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Methods to improve the efficacy of swine barley rations were evaluated. A literature review pertaining to the subject, three feeding trials involving 104 swine, and a laboratory investigation were used in the study.

The effects of pelleting with a new modified pellet die that produces a dense pellet; supplementation with 5 percent stabilized beef tallow or with a cellulase preparation[1]; adding water to the ration at the time of feeding; soaking the ration 9 to 15 hours prior to feeding; the use of temperature control with mash rations, and several interactions of these methods have been evaluated.

Pelleting barley rations significantly ($P < .01$) improved the feed conversion over similar rations fed as meal, but had no significant ($P > .10$) effect on daily feed consumption or average daily

[1] Cellulase 4000, supplied gratis by Miles Laboratories, Elkhart, Indiana.

gains. Meal rations were 7 percent bulkier than pellets, and it is suggested that the increased density of pellets is responsible for the improvement in feed conversion due to pelleting. Fat supplementation was additive with pelleting when the modified pellet die was used; together the two significantly ($P < .05$) improved the feed conversion of the control ration.

Supplementation with 5 percent stabilized beef tallow brought about no significant ($P > .05$) changes in average daily gains, feed consumption, or feed conversion. However, fat supplementation tended to improve the utilization of barley rations more than pelleting or cellulase supplementation. Fat additions apparently lowered cellulase activity as determined *in vitro*, but fat apparently was not detrimental to cellulase activity *in vivo* except in pelleted rations.

Cellulase 4000 did not bring about any significant ($P > .10$) changes in average daily gains, feed consumption or feed efficiency although there was a slight but consistently favorable trend to do so. Carcass shrinkage was significantly ($P \leqslant .05$) lower following cellulase feeding, whether the ration was soaked or dry. Backfat was significantly ($P < .05$) thicker on soaked rations, but not on dry rations, when Cellulase 4000 was supplemented. The use of this enzyme apparently increases the average daily gains but not the feed efficiency of soaked rations, at least in the absence of temperature control.

Soaking the ration 9 to 15 hours prior to feeding or simply wetting the ration at the time of feeding tended to increase the average daily gains and feed consumption, but lowered the efficiency of feed utilization. When temperature control was applied to the mash rations, average daily gains were significantly ($P < .05$) improved over the controls, shrinkage losses apparently increased ($P < .05$ with the "soaked" group), but the feed efficiency tended to decrease as did the backfat thickness and the iodine numbers of the backfat ($P < .05$ with the "soaked" group).

The laboratory study provided some evidence that Cellulase 4000 brought about reduction in cellulose, but that the pH of barley rations was not optimum for cellulase activity. Reducing sugars and crude fiber were found to increase with the ration soaking time.

IMPROVEMENT OF BARLEY UTILIZATION THROUGH FEED PROCESSING OR SUPPLEMENTATION

by

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IMPROVEMENT OF BARLEY UTILIZATION THROUGH FEED PROCESSING OR SUPPLEMENTATION

INTRODUCTION

The Department of Animal Science at Oregon State University has been investigating various nutrient:energy relationships in swine rations. Such a study is intended to provide information that will elicit more efficient conversion of feed to meat, more rapid gains, greater economic return, and will produce a more desirable product. In the Pacific Northwest, barley is the major component of swine rations because of its favorable cost and useful nutrient properties. However, it is generally believed that barley is not as valuable as a source of nutrients for swine as is corn. It appeared logical that feed processing or supplementation be investigated as means of improving utilization of barley rations.

Pork is a desirable product, since it contains a high quality protein and is an excellent source of thiamine. Moreover, swine are efficient converters of grains but cannot utilize roughage as effectively as ruminants. If they are to continue to be useful to man, therefore, efforts should be made to improve their conversion of fibrous grains, like barley, which are not vitally necessary for human existence. Broadly speaking, the increasing concern relative to the human population explosion justifies accelerated research into more efficient means of producing food for human consumption.

The National Research Council (70, p. 6, 10) reports that barley contains equal or greater gross calories per pound than corn. Yet, Morrison (68, p. 448) reported that barley has only 91 percent of the feed value of corn, while Larsen (55, p. 46-48) found only 86 percent. The poultry industry appears to have a similar problem in feeding barley to broilers (7, p. 660-661). Fraps (40, p. 17-18) gave barley approximately 70 percent of the productive value of corn. The reasons suggested for the poorer performance with barley include its increased fiber content, possible presence of a metabolic inhibitor, or deficiency of enzymes to digest the grain. One or more of these reasons may well be the problem, and the possibility of interrelationships cannot be discounted.

REVIEW OF LITERATURE

General

Arscott (7, p. 655) and Fry *et al*. (41, p. 281) suggested that the depressed growth and feed efficiency noted with barley rations for chicks were due to a deficiency of available energy. It is not known for certain where in the metabolic scheme the limitation of energy occurs, and the problem may well vary with different animal species. Larsen (55, p. 62) concluded that the barley hull imposes an energy limitation on swine that can be partially overcome by pelleting or fat supplementation. On the other hand, the work of Hill (46, p. 573-579) might be offered as evidence to suggest that the starch fraction is somewhat unavailable to chicks. Hill found pearled barley has a lower metabolizable energy value for chicks than does regular barley (1250 vs. 1370 Calories per pound respectively). In swine, however, Larsen (55, p. 59) reported gains ($P < 0.05$) and feed efficiency ($P < 0.01$) were significantly improved when pearled barley was fed compared to regular barley rations.

Jensen *et al.* in 1957 (51, p. 919-921) suggested that barley contains a factor inhibiting growth in poultry. Arscott *et al.* (8, p. 270) also believed an inhibitor or an inhibitory action could be involved in barley rations for chicks. Larsen (54, p. 47) concluded the lack of response to various amylolytic enzymes in attempting to improve swine rations could possibly be due to a growth-inhibiting substance in barley which is not itself inactivated by the enzyme preparations. He (55, p. 32) fed swine pearled barley either diluted to the same fiber level with pure cellulose (sulfite-treated, lignin-free wood pulp) or barley hulls, and observed a greater growth depression in the case of the barley hulls. The fraction of the barley kernel removed in the pearling process contained 55 percent of the crude fiber and 60 percent of the lignin found in the entire kernel. Actually 20 percent of the grain component was substituted with barley hulls and only 3. 3 percent with purified cellulose. Larsen's (55, p. 27-36) work indicates that an inhibitor could exist in the barley hull but it is quite likely the pig is deficient in the enzymes required to digest the lignin-cellulose complex, fractions of pentosans, gums, or other relatively indigestible materials found in barley hulls that might not be found in purified wood cellulose.

The influence of geography and variety of barley might govern the feeding value of such a grain. In turn these factors could be responsible for some of the variability noted in feeding trials. Jensen (49, p. 150-151) reported Western barley responds more readily to enzyme or water treatment when fed to chicks than does

Midwest or Eastern barley. Arscott[1] also believes that Midwest barley differs in feeding value with "West Coast" barley. He mentioned, however, that Midwest and Northwest corn gave similar growth responses to chicks. Willingham et al. (94, p. 539-544) found eight varieties of barley grown in approximately the same area produced equivalent chick growth. However, Gill et al. (44, p. 1-7) found growth differences with rats when fed different varieties of barley grown in approximately the same environment.

The differences in the feeding values of barley samples might be due to chemical composition. Morrison (68, p. 446-447) reported "West Coast" barley is often lower in protein and has a somewhat thicker hull than does barley grown in other areas of the United States. However, Morrison did not mention the variability in "West Coast" barley in regard to chemical composition. Some of the better "West Coast" barley is quite comparable to barley grown in other geographical areas. Follstad and Christensen (39, p. 331-336) found microflora were more abundant on grain in the Central states than the Western states. They concluded that microorganism invasion of barley kernels is mainly a function of weather during the time the kernels are growing and maturing. They also found species differences in resistance to microorganism invasion.

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1 Arscott, G. H. Personal communication. Poultry Science Department, Oregon State University. May 21, 1963.

It appears that barley is in some manner not yielding the energy expected in swine rations. Methods to increase the energy utilization include: add exogenous fat, add enzymes to digest the fiber or other complexes, and/or process the grain to inactivate the suspected inhibitor. Probably other means could be used to produce the desired effects, though at present no other explanations appear as feasible.

Fat Supplementation

The National Research Council (69, p. 2) reported that the minimum levels of fat and/or fatty acids required by swine are not known. Neither level of fat nor qualitative aspects of fatty acids are considered in balancing most swine rations. The National Research Council reviewed the literature and concluded that adding fat to swine rations at levels of 10 to 20 percent has increased growth rate 7 to 10 percent and improved feed efficiency up to 43 percent at the 20 percent fat level. However, the latter level of fat increased backfat thickness 24 percent. The Council further suggests that apparently fat has a linear effect on gain, feed efficiency and backfat thickness when included at levels up to 10 percent.

Combs, of the University of Maryland, is given credit for first investigating the Calorie-protein ratio in poultry. Swine nutritionists have followed Combs' example but disagree as to the proper ratio or to its value. Boenker *et al.*, at the University of Missouri (19, p. 1248), reported that the ratio had no influence on growth, feed efficiency or ration digestibility. They used three levels of metabolizable energy (approximately 1266, 1430, and 1952 Calories per pound) with rations containing 13, 16, or 19 percent protein (reduced to 10, 13, and 16 percent after the pigs reached 125 pounds). However, Clawson *et al.* (25, p. 1421), Lowerey *et al.* (65, p. 1165), and Noland *et al.* (72, p. 67-74) report with different ratios, that beneficial improvement in growth rate and feed efficiency can be obtained. It is difficult to compare directly results of the various researchers because many do not use the same standards; for instance, some use digestible energy while others use metabolizable or sometimes net energy. Thrasher *et al.* (90, p. 1297) found sex differences in responses to tallow additions to swine rations.

Fat additions and manipulation of Calorie-protein ratios are feasible only as long as minimal nutrient requirements are met. If the ration is deficient in protein and if fat is added, no benefit can be expected. Actually the cost of gain will increase (13, p. 1165). The ratio will change with age and type of production expected.

Further, the type of fat to be fed must be evaluated or poor results may be obtained. Oldfield and Anglemier (75, p. 917-921) added crude and altered Menhaden oils to swine rations, and noted that when either alkali-washed or crude oil was fed at the 5 percent level a pronounced fishy odor and taste developed although growth rate was enhanced. Polymerized oil produced inferior growth but no objectable odor or taste. Anglemier and Oldfield (5, p. 922-926) reported no change in growth rate or feed efficiency when levels of 2.75 or 5.5 percent of Pilchard (California sardine) oil was added to the ration. When fed at 8.25 percent of the ration, the animals eventually failed to eat and gain satisfactorily. Maynard and Loosli (66, p. 67) report monogastric animals deposit dietary fat in a relatively unchanged condition. Therefore, type of fat will influence carcass quality. Antioxidants must be added to the fat if adequate natural antioxidants (i.e. tocopherols or vitamin E) are not present in proper quantities. Rancid fat interferes with the stability of vitamins A, D, E, and K, as well as most of the B complex (53, p. 538-542).

There are numerous advantages to adding fat to livestock rations. Doty (36, p. 8-9), of the United States Department of Agriculture Economic Research Service, interviewed approximately one hundred firms engaged in feed production or processing which utilized over 60 percent of the fat added to feeds about 1960. He summarized from the results of the interviews that the advantages of feeding fats include: improvement of palatability, reduction of dustiness, improvement of texture, increased Calorie level, improvement of feed efficiency, increased ease of pelleting, increased die life, stabilization of the stratification of mixed feed, competitive price relationships, production of larger eggs, and supply of an unknown growth factor. Sewell and Nugara (81, p. 951) reported a level of 12 percent corn oil reduced the vitamin B_6 requirements approximately 40 percent in a purified diet for 21 day-old pigs.

Meade (67, p. 54-55) summarized the effect of 4 to 12 percent fat in rations adequate in level and balance of amino acids. Daily gain was increased or not affected, less dry matter was required per unit of gain, digestible energy required per unit of gain was decreased or not affected, only small changes occurred in carcass data, backfat tended to increase but without accompanying deleterious changes in loin eye area or yield of trimmed cuts, and daily feed intake decreased.

The mechanisms by which fat elicits its beneficial responses are not entirely known. Donaldson (35, p. 1106-1108) reported chicks responded to 10 percent added fat in an old, dirty environment but not in a new, clean environment. He referred to Supplee's work (30, p. 229) reporting a positive growth rate interaction in poults from the addition of corn oil and oleandomycin. Donaldson suggested that the fat response might be associated with the type or quantity of intestinal microorganisms. It is possible that oil could have a depressing effect on some microorganisms. Rand *et al.* (77, p. 1083) observed growth responses with corn oil fed to chicks which could not be attributed to variations in energy intake or intake of other nutrients. They proposed that the observed growth response was due to increased efficiency of utilization of metabolizable energy, improved utilization of dietary protein, and/or provision of an unidentified growth factor. Chapin (24, p. 52) reported that 5 percent added beef fat significantly ($P < .025$) increased the apparent digestibility of ether extract but had no effect on digestibility of dry matter, crude protein, ash, gross energy, and nitrogen free extract. The apparent digestibility of crude fiber was higher for the 5 percent added fat diet. Chapin thought this was due to the dilution of fiber intake and not to any effect of fat *per se.*

Enzyme Supplementation

Clickner and Follwell (26, p. 241-247) first reported the use of added enzymes in farm animal diets in 1925. They found improved growth in chickens when a crude fungal enzyme preparation was added to the ration. It was not until the 1950's, however, that research with enzyme supplementation received much attention in rations for swine and other species. Generally speaking, enzyme supplementation has been practically effective only with certain poultry diets and it has not been proven successful to date in other species.

Poultry respond most consistantly to enzymes containing amylolytic activity used as supplements to Western barley. [1] Barley in layer rations is as useful as any other grains but takes slightly more feed to produce a dozen eggs (4, p. 1230). Nelson and Hutto (71, p. 1229) found hatchability to be significantly improved and feed efficiency as well as egg production somewhat increased when amylase was added to barley rations. Barley has been used in so-called high efficiency broiler rations but must be pelleted and supplemented with fat to give comparable results to corn mash diets (10, p. 122). Replacing one-eighth to one-quarter of the barley with corn proved equally effective to an amylolytic enzyme supplement in broiler rations (6, p. 304). Barley, unless supplemented with an amylase or with corn, brings about increased water consumption and an adverse litter condition (6, p. 301-304).

The situation with ruminant animals is different, but some aspects are pertinent. Ruminants have tissues that produce endogenous

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[1] Arscott, G. H. Personal communication. Poultry Science Department, Oregon State University. May 21, 1963.

enzymes as well as a large microbial population that is a source of enzymes. The young ruminant is deficient in certain digestive enzymes but does not benefit from addition of pepsin, malt diastase, papain, animal diastase or pancreatin powder to various rations (95, p. 322-324). Neither addition of papain or pancreatic powder to the milk replacer (92, p. 975-980), nor addition of cellulase to the dry ration (59, p. 1460-1464), was beneficial to the calf.

Burroughs et al. 1959 (21, p. 1-8) first reported Agrozyme (an amylolytic-proteolytic enzyme preparation[1]) benefited low moisture ground ear corn in fattening rations. The work has not been confirmed by other research stations although it has been attempted by the Ohio Experiment Station (52, p. 13-16). Researchers in this area have been concerned with optimum levels, types, and combinations of enzymes with various rations. Both beneficial and negative results have been reported and thus enzyme supplementation cannot be recommended without qualification at this time in ruminant rations.

Becker and Terrill in 1954 (15, p. 178-183) reported that less than week-old pigs had difficulty digesting sucrose or starch but could digest lactose. Older pigs had difficulty digesting lactose (17, p. 399-403). Bailey et al. (12, p. 51) reported lactase activity in

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[1] A product of Merck and Co., Rahway, New Jersey.

baby pigs is high at birth but drops to a minimum at two weeks of age. Maltase and sucrase activities are low at birth and increase to a maximum at three to four weeks of age. Catron (23, p. 2) reported that the lipotrophic and proteolytic "enzyme" systems are underdeveloped until five weeks of age. Lewis et al. (62, p. 1047-1050) found that pepsin benefitted pre-starter rations particularly those containing soybean protein in place of milk protein. The stress of scours apparently increased the response to pepsin. Catron et al. (22, p. 23-47) reported pepsin and pancreatin improved soybean-containing pre-starter rations as did Combs et al. (27, p. 932-937) with practical rations for pigs weaned at approximately 10 days of age.

The use of enzymes in growing-finishing swine rations has been generally discouraging. Dinusson (30, p. 28-30) added five different enzyme preparations to barley rations without obtaining growth responses. Larsen (54, p. 46-48) investigated with swine the use of amylolytic enzymes that were used successfully with poultry and reported either slight improvement or depressed gains depending on the enzyme. He used levels of 0.5-2.0 grams of enzyme per pound. Barley malt at levels of 2.5 percent of the ration slightly improved feed efficiency but did not enhance growth rate (55, p. 25). When levels of 10 percent barley malt were employed, growth depression and lowered feed intake occurred. Larsen (54, p. 46-48; 2, p. 62) and Chapin (24, p. 63) reported a depressed growth rate and feed efficiency when several cellulase enzymes were added to the diet. Chapin (24, p. 63) suggested, further, because most enzyme preparations are crude (i. e., they contain more than one type of activity), the possibility exists that the enzyme supplement may inactivate the pig's endogenous enzymes, thereby decreasing the animal's ability to digest food. Chapin (24, p. 72) reported a significantly ($P < .01$) increased rate of gain (21 percent increase over non-supplemented controls) and a 1.3 percent increased efficiency of gain with Cellulase 4000. Thus, it might yet be possible to obtain beneficial results with enzyme supplementation.

Oldfield (73, p. 78-80) reviewed the use of enzymes in both baby pig and growing-fattening swine rations. He concluded the digestive tract differences between swine and poultry offered a logical explanation why swine did not respond as well as poultry to certain enzyme supplementation. Gill et al. (44, p. 1-7) suggested that the chick has a crop that allows sufficient time and a suitable pH to allow enzymes to become effective while the rat has no structure to provide the proper environment or time for enzymes to act. Oldfield (73, p. 78-80) thought possibly enzymes having high acidity activity characteristics or pre-treatment of feed with enzymes under optimum conditions prior to offering in the diet would enhance their activity. Chapin (24, p. 71) found no benefit with an enteric-coated "enzyme," Milezyme P, when employed at levels of 1.75 pounds per ton, nor did Larsen (55, p. 62) with levels of 20 grams per ton.

Providing the proper time and environment for enzymes to act is essential in order to obtain expected conversions. Leatherwood et al. (58, p. 1539) reported significant lowering of the cellulose content of alfalfa silage when a cellulase was added at the time of ensiling. This is further evidence that pre-treatment prior to feeding might be a logical approach to improved feeding value.

Enzymes are quite specific and thus the proper enzyme must be selected to utilize the substrate in question. Certain plant materials contain substances that actually inhibit certain enzyme activities. For example, leaf extracts of certain plant species were shown by Bell and Etchells (18, p. 220-223) to inhibit pectinase and cellulase.

Enzymes are proteins and thus subject to heat inactivation. Thus, it is possible in some of the enzyme studies that the pelleting process will inactivate the enzyme. Willingham et al. (93, p. 857), however, did not find this to be the case. They also reported that long storage (up to nine months) did not harm enzyme activity.

Pelleting

Dinusson and Bolin (31, p. 16) reported that pelleting barley causes less waste, greater palatability, increased density, and saves labor. Pigs as young as two weeks of age gain more rapidly and efficiently when fed pelleted rations compared to meal rations (48, p. 1491). Dinusson et al. (33, p. 1256) reported research at the North Dakota Station which found pelleted barley to increase gains 12 to 15 percent and increase feed efficiency 14 to 20 percent with swine.

Larsen (55, p. 14) found, in reviewing the literature, a direct association between crude fiber content of the diet and the efficacy of pelleting. Dinusson et al. (32, p. 930) reported a significant improvement in average daily gain and feed efficiency with pelleted oat rations when the fiber level varied from 2. 9 to 16 percent. Pelleting corn, a low-fiber grain, has not proved advantageous in swine rations (33, p. 1256; 57, p. 440-444).

The mechanisms by which pelleting improves performance are not entirely clear. Jensen (50, p. 50-51) believes the greatest part of the pelleting response is probably due to an increased density. Increased density of feed allows the pig to consume more feed per day if it is necessary, however, the pig is thought to eat on an energy basis (32, p. 930; 29, p. 18). There is evidence that pelleted rations do not always increase feed consumption (33, p. 1256; 55, p. 45). In some cases feed consumption will increase with pellets (31, p. 16-20) while in other cases feed consumption decreases (55, p. 22; 33, p. 1256). Sibbald et al. (82, p. 441-446) found a linear relationship between concentration of nutrients per unit volume of feed and weight gains of chicks. They found nutrient concentration, expressed in terms of weight per unit volume, is more satisfactory than expressing nutrient concentration in terms of weight only. In most cases feed utilization is improved by pelleting. This is especially evident in the work of Seerley et al. (80, p. 1291) where pigs which were fed free choice or on a limited basis were compared. They also found the mean feed retention time was significantly less for pellets than meal.

The advantage to pelleting barley for swine is lost when the pellets are reground (55, p. 61; 31, p. 18). Yet, a significant growth response occurred in chicks when they were fed reground pellets that had a similar particle size and density as the original meal (2, p. 1284-1289), however, the pellets still out-performed the reground pellets (50, p. 50-51). These poultry rations were based on corn and rye. Pearled barley, unlike corn or rye, was similar to the control mash for chicks when reground after pelleting (2, p. 1287). Arscott et al. (9, p. 1388-1389) could not confirm these findings. It is interesting to note that Allred et al. (2, p. 1286) found corn to be significantly improved when pelleted and fed to chicks. Thus certain cereals appear more responsive to pelleting than others and the response varies with the species to which the grain is fed. Larsen (55, p. 46) found no advantage in subjecting barley to wet autoclaving at 220° F and seven pounds of pressure in order to test the effect of heat and moisture. However, he did find a reduction in crude fiber in the process. Dinusson and Bolin (31, p. 16-20) reported there is no advantage to pelleting three times compared to only once.

There appear to be some chemical changes involved during the pelleting process. Crude fiber is reduced about one-half to one percent (31, p. 16-20; 56, p. 601-606; 48, p. 1491). Cellulose has also been reported to be lowered without any increase in either reducing sugar or total soluble carbohydrate (56, p. 601-606). Gorrill et al. (45, p. 82-93) found increased energy digestibility coefficients but a lowered protein digestibility coefficient after pelleting mixed wheat and barley rations. Troelsen and Bell (91, p. 63-74) reported that pelleting improves digestibility of dry matter and energy. The digestible energy was increased by 10 to 15 percent. Jensen (50, p. 50-51) mentioned that possibly nutrient requirements expressed per unit of feed are higher for poultry fed pellets than those fed mash. The reason suggested is that pelleting increases the available energy and thus alters the relationship with other nutrients. Jensen referred to unpublished data from the Washington Station to support this idea.

Larsen and Oldfield (56, p. 601-606) believe the greatest response of pelleting is due to lowered wastage. The percentage of fine material produced during the pelleting process or handling of pellets will influence the wastage factor of pellets themselves, because these "fines" are often rather dusty and unpalatable. Jensen (50, p. 50-51) found little difference in the number of times poults went to the feed trough when fed mash or pellets, but they spent 19 percent of a 12-hour day eating mash and only 2. 2 percent of the day eating pellets. Certainly time and energy are conserved with poults fed pellets.

Chapin (24, p. 29) reviewed the literature and concluded increasing available energy by adding fat and by pelleting has not proven to be additive in most experiments. Larsen (55, p. 62) suggested that crumbling of fat-containing pellets might be the reason no additive effect was obtained. Chapin (24, p. 30) suggested that by increasing the thickness of the pellet die or by increasing the taper of the holes in the die, pellets that will not crumble could be made with added fat.

Water Treatment

In the early part of this century the meal given to pigs was commonly soaked for varying lengths of time prior to feeding. This practice was used both in the United States and abroad. Barber et al. (14, p. 313) concluded that there does not appear to be any evidence to substantiate the value of soaking feed, and the practice is no longer being widely used in England although it is in several other countries. Wetting the feed at the time of feeding is again being used today on certain farms but there is still little in the way of conclusive data to defend such a practice.

A Kansas agricultural bulletin (47, p. 382-390) in 1909 stated that as much pork can be produced from a given amount of feed either in the wet or dry form provided an abundance of drinking water is supplied. Smith and Lucas (84, p. 220-235) found there was no advantage to feeding 8 to 25 pound pigs one part meal to two parts water. Actually the pigs tended to scour more on wet feed than with dry meal. Morrison (68, p. 448-449) reports that it is advantageous to soak hard or small kernel grains when it is not convenient to grind or crush them. He mentioned it will be useful to wet the meal under windy conditions to prevent loss by blowing. Leitch and Thomson (60, p. 197-223) cite Crowther as reporting that the warming up and disposal of the excess water consumed may involve an actual wastage of energy.

Thomas and Eden (87, p. 553) reported wetting the ration cured a particular dermatitis condition that has been found in England. Appetite of the pigs is affected by the dermatitis but the mechanism involved is unknown. Lewis et al. (63, p. 927) found wet feeding of a high calcium diet lessened the incidence of parakeratosis and increased the average daily gains. When zinc was added to the ration, method of feeding did not alter gains. Siegl (83, p. 307-321) in a behavior study found swine chose one-third of their barley meal ration in a dry form and two-thirds in a wet form. The swine spent 51 minutes of a 12-hour day consuming the dry meal and only 31 minutes consuming the wet feed.

Quilang in 1939 (76, p. 44-51), studied the ratios of water to feed with a corn and rice bran-type diet. Statistics were not used in the study but Quilang found a ratio of 5:1 (water to grain) gave the most economical results although growth was retarded compared to that on other rations with a higher percentage of grain. A mash ratio of 2:1 gave good growth but was least economical. A ratio of 3:1 gave the best average daily gain and was relatively efficient. Oregon State College (38, p. 75-76) feeding experiments during 1929-1930, showed that a ratio of 1 to 4 pounds of water to 1 pound of grain did not materially affect the rate or economy of gain.

Seerley in 1962 (79, p. 1-3) at South Dakota State College found in two trials that pigs self-fed a wet corn-soy-tankage ration gained 5.5 percent faster than pigs fed the dry ration. In their first trial the wet-fed pigs consumed less feed per day and were more efficient, however, a second trial showed the wet-fed pigs consumed more feed per day and were less efficient. Becker et al. (6, p. 6) in 1963 at the Illinois Station compared feeding four pounds per head per day of a corn-soy ration either dry or wet (1:1) to 100 to 200 pound swine. The dry-fed group gained 1.19 pounds per day with a feed conversion of 3.36, and the wet-fed group 1.35 pounds per day with a feed conversion of 2.96. Statistics were not applied to either the South Dakota or Illinois studies, however, it seems feeding a corn-soy ration wet will increase average daily gains and might increase efficiency.

Larsen (54, p. 29) postulated that the acidity of the swine's stomach might inactivate any enzyme supplement to barley rations. In an attempt to allow the action of these enzymes prior to entering the digestive tract, whole barley was soaked for eight hours with sufficient water to cover the grain. The barley was then dried for 8 to 12 hours at 110 to 140°F. The control dry-fed animals gained 1.46 pounds per day with 4.11 pounds of feed per pound of gain. The animals receiving the soaked ration gained 1.44 pounds per day with a feed efficiency of 4.18. Larsen also compared the effect of adding either 2.5 percent or 10 percent barley malt in either the dry or soaked form. It was thought barley malt would contain enzymes specific to barley and thus release components of the kernel that are unavailable to the pig. Soaking with the malt resulted in a trend toward improved feed efficiency, however, increased growth rate was noted only at the 2.5 percent level of malt. It was postulated that palatability was affected with the higher malt level because feed consumption decreased. Larsen thought the lack of response to soaking whole barley might in part be due to poor water penetration through the hull, and he pointed out there is a possibility that not enough water was used to activate the barley enzymes. Larsen's work showed some promise particularly when barley was water-soaked together with 2.5 percent malt.

Fry et al. (43, p. 249-251) reported cold water (40°C) treatment significantly ($P < .01$) improved average daily gains and feed efficiency in chicks. Treated barley was equal to corn for growth and was significantly better than corn for feed efficiency.

Water treatment has been used successfully to inactivate a pyridoxine antagonist present in linseed oil meal, and this prompted the water treatment studies with barley for poultry (43, p. 249-251). In general, barley responds more to water treatment than to enzyme additions with poultry (1, p. 1185-1186). The greatest advantages of water treatment are obtained when enzymes are soaked with barley (3, p. 1571-1584).

The water treatment varies with the research station but consists chiefly of soaking coarsely ground barley with an equal weight of tap water for zero to eight hours at room temperature (21°C), spreading on trays to a depth of 3/4 to 2 inches, and drying at 50 to 70°C for 15 to 24 hours (43, p. 249-251; 82, p. 124-130). Jensen (49, p. 150-151) reported that work at the Washington Station demonstrated oven temperature, tap water temperature, and state of grind are important in determining whether or not a response will be noticed. Jensen (49, p. 150-151) reported water treatment gave significant responses to most barleys with poultry but "West Coast" varieties respond to the greatest extent. Corn, wheat, oats, and milo were improved with water treatment (34, p. 1119; 1, p. 1185-1186).

The mechanism by which barley is improved for poultry by water treatment is not known. Fry _et al_. (41, p. 281-288) and Leong _et al_. (61, p. 36-39) believe an antibiotic is synthesized during the treatment which possibly controls microflora of the gut, increases digestibility and causes increased intestinal permeability. Thomas _et al_. (89, p. 1204-1208) found the incorporation of certain antibiotics into wet barley effectively prevented the beneficial effects normally encountered. Evidently the inhibition was brought about by inhibiting the action of contaminating microorganisms. Fry et al. (42, p. 1119) believe the improvement is due to an increased availability of energy as a result of enzyme activity inside the grain. Willingham et al. (94, p. 539-544) reported barley that had been autoclaved was not improved by subsequent water treatment.

Fry et al. (43, p. 249-251) thought barley might contain an inhibitor that might be inactivated by water treatment. Arscott et al. (8, p. 269) found evidence to support the inhibitor theory when they found autoclaving for one hour at 15 pounds pressure either before or after soaking barley did not destroy the beneficial effects derived from soaking, but did destroy the improvement brought about by an enzyme supplement.

The drying process apparently is quite important in determining whether or not a response will be obtained. Arscott[1] found no improvement with water treatment followed by freeze drying, yet oven drying gave the expected result, which may suggest that microorganisms are involved in the water treatment process. Thomas et

[1] Arscott, G. H. Personal communication. Poultry Science Department, Oregon State University. May 21, 1963.

al. (88, p. 198-200) found water-treated barley taken from the oven contained many more bacteria than untreated barley. They reported the drying temperature of barley during water treatment was favorable for microbial growth, especially during the first seven hours of drying because of evaporation. Jensen (49, p. 150-151) reported that water-treated barley that was dried at 70°C was markedly improved over controls. When the grain was wet-autoclaved and dried at 95°C, no improvement was made. Jensen isolated an organism in his laboratory and found performance was similar to water treatment when the organism was inoculated on barley that had been wet autoclaved.

GENERAL EXPERIMENTAL PROCEDURE

The literature reviewed indicates several promising avenues for improving the utilization of barley by swine. More specifically, the methods include pelleting, enzyme supplementation, fat supplementation, and/or water treatment. Feeding trials during 1962 and 1963 were conducted with swine at Oregon State University to investigate the above-mentioned methods and determine their effects on rate of gain, feed conversion, average daily feed consumption, carcass shrink and fat quality. The designs for the feeding trials can be found in Table 1.

TABLE 1

Experimental Designs of the Feeding Trials

Experiment 62-1 — 2 x 4 Factorial Design

Treatment	Control	Cellulase 4000	Fat	Cellulase 4000 + Fat
		Ration Number		
Meal	1	2	3	4
Pellets	5	6	7	8

Experiment 62-2 — Randomized Block Design

Ration No.	1	2	3	4
Treatment	Control	Soak	Wet	Cellulase 4000 + Fat

Experiment 63-1 — Randomized Block Design

Ration No.	1	2	3	4	5
Treatment	Control	Cellulase 4000	Wet	Soak	Soak + Cellulase 4000

Finally, a laboratory study was undertaken to investigate the influence of wetting or soaking several substances for various time intervals, with or without Cellulase 4000[1], and investigate their effects on cellulose, crude fiber and reducing sugar content.

The use of pellets has been shown to increase average daily gains and improve feed conversion of swine barley rations. Fat supplementation has produced results similar to pelleting but the two have not been additive in improving performance. Chapin (24, p. 69-70) suggested that a modified pellet die with a taper designed to produce a harder pellet might bring about an additive effect with pelleting and fat supplementation. Experiment 63-1 was designated to investigate such a die with a barley control ration as well as a 5 percent fat supplemented ration. Cellulase 4000 was also included in several treatment rations.

Supplementation of growing-finishing swine rations with enzymes has not given as consistent improvement as it does with certain poultry rations. It is possible that the deficient enzymes have not been used and, therefore, such enzymes must yet be identified. Chapin (24, p. 72) reported that Cellulase 4000 significantly ($P < .01$) improved average daily gains although only slight improvement in feed conversion was shown. Such an enzyme appears

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[1] Product of Miles Laboratories, Elkhart, Indiana.

logical for use with barley rations and, therefore, was included in rations for Experiments 62-1, 62-2, and 63-1. The rations were similar to Chapin's except herring meal replaced meat and bone scraps, steamed bone meal replaced limestone flour, and small changes in quantities of feedstuffs were made in order to balance the rations.

Feeding barley rations in either a wet or soaked form was investigated and compared to a dry control ration in Experiment 62-2. The wet form consisted of applying water to the ration at the time of feeding. The soaked ration was prepared by soaking the ration 9 to 15 hours depending upon whether the ration was prepared in the morning or evening. Experiment 63-1 was similar to Experiment 62-2, except the water used in the wet rations and the soaked ration itself was kept under some temperature control in order to eliminate the wide fluctuation in water temperature caused by environmental conditions. It is possible these methods of feeding will inactivate any inhibitor action that might be present in barley, possibly increase palatability, activate endogenous enzymes, provide an environment for microorganism growth, and/or provide an environment with soaked rations for the cellulase preparation to effectively reduce cellulose.

Experiment 62-1

The objective of Experiment 62-1 was to determine whether an additive effect with regard to improved daily gains and feed conversion could be obtained with fat supplementation and pelleting through the aid of a modified pellet die. The die was manufactured with a taper designed to produce a dense pellet. A further objective was to confirm the increased average daily gains reported by Chapin (24, p. 72) in which Cellulase 4000 was incorporated in a similar barley-based ration.

Materials and Methods

A randomized 2 x 4 factorial experimental design was used with eight treatments and six replications. Forty-eight Yorkshire-Berkshire crossbred weaner pigs from the University swine herd were assigned by weight to the various replications and then assigned to treatments in a manner which provides approximately equal initial weights for each treatment. In a few cases pigs were reassigned treatments in order to prevent excessive use of pigs from one sex or one litter. The range of weight within each group was approximately 25 pounds. The eight treatments were as follows:

1. Basal barley, meal
2. As 1, plus enzyme preparation

3. Basal barley, meal, plus 5 percent beef tallow
4. As 3, plus enzyme preparation
5. Basal barley, pellet
6. As 5, plus enzyme preparation
7. Basal barley, pellet, plus 5 percent beef tallow
8. As 7, plus enzyme preparation

The rations were prepared under University supervision at a local mill. Stabilized beef tallow replaced 5 percent of the barley component. The enzyme was added to the ration at the rate of one pound of enzyme preparation to 1000 pounds of ration. The enzyme preparation consists chiefly of cellulase but some pectinase, hemicellulase and negligible amounts of other enzymes are present. The pellets were subjected to approximately 55 pounds of steam per square inch for less than 30 seconds. The modified pellet die was one-quarter inch thicker than the normal die and had a five-eights inch taper on the inside. It produced pellets three-sixteenths of an inch in diameter.

The compositions of the experimental rations are given in Table 2. The rations were balanced to meet the National Research Council (69, p. 8-9) recommendations with the exception of energy.

The swine were individually housed in 4' x 6' pens, and were randomized to the various pens in order to eliminate the

TABLE 2

Ration Ingredients For Experiment 63-1

Feedstuffs	Ration 1, 2, 5, 6	Ration 3, 4, 7, 8
Barley	86.6	81.6
Herring Fish Meal	4.5	4.5
Stabilized Tallow	---	5.0
Soybean Oil Meal	7.0	7.0
Steamed Bone Meal	1.3	1.3
Iodized Salt	0.5	0.5
Premix	0.1	0.1

Premix	Grams per 100 lbs. of Ration
Vitamin A. Supplement - Nopco, 10,000 U.S.P. units/g to supply 500 units/lb.	40.00
Riboflavin - Pfizer, R3.63 to supply 25 mg/lb.	31.00
TM 10 - Pfizer, to supply 5 mg/lb.	227.00
Pantothenic acid - NBC, 92% Calcium Pantothenate to supply 1.4 mg/lb.	10.00
Vitamin D_2 - Nopco, 4,000,000 U.S.P. units/g to supply 60 I.U./lb.	6.82
	306.34

Cellulase 4000 1 lb./1000 lbs. for Rations No. 2, 4, 6, 8

environmental influence on treatments. The pens were located inside an aluminum structure that did not permit any direct sunlight. Wooden pallets 2' x 4' in length were placed over the concrete floor and used in place of bedding. Feed was offered ad libitum from a self-feeder as was water from an automatic waterer. The self-feeders were checked daily to prevent wastage and were cleaned only once, approximately four weeks from the date the experiment began. The pigs were weighed weekly and removed from the experiment the week they reached or exceeded 190 pounds.

Proximate analyses of the rations were determined on a dry matter basis and are reported in Table 3. The feed samples were ground in a Wiley mill through a 20 mesh screen. The samples were processed by the methods recommended by the Association of Official Agricultural Chemists (11, p. 367-373) except protein was determined with Oldfield's (74) modification which consists of collecting the distillate in 4 percent boric acid and using an indicator composed of 0.1 percent bromcresol green in 95 percent alcohol (2 ml). Gross energy was determined with a Parr oxygen bomb calorimeter. Pellet hardness was determined with the use of a Christel Modified Shear Press. The feed samples were collected at the initiation of the experiment but were not analyzed for hardness or density until completion of the experiment. Ration density was measured by dropping feed from a uniform height and at a constant rate into a straight-sided can with known volume. The top of the can was leveled and the can weighed.

TABLE 3

Proximate Composition Of Rations Used In Experiment 62-1

Ration	Dry Matter %	Crude Protein %	Ether Extract %	Crude Fiber %	Ash %	NFE %	Energy K Cal/gm
1. Basal meal	89.20	14.35	1.36	4.61	4.04	75.64	4.107
2. Basal meal + Cellulase 4000	89.25	14.44	1.74	4.48	4.78	74.56	4.128
3. Basal meal + 5% fat	89.92	14.29	6.88	4.16	4.74	69.93	4.335
4. Basal meal + Cellulase 4000 + 5% fat	89.11	13.46	6.36	4.74	4.38	71.06	4.320
5. Basal pellet	90.79	14.24	1.92	4.62	4.68	74.54	4.075
6. Basal pellet + Cellulase 4000	89.54	13.74	1.45	4.57	4.50	75.74	4.150
7. Basal pellet + 5% fat	89.48	13.72	6.74	4.14	4.32	71.08	4.330
8. Basal pellet + Cellulase 4000 + 5% fat	89.39	13.76	6.75	3.97	4.24	71.28	4.360

Results and Discussion

Table 4 contains the initial weight of the pigs, average daily gains, feed conversion, and average daily feed consumption. Statistical analysis for the randomized block factorial experiment, as described by Li (64, p. 316-318) was used on the data. Duncan's (37, p. 1-42) new multiple range test was used to evaluate differences among treatments and is reported as such in Table 4.

The data showed that the control rations were approximately 7 percent bulkier as a meal than as pellets. Chapin (24, p. 73) reported approximately a 12 percent difference with similar type rations. Fat-containing pellets were equally bulky in either the meal or pellet form. It took approximately 32 percent less force to crush fat containing pellets than control pellets. It appeared that the modified die did not produce as dense a pellet when fat was added as it did with the control ration. However, the die was new and might have presented some abnormal friction problems. In support of this theory, it may be related that approximately 1000 pounds of additional feed per treatment were prepared as the experiment was drawing to a close in order to complete the trials. Neither hardness nor density was determined in the latter mix but the pellets appeared considerably harder. Even the fat-containing pellets appeared to hold up well in the feeders.

TABLE 4

Summary Of Results For Experiment 62-1

	Meal				Pellet			
Treatment	1	2	3	4	5	6	7	8
	Control	Cellulase 4000	Fat	Cellulase 4000 + Fat	Control	Cellulase 4000	Fat	Cellulase 4000 + Fat
Number of Pigs	8	8	8	8	8	8	8	8
Average Initial Weight (Lbs.)	72.00	71.33	71.17	70.33	71.50	70.83	72.17	71.33
Average Daily Gain (Lbs.)	2.09	2.14	2.24	2.22	2.15	2.24	2.25	2.26
Average Daily Feed Intake (Lbs.)	7.04	7.12	7.04	6.83	6.91	6.76	6.44	7.01
Feed Conversion (Lbs.)	3.37 a *	3.32 ab	3.15 abc	3.08 bcd	3.21 abc	3.02 cd	2.86 d	3.10 abcd

* Values with the same letters within a column do not differ significantly (P > .05) according to Duncan's (37, p. 1-42) new multiple range test.

Pooled data of the treatments comparing fat supplemented versus non-fat supplemented rations, showed fat supplementation caused a 6 percent increase in efficiency of feed utilization, with a 2 percent reduction in average daily feed intake. It made no significant ($P > .05$) change in average daily gains or daily feed consumption but caused significant changes in feed conversion when only pelleted and meal data were pooled. With the latter pooled data, the fat supplemented group was shown to have a significantly ($P < .01$) lower feed conversion efficiency than the controls. The group supplemented with fat and Cellulase 4000 approached significance ($P > .05$) in deviating from the controls with respect to feed conversion.

Larsen (55, p. 62) noted that addition of 5 percent beef tallow enhanced growth rate and efficiency of feed utilization of meal-fed pigs ($P < .01$) but not of pellet-fed swine. Results from this experiment showed fat supplementation increased daily gains of both a control-meal and a control-pellet ration. Fat supplementation increased efficiency of utilization of the control-meal and control-pellet rations but was only significant ($P < .01$) with the pelleted ration. The pelleted fat containing ration significantly ($P < .05$) differed from the control-pellet ration. Thus an additive effect was found with pelleting and fat supplementation in respect to feed conversion. The addition of both Cellulase 4000 and fat tended to reduce the beneficial effect of either supplementation in the pelleted medium.

Pelleting markedly improved feed conversion (P .01) but not the average daily gains as shown with pooled meal versus pellets data. This generally agrees with Larsen's (54, p. 46) work where average daily gains and feed conversion were significantly (P $<$ .01) improved by pelleting barley rations. This experiment showed pelleting was most effective in the non-fat supplemented type of rations which is in agreement with Larsen (55, p. 14) where he found in reviewing the literature that higher-fibered rations respond greatest to pelleting. However, there was an additive effect, as mentioned with pelleting and fat supplementation with regard to feed conversion. Daily feed consumption was decreased by pelleting except with ration 8 which contained both fat and enzymes. Larsen (55, p. 45) noticed that feed consumption decreased when a barley control ration was pelleted. He found no difference in consumption when the ration contained 5 percent added tallow and was pelleted. It is possible that ration 8 produced more "fines" than ration 7 and, therefore, reverted more toward the meal form. This appears unlikely, however, because samples of ration 8 were found to be approximately 11 percent harder than ration 7. There was no consistent reduction in crude fiber noticed in this experiment.

Pooled data for meal and pelleted control rations showed Cellulase 4000 increased daily gains 3 percent and decreased daily feed consumption, as well as the amount of feed to produce a pound of gain, by 4 percent. These results do not confirm Chapin's (24, p. 72) findings where Cellulase 4000 improved average daily gains by 21 percent ($P < .01$). However, they surpassed Chapin's findings of only a 1.3 percent improvement in feed conversion with Cellulase 4000 supplementation. Similar pooled data for fat supplemented rations showed no difference in average daily gains, but daily feed consumption slightly increased as did feed conversion.

Miles Chemical Company analyzed samples of the experimental rations and recorded a depression in Cellulase activity with fat supplementation. Members of their staff suggested that fat either changed the solubility of the enzyme or interfered with the assay procedure. They mentioned further that pelleting brings about some inactivation of Cellulase activity. However, in the animal experiments Cellulase 4000 supplementation actually showed greater performance improvement with pelleted rations than with meal rations.

Experiment 62-2

The objective of Experiment 62-2 was to determine whether inherent or added enzyme activity could be enhanced by wetting or soaking the ration prior to feeding.

Material and Methods

A four-treatment randomized block design with six replications was utilized. Twenty-four crossbred Yorkshire-Berkshire pigs were allocated to treatments in a similar manner as in Experiment 62-1, except that there was no reassignment of pigs necessary to prevent excessive use of littermates or pigs of the same sex. The resulting treatments had approximately equal initial weights. The range of weight within each group was approximately 54 pounds. The four treatments were as follows:

1. Basal barley, dry meal
2. As 1, fed wet (2 parts tap water: 1 part concentrate)
3. As 1, soaked and fed in the wet form (2:1)
4. As 3, plus Cellulase 4000

The rations were prepared in meal form at the Oregon State University Swine Barn. The ration used was the same as ration 1 in Table 2. Cellulase 4000 was added at the same level as with ration 2 in Table 2. Representative samples of the rations were obtained at the completion of the experiment, and proximate analyses, as described in Experiment 62-1, were determined on them. The analyses are given in Table 5.

TABLE 5

Proximate Composition of Rations Used In Experiment 62-2

Ration	Dry Matter %	Crude Protein %	Ether Extract %	Crude Fiber %	Ash %	NFE %	Energy K Cal/gm
1. Basal Meal	90.20	17.02	1.87	5.82	4.46	70.83	4.173
2. Basal Meal + Cellulase 4000	91.05	17.32	2.12	5.48	4.04	71.04	4.220

The treatments were randomly assigned to large pens and the pigs of each treatment were raised as a group. The pens had wooden pallets, in lieu of bedding, placed over part of the concrete floors. The pens were partly covered, therefore providing shelter as well as some direct sunlight. Each pen was equipped with an automatic waterer and pigs were fed on an ad libitum basis in either metal troughs or in conventional self-feeders. The troughs were metal and contained dividers spaced eight inches apart to prevent feed wastage and contamination. The animals were fed at approximately 8:00 A. M. and 5:00 P. M. Feed was collected from the troughs as was the material that was deposited around the trough. This "weigh back" material was sampled for dry matter, corrected to an air-dry basis, and subtracted from the feed cost of the group. The soaked or wet rations contained one part concentrate to two parts tap water. This ratio allowed about one inch of water to remain over the feed after soaking for the prescribed time. At the time of feeding, a new batch of feed was prepared for soaking thus allowing 9 to 15 hours actual soaking prior to feeding.

The pigs were weighed weekly and removed from the experiment the week they reached or exceeded 190 pounds. The animals were weighed at 1:00 P. M. (midway between feedings) in an attempt to prevent a large fill weight for the animals receiving water-treated rations.

Results and Discussion

Table 6 contains average initial weights, average daily gains and the average feed conversion of the treatments. Only average daily gains could be treated statistically. These were found to be linear with average initial weight according to the method described by Li (64, p. 295-298) but further tests described by Li (64, p. 344-349; p. 370) showed the data were applicable to the analysis of variance. The latter method was, therefore, used on the randomized block design.

There were no significant differences ($P > .25$) in daily

TABLE 6

Summary of Results for Experiment 62-2

Treatment	1 Control	2 Wet	3 Soak	4 Soak + Cellulase 4000
No. of Pigs	6	6	6	6
Average Initial Weight (Lbs.)	63.00	63.50	64.17	64.00
Average Daily Gain (Lbs.)	1.93	2.04	2.07	2.18
Average Daily Feed Intake (Lbs.)	5.80	7.39	7.40	7.91
Feed Conversion (Lbs.)	3.01	3.62	3.57	3.63

gains among the treatments. Possibly the large variation within a treatment (average daily gains ranged over 0.5 lbs. per treatment) and the small sample size masked any differences. However, the "soak plus Cellulase 4000" group, "soak" group, and the "wet" group gained 13, 7, and 6 percent faster, respectively, than the controls. There appear to be only slight differences between soaking and wet feeding with respect to daily gains. Cellulase 4000 tends to bring about an additive effect with soaking.

The controls required approximately 0.6 pounds less feed to produce a pound of gain than any other treatment. The other treatments had quite similar feed conversions as the variation among them was only .06 pounds. Average daily feed consumption was lowest for the controls and highest for the "soak plus Cellulase 4000" group.

The findings in this experiment, that water treatment brings about increased daily gains, agrees with Seerley's work (79, p. 1-3) at South Dakota State College and the University of Illinois study (16, p. 1-6) with corn-soy rations. The increased daily feed consumption due to wetting or soaking the ration and the less efficient utilization of it agrees with Seerley's trial number 2 but not with his trial number 1 or the University of Illinois' findings.

It appears likely that the mechanism involved in the increased daily gains of the "wet" or "soaked-fed" groups is largely concerned with palatability. Certainly, feed consumption is increased. Feed conversion probably would be improved if the mechanism was due to improvement in digestibility of the ration. Palatability is also suspected as the mechanism because feed conversion is not decreased and would not be expected to decrease if Brody's (20, p. 97) findings are correct. Brody reported that as feed consumption increases above maintenance, net energy per unit of feed decreases in accordance with the principle of diminishing returns. Of course, growth increases as feed consumption increases above maintenance cost. Also, the fresh wet and soaked rations appeared quite palatable, for the swine fought for the ration at feeding time. Related is the statement made by Morrison (68, p. 165) that succulent feeds are relishes for farm animals. It is interesting that the group receiving Cellulase 4000 gained the fastest, yet, were the least efficient feed converters. The results of this experiment do not entirely confirm the value of supplementation with a cellulase enzyme in a soaked medium.

Experiment 63-1

The goal of Experiment 63-1 was to clarify further the practice of wetting or soaking the barley ration prior to feeding. Cellulase 4000 was supplemented in both a dry ration and a soaked ration to confirm the efficacy of this preparation in swine barley rations.

Materials and Methods

Forty crossbred Yorkshire-Berkshire weaner pigs were assigned exactly as in Experiment 62-2 to a five treatment randomized block design. Again the treatments were randomized to pens in order to eliminate any biased effect due to pen assignment. The resulting treatments had approximately the same initial weights. The range within each treatment was about 48 pounds. The five treatments were as follows:

1. Basal barley, dry meal
2. As 2, plus Cellulase 4000
3. As 1 , fed wet
4. As 1, soaked and fed in the wet form

5. As 4, plus Cellulase 4000.

The rations were identical to those of Experiment 62-2, and were prepared in the same manner. Proximate analyses of the rations are given in Table 7. However, unlike Experiment 62-2,

TABLE 7

Proximate Composition of Rations Used In Experiment 63-1

Ration	Dry Matter %	Crude Protein %	Ether Extract %	Crude Fiber %	Ash %	NFE %	Energy K Cal/gm
1. Basal Meal	89.80	17.00	2.12	5.54	4.61	70.73	4.177
2. Basal Meal + Cellulase 4000	89.46	16.39	1.77	5.65	4.54	71.65	4.127

temperature control was utilized to prevent the fluctuation that often occurred in the water temperature of the soaked or wet-fed ration. The water was pre-warmed to 80° F prior to use with the soaked rations or with the wet-fed rations. The soaked rations were placed, along with the water to be warmed, in cans located in a small enclosure containing an electric heater. Temperatures of various locations in the enclosure, as well as water temperature and soaked ration temperatures, were noted.

The pigs were weighed in a similar manner as in Experiment 62-2 but were removed from treatment the week they reached or exceeded 200 pounds. On removal from the treatments they were subjected to a 24-hour shrink in individual 4' x 6' pens and given only water.

The pigs were weighed, measured for backfat thickness, and a core of fat (approximately 0.5 to 1.0 gram) removed upon completion of the 24-hour shrink. Iodine numbers were determined with a modification of the procedure (Hanus) recommended and described by the Association of Official Agricultural Chemists (11, p. 464-465). The modification required only three minutes standing after adding mercuric acetate, and not 30 minutes as in the Hanus method.

Results and Discussion

During the sixth week of the experiment, approximately 25 percent of the animals showed signs of some growth depression apparently due to the residues of carbon tetrachloride treatment of stored grain used in the rations. None of the animals in the wet-fed group were affected.

The affected animals were given a combination of penicillin and streptomycin at this time. Their subsequent daily gains rapidly increased to approximately the level of the "non-affected" animals, and, therefore, the exposed animals were not removed from the experiment. In the following weeks one animal from treatment 4 and two from treatment 5 became lame and had to be removed from the experiment. In view of the complications encountered, it was decided to discontinue the experiment during the tenth week.

The results of the experiment are given in Table 8. A number of the pigs reached 200 pounds and were removed from the experiment prior to its discontinuance. However, the data were treated by the methods described by Li (64, p. 295, 344-349, 370) and corrected with covariance where necessary. Dummy values were determined by Li's method (64, p. 290-312) and used with any data that was subjected to statistical analysis and found linear.

The results for the average daily gains were somewhat similar to Experiment 62-2. It is interesting to note that the "soak plus Cellulase 4000" group grew the fastest. Yet, when two dummy values were used and the data adjusted to a common mean, this group no longer was the most rapid gaining. Again, however, the "soaked" group, with one dummy value, slightly outgained the "wet" group. Cellulase 4000 brought about a slight, though non-significant ($P > .05$), improvement over the controls.

Results for average daily feed consumption and feed conversion were not subjected to statistical analysis. Estimations were made in order to correct for the feed consumption of animals removed from treatments. Cellulase 4000 in Experiment 62-1 apparently brought about a slight increase in daily feed consumption and a slight improvement in feed conversion. In this experiment there was an increase in feed consumption but a small decrease in feed

TABLE 8

Summary of Results for Experiment 63-1

Treatment	1 Control	2 Cellulase 4000	3 Wet	4 Soak	5 Soak + Cellulase 4000
Number of Pigs	8	8	8	7	6
Average Initial Weight (Lbs.)	68.87	70.25	68.88	72.57	69.33
Average Final Weight (Lbs.)	186.00	182.12	196.88	195.86	189.50
Average Daily Gain (Lbs.)	1.75	1.76	1.99	1.96	2.02
Adjusted Average Daily Gain **	1.77a*	1.80a	2.03b	2.07b	1.91ab
Average Daily Feed Intake (Lbs.)	5.60	5.80	7.22	7.21	7.91
Feed Conversion	3.20	3.30	3.63	3.68	3.92
Average Backfat (Inches) **	1.25 1.32ab	1.16 1.29ab	1.32 1.20b	1.22 1.15b	1.41 1.39a
Average Shrink (%) **	5.77b	4.56c	6.21b	7.58a	5.05bc
Average Iodine Number	48.5 49.7 (7)***ac	49.2 49.0 (7) a	46.0 45.2 (6) bc	43.7 46.2 (4) b	45.0 47.6 (5) b

* Values with the same letters within a column do not differ significantly (P > .05) according to Duncan's (37, p. 1-42) new multiple range test.

** Includes dummy values.

*** Numbers inside of parenthesis refer to number of animals sampled per treatment during the second iodine number determinations.

utilization. As in Experiment 62-2, the "soak plus Cellulase 4000" group had the largest daily feed intake and was the least efficient. In Experiment 62-2, the "wet" group consumed slightly less feed and was less efficient than the group receiving the soaked ration, but the positions changed in this experiment.

Part of the reason for the somewhat poorer performance of the "soaked" groups compared to the wet-fed group might be due to the temperature control imposed. The average temperature of the enclosure was 94°F, the average temperature of the water was 80°F, and the average temperature of the soaking rations was 85°F. At these temperatures some fermentation losses occur, especially after eight hours of soaking. Possibly the Cellulase 4000 was quite effective in the warm soaking environment and contributed to a greater degradation loss because this group had a much poorer feed conversion than in Experiment 62-2. The temperature control might be responsible for the somewhat better feed conversions and daily gains for the "wet" and "soaked" groups compared to the controls. A warm mash on a cold day might be rather palatable and certainly the warm water will eliminate some of the maintenance cost for heat production. These trials occurred during January through April during rather cold weather. Possibly in warmer weather the warmer mashes would be less beneficial.

Average final weight influenced the amount of backfat, however, according to Li (64, p. 366-370), covariance was the test to be applied to this analysis and in turn it corrected for the situation. The only significant ($P < .05$) difference was that the "soak plus Cellulase 4000" group had a thicker backfat than the "soak" or "wet" group. The control and the "control plus Cellulase 4000" group had adjusted mean backfats of 1.32 and 1.29 inches respectively. The wet-fed group and the soak-fed groups had backfats of 1.20 and 1.15 inches respectively. These latter measurements averaged 11 percent lower than the "dry" groups. The "soak plus Cellulase 4000" group had a backfat 5 percent larger than the controls, 8 percent larger than the "control plus Cellulase 4000," and 21 percent larger than the "soak" group. It seems mash feeding reduces backfat only in the absence of Cellulase 4000.

It was found unnecessary to adjust the means for percent shrink and, therefore, analysis of variance was used on the data. The "soak-fed" group was highly significantly ($P < .01$) larger than groups 1, 2, and 4; it was significantly larger ($P < .05$) than group 3 with respect to percent shrink. The "wet" group was significantly larger than "Cellulase 4000" group ($P < .01$) and the "soak plus Cellulase 4000" group ($P < .05$). Apparently feeding in a mash form tended to cause a higher percent shrinkage loss except when Cellulase 4000 was present. The reason for this is not known but might be due in part to increased water consumption and the decreased fat production. It is interesting to note that Cellulase 4000, in either the dry or soaked ration, tended to decrease shrinkage over the controls and mash-fed groups. In fact, the "Cellulase 4000" group had a significantly ($P < .05$) lower shrinkage.

Iodine numbers were first determined on eight animals that had reached or exceeded 200 pounds. Upon discontinuing the experiment, the other animals' fats were analyzed. When the two runs were pooled, no significant differences were noted ($P > .10$). Yet, a significant ($P < .05$) difference among the treatments was noticed when the second run only was analyzed statistically. The "Cellulase 4000" group had a larger iodine number than the "soak" group ($P < .01$), "soak plus Cellulase 4000" group ($P < .01$) and the "wet" group ($P < .05$). The controls had a larger iodine number than the "soak" group ($P < .01$), the "soak plus Cellulase 4000" group ($P < .05$) and the "wet" group (approached the $P > .05$ level). Considering both runs, the trend was identical with respect to differences between dry feeding and mash feeding. Mash feeding produces a harder or more saturated fat. Cellulase 4000 appears to have little or no influence on iodine numbers. Also there was no linearity between final weight and iodine number.

Laboratory Study

The objective of the laboratory study was to determine the extent to which Cellulase 4000 would reduce the cellulose content of either Solka Floc[1], which is a pure source of wood cellulose, or in the control barley ration. Another goal of this experiment was to study the chemical changes in reducing sugar content, cellulose, hydrogen-ion concentration, or crude fiber which were initiated due to the wetting or soaking of the experimental rations. Interactions between soaking or wetting with or without Cellulase 4000 were also studied.

Materials and Methods

A sample of the control barley ration was obtained from Experiment 63-1. It was ground through a number 40 screen in a Wiley Mill as was the Solka Floc. A portion of these materials was mixed in the laboratory with Cellulase 4000. The following substrates were used:

1. Control barley ration
2. Control barley ration plus Cellulase 4000
3. Solka Floc

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[1] Product of the Brown Co., Berlin, New Hampshire.

4. Solka Floc plus Cellulase 4000

The substrates were soaked for either 0, 4, or 12 hours. It was assumed that the four-hour interval would correspond to the "wetting" process used in the animal trials where some feed would remain in the trough about that length of time. The samples were soaked in glass containers instead of pails, but otherwise subjected to the same temperatures as in Experiment 63-1. The pH of each mixture was determined with a Beckman Zeromatic pH meter.[1] The samples were dried in a 100°C oven for at least 24 hours and then reground with the same size screen, after which they were re-dried prior to their use.

Cellulose content was determined with only the Solka Floc rations because the procedure was not consistent with higher fat- or carbohydrate-containing substrates. A modification of the Crampton and Maynard (28, p. 383-395) procedure was used. Briefly, the modification consisted of heating centrifuge tubes containing 0.5 gram of sample in a water bath for 30 minutes instead of refluxing. Then 20 mls. of ethanol were added to each tube and allowed to stand 20 minutes before filtering into Gooch crucibles. Crude fiber analysis was then performed. The method for blood sugar analysis (85, p. 375-380) was used on all of the substrates.

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[1] Beckman Instruments, Inc. Fullerton, California.

The samples were prepared for blood (or reducing) sugar analysis by soaking one gram of sample in a graduated test tube diluted with tap water to the 10 ml. mark for 30 minutes. One ml. of the solution was used in preparing the Folin-Wu filtrate. The results of the laboratory study are summarized in Table 9.

TABLE 9

Summary of Results for the Laboratory Study

Ration	pH			Reducing Sugar mg%			Crude Fiber %			Cellulose %		
	0	4	12	0	4	12	0	4	12	0	4	12
1. Control barley	6.23	6.35	6.22	2.2	24.8	38.0	5.59	5.75	6.12	-	-	-
2. Control barley + Cellulase 4000	6.23	6.31	6.22	6.2	28.0	>40.0	5.32	5.66	7.22	-	-	-
3. Solka Floc	6.82	6.80	6.65	-	-	-	-	-	-	98.46	97.26	96.76
4. Solka Floc + Cellulase 4000	6.82	6.72	6.58	-	-	-	-	-	-	97.38	97.24	97.22

Results and Discussion

The pH of the samples was lower in the presence of Cellulase 4000. They reached the same point after 12 hours for the barley ration but the Solka Floc plus Cellulase 4000 was about 0.1 pH unit lower than Solka Floc. Cellulase 4000 is most active in a pH range of 3.0 to 5.0 but is supposed to operate effectively between pH 3.0 and 8.0. Possibly the higher pH of barley rations (6.2 - 6.3) explains in part why Cellulase 4000 has not been more successful in feeding trials.

The data in Table 9 show an increasing concentration of reducing sugars as the barley ration soaks for increasing periods of time up to 12 hours. Apparently Cellulase 4000 is contributing to the cellulose breakdown and release of glucose units. This is readily noticeable as the ration containing the enzyme has a higher reducing sugar content than the control ration. Solka Floc, with or without Cellulase 4000, had less than 0. 5 mgs. percent reducing sugar with any time interval. The concentration of Solka Floc was doubled, compared to the barley ration, and yet the reducing sugar concentration was not in a range to be accurately read on the Beckman Model DU Quartz Spectrophotometer.[1]

Cellulose concentration in Solka Floc was shown to be decreased in a linear manner with soaking time. When Cellulase 4000 was added to the Solka Floc, the same relative decrease in cellulose concentration with soaking time was observed. The initial cellulose concentration at 0 hour was lower in the presence of Cellulase 4000, but actually was higher than the "control" Solka Floc at the twelfth hour. These results can be judged only on a relative basis. The analysis is not completely accurate because Solka Floc is supposed to be essentially pure cellulose. Yet, the analysis did not show this

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[1] Beckman Instruments, Inc. Fullerton, California.

to be so. Within certain limits, however, a pattern apparently exists.

Crude fiber concentration was shown to increase proportionally in barley rations with the soaking time. There was a greater increase in crude fiber when Cellulase 4000 was added. Actually, there was probably little or no change in crude fiber content *per se*. In the presence of Cellulase 4000, one would expect a reduction in cellulose. The enzyme would free cellobiose from cellulose, and this would contribute more toward fermentation resulting in dry matter losses. As mentioned earlier, fermentation was occurring while the rations were soaking. Even in a 100^{o}C drying oven some fermentation could occur due to evaporation. Thomas *et al*. (88, p. 198-200) supported the view that microbial growth was favored for the first seven hours when wet barley was dried at 70^{o}C. If fermentation was occurring and the samples were dried, volatile fatty acids, carbon-dioxide and ethanol would be given off and lost. Subsequently, if crude fiber was analyzed on these samples, a larger percentage of crude fiber in proportion to the rest of the sample would appear. An oven-dry sample was weighed, soaked for four hours, dried, and reweighed. One percent of the dry matter was lost in the process.

Soaking samples in the laboratory for various lengths of time showed a slight decrease in cellulose content of Solka Floc and an increase in crude fiber in barley-based samples. The discrepancies are probably due to the difference in substrates. Solka Floc probably did not undergo degradation. Possibly Solka Floc was not contributing adequate nutrients to sustain fermentation.

GENERAL DISCUSSION

The subject matter discussed earlier was rather specific. A general discussion relating the broad scope of these experiments and the results obtained is in order.

Basically the objectives of the described experiments have been to improve the utilization of barley rations through feed processing or supplementation. Feed processing involved pelleting, wetting, or soaking the rations while feed supplementation included stabilized beef tallow or cellulase enzyme additions to the rations. These methods have been investigated in order to correct the "limiting" factors that are thought responsible for the somewhat poor performance given by barley in swine rations compared to corn. The "limiting" factors are not known, but theories describing them include: increased fiber content, deficiency of available energy, undesirable release of nutrients in the digestion of barley, presence of an inhibitor, or a deficiency of enzymes to digest the grain. It will be recognized that these all really refer to impeded energy utilization.

Pelleting markedly improved feed conversion of the control ration and tended to reduce feed consumption as well as the amount of feed required to produce a pound of gain. The majority of the response to pelleting in this experiment seems to be due to the physical factors involved. Pelleted rations were denser, and as such could allow the pigs to consume feed on an energy basis, particularly when they were young and the size of their digestive tract limited their feed consumption. However, this does not explain the additive effect on feed conversion noted with fat supplementation and pelleting. As mentioned, the density of the fat supplemented ration was not improved by pelleting. No consistent chemical changes were noted between meal and pelleted rations, or at least none were detected with the methods applied. The lower energy rations apparently benefited most from pelleting. Pelleting appears generally to be an effective method of improving barley utilization.

Supplementation with 5 percent stabilized beef tallow brought about a greater increase in animal performance than did pelleting. The two appeared additive in effect on daily gains and feed consumption, although only feed conversion was significantly improved ($P < .01$).

Cellulase 4000 supplementation was not as effective as pelleting in improving swine performance. While neither significantly ($P > .05$) improved feed conversion by itself, Cellulase 4000 was additive with fat supplementation in the meal. The two were effective together in improving feed conversion and tended to reduce feed consumption. However, they appeared to reduce the daily gains below the level noted for fat supplementation only. In pelleted rations, either supplement fed alone was better than the combination. Animals receiving Cellulase 4000, in either wet or dry rations, tended to have lower shrinkage losses (significant in some cases) and apparently this enzyme was responsible for increasing backfat with the "soak" treatment. The significance of these latter findings is not clear.

Soaking or wetting the barley ration increased shrinkage, reduced the iodine number of backfat and increased the average daily gains of control or cellulase-supplemented swine in Experiment 63-1. Water treatment also increased feed consumption and feed conversion; however, statistics could not be applied on the latter two criteria. Soaking the feed tended to give a slightly larger average daily gain than did merely wetting. The feed conversion for the two were about the same.

The mechanism (s) by which wetting or soaking the ration increase average daily gains over controls may involve an increase in palatibility. Certainly, feed consumption is increased with mash rations. However, it cannot be ruled out that inherent enzymes are activated, an inhibitor is inactivated, or microbial growth is favored and contributes in some manner. Reducing sugar content has been found to increase with soaking time. This may reflect the fermentation occurring and, in turn, explain why the crude fiber content increases with the soaking time.

Cellulase 4000 appears responsible for the increased average daily gains of the "soak" treatment in Experiment 62-2. Temperature control of the mash rations apparently altered this response in Experiment 63-1 and prevented any additional improvement with this enzyme supplement. Some evidence supports the idea that Cellulase 4000 is effective in reducing the cellulose of barley rations, however, the 100°C drying temperature might have inactivated the enzyme in the laboratory studies.

SUMMARY

1. Pelleting barley rations with a new modified pellet die significantly ($P < .01$) improved the feed conversion but not the average daily gains as shown with pooled meal versus pellets data. Control rations were 7 percent bulkier than pellets and it is suggested that the majority of the pelleting response is due to increasing the feed density.

2. In contrast to previous results from this station, pelleting improved utilization of barley rations containing 5 percent animal fat. In this case the improvement was not due to compacting the feed, since the density of the fat-containing ration was not noticeably increased.

3. Supplementation with 5 percent stabilized beef tallow tended to improve apparent performance of barley rations more than either pelleting or supplementation with Cellulase 4000. However, no significant ($P > .05$) changes were noted in regard to average daily gains, feed conversion or feed consumption. An additive effect was noted between Cellulase 4000 and fat supplementation in the meal ration which significantly ($P < .05$) improved the feed conversion over the control ration. Fat supplementation lowered the laboratory findings for cellulase activity, and when the two

supplements were pelleted together, their effectiveness with feed conversion was reduced *in vivo*.

4. Cellulase 4000 in two feeding trials tended to improve average daily gains by 1 to 3 percent, reduce average daily feed consumption by 4 percent, and reduce the amount of feed to produce a pound of gain by 3 to 4 percent. These differences were not significant. Cellulase 4000 significantly ($P < .05$) lowered the shrinkage loss and appeared to be more effective in increasing average daily gains with a soaked medium than in a dry ration; however, feed consumption and the amount of feed required to produce a pound of gain increased. When the soaking medium was under temperature control, Cellulase 4000 addition brought about no further improvement.

5. Water treatment (either "wetting" or "soaking") tended to increase the average daily gains, increase feed consumption but decrease the efficiency of feed utilization more than did the other methods evaluated in this study. Temperature control of the mash rations brought about a further increase in average daily gains ($P < .05$) compared to the controls, tended to increase the live-weight shrinkage losses and reduce the iodine numbers of the back-fat ($P < .05$ with the "soaked" group).

6. A laboratory study showed that the pH of barley rations

was not in the optimum range for maximum activity of Cellulase 4000. However, the enzyme preparation did bring about some reduction in a pure cellulose medium and an increase in the reducing sugars of a barley ration. Increasing the soaking time reduced the cellulose content of Solka Floc, and increased the reducing sugar content as well as the crude fiber content of barley rations.

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