in both rate of feed waste and in time spent feeding, and a reduced intake of energy. The following example taken from the data collected during Experiment II shows how a slight difference in caloric intake can cause a marked difference in rate of gain and feed efficiency.

During this experiment the feed consumptions of lots II-2 and II-4 were nearly identical. Due to the added fat in ration II-4 it contained 1966 Calories per pound whereas ration II-2 contained 1861 Calories per pound. Maintenance requirements of the pigs were not measured during the tests but if three different maintenance values are selected, the predictable difference in growth rate will illustrate how a slightly reduced or elevated daily caloric intake will affect growth rate markedly. The pigs in this trial consumed feed at a rate of about 6. 20 pounds per day. Lot II-2 would than have an average intake of 11, 538 Calories per day and lot II-4 12,189. With a maintenance requirement of 6000 Calories per day the pigs in lot II-4 should have grown at a rate 11. 76 percent faster than lot II-2. Expected rates of growth would have been 9. 96 and 8. 64 percent faster if the maintenance requirement had been 5000 and 4000 Calories per day respectively. Ration II-4 contained only 5. 64 percent more Calories per pound than did ration II-2. During the trial the pigs on ration II-4 gained 6. 14 percent faster than did those on ration II-2. In the actual trial the pigs in lot II-2 had an average feed consumption of 6. 23 pounds or slightly higher than the value used in the above calculation.

It has been shown that when a high barley ration is pelleted feed intake, feed efficiency and rate of gain are improved. Prior to the collection of data on feed waste the difference in the rate of feed intake between meal and pelleted rations was often overlooked, since pigs fed meal rations often waste enough feed so that apparent feed intakes appear similar. The theory that pelleting changes and improves feeds appears invalid since Larsen (28, p. 61) showed that any benefit derived from pelleting was destroyed upon regrinding the pellets. The apparent advantage to pelleting a high barley ration can now be explained on the basis of an increased caloric intake.

It is not known why barley hull is objectionable to pigs. The crude fiber content of barley is not much higher than that of other cereals with which pigs seem to have little trouble. Observation shows that barley hull tends to splinter during grinding and pass through the screens of either the hammer mills used at the feed plants or the fine screens of Wiley mills used in laboratories. The ground barley used in these experiments had numerous splinters of barley hull which were 0.25 to 1.50 mm. in diameter and about 4 to 8 mm. in length. Barley hull splinters recovered from the floor near the feeders where a barley ration was offered in the meal form (fed either wet or dry) was to the upper limits of the dimensions given above. Thus it appears that the pigs must sort out the larger pieces of barley hull when the ration is offered in meal form. Pigs fed whole soaked barley were observed discarding barley hull while eating. Barley hull does not soften upon soaking to any great extent and appears to retain its structural rigidity. It is easily removed from the seed after soaking by the pigs and some animals become quite proficient at removing it, without any apparent benefit in terms of growth or feed efficiency.

Depression of feed intake was not the major factor contributing to the poor rates of growth during Experiment I where whole barley was fed. During this trial average daily feed intake was highest for lot I-3. Both rate of gain and feed efficiency were significantly lower than lots I-1 and I-2 where ground barley was fed. Considerable amounts of whole barley passed through these pigs intact. This could indicate that the hull of the barley interfered with the digestive process. The impermeability of barley hull has been discussed previously.

Attempts to improve whole barley by soaking it for 24 hours at 30° C. were unsuccessful as was enzyme treatment of whole barley. Soaking of ground barley under the above condition caused a slight improvement over the same ration fed dry. This difference was not statistically significant ($P < .05$). Laboratory studies of the reaction rates of the cellulase enzyme preparation used in these tests showed that its reaction rate is extremely slow. The slowness is believed to be due to lack of susceptibility to attack of the native cellulose. Other workers have shown that it is necessary to swell the structure through rather severe pretreatment prior to addition of the enzyme if any degree of cellulose breakdown is to be accomplished.

Further work needs to be done in the area of enzyme treatment of barley. Present data indicate that a reduction of about six percent of the cellulose in barley was of no benefit to the animals.

The addition of fat to high barley swine rations was shown to increase efficiency of gains. Fat addition by increasing the caloric intake tends to overcome the lowered intake of high barley rations. Fat was added at the rate of five percent in these tests and this level did not affect average daily intake compared to the standard ration. The pelleting of rations with five percent added fat gave an additional response. However it took a special pellet die to make these pellets. Without the special die it had not been possible previously to produce an equivalent response due to the fact that the pellets crumbled during handling.

The reason for lowered performance of high barley swine rations has been investigated in several trials at this Station. The evidence collected strongly implies that the barley hull is primarily responsible for lower performance of rations in which it is present. Feed barleys in the United States are nearly always hulled varieties for two reasons. The first is that the naked varieties fail to yield as well as the hulled varieties. The second and most valid reason is that the hulless varieties do not have acceptable malting qualities. Barley hull plays two very important roles in the malting process, that of its mechanical regulation of the germination process and as filter in the filtration and clarification of wort.

For these reasons barley breeders have made little attempt to develop hulless varieties or to breed for thinner hull on the hulled types. Feed barleys are usually either rejected malting varieties or varieties which failed to meet the malting standards but which yielded well in their developmental tests.

The logical solution to the problem of poor performance of barley in swine rations may lie in the hands of the barley breeder. Joseph (25, p. 18) demonstrated about 30 years ago that the naked varieties of barley are equal in feeding value to corn and Larsen (28, p. 32) demonstrated recently that pearled barley has as high feeding value as does corn.

Animal research has been limited by an almost complete lack of hulless varieties for experimental work, but work with hulled and pearled barleys indicates the importance of investigating the possibility of the development of hulless varieties for swine feeding.

SUMMARY

Previous work at this Station has shown that barley hull is implicated in the poor growth response of barley as compared to corn in swine rations. Four experiments involving a total of 129 pigs and a laboratory study were conducted to study the effect of feed treatment, supplementation of energy, and animal behavior in relation to their effect upon performance of high barley rations.

The first experiment compared the effect of soaking ground or whole barley for 24 hours at 30° C. Two lots of pigs were fed whole barley which had been soaked for 24 hours at 30° C. with constant aeration. A cellulase enzyme preparation was added to one of these treatments just prior to the soaking. The method of soaking was unique since the soaking temperature was accurately controlled to ± 0.5° C. and the protein supplement portion of the ration was added after soaking and just prior to feeding. Laboratory studies were conducted in conjunction with this experiment to study the effect of the enzyme and soaking upon chemically-measurable changes in the grain.

Previous work at this Station showed that the addition of five percent fat to high barley rations improved feed efficiency and rates of gain. The pelleting of these fat-containing rations had not given the usual increase in performance associated with the pelleting

of high barley rations. The fat-containing pellets were found to be 12 percent less dense than the standard pellet. The availability of a special pellet die for experimental purposes made it possible to test the animal response to a fat-containing pellet with a comparable degree of hardness to the standard barley ration pelleted through a conventional die.

During the first two tests it became apparent that feed waste was an important factor effecting the interpretation which might be placed upon the results obtained. Feed waste was measured during two experiments to obtain correction factors to use with the data collected during the first two experiments and to study the causes of feed waste. Electronic devices were constructed to measure feeding time of pigs consuming the same ration in either meal or pelleted form. These studies were augmented with a photographic study and chemical analysis of both the original ration and wasted feed collected in specially constructed chambers placed beneath and around the feeders.

The most salient observations made during the course of these experiments are as follows:

1. Pigs fed ground soaked barley grew significantly faster ($P < 0.5$) with less feed than those fed soaked whole barley. There was no difference ($P < 0.5$) in rate of gain and efficiency when dry and soaked ground barley were compared.

2. The addition of cellulase 4000 enzyme preparation to soaked barley did not affect rate nor efficiency of gains ($P < .05$). There was a six percent reduction in the cellulose content of the soaked grain due to enzyme treatment.

3. The production of a pellet containing five percent added fat with the same density as standard pellets made it possible to obtain an additive response with the addition of fat and pelleting of a swine ration. The standard ration and the fat containing ration were each fed in both the meal and pelleted form. With the standard rations, average daily gains and feed per pound of gain were 1.89, and 3.74 pounds and 1.84 and, 3.48 pounds respectively for the meal and pelleted form. Gains and feed efficiency for the ration containing added fat were 1.89 and 3.50 pounds and 1.96 and 3.27 pounds for the meal and pellet respectively. Animals which received the high-fat pellet were significantly fatter ($P < .05$) than the other lots.

4. The experimental data suggest that feed waste by pigs fed high barley rations is of great economic significance. Waste varied from 3 to 25 percent with group fed pigs depending upon the form of the ration and upon type of feeder used. Individually fed pigs wasted from 7 to 36 percent of the feed fed when fed alike indicating that waste varies greatly from one pig to another. Efficiencies of gain among a large group of individually fed pigs became much more homogenous when the data were corrected for feed waste. Pelleting

and wetting or soaking of the ration appears to reduce the rate of feed waste but there is considerable variation depending upon feeder design and frequency of feeding.

5. Electronic measurements of feeding time of pigs fed either the meal or pelleted form of the same ration showed that pigs spent 16. 75 percent of the day consuming meal and only 7. 34 percent of the day when eating pellets. A photographic study and close observation showed that pigs fed the ration in the meal form spend considerable time sorting out the barley hull. Chemical analysis of material wasted out of the feeder had a fiber content 2. 5 times as high as the original ration. Pigs consuming the same ration pelleted consume more feed than those offered the ration as a meal.

The studies conducted lead to the conclusion that barley hull is for the most part responsible for the poor performance of pigs fed barley rations in the meal form. The limitation imposed by the barley hull acts upon the intake of energy. Pelleting which increases ration density, or the addition of energy to the ration in the form of supplemental fat both increase the energy intake of the animals. Barley hull appears to reduce the amount of feed which the animal will consume. Pelleting tends to overcome this limitation. Theories put forth in the past which attributed the poor performance of barley rations to the inhibition of the digestive and absorptive processes by the barley hull need to be re-evaluated. Pelleted rations pass through the digestive tract more rapidly than do meal rations yet animals grow more efficiently on them. The feed waste studies show that animals consuming pellets have a higher intake of energy; thus, it is possible that the differences in efficiency between pelleted and non-pelleted ration are due to a greater supply of energy above maintenance to the pigs consuming pellets.

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APPENDICES

Appendix A. Individual pig performance data collected from experiment on the value of soaking barley for swine rations.

Pig No.	Gain (pounds)	Feed Offered (pounds)	Amount Wasted (percent)	Actual Consumption (pounds)	Feed Per Pound Gain	
					Corrected	Uncorrected
Lot S-1: Dry ground barley ration (control)						
1	146	594.2	11.8	524.4	3.59	4.07
6	165	619.2	12.2	543.6	3.29	3.75
10	143	551.2	1.4	543.6	3.81	3.85
16	140	532.7	2.3	520.2	3.72	3.81
21	132	467.2	4.8	444.6	3.37	3.54
26	176	714.7	15.5	603.6	3.43	4.08
36	148	530.2	5.7	500.0	3.38	3.58
47	140	546.2	9.2	496.1	3.54	3.90
48	169	634.2	4.4	606.3	3.59	3.75
Lot S-2: Ground barley portion of ration soaked						
2	160	585.0	6.5	547.2	3.42	3.66
7	151	576.3	6.4	539.7	3.57	3.82
12	162	613.4	6.0	576.3	3.56	3.79
17	162	600.4	8.2	551.0	3.40	3.71
22	171	620.1	2.8	603.0	3.53	3.63
27	146	612.0	12.7	534.2	3.66	4.19
32	152	598.5	22.7	462.4	3.04	3.94
37	154	625.2	26.4	460.2	2.99	4.06
42	164	628.4	7.9	578.8	3.53	3.83

Appendix A. (continued)

Pig No.	Gain (pounds)	Feed Offered (pounds)	Amount Wasted (percent)	Actual Consumption (pounds)	Feed Per Pound Gain	
					Corrected	Uncorrected
			Lot S-3: Whole barley portion of ration soaked			
3	146	718.0	13.0	624.4	4.28	4.92
13	139	727.7	14.2	624.4	4.49	5.24
18	152	741.5	16.8	616.7	4.06	4.88
23	140	674.9	17.4	557.4	3.98	4.82
28	165	748.3	9.3	679.0	4.12	4.53
33	134	684.9	21.0	541.0	4.04	5.11
38	141	724.1	20.3	576.8	4.09	4.78
43	158	754.9	8.3	692.0	4.38	4.78
46	177	741.3	12.9	645.5	3.65	4.19
			Lot S-4: Ground barley portion of ration soaked with aeration			
4	160	704.1	14.9	599.5	3.75	4.40
9	139	654.1	16.8	544.3	3.92	4.71
14	137	657.9	12.1	578.5	4.22	4.80
19	137	665.2	33.4	442.8	3.23	4.86
24	148	693.6	7.3	643.2	4.35	4.69
29	141	689.7	15.3	584.1	4.14	4.89
34	149	695.5	7.4	644.1	4.32	4.67
39	149	693.4	11.0	617.2	4.14	4.65
44	135	681.0	9.6	615.8	4.56	5.04

Appendix A. (continued)

Pig No.	Gain (pounds)	Feed Offered (pounds)	Amount Wasted (percent)	Actual Consumption (pounds)	Feed Per Pound Gain	
					Corrected	Uncorrected
Lot S-5: Enzyme treated ground portion of ration soaked with aeration						
5	135	742.9	22.0	579.7	4.29	5.50
11	148	717.3	20.1	573.1	3.87	4.85
15	145	731.0	11.9	643.9	4.44	5.04
20	155	756.7	11.4	670.1	4.32	4.88
25	172	767.7	14.3	657.6	3.82	4.46
30	173	755.6	5.6	713.2	4.12	4.37
35	153	746.3	24.5	563.7	3.68	4.88
40	131	712.5	14.5	609.0	4.65	5.44
45	156	752.1	15.4	636.5	4.08	4.82