ATTEMPTS TO IMPROVE UTILIZATION OF BARLEY BY SWINE THROUGH ENZYMES

by

LELAND MURRAY LARSEN

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1959

APPROVED:

[redacted]

Associate Professor of Dairy and Animal Husbandry in Charge of Major

[redacted]

Head of Department of Dairy and Animal Husbandry

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

Date thesis is presented May 8, 1959

Typed by Patricia Malango

ACKNOWLEDGEMENTS

The author wishes to extend his most sincere appreciation to Dr. James E. Oldfield for his counsel and encouragement during the course of this study and for his advice in the preparation of the thesis.

For their aid in care of the experimental animals and for advice during the course of the experiments, my heartfelt thanks are extended to Thomas K. Johnson and Marvin Heupel.

The supplementary enzymes were supplied through the courtesy of Merck, Sharp and Dohme Research Laboratories, Rahway, N. J., and Takamine Laboratory, Clifton, N. J. The barley malt used in Experiment 3 was donated by the Great Western Malting Company, Vancouver, Washington.

I wish to particularly thank my wife, Jean, for her active help, patience and encouragement during the course of this study.

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INTRODUCTION

It has long been recognized that barley is inferior to corn in supporting growth of swine (35, p. 448-449). Pigs fed barley rations do not grow as rapidly nor as efficiently as pigs fed a similarly supplemented diet in which corn is the major grain component. In the United States, however, there are large portions of land better suited to the production of barley than of corn, a situation that is particularly marked in the West. To illustrate this point, Agricultural Statistics (41, p. 36-53) reveals that barley production in the 11 Western states during the years 1945-54 averaged five times that of corn (132 million bushels versus 27 million bushels). This situation poses a serious economic problem in swine production in this area, often resulting in an unfavorable price-relationship between barley and corn.

Swine cannot consume large amounts of roughage, and therefore require concentrated sources of nutrients. Approximately 80 per cent of the feed consumed by pigs is one or another of the cereal grains, thus hogs compete with the direct consumption of such grains by the growing human population. It is certainly apparent that an increasing population will force the most economical use of cereal grains, whether this means their utilization as food or as feed.

Nevertheless, human need for proteins of animal origin should encourage a continual increase in the production of meat animals, but the efficiency of their production must be improved to permit such an increase.

Improved utilization of barley by hogs would obviously be an important advance in increasing the efficiency of their production. Such an improvement would allow more extensive use of this grain, of benefit to both the swine and barley producers. Many attempts have been made to improve barley for swine by subjecting it to various treatments. Although many of these early efforts were successful, recent work in the fields of swine and poultry nutrition has shed light on new methods which show even greater promise. Pelleting, water treatment, and the use of enzymes (either naturally in, or added to, barley) have all proved sucessful in improving poultry rations to varying degrees (1, p. 1284-1289) (23, p. 249-251) (24, p. 584-586) (27, p. 919-921), whereas the latter two treatments have not been subjected to more than cursory research thus far with swine. The reasons for the improvement due to such methods of treatment are not fully known. An interrelationship among these three treatments may exist.

With the incentive in mind of increased efficiency of pork production through barley improvement, a review of the literature was undertaken. The chemical composition and feeding values of barley and corn were compared for possible differences that might explain the lower feeding value of barley, and the scope of previous work relating to the treatment of barley and the effectiveness of such treatment were explored. Special note was taken of evidence supporting a possible extension of methods previously employed, and application to swine of methods successfully used with other classes of livestock or with poultry. Basically, it was felt that the growth-promoting value of barley for swine would be enhanced by the initiation of an enzymatic action, either by activation of enzymes innate to the barley kernel, or by addition of suitable enzymes to barley or barley-containing rations.

Three feeding experiments were conducted to evaluate the growth-response of swine to supplementary enzyme preparations of an amylolytic nature. The first of these also compared a ration based on barley with one based on corn. The second experiment was conducted to determine the value of an enzyme preparation different from that employed in the first experiment. The third experiment combined enzyme supplementation with a pretreatment of barley by a soaking and drying procedure prior to inclusion in the ration, in an attempt to initiate an enzymatic action before ingestion of the ration by the animal.

The results of these three trials were examined in the light of pertinent literature, and were evaluated in respect to their possible implications to the swine industry. The results of these experiments were also used as a basis for recommendations for further investigation that might be expected to yield more information on this problem.

REVIEW OF LITERATURE

Comparison of Barley With Other Grains

On the basis of numerous experiments, it has been established that corn has a higher feeding value for swine than does barley, both with respect to rate of gain, and to efficiency of feed utilization. In 1930 Loeffel (33, p. 1-20) reported, on the basis of his work, that barley was from 78 to 86 per cent as efficient as corn per unit of weight, depending on the manner fed and treatment of the grain. Robison in 1939 summarized the results of a large number of feeding trials and determined that the average worth of barley for pigs in dry lot was 92.6 per cent that of corn during the growth period from 61 to 215 pounds (38, p. 11-14). The latter estimate corresponds more closely to the value of barley as reported by Morrison in his summary of a vast number of trials (35, p. 448-449). He reports that barley is 91 per cent as valuable as corn. Morrison (35, p. 446-447) also indicates that some of the barley varieties grown in the West have a lower feeding value than those grown in the Midwest. He attributes this reduction in value to a lower protein content and to a higher percentage of crude fiber. This is borne out by the analyses reported in Table 1.

In many instances, feeding barley has resulted in a response equal to that of corn when the barley has been of good quality. This level of response seems, from the work of Wright (42, p. 1-7), to be directly proportional to the weight per bushel; however, even the heaviest barley (56 pounds per bushel) tested by this worker required more feed per pound of gain than with corn, though the rate of gain resulting from the feeding of each grain was the same.

Wheat is reported by Morrison to be slightly superior to corn for hogs. He also indicates that 107.8 pounds of barley plus 2.1 pounds of tankage is equal to 100 pounds of wheat (35, p. 440). Freeman (21, p. 114-116) compared corn, barley and wheat, and found that corn and wheat were equal and that both of these grains were superior to barley.

The chemical analyses of barley, corn and wheat have been examined for an explanation of the difference in feeding value. Table 1 provides a summary of the proximate analyses of these three grains as reported by Morrison (35, p. 1044-1066). It will be noted that a striking difference between these grains is the higher fiber content of barley. Although Morrison reports that Pacific Coast barley is low in protein, a recent publication of the National Research Council places the crude protein of barley from the Northwest states at an average of 12.0 per cent--higher than that of corn (36, p. 1-3). In addition, the protein of barley has been shown to be of a higher biological value than corn for growing rats, as reported by Block and Mitchell (9, p. 263).

TABLE 1
Proximate Composition of Barley, Corn and Wheat*

Grain	Dry Matter (%)	Crude Protein (%)	Crude Fat (%)	Crude Fiber (%)	Nitrogen Free Extract (%)	Ash (%)
Barley, Pacific Coast States	89.9	9.6	2.1	6.3	79.1	2.9
Barley, Common, not Including Pacific Coast States	89.4	14.2	2.1	6.0	74.6	3.1
Corn, Dent No. 2**	85.0	10.5	4.6	2.4	81.0	1.5
Wheat, Average of all Types	89.5	14.7	2.1	2.9	78.2	2.1

* Converted from Morrison to a dry matter basis (35, p. 1044-1066).

** Average values of corn in a good year and corn in a year with much soft corn.

A deeper look into the chemical analyses of barley and corn reveals that, according to Kent-Jones and Amos (29, p. 449) and Morrison (35, p. 1107), yellow corn is much higher in vitamin A activity, while barley has a higher content of the water-soluble vitamins.

The Effects of Crude Fiber in Swine Diets

Since fiber content seems to be a major difference between barley and corn, a perusal of the effect of fiber in the diet of swine seems appropriate. Estimates of the "optimum" or "maximum" fiber content in rations of growing-fattening pigs have varied, no doubt largely due to the source of fiber and the age of the pigs involved in investigations. (The relative merits of the terms "optimum" or "maximum" in reference to the amount of crude fiber in the diet are considered to be out of the scope of this discussion. It should be noted that there is some controversy as to which term is more appropriate.) Axelsson and Eriksson (6, p. 881-891) report 6.57 per cent fiber as optimum to gain in weight and 7.26 per cent as optimum to feed efficiency when wheat straw was used as a source of fiber in the diet. It would appear from the results of Dinusson (15, p. 28-32), and from the purified diet studies of Teague and Hanson (39, p. 206-214), that approximately 5 per cent crude fiber is a maximum; higher amounts resulted in a lowering of animal performance. Dinusson used dehydrated and suncured alfalfa, oat straw and corn cobs as sources of fiber for comparison. Teague and Hanson employed "Ruffex", a cellulosic material from rice straw, in their purified diets. From the above studies, the ability of swine to utilize efficiently diets with a fiber content of over 5 per cent seems to depend on the source of the fiber in the diet; nevertheless, the maximum amount of crude fiber permitting maximal gains seems to be approximately 7 per cent.

The addition of barley to common swine rations for growing-fattening pigs frequently results in rations containing over 5 per cent fiber. The following table of sample rations will serve to illustrate this point:

Feedstuff		Ration A	B	C	D	E
		(lbs)	(lbs)	(lbs)	(lbs)	(lbs)
Corn, Dent No. 2	(2.1)*	72		89		
Barley, Common	(5.4)		72		89	
Barley, Light	(7.4)					89
Tankage, 60%	(1.9)	6	6	3	3	3
Soybean Oil Meal	(5.8)	17	17	3	3	3
Alfalfa Meal	(24.0)	5	5	5	5	5
Total		100	100	100	100	100
Crude Fiber (%)		3.81	6.19	3.30	6.24	8.02

* Per cent crude fiber (air dry basis) from Morrison (35, p. 1000-1069).

It is fairly evident from these examples that the use of barley results in a ration containing almost twice as much fiber as one utilizing corn. In the case of ration E, the light barley would cause the ration definitely to exceed all the previously cited estimates of maximum crude fiber content.

The effects of surpassing the maximum allowable amount of fiber are varied, and have been reported by many workers. These effects have included lowered rate of gain and feed efficiency (6, p. 881-891) (39, p. 206-214) (10, p. 499-506) (12, p. 41-47) (15, p. 28-32), depressed digestibility of the more digestible portions of the diet--crude protein, nitrogen free extract, ether extract--(39, p. 206-214), lower dressing percentages, lighter carcass weights, thinner back fat, lower yield of fat cuts, and higher yield of lean cuts (10, p. 499-506) (12, p. 41-47). It will be recognized that not all of these effects are undesirable.

Reduction in the amount of available energy has been postulated as the reason for the lower level of animal performance in swine and poultry on high fiber diets. To add strength to this hypothesis, fat--a concentrated source of readily available energy--has been added to barley rations for poultry by Arscott _et al._ (4, p. 655-662) and Fry _et al._ (22, p. 281-288). Similar work with swine has been carried out by Heitman (25, p. 233-236). All these workers found that addition of fat to barley rations improved rate of gain and feed efficiency of the animals concerned. Anglemier and Oldfield (2, p. 922-926) found that addition of 5.5 per cent California Sardine oil to a swine barley ration improved efficiency of feed utilization. In another experiment (37, p. 917-921) these workers found that the use of a crude or an alkali refined and bleached Menhaden oil resulted in an improved rate of gain and feed efficiency of pigs on rations in which barley and oats were the grains employed.

The feeding of hull-less varieties of barley improves performance of pigs over that noted on hulled barleys (28, p. 44-50) (38, p. 18) while removing the fibrous hull of barley by the process of pearling has resulted in no improvement of growth in poultry according to Fry _et al_. (22, p. 281-288).

On the basis of these experiments it appears that lack of energy is a very important consideration in high fiber diets; the fibrous hull of the barley kernel, however, does not seem to account fully for the lowered feeding value in comparison to corn.

Treatment of Barley

In attempts to improve the feeding value of barley for hogs and poultry, the grain has been subjected to various treatments, some of which have already been mentioned. Recently, successful treatment of barley in poultry rations has included soaking of the ground grain followed by drying prior to inclusion with the ration, as reported by Fry et al. (1, p. 1284-1289), and Arscott (3, p. 39-40). In many instances, chicks fed rations including barley treated in this manner have equalled or excelled the growth rate of chicks on corn rations. This response of chicks to water-treated barley is believed to be due either to an enzymatic action within the grain, initiated by the added moisture, or to the inactivation or counteracting of inhibiting substances during the soaking or drying processes. The chick may be unable to digest certain components of the grain due to a lack of specificity or insufficient concentration of enzymes secreted (27, p. 919-921) (24, p. 584-586).

Pelleting

Pelleting of barley rations has resulted in an enhanced feeding value with swine (17, p. 56-62) (40, p. 1-11) (18, p. 1256) and poultry (1, p. 1284-1289). This processing of the grain may parallel the water treatment of barley in that both operations include an addition of moisture accompanied by elevated temperatures (in the form of steam in the pelleting process). Explanations for the effects noted in pelleting have included a change in the physical form of the ration (compression into a smaller volume and change in texture) and other as yet unknown factors which have been demonstrated to exist by Allred et al. (1, p. 1284-1289). These workers have demonstrated with poultry that in grains that are improved by pelleting, a degree of improvement remains even after the pellets have been reground and fed in a meal form. They also found that pearled barley was not improved by pelleting.

Dinusson and Bolin (16, p. 16-20) have also provided evidence that there is some change, in addition to a physical change, that takes place during pelleting. Analysis indicated a drop of 0.5 to 1.0 per cent in crude fiber content of rations that were pelleted or pelleted and reground compared to the same ration in a meal form. Substantiating evidence for such a chemical change was accumulated by England (20) who found that pigs on pelleted rations gained significantly faster ($P < 0.01$) than pigs on the same rations in a meal form. This was the case even though the pellets crumbled rather badly when fed in self feeders. There is strong evidence that the greatest benefits to pelleting result when fibrous, rather than non-fibrous rations are pelleted (18, p. 1256).

Enzyme Additions

With chicks, the postulated explanation for an increase in the value of barley by water treatment, i.e., that it may be due to an enzymatic action, led many workers to believe that the same change in the barley grain might be initiated in a simpler way by addition of certain enzymes to rations for poultry and other classes of livestock. Early use by Hastings (24, p. 584-586) of a crude enzyme preparation of fungal origin in poultry rations met with considerable success when the ration was high in fiber, but gave no response in rations low in fiber, viz., corn diets, a situation that also exists with pelleting (18, p. 1256).

Later experiments by Jensen (27, p. 919-921) and Arscott (3, p. 39-40) have confirmed the effectiveness of certain enzymes in poultry rations. Successful enzymes employed have been those from bacterial or mold sources, or from specially malted barley (34, p. 58). It has not as yet been possible to correlate the animal response induced by enzyme additives to a particular class of enzymes--amylolytic, proteolytic, cellulolytic, etc. Further, the response to added enzymes has not been as consistent, nor of as great a magnitude, as that observed with water-treated ground barley.

Enzyme insufficiencies were demonstrated in baby pigs prior to weaning age by Kitts _et al_. (30, p. 45-50), Bailey _et al_. (7, p. 51-58), and Catron _et al_. (11, p. 23-47). Pancreatic amylase, sucrase, maltase and pepsin were found to be deficient until pigs were approximately five weeks of age. Addition of pepsin, pancreatin, animal diastase, or a fungal amylase to baby pig pre-starters or milk substitutes resulted in improved utilization of certain components of the diet which are not normally handled efficiently by baby pigs (11, p. 23-47). Conversely, Cunningham and Brisson (13, p. 370-376) found that neither malt nor pancreatic amylase improved the digestibility of starch or the condition of baby pigs on either raw or cooked starch diets.

The sufficiency of digestive enzymes has not been established in pigs beyond five weeks of age. Beneficial results from addition of digestive enzymes to rations for older pigs can only be expected when such addition is in fact a supplementation of an enzyme or enzymes in the pig that are deficient in quantity or quality for maximum utilization of the components in the ration. The validity of this assumption was demonstrated as early as 1936 by Ivy, Schmidt and Beazell (26, p. 59-83). Their experiments were performed on canine and human subjects, and should perhaps parallel results anticipated in pigs more closely than does the work with poultry. They found that addition of malt amylase to an ingested starch or wheat paste improved the digestibility of these substrates only when salivary amylase was excluded as much as possible. (The saliva of dogs is, of course, extremely low or completely lacking in ptyalin (19, p. 315-316) and this was in fact a condition of salivary amylase deficiency.) Nonetheless, their findings indicate that the use of malt amylase was superfluous in normal subjects possessing a sufficiency of salivary or pancreatic amylase.

EXPERIMENTAL

Considerable evidence has been cited in the literature to show that treatment of barley by soaking or by addition of enzymes has resulted in improved growth and efficiency of feed utilization in poultry (23, p. 249-251) (27, p. 919-921) (24, p. 584-586) (3, p. 38-49). Since the pig, like the chicken, is monogastric, there is the suggestion that these results may be duplicated in swine by similar treatment of the barley used in swine rations. Effective enzyme supplementation of rations for baby pigs has been accomplished (11, p. 23-47), but little information is available on work with older growing-fattening pigs.

Lack of available energy in the barley kernel may be partially responsible for its lower feeding value in comparison to corn (22, p. 281-288). Activation of enzymes innate to the barley kernel or addition of other enzymes to barley rations for swine offers the possibility of increasing the energy available to animals consuming this grain. The primary energy source in barley, namely the carbohydrate constituents, may not be available to the pig by reason of insufficiency or lack of specificity of enzymes secreted by the pig. Such enzyme insufficiencies have been demonstrated in baby pigs prior to weaning (30, p. 45-50) (7, p. 51-58) (11, p. 23-47). Characterization of the enzymes present in the digestive tract of an older pig, and estimates of the quantity or strength of these enzymes, has not been accomplished sufficiently to permit a similar generalization in the case of these older animals.

Crude enzyme preparations that had previously led to success in poultry rations were selected for evaluation in suitable swine feeding trials. These enzymes were primarily of an amylolytic nature; however, they also possessed other forms of activity. Included were enzymes that were prepared from fungal and bacterial sources and from malted barley. A series of three feeding trials was carried out, along with chemical determinations incident to the trial concerned. The first two experiments involved testing the effectiveness of a simple inclusion of one of the above mentioned enzyme preparations in ration mixtures for swine, in which barley served as the sole grain in the mixture. The third experiment compared the effectiveness of different enzyme additions to a basal ration, and combined this treatment with a pretreatment of whole barley, i.e., soaking and drying, prior to grinding and inclusion in the complete ration.

EXPERIMENT I

Methods and Materials

A group of 40 weaned, purebred Berkshire pigs from the Oregon State College herd were utilized in this first experiment. These animals were selected from seven litters of approximately the same age, farrowed in the fall of 1957. and were randomly divided into four groups of ten pigs each. On the basis of initial weight, each of these four groups was further subdivided into two groups of five pigs each, one a light group averaging 71 pounds and the other a heavy group averaging 81 pounds. One light and one heavy group was randomly assigned to each of four treatments as follows:

1. Basal barley ration.
2. Basal barley ration plus 0.5 g. amylolytic enzyme* per pound.
3. Basal barley ration plus 2.0 g. amylolytic enzyme* per pound.
4. Corn control ration in which corn was substituted for barley in the basal ration.

Table 2 gives the composition of the experimental rations employed.

Each group of five pigs was housed in an inside pen.

*"Amylolytic Enzyme" supplied by Merck, Sharp & Dohme Research Laboratories, Rahway, New Jersey.

TABLE 2
Composition of Rations Used in Experiment 1

Feedstuff	Ration 1 Control	Ration 2 Low Level of Enzyme	Ration 3 High Level of Enzyme	Ration 5 Corn Control
	(pounds)	(pounds)	(pounds)	(pounds)
Ground Barley	780	780	780	
Ground Corn				780
Tankage	70	70	70	70
Soybean Oil Meal	70	70	70	70
Alfalfa Meal	65	65	65	65
Oyster Shell Flour	10	10	10	10
Iodized Salt	5	5	5	5
Total	1000	1000	1000	1000
Aurofac 10	0.75*	0.75*	0.75*	0.75*
Amylolytic Enzyme (Merck)+		1.10**	4.40***	

* To supply 15mg of aureomycin per pound.

** Equivalent to 0.5gms. of enzyme per pound of ration.

*** Equivalent to 2.0gms. of enzyme per pound of ration.

\+ Courtesy Merck, Sharp and Dohme Research Laboratories, Rahway, New Jersey.

Groups were alternated in their access to an outside concrete runway so that half of the groups had access to the outside at one time. The animals had free access to water at all times and were fed ad libitum in groups from self feeders. Feed not eaten was weighed out of the feeders at bi-weekly intervals. Feed efficiency, expressed as the pounds of feed consumed per pound of liveweight gain, could then be calculated by periods on a group basis. The pigs were weighed individually at weekly intervals, the identity of each animal being established by means of ear notches.

A proximate analysis was performed on samples of the experimental rations according to the official methods of the Association of Official Agricultural Chemists (5, p. 367-373) with the exception of the protein determinations which were carried out according to the following modifications recommended by Oldfield*: (a) the distillate was collected in 4% boric acid; (b) the indicator was composed of 0.1% bromcresol green in 95% alcohol (2 ml.). The results of these determinations are given in Table 3 on a dry basis (with the exception of the figures for dry matter content). Data for average daily gain were treated statistically by analysis of variance computed according to the method outlined by Li (32, p. 159-163). Similar analysis of the

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* Oldfield, J. E. Unpublished modifications of the Kjeldahl procedure, Corvallis, Oregon State College, Animal Nutrition Laboratory, Department of Animal Husbandry, 1952.

TABLE 3
Proximate Composition of Rations Used in Experiment I

Ration	Dry Matter	Crude Protein *	Ether Extract	Crude Fiber	Ash	Nitrogen-Free Extract**
	%	%	%	%	%	%
1. Basal Barley Ration	88.67	18.90	1.55	8.05	4.32	55.85
2. Basal Ration plus o.5g enzyme/lb.***	87.74	18.91	1.09	7.34	4.96	55.44
3. Basal Ration plus 2.0g enzyme/lb.***	88.04	18.57	1.23	7.50	4.41	56.33
4. Corn Control ration	88.45	18.61	2.60	5.53	3.24	58.47

* N x 6.25

** Calculated by difference

*** "Amylolytic Enzyme" supplied by Merck, Sharp and Dohme Research Laboratories, Rahway, New Jersey.

data on feed consumption and feed efficiency was not possible since only an average figure for each group was available due to group feeding.

Results and Discussion

A summary of the results of Experiment I is given in Table 4. Figures are given for average initial and final weights, average daily gain, efficiency of feed utilization, and average daily feed intake.

Although only average figures are available for feed efficiency it should be noted that the pigs on corn evidenced a markedly superior feed conversion to those on barley rations. This difference holds true for both the light and heavy groups of pigs. The light pigs consuming enzyme-supplemented rations converted their feed more efficiently than pigs on the barley control ration; however, this response is not duplicated in the heavy pigs.

The corn rations promoted a rate of gain that was significantly higher ($P < 0.01$) than that evidenced by the animals on barley rations. The barley rations in this experiment had a value of 86 per cent that of the corn rations with respect to rate of gain, and it required 10 per cent more feed per pound of gain when barley was the grain in the ration. These figures correspond very well with the comparative values of barley and corn quoted in the

TABLE 4
Summary of Results on Experiment I

Treatment	1 Basal		2 Basal plus 0.5gms. Enzyme per pound		3 Basal plus 2.0gms. Enzyme per pound		4 Corn Control	
Weight Group	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy
Number of pigs	5	5	5	5	5	5	5	5
Average Initial Weight (pounds)	71.2	79.8	71.4	80.0	69.4	82.8	71.4	81.6
Average Final Weight (pounds)	185.6	213.0	196.8	214.8	191.4	203.2	216.0	224.0
Average Daily Gain (pounds)	1.36	1.59	1.49	1.60	1.45	1.43	1.72*	1.70*
Pounds of Feed per Pound Gain	3.944	4.066	3.917	4.033	3.787	4.186	3.452	3.775
Average Daily Feed Intake (pounds)	5.37	6.45	5.85	6.47	5.50	6.00	6.18	6.40

* Significantly higher ($P < 0.01$) than barley rations.

preceding review of literature. The figures for average daily gain also indicate that the light pigs on both levels of enzyme gained more rapidly than those on the basal ration. These differences were not significant, however, and the heavy pigs on enzyme-supplemented rations did not duplicate this response of the light pigs. The heavier pigs equalled their basal counterparts in the case of the low level of enzyme and did poorer than the basal group in the case of the high level of enzyme.

The failure of the heavy pigs to respond to the enzyme addition in the same manner as the light pigs leads one to question whether a response to the enzyme was actually obtained in the light group or whether this is merely a chance occurrence. The lack of statistical significance in the differences between the basal and enzyme-supplemented groups strengthens the conclusion that the pigs failed to respond to the enzyme treatment. Certainly the response was too small to attribute it definitely to the enzyme. It might also be suggested that the growth requirements of the lighter pigs may have been more critical than those of the heavier pigs. Enzyme supplementation in such a case may have aided in meeting these requirements, leading to a growth response. The small difference in initial weight-- 10 pounds--may not warrant such speculation.

EXPERIMENT II

Supplementation with enzymes in rations for chickens has revealed that certain enzyme preparations are more active than others, for unknown reasons (34, p. 58). Certainly, the same situation is possible in swine. It was therefore concluded that attempts to improve barley rations for swine through the use of enzymes should not be abandoned due to the lack of a consistent response to the particular enzyme preparation used in Experiment I. Experiment II was designed to test the effectiveness of another amylolytic enzyme mixture.

Methods and Materials

Eighteen weaned Berkshire pigs, of the same description as those employed in Experiment I, were selected from four litters farrowed in the spring of 1958. The initial weights of the animals varied from 39 to 88 pounds. Animals were paired on the basis of litter, sex and initial weight. One animal randomly chosen from each pair was assigned to a control group and fed the basal barley ration used in Experiment I, as given in Table 2. The other animal of the pair was assigned to the experimental ration--basal ration plus five pounds of MK-124 enzyme supplement* per ton of ration

* Merck, Sharp and Dohme Research Laboratories, Rahway, New Jersey.

mix (1.13 grams per pound). The enzyme mixture was primarily amylolytic in nature, though other forms of activity were recognized as being present. This division of experimental animals resulted in nine animals per treatment group, a randomized block design with two treatments and nine replications.

The nine animals in each treatment were housed in a group pen with an outside concrete runway. The pigs were fed *ad libitum* from self feeders and had free access to water at all times. Weights of individual pigs were taken weekly and feed not eaten was weighed out of the feeders at biweekly intervals. At the initiation of the feeding period the average weight of the pigs in the control group was 62.4 pounds and the pigs in the experimental group 64 pounds. The feeding period was 70 days in duration, after which the average weight of the pigs was 167.8 and 172.4 pounds in the control and experimental groups, respectively.

Results and Discussion

The results of this experiment in terms of average daily gain and feed efficiency are presented in Table 5. Although a slight increase in average daily gain resulted in the enzyme supplemented lot, this difference was not statistically significant ($P > 0.05$) and rather small in magnitude. In spite of the effort to pair like animals, the average daily

TABLE 5

Summary of Results on Experiment II

Treatment	Basal Ration	Basal Ration plus 1.13gms. Enzyme*/Pound
Number of Pigs	9	9
Average Initial Weight (pounds)	62.4	64.0
Average Final Weight (pounds)	167.8	172.4
Average Daily Gain (pounds)	1.51	1.55
Pounds of Feed/Pound Gain	3.681	3.704
Average Daily Feed Consumption (Pounds)	5.5	5.7

* MK-124 Enzyme Preparation supplied by Merck, Sharp and Dohme Research Laboratories, Rahway, New Jersey.

gain of the two animals within a pair was highly variable.

There was virtually no difference in feed efficiency between the control and experimental groups, as evidenced by the figure of 3.68 pounds of feed per pound of gain for the control group versus 3.70 pounds of feed per pound of gain for the enzyme-supplemented group.

Again, as in Experiment I, there appears to be a failure of the enzyme-supplemented barley ration to show any marked improvement over a barley ration without added enzymes. Three possible explanations for this may be offered: 1) Lack of response to the added enzymes may be due to a lack of specificity of these enzymes for the components of the barley kernel that are unavailable to the pig. In other words, the enzymes do not provide the supplementary or complementary action anticipated. 2) The presence of an inhibitor in the barley kernel may be responsible for a feeding value that is lower than expected on the basis of gross composition. The action of this inhibitor may not be overcome by simple enzyme addition. 3) Certain factors in the digestive tract of the pig--low pH, activity of proteolytic enzymes, or others--may destroy or inhibit the action of the added enzymes before they have a chance to act on the feed ingredients. (In this regard, an important difference may exist between swine and poultry.) These three possibilities were taken into consideration in the formulation of plans for the third experiment.

EXPERIMENT III

Methods and Materials

Several factors have been suggested as possible explanation for the lack of marked growth response by pigs to amylolytic enzyme additives to barley rations in Experiments I and II. The procedures employed in Experiment III were designed to overcome these factors. First, it was postulated that enzymes innate to the barley kernel and responsible for its germination might be more specific and through their activity release components of the kernel that are unavailable to the pig. For this reason, ground barley malt with a high diastatic power was added to barley rations identical in composition to those employed in the previous experiments.

Secondly, to allow for the action of these enzymes prior to entering the digestive tract, whole barley (or whole barley mixed with whole barley malt) was soaked for a period of eight hours in 50 gallon drums with sufficient water to cover the grain, after which the unabsorbed water was drained off. (The moisture level after this period of soaking was between 25 and 30%.) The grain was then dried for 8-12 hours at 110 to 140°F. in a forced-draft hop dryer. The mildly elevated temperature during drying was an attempt to hasten the enzymatic action desired or to inactivate the effect of the inhibitor postulated to be present in barley. (Soaking the grain in the ground state would perhaps have been more desirable to allow for maximum water penetration; however, available facilities were not suitable for drying of ground grain.) After drying, the grain was ground through a hammer-mill for inclusion in the various rations.

In addition, a crude enzyme preparation of fungal origin was evaluated in this experiment, both by adding it to the dry barley ration as in previous experiments, and by prior soaking of whole barley in a solution of the enzyme. The soaking and drying was carried out as described above with barley malt.

Ten litters of weaned Berkshire pigs farrowed in the fall of 1958 were the source of the animals used in Experiment III. These animals were similar to those described in Experiment I. From these ten litters 16 barrows and 24 gilts were selected on the basis of uniformity of weaning weights. Two barrows and three gilts were assigned at random (except that steps were taken to assure groups of approximately the same average initial weight) to each of eight experimental treatments as follows:

1 and 2. Basal barley ration.

3 and 4. Basal barley ration with 2.5 per cent of the barley replaced with barley malt.

5 and 6. Basal barley ration with 10 per cent of the barley replaced with barley malt.

7 and 8. Basal barley ration with 0.5 grams of HT440 enzyme preparation* added per pounds of barley.

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* Takamine Laboratory, Clifton, New Jersey.

The composition of the experimental rations is given in Table 6. Rations 1, 3, 5, and 7 included grain that had not been subjected to soaking and drying, whereas in rations 2, 4, 6, and 8 the barley, or barley plus added malt or enzyme, was subjected to the soaking and drying treatment described above.

The design of the experiment was a 2 x 4 factorial with five animals per treatment group. The average weight of the animals at the start of the trial was 50.2 pounds, at the completion of the experiment 176.8 pounds. The duration of the feeding period was 91 days (13 weeks).

Experimental animals were housed in 4' x 6' individual concrete floored pens, bedded with wood shavings. Feed and water were offered ad libitum from self feeders and automatic waterers, respectively. Animals were weighed at weekly intervals and feed consumption figures were taken at 2, 4 and 6 weeks and at the conclusion of the experiment.

Composite samples of the experimental rations employed were subjected to proximate analysis according to the method described in Experiment I, page 21. The results of these analyses are reported in Table 7 on a dry matter basis (with the exception of the figures for dry matter content).

Figures for average daily gain and feed efficiency were subjected to statistical analysis by means of the analysis of variance computed according to the method outlined by Li (32,

TABLE 6
Composition of Rations Used in Experiment III

Feedstuff	Rations 1 and 2 Control	Rations 3 and 4 2.5% Barley Malt	Rations 5 and 6 10% Barley Malt	Rations 7 and 8 HT-440+
	(pounds)	(pounds)	(pounds)	(pounds)
Ground Barley	780.0	760.5	702.0	780.0
Barley Malt		19.5*	78.0**	
Alfalfa Meal	65.0	65.0	65.0	65.0
Tankage	70.0	70.0	70.0	70.0
Soybean Oil Meal	70.0	70.0	70.0	70.0
Oyster Shell Flour	10.0	10.0	10.0	10.0
Iodized Salt	5.0	5.0	5.0	5.0
TOTAL	1000.0	1000.0	1000.0	1000.0
HY-440+				0.859***
Aurofac-10	1.5++	1.5++	1.5++	1.5++

* Calculated to replace 2.5% of the barley by weight.
** Calculated to replace 10% of the barley by weight.
*** Equivalent to 0.5 grams of HT-440 per pound of barley grain.
+ Amylolytic enzyme product supplied by Takamine Laboratories, Clifton, New Jersey.
++ To supply 15mg of aureomycin per pound of ration.

TABLE 7

Proximate Analysis of Rations Used in Experiment III

Ration	Dry Matter (%)	Crude Protein* (%)	Crude Fat (%)	Crude Fiber (%)	Nitrogen Free Extract** (%)	Ash (%)
1. Basal Barley Ration, Unsoaked	87.48	23.04	2.08	7.46	61.94	5.48
2. Basal Barley Ration, Soaked	85.22	22.30	2.30	8.56	60.38	6.46
3. 2.5% Barley Malt, Unsoaked	88.55	19.91	2.21	7.86	64.61	5.41
4. 2.5% Barley Malt, Soaked	86.84	23.51	1.22	8.31	60.95	6.01
5. 10% Barley Malt, Unsoaked	88.12	20.10	1.23	6.84	66.10	5.73
6. 10% Barley Malt, Soaked	87.60	20.80	1.26	7.80	64.06	6.08
7. HT-440, Unsoaked	87.18	21.83	1.39	9.33	60.93	6.52
8. HT-440, Soaked	87.00	21.18	1.34	8.49	62.74	6.25

* N x 6.25

** Calculated by difference.

p. 316-318). Individual treatment means were compared through the use of Duncan's new multiple range as given by Li (32, p. 238-241).

Results and Discussion

The results of Experiment III are summarized in Table 8. Lack of consistent growth response to the soaking treatment is evident. The daily gain for the pigs on the unsoaked barley rations was 1.40 pounds on the average, and for the pigs on the soaked barley rations, 1.39 pounds. Feed efficiency figures reveal that the soaking of barley with the barley malt additive resulted in an improved feed efficiency of swine on these rations but this improvement was not statistically significant ($P > 0.05$). In the case of the crude enzyme soaked with barley the feed efficiency of the pigs was not improved over that of the unsoaked control. Soaking of whole barley alone was of no advantage, either in respect to rate of gain or feed efficiency. This lack of response to soaking of whole barley may be in part due to the difficulty of water penetration through the intact hull. A typical water absorption curve for barley in steep (14, p. 710) reveals that the moisture content should have been in excess of 30 per cent at the end of eight hours; this may not have been adequate to initiate the action desired.

The methods of feeding barley malt deserve some attention in view of the contradictory results in this trial. At the

TABLE 8
Summary of Results on Experiment III

PRETREATMENT	UNSOAKED				SOAKED			
Ration	1 Basal	3 2.5% Malt	5 10% Malt	7 HT-440	2 Basal	4 2.5% Malt	6 10% Malt	8 HT-440
Number of Pigs	5	5	5	5	5	5	5	5
Average Initial Weight (pounds)	48.2	48.2	49.0	53.0	51.8	52.2	50.2	49.0
Average Final Weight (pounds)	181.0	177.8	170.0	177.8	182.6	190.2	172.8	161.8
Average Daily Gain (pounds)	1.46	1.42	1.33	1.37	1.44	1.52	1.35	1.24
Pounds of Feed/Pound gain	4.110	4.095	4.217	4.505	4.183	3.947	3.978	4.137
Average Daily Feed Consumption (pounds)	6.0	5.8	5.6	6.2	6.0	6.0	5.4	5.1

low level (2.5 per cent) soaking of barley with malt seemed to be effective in improving rate of growth. This stimulation to growth was not duplicated when a higher level (10 per cent) of malt was soaked with barley, although at both levels there was an improvement in feed utilization with respect to the animals on the control rations. One of two factors may be influencing this depression of growth rate at the higher level of malt addition. A palatability factor may be present. Malt at the higher level may not be palatable to swine, consequently less feed would be consumed, slowing rate of gain, yet feed efficiency could remain high as it did in this experiment. There was an indication in this study that palatability might be involved in the lower feed consumption of the animals on 10 per cent malt compared to the amount consumed by the control or 2.5 per cent malt groups.

Another factor that could have been operating to cause a poorer growth response in the high levels of malt would be dilution of a particular nutrient or nutrients by the malt, introducing in this way a limiting factor that would not be operable at the lower level of barley malt. This would be in accord with the early work of Lawes and Gilbert (31, p. 1-137) which indicated that a given quantity of barley grain is of more value to livestock than the amount of barley malt which can be made from it. This explanation does not seem likely, however, in view of the relatively small proportion of malt to barley. The chemical analyses of barley and barley malt do not reveal marked differences (36, p. 1-2). Furthermore, feed efficiency was not different between the two levels, and limitation of a certain nutrient or class of nutrients would certainly be expected to adversely affect feed efficiency as well as rate of gain.

The crude enzyme preparation, HT-440, gave very poor results in all respects. Animals on the rations including this addition exhibited a rate of gain slower than that of the control rations. The unsoaked HT-440 group evidenced a feed efficiency that was significantly inferior ($P < 0.05$) to all other treatments.

Mention should be made of the results of the proximate analyses performed on samples of the experimental rations as reported in Table 7. The crude protein content of these rations was much higher than had been calculated, and was much higher than the protein content of the similar rations employed in Experiment I (see Table 3). The explanation for these unexpectedly high values for crude protein lies in the fact that the barley grain included in the rations was of extremely high protein content for this area, possibly due to lack of rainfall during the growing season. It is conceivable that this high level of protein may have masked some of the effects due to treatment in this experiment. In any event, some consideration should be given to the possibility that the barley employed was perhaps not representative of the quality of barley normally fed to livestock in this geographic locality.

On the basis of this experiment, it can be concluded that the soaking of whole barley alone is of no value to swine, nor is the addition of barley malt or the enzyme preparation HT-440 of value when added to a dry barley ration. The soaking of barley malt with barley shows some promise for improving the value of this grain for swine. The consistently improved feed efficiency of swine subsisting on rations with barley treated in this manner offers an indication of its potential value, though the growth response is not as definite, nor as consistent as would be necessary to make such a process economically feasible at present. It is very possible that soaking of barley in the ground state would yield more promising results. Difficulty in penetration of the hull of barley by water or enzymes is undoubtedly a very important factor. Further investigations along this line should be carried out, in order to determine the factors present in the barley kernel that have an affect on its feeding value, and to develop means of improvement by taking advantage of such knowledge.

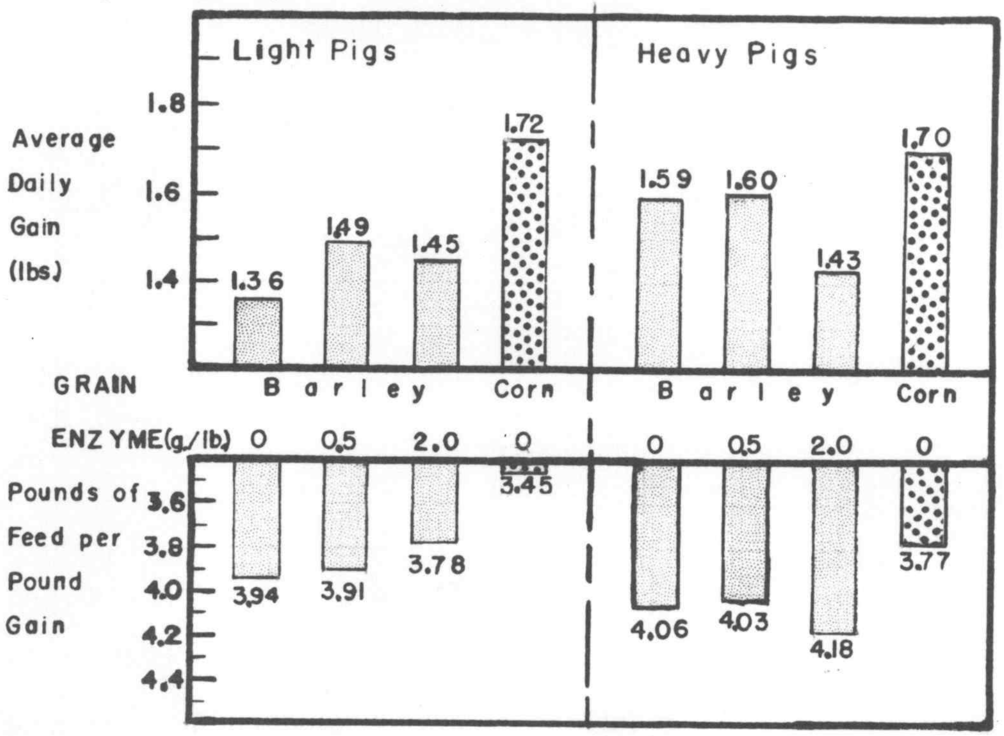
GENERAL DISCUSSION

On the basis of the results of the three experiments conducted and described herein, it would seem that a general evaluation of the enzymatic approach to barley improvement is in order, specific points having already been discussed under the individual experiments. (A graphic summary of these results is presented in Figures 1 and 2.) A total of four enzyme preparations has been evaluated in these feeding trials. These enzyme supplements have all been primarily of an amylolytic nature, and had promoted successful improvement of barley rations for poultry. The results obtained indicate that enzyme-supplementation of barley rations for growing-fattening swine is ineffective in improving the value of this grain at least under the conditions imposed in these experiments. In certain instances, there was a trend toward improved growth rate or feed conversion which was not statistically significant, and therefore may have been due to chance. At least, the increments obtained were not large enough to make such supplementation economically feasible at this time.

Several interpretations of the results of these experiments are possible. It is, of course, possible that pigs of the age utilized in these studies are not deficient in amylolytic enzymes (or other enzymes present in the products used) and that enzyme addition is superfluous as

Figure 1
Effect of Amylolytic Enzymes on Pig Performance

Experiment 1:



Experiment 2:

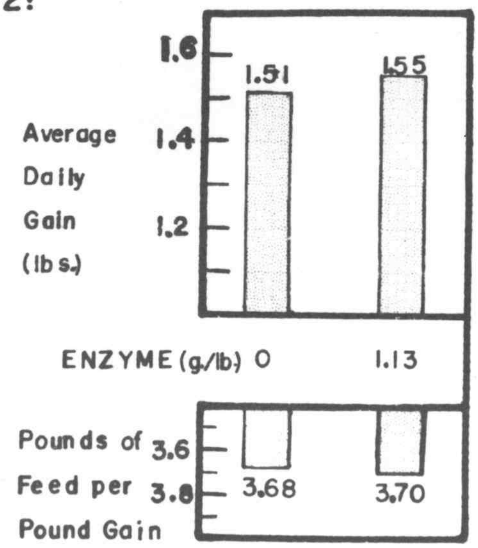
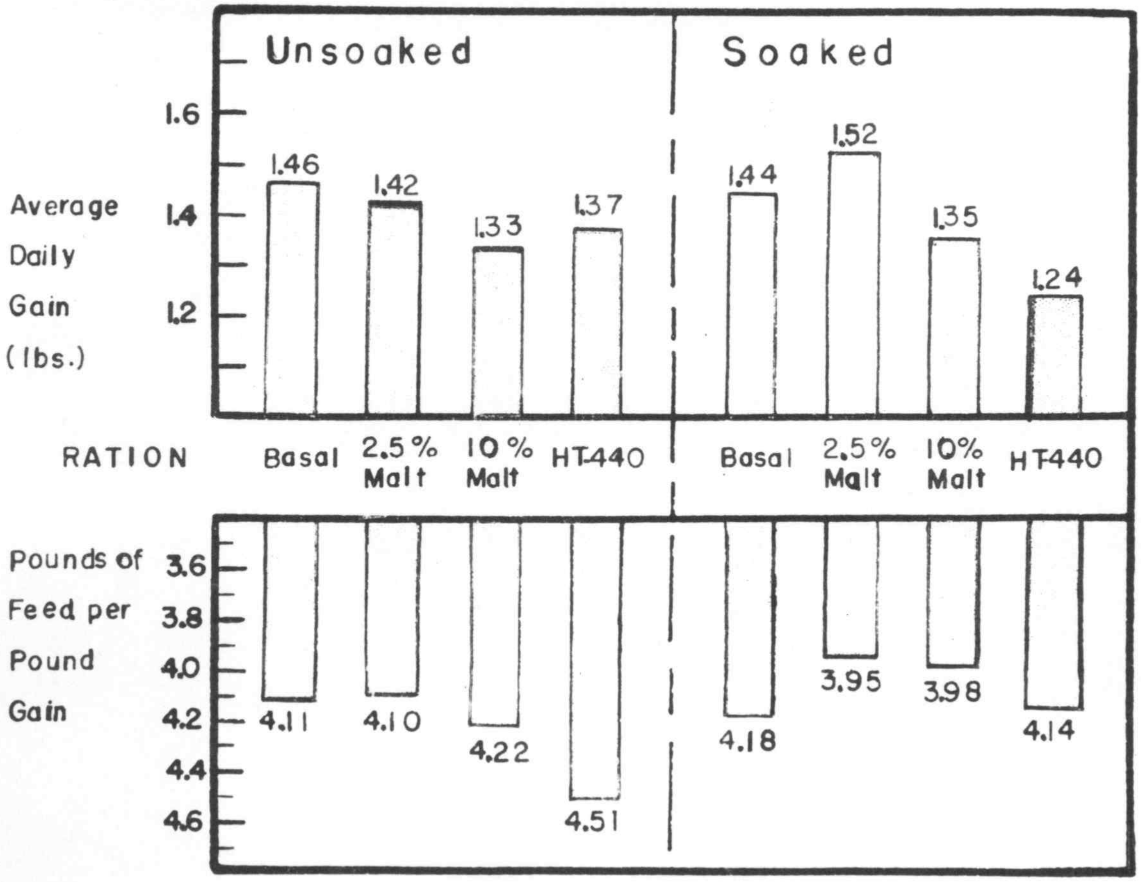


Figure 2

Effect of Amylolytic Enzymes and Water-treatment of Barley on Pig Performance

Experiment 3



Ivy *et al.* indicated with human and canine subjects (26, p. 59-82). Such an interpretation is in agreement with the work of Kitts *et al.* (30, p. 45-50), Bailey *et al.* (7, p. 51-58) and Catron *et al.* (11, p. 23-47) which indicated that baby pigs are deficient in certain enzymes until five weeks of age. Supplementation of pre-starter rations for baby pigs was of value until this age (11, p. 23-47) but was of questionable value subsequent to five weeks of age.

A second interpretation of these results was mentioned in connection with Experiment II. The acidity or the action of proteolytic enzymes in the stomach may result in an inactivation of the supplementary enzymes before their action can be initiated in the digestive tract. On the other hand, the low feeding value of barley may be due to the presence of an inhibitor in the grain, the action of which is not overcome by simple enzyme addition to complete rations. Such an inhibitor has been postulated by many workers (27, p. 919-921) (1, p. 1284-1289) (23, p. 249-251) (22, p. 281-288).

The experiments reported in this study point to some similarities and differences in the response to supplementary enzymes between poultry and swine. A similarity exists, in that the greatest response of poultry to enzymes has been in chicks during the growth period from birth to four weeks of age (3, p. 39), which has a parallel in the reported response to enzymes in baby pigs prior to five weeks of age (11, p. 23-47). In most instances, it has not been possible to demonstrate beneficial effects due to supplementation of barley rations for older laying hens (8, p. 13-19). Eighteen week old turkeys, however, do respond to enzymes (34, p. 58). A parallel response was not noted in the experiments reported in this study.

The same factors may not be responsible for the low feeding value of barley in both poultry and swine, therefore enzyme supplementation which effectively enhances the value of barley for poultry would not be effective with swine. Conversely, the same factors could be operating in each case, but due to differences in physiology of the animals and feeding practices, different techniques for successfully overcoming these factors would be necessary. In this regard, information is lacking on the character of the digestive enzymes in older pigs and in chickens of all ages. In addition, the effects on enzyme activity exerted by low pH, proteolytic action, and other conditions in the digestive tract should be investigated.

It must be reiterated that the water-treatment of barley in Experiment III was carried out with the whole grain. Although no response to such soaking was noted, it does not eliminate the possibility that soaking of the ground grain might prove beneficial, as has been experienced with chickens

(23, p. 249-251). The fibrous hull of barley may have been the limiting factor in this trial, and its possible role in interfering with the action of digestive enzymes is worthy of additional investigation. For this reason, the evaluation of water-treatment as a means of improving barley must be considered incomplete.

The results of Experiment III indicate that soaking of barley with barley malt may be of value in enhancing rate of growth and feed efficiency of growing swine. Further investigation on the methods of incorporation of barley malt in swine rations is, therefore, indicated to be of value.

SUMMARY AND CONCLUSIONS

1. The effects on growth and feed conversion of growing-fattening pigs resulting from supplementation of barley rations with enzymes of an amylolytic nature have been investigated. A series of three feeding experiments involving 98 animals has been carried out. The first of these compared the relative merits of identically supplemented corn and barley rations and also evaluated the supplementary value of a commercial enzyme preparation added to the barley. A second commercial enzyme preparation was tested in Experiment II. The third experiment combined the use of supplementary enzymes (a crude enzyme preparation and barley malt) with a pretreatment of barley by soaking and drying prior to grinding and inclusion in the rations.

2. Barley was demonstrated to be 86 per cent as valuable as corn in promoting rate of gain. Also, the barley rations required 10 percent more feed per unit of gain.

3. Amylolytic enzyme supplementation of barley rations for swine failed to improve growth rate or feed efficiency to any great extent. Trends toward improvement were noted in certain instances and, while they were not statistically significant, they were encouraging enough to prompt further study.

4. Explanations proferred for lack of growth response of pigs to supplementary enzymes under the conditions of these experiments are: (a) failure of the added enzyme to possess a supplementary action to the digestive enzymes innate to the pig; (b) inactivation or destruction of the added enzymes due to low pH, action of proteolytic enzymes, or other factors in the stomach; and (c) the possible presence in barley of a growth-inhibiting substance which is not itself inactivated by the enzyme preparation.

5. Water-soaking of whole barley alone, or with crude amylolytic enzyme preparations did not enhance the feeding value of this grain for swine, however, in these studies the grain was soaked in the whole state. This procedure may not have allowed for sufficient moisture uptake by the grain, thereby limiting the extent of enzymatic action. Evaluation of water-treatment as a means of improving barley for swine must be considered incomplete until this treatment can be employed with the ground grain.

6. Barley malt added at a level of 2.5 per cent, when soaked with whole barley, resulted in a trend toward more rapid growth of pigs. When malt at a level of 10 per cent was soaked with barley, growth of animals was not improved, although, both the 2.5 and 10 per cent water-treated malt groups evidenced a more efficient feed conversion than all

other treatments employed in Experiment III. This superior feed conversion was not significant statistically ($P > 0.05$), but is noteworthy. The lack of growth improvement on 10 per cent malt was believed due either to a palatability factor or to nutrient dilution. Animals on this diet ate less yet converted their feed efficiently. Further study is indicated to be of value in assessing various methods of utilizing barley malt in swine rations.

7. The fibrous hull of barley may have been the limiting factor in these experiments. Elucidation of the role of this fiber in interfering with the digestibility of the more digestible nutrients, or dilution of these nutrients in the ration, should be subjected to more exhaustive research. A high content of fiber may not be the only factor limiting growth and feed efficiency of swine consuming barley rations, and future investigations should include procedures that will yield more information on this problem.

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