A nutritional evaluatin of the protein quality in the Carlsberg II Riso 86 mutant barley
by Patrick Neil Alexander

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OE SCIENCE in Animal Science
Montana State University
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Abstract:
Proximate analysis, Osborne protein fractionating and amino acid analysis were performed on Carlsberg II (C II) barley, its high lysine isogene Carlsberg II Risø mutant 86 (C II-R86) and Unitan barley grown at two locations on the Montana Agricultural Experiment Station near Bozeman, Montana (Unitan-FE and Unitan-Boz). Nine isocaloric diets were fed to rats in growth trial I and nitrogen balance trial Ia which consisted of C II, C II-R86 and Unitan-FE barleys represented within each of three protein-amino acid levels including 10 and 12% protein and 12% protein with additional lysine and methionine. Isonitrogenous 10% protein diets fed to rats in growth trial II and nitrogen balance trial IIa included three diets which contained C II, C II-R86 and Unitan-FE barleys as the only protein source and a diet containing C II barley supplemented with lysine and methionine and a Unitan-FE barley diet supplemented with lysine only to achieve these amino acid levels present in the C II-R86 diet. A casein diet was fed in trial II to permit calculation of adjusted protein efficiency ratios (PER). Diets fed in the swine growth trial were vitamin, mineral and antibiotic fortified barley-soybean meal grower and finisher diets containing C II, C II-R86 and Unitan-Boz barleys. Three barrows were fed each of the three grower diets to determine apparent nitrogen (ADN) and dry matter digestibility (DMD). Crude protein and either extract content of C II-R86 barley were higher than other barleys. Lysine content of C II-R86 was higher compared to other barleys due to an increase in albumin + globulin content at the expense of hordeins.

The C II, C II-R86 and Unitan-FE 10% protein diets produced similar PERs in rat trial I. The C II-R86 diet in rat trial II produced superior ($P<.05$) PER compared to the Unitan-FE all barley protein diet but did not differ significantly from other barley or barley-amino acid diets in that trial. The PERs of C II-R86 diets containing 12% protein or 12% protein + lysine and methionine were inferior to that of C II and Unitan-FE at those protein-amino acid levels. Pigs fed C II-R86 gained slower and less efficiently ($P<.01$) than those fed C II or Unitan-Boz diets, but required 34 and 84%, respectively, less soybean meal to reach 100 kg weight. Loin eye area, backfat and carcass yield were reduced in pigs fed the C II-R86 diet ($P<.05$). Biological value (BV) of C II-R86 diets was higher ($P<.05$) than that of Unitan-FE diets and appeared to be higher than that of C II diets in trial Ia, and BV did not differ between diets in trial IIa. The protein digestibility of C II-R86 diets was lower ($P<.05$) than that of other diets in both rat trials as was the ADN ($P<.01$) in the swine digestibility trial. Net protein utilization of C II-R86 diets in both rat trials was consistently lower than that of other diets although some of the differences were not significant. The higher protein diets in rat trial I and swine diets which contained C II-R86 produced inferior results compared to C II or Unitan barleys. Differences between Unitan and C II barleys in rat and pig trials were consistent and generally nonsignificant.

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A NUTRITIONAL EVALUATION OF THE PROTEIN QUALITY IN THE CARLSBERG II RISØ 86 MUTANT BARLEY

by

PATRICK NEIL ALEXANDER

A thesis submitted in partial fulfillment
of the requirements for the degree

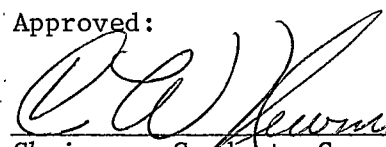
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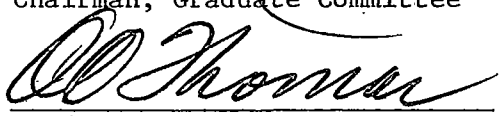
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ABSTRACT

Proximate analysis, Osborne protein fractionation and amino acid analysis were performed on Carlsberg II (C II) barley, its high lysine isogene Carlsberg II Risø mutant 86 (C II-R86) and Unitan barley grown at two locations on the Montana Agricultural Experiment Station near Bozeman, Montana (Unitan-FE and Unitan-Boz). Nine isocaloric diets were fed to rats in growth trial I and nitrogen balance trial Ia which consisted of C II, C II-R86 and Unitan-FE barleys represented within each of three protein-amino acid levels including 10 and 12% protein and 12% protein with additional lysine and methionine. Isonitrogenous 10% protein diets fed to rats in growth trial II and nitrogen balance trial IIa included three diets which contained C II, C II-R86 and Unitan-FE barleys as the only protein source and a diet containing C II barley supplemented with lysine and methionine and a Unitan-FE barley diet supplemented with lysine only to achieve these amino acid levels present in the C II-R86 diet. A casein diet was fed in trial II to permit calculation of adjusted protein efficiency ratios (PER). Diets fed in the swine growth trial were vitamin, mineral and antibiotic fortified barley-soybean meal grower and finisher diets containing C II, C II-R86 and Unitan-Boz barleys. Three barrows were fed each of the three grower diets to determine apparent nitrogen (ADN) and dry matter digestibility (DMD). Crude protein and either extract content of C II-R86 barley were higher than other barleys. Lysine content of C II-R86 was higher compared to other barleys due to an increase in albumin + globulin content at the expense of hordeins. The C II, C II-R86 and Unitan-FE 10% protein diets produced similar PERs in rat trial I. The C II-R86 diet in rat trial II produced superior ($P<.05$) PER compared to the Unitan-FE all barley protein diet but did not differ significantly from other barley or barley-amino acid diets in that trial. The PERs of C II-R86 diets containing 12% protein or 12% protein + lysine and methionine were inferior to that of C II and Unitan-FE at those protein-amino acid levels. Pigs fed C II-R86 gained slower and less efficiently ($P<.01$) than those fed C II or Unitan-Boz diets, but required 34 and 84%, respectively, less soybean meal to reach 100 kg weight. Loin eye area, backfat and carcass yield were reduced in pigs fed the C II-R86 diet ($P<.05$). Biological value (BV) of C II-R86 diets was higher ($P<.05$) than that of Unitan-FE diets and appeared to be higher than that of C II diets in trial Ia, and BV did not differ between diets in trial IIa. The protein digestibility of C II-R86 diets was lower ($P<.05$) than that of other diets in both rat trials as was the ADN ($P<.01$) in the swine digestibility trial. Net protein utilization of C II-R86 diets in both rat trials was consistently lower than that of other diets although some of the differences were not significant. The higher protein diets in rat trial I and swine diets which contained C II-R86 produced inferior results compared to C II or Unitan barleys. Differences between Unitan and C II barleys in rat and pig trials were consistent and generally nonsignificant.

INTRODUCTION

Increased economic importance has been placed on the world production of farm and ranch products. In recent years, there has been a trend for the number of agricultural producers and the area of land under cultivation and pasture to decrease while the world population has steadily increased. This phenonmenon has resulted in increased pressure on the remaining producers to be more efficient in their production as well as to increase product quality.

Barley ranks fourth in the world production of cereal grains, exceeded only by maize, wheat and rice. The Food and Agriculture Organization of the United Nations (1977) reported that there were 93,446,000 hectares of barley harvested in 1976. The United States ranked fourth in hectares harvested (3,407,000), exceeded only by the USSR, China and Canada. The three top states in the U.S. in order of hectares planted were North Dakota (866,046), Montana (473,493) and California (408,741) (USDA, 1977). Montana was ranked third in total barley production at 1,133,455 metric tons and barley is the major feed grain grown in the state. Currently wheat and rice are used primarily for human consumption and barley is used principally in feed for animals and in production of ethanols. The increased demand for all cereal grains including barley in human diets has been brought about by the present growth in the world population. Much of the barley, sorghum and maize presently fed to domestic farm animals will likely be channeled in greater quantities into the human feed chain in future generations.

The need to produce cereal grains of high nutritional quality is evident to students of animal and human nutrition. Barley, because of its adaptability to an infinite scope of environmental conditions and genetic variance, lends itself well to this purpose. Barley can be successfully cultivated under many different climatic and soil conditions. It has been cultivated at more northerly latitudes, at higher elevations and under poorer soil conditions than any other cereal grain.

Barley is raised primarily as a livestock feed or for malting in the Northern hemisphere of the Western World. Among the barley cultivars currently in commercial production, there is much variation in nutritional value with respect to protein quality and quantity. Lysine is the first limiting amino acid in most cereal grains and barley is no exception. Increasing the lysine content of barley should therefore improve the nutritional value. The presence of proteins normally absent in a barley cultivar or the depression or increase of the content of a certain storage protein can result in improved lysine content in that cultivar. In the latter case, by increasing the lysine rich proteins at the expense of those poor in lysine, this effect could be achieved. A change of this nature can be obtained by the action of carbohydrate supressor genes or genetic mutations which alter the quantitative relationship among the reserve proteins.

Barley cultivars with improved protein quality accompanied by desirable agronomic characteristics would give a definite boost to livestock industries which utilize barley. This improved quality of protein would be especially notable in a savings of expensive protein supplement. A positive influence on the human food supply could also be noticed through direct cereal consumption or increased animal production, especially in areas where barley can be produced more readily than other cereals.

The purpose of this thesis project was to study the nutritional value of the Carlsberg II Risø mutant 86, a high lysine cultivar developed at the Danish Atomic Energy Research Institute, in comparison with its parent, Carlsberg II, and Unitan, a common Montana feed barley in the diets of growing-finishing pigs and weanling rats.

LITERATURE REVIEW

Proteins and Amino Acids

The word protein was first suggested by Berzelius in 1838. It was derived from the Greek word proteios meaning of first or of primary importance (Coulter and Hann, 1971). The term was very aptly coined as proteins serve in many diverse functions including storage, transport, enzymatic and hormonal activity, muscle contraction, structural support and protection from disease agents foreign to the body of higher animals.

Lehninger (1975) described proteins as high molecular weight organic compounds consisting of unbranched chains of L-amino acids united in a head to tail arrangement through substituted amide linkages known as peptide bonds. There are twenty different amino acids commonly found in proteins which are classified by the physical or chemical nature of their side chains. All amino acids consist of at least one carboxyl group and one amino group in the alpha position. The α-amino group of almost all amino acids found in nature assumes the L- configuration. The number and sequence of amino acids present and the structural layering give a protein its physical and chemical characteristics. Proteins which yield only amino acids upon hydrolysis are referred to as simple proteins while those that contain amino acids as well as other organic and/or inorganic compounds are termed conjugated proteins.

Cereal Proteins

Cereal grains display a rather large variation in protein and amino acid content. The first limiting amino acid in most cereals

is lysine. The four most limiting amino acids in barley protein are lysine, methionine, threonine and tryptophan in order of decreasing deficiency (Howe et al., 1965). It has been reported by the National Research Council (N.R.C., 1970) that barley contains 13.0% protein and .52% lysine on a dry matter basis. These figures represent an average of commercial varieties grown in the United States. Montana barleys usually contain about .45% lysine and 13% protein on a dry matter basis (C. W. Newman, personal communication). Munck (1975) has indicated that barley protein content may range from 8 to 15% thereby increasing the importance of a protein analysis on representative samples prior to incorporating barley into a livestock feed.

Cereal protein including barley consists of four different fractions based on their solubility in various reagents. These include the albumins, globulins, glutelins and prolamines which are soluble in water, weak salt solutions, alkaline solutions and alcohol, respectively, (Osborne, 1895). The prolamine in barley is referred to as hordein. A portion of the hordein fraction is glycoprotein in nature which means that it is a conjugated protein with carbohydrate as the prosthetic group (Waldschmidt-Leitz, 1959). Danielson (1949) has classified the globulins of barley using ultra centrifugation into four separate components based on their molecular weight. Two of these components are not present in any other species of the Graminae family. Ingverson and Kǿie (1973a) have indicated the presence of three high lysine groups

in the water and salt soluble portion (albumins and globulins) of protein in Emir barley, a Swedish feed barley. It was also reported in the same study with Emir that the water and salt soluble fraction accounted for 44% of the total lysine and 24% of the total protein. Glutelins accounted for 38% and 33% of the total lysine and protein, respectively, while the hordeins accounted for only 9% of the total lysine, yet constituted 35% of the protein.

Munck (1964a) divided the barley kernel into two segments, the multicellular aleurone and the endosperm. He found the protein in the aleurone layer to be higher in quality than that in the endosperm as it was higher in lysine, arginine and histidine. The endosperm was more readily digested but was rich in lysine-poor hordeins compared to aleurone. For that reason, the endosperm protein was not utilized as effectively by animals as large amounts of nitrogen were lost in the urine. Lysine is the least available of the essential amino acids for rats (Eggum, 1973b) and pigs (Sauer et al., 1974) when the individual amino acids of barley protein are studied. This is probably due to the various protein fractions where the lysine is concentrated. Lysine concentration is highest in the albumin and globulin fractions which are found primarily in the outer part of the kernel, namely the aleurone cells (Eggum, 1977).

Wheat bran, a by-product of the flour milling industry, is composed primarily of the aleurone layer of the kernel. Saunders et al. 1969) found that steam pelleting wheat bran increased the protein

digestibility by chicks compared to autoclaved or untreated wheat bran mash. Microscopic studies of the fecal material indicated that the shear and compression forces of pelleting had fractured cell walls allowing digestive enzymes greater access to the cellular contents, thus improving protein digestibility. Saunders and Kohler (1972) suggested that wheat bran aleurone protein may be of limited digestibility either due to the thick cell wall matrix interferring with digestion or that the protein is tightly bound to the cellulosic matrix of the aleurone cells. These scientists pretreated wheat bran with cellulase enzyme demonstrating a 25% increase in _in vitro_ promase digestibility. According to Munck (1964a) the protein from the endosperm portion of the barley kernel are more digestible _in vitro_ than those in the aleurone portion. Eggum (1977) indicated that this was also the case _in vivo_ for rats and pigs. Buchman (1977) reported that the protein digestibility of decortified barley fractions decreased as crude fiber content of the fraction increased with digestibility being highest nearer to the center of the seed.

For most barleys, as total nitrogen increases lysine expressed as g/16g N decreases. This phenomena can be explained by an increase in hordeins accompanied by a decrease in albumins and globulins expressed as a percentage of the total protein. Hordeins are very low in lysine while albumins and golbulins are low in lysine. Glutelins remain fairly constant and low in lysine. If this

relationship could be reversed without seriously affecting the agronomically important characteristics of barley, a considerable savings of expensive protein supplements in livestock diets would be possible.

Methods of Protein Evaluation

Various methods by which the nutritional value of a feed or feedstuff may be estimated either chemically or biologically have been studied over the years. Chemical methods of protein evaluation are relatively simple as they are based on an amino acid analysis. Biological estimates take longer and are more difficult to obtain although are more accurate as they account for availability and antagonisms between proteins and amino acids (Eggum, 1969).

The chemical score method developed by Mitchell and Block (1946) estimates protein quality by comparison of the amino acid composition of the protein in question to that of whole egg protein. Those amino acids that are deficient with respect to the reference protein are termed limiting amino acids. Calculation is based solely on these amino acids and availability of amino acids is not considered.

Oser (1951) incorporated all of the essential amino acids into a similar calculation known as the Essential Amino Acid Value (EAAV). The use of this method resulted in closer agreement with biological value, yet it still did not account for availability or antogonism.

Essential Amino Acid Value could be used with reasonable success in estimating the results of feedstuff supplementation with amino acids either individually, in groups, or in intact complementary proteins.

By using all the amino acids in a multiple regression equation, Hansen and Eggum (1973) derived the Total Amino Acid Value (TAAV). When this estimate was compared with EAAV described above, even closer agreement with biological value occurred. When separate constants were used within groups of similar feedstuffs, the correlation was higher. Non-essential amino acids were found to exert a small effect on the biological value of feedstuffs in this study. This is an agreement with Rose et al. (1948) who demonstrated that rats utilized diets containing 19 amino acids somewhat more efficiently than those containing only the 10 essential amino acids.

The protein efficiency ratio (PER) of a feed is defined as the grams of body weight increase divided by the grams of protein consumed over a specified period of time (Chapman et al., 1959). A casein control diet is suggested by Chapman et al. (1959) with the average PER of the rats on the casein control being adjusted to 2.5. This is accomplished by dividing 2.5 by the observed casein PER to derive an adjustment constant. That constant is then multiplied by the PER values from the other treatment groups to obtain the adjusted PER of each group. As an example, if a rat gains 75 g while consuming 400 g of a 10.0% protein diet, the PER would be 75/400(.10) = 1.90. If

the observed PER of rats fed the casein control diet is 2.45 the adjustment factor would be 2.50/2.40 = 1.0204. If the PER were 2.55 the adjustment factor would be 2.50/2.55 = .9804. Adjustment of PER places the researcher's values on a similar basis with those obtained by other workers performing similar experiments in different laboratories. Several factors may affect the PER of a given diet. Higher PER values may be obtained with female rats than male rats, as is the case when younger rats are compared to older rats (Morrison and Campbell, 1960). The quantity and quality of the protein in the diet will affect PER significantly, especially for younger rats. As a valid method of protein evaluation PER has been criticized by Eggum (1969) as it assumes that weight increase is a direct index of protein synthesis and does not account for protein utilized in body maintenance. However, growth (weight increase) occurs only after maintenance requirements are met.

The biological value (BV) of a protein is an estimate of the percentage of the absorbed nitrogen of dietary origin that is actually retained for protein synthesis (Mitchell, 1924). The method requires measurement of fecal and urinary nitrogen of dietary origin and is considered to be a fairly accurate estimate of the protein quality of a given feed. In experiments with the growing albino rat, Mitchell and Bert (1954) determined that a linear relationship existed between the ratio of fecal nitrogen to the dry matter consumption and dietary

protein level between 0 and 20 percent. It was suggested that metabolic fecal nitrogen be determined as the nitrogen voided in the feces per unit of nitrogen free diet consumed and that this value be subtracted from the fecal nitrogen in calculating BV. Urinary nitrogen of endogenous origin is determined in a similar manner and is reported as nitrogen excreted per day per animal.

Eggum (1973a) defined true protein digestibility (TPD) as that percentage of dietary protein which is hydrolyzed and absorbed. When BV is multiplied by TPD, an accurate estimate of the dietary protein which is actually available for maintenance and growth known as net protein utilization (NPU) is obtained.

High Lysine Barley Cultivars

It has been demonstrated that the addition of .05% L-lysine HCl to corn or barley-soybean meal diets limiting in protein would enhance daily gains and feed efficiency in swine (Nielson et al., 1963). Shortly afterward the opaque-2 mutant of maize with improved lysine content was discovered (Mertz et al., 1964) bringing increased interest to the area of high lysine cereal research. Cromwell et al. (1967) reported that feeding opaque-2 maize in swine rations resulted in faster, more efficient gains with less soybean meal added to the diet. Normal corn had to be supplemented with lysine and tryptophan to produce similar results.

Screening of 1000 varieties from the World Barley Collection using the dye binding capacity (DBC) technique resulted in the discovery of the high protein, high lysine Ethiopian barley Hiproly (CI 3947) (Hagberg and Karlsson, 1969). Hiproly Normal (CI 4362), a sister line with high protein, normal lysine level and nutritional quality inferior to Hiproly, was discovered at the same time. The DBC technique involves the use of the acid dye Acilane Orange G, which combines with basic groups of amino acids from cereal proteins in suspension of pH 2.6 (Mossberg, 1969). The technique can be used to colorimetrically compare the basic amino acid composition of cereals having similar protein content. This procedure has been recommended as a mass screening technique to discover barleys with improved lysine content.

Munck et al. (1969) described Hiproly as an erectoid, two-row barley with naked, slightly shriveled seeds. Amino acid and Kjeldahl analysis show that Hiproly contains about 50% more protein than normal commercial barleys accompanied by a 30% increase in lysine as a percent of the total protein. The major drawback in using Hiproly as a feed barley is its poor agronomic characteristics, including yield, disease susceptibility and straw quality. Hiproly has been reported to yield only about 30% of that expected from commercial barley varieties (Hagberg et al., 1970).

Characterization of Hiproly by Osborne protein fractions indicates a slight increase in water soluble proteins, a decrease in the ethanol soluble fraction and increases in the salt and alkali soluble fractions as a percent of the total protein compared to commercial barleys with high or low protein content (Munck et al., 1969). Ingverson and Kóie (1973b) attributed the lysine superiority of Hiproly to a change in the control mechanism which regulates the synthesis of quantitatively important b-proteins rich in basic amino acids. Scanning election microscope studies showed no change in the morphology of the protein bodies of Hiproly compared to Hiproly Normal (Munck, 1972b). The improved endosperm lysine content was reportedly due to the presence of nearly double the amount of water soluble endosperm proteins accompanied by a small reduction in hordeins.

Studies of the genetic principle of the high lysine character based on the lysine:ammonia ratio of the F_2 plants from a cross between Hiproly and a Swedish barley, SV64625, have indicated that the character is due to a single recessive gene segregating not differently than an expected 1:3 ratio of deviating to normal plants (Munck et al., 1970). Seeds from the deviating F_2 plants were allowed to grow to determine if the cross had improved the yield. These plants yielded 75% of the yield produced by SV64625 while Hiproly only yielded 30% indicating that there are a number of genes that affect the agronomic characteristics without influencing the high

lysine character. Similar studies in which Hiproly was crossed with the Swedish barley Mona have shown 12 out of 128 plots produced from high lysine F_2 seeds to yield over 90% of the Mona (Hagberg et al., 1970). Six of these yielded over 96% while two yielded better than Mona. Lysine analysis has shown the best lysine yield per hectare to exceed Mona by 140 percent. Karlsson (1972), through linkage studies, has indicated that the gene for the high lysine character in the cultivar is located near the centromere of chromosome 7. The gene has been designated lys.

If increased lysine content does improve nutritional value of barley protein as expected, then feeding trials with Hiproly and its crosses should verify the potential of Hiproly in breeding programs for improved nutritional quality. Munck et al. (1970) fed rats Hiproly and the offspring of the F_2 deviates from the Hiproly x SV64625 cross demonstrating improvements in PER, TPD, BV and NPU for all higher lysine varieties compared to SV64625 with normal lysine content. The high lysine offspring of the cross Hiproly x Kristina improved BV and NPU compared to the normal control (Munck, 1972a). In comparison with Hiproly Normal and Naked Compana (CI 16185), Newman et al. (1974) found Hiproly to produce faster, more efficient gains, therefore, a higher PER, even though protein digestibility was decreased. Stutz (1976) reported similar findings when Hiproly was compared to normal commercial varieties. He was also able to report

a significant positive correlation between the percent lysine in barley protein and gain, feed gain ratio, and PER.

Another barley cultivar with improved lysine content due to an increase in albumins and globulins and reduction in hordeins is the high amylose mutant of Glacier (CI 9676), designated Glacier Ac38 (Newman et al., 1978b). In feeding trials with rats these workers demonstrated an increase in BV accompanied by a decrease in TPD of high amylose Glacier compared to Glacier. These differences were attributed to the respective differences in protein composition of the two barleys. Similar changes in the protein composition of Hiproly (Munck et al., 1969) could possibly explain the lower TPD values of that cultivar demonstrated by Newman et al. (1974) and Stutz (1976).

Generally, as the protein content of a barley cultivar increases, the concentration of the storage proteins (hordeins and glutelins) increases while the concentration of albumins and globulins decreases as does the lysine expressed as a percent of the protein (Pomeranz et al., 1972). Killen (1977) demonstrated little change in protein composition or content of Hiproly due to nitrogen fertilizer whereas in two commercial barleys (Compana, CI 5438; and Unitan, CI 1042) the protein was increased and lysine as a percent of the protein decreased. Biological value, NPU and TPD remained constant when rats were fed Hiproly raised in Montana under three fertilizer levels, while BV and

NPU decreased as protein in the two commercial varieties increased due to nitrogen fertilizer. The latter results agree with Munck (1964a) when rats were fed normal barley at varying fertilizer levels.

As the digestive system of the pig is similar to that of the rat, similar findings could be expected in this species. Thomke and Widstromer (1975) fed pigs Hiproly and the offspring of a high lysine F_2 barley line resulting from crossing Hiproly and Pallas. These scientists found TPD, BV and NPU of these barleys to be higher than the values for the normal Swedish variety Ingrid. When the Pallas X Hiproly cross was fed to pigs without supplemental protein, the gains and feed conversion were similar to those obtained feeding pigs Ingrid with supplemental protein and superior to those obtained feeding Ingrid without supplemental protein, Newman et al. (1977) reported similar results for Hiproly compared to Hiproly Normal and Unitan or Glacier (CI 9676) in swine diets. Newman et al. (1978a) also used Hiproly and free amino acids (L-lysine and DL-methionine) as partial substitutes for soybean meal in swine diets. These authors calculated a 27.1 and 47.6% savings of soybean meal in growing and finishing diets, respectively, through the use of Hiproly. Thomke et al. (1978) reported the advantage of using Hiproly cross barleys was a savings of protein supplement in diets of growing pigs and broilers.

The use of mutagenic agents in plant breeding has resulted in the discovery of several high lysine mutants of barleys from the World

Barley Collection. Several have been derived from the Swedish barley Bomi. Risø mutant 1508, the result of ethyleneimine treatment of Bomi (Ingverson et al., 1973a), appears to be one of the more promising high lysine mutants. Ingverson et al. (1973b) reported a 44% increase in lysine, a 36% increase in threonine, and increases in several other essential amino acids expressed as g/16g N. A 69% reduction in hordeins (from 29% in Bomi to 9% in 1508) is accompanied by a 70% increase in albumins and globulins (from 27% in Bomi to 46% in 1508). The grain yield in this report was depressed approximately 10% compared to the parent variety Bomi, however, later reports have indicated a 20% depression in grain yield (Doll and Køie, 1978). The grain yield of 1508 was found to be reduced 25% from that of Bomi in yield trials at the Montana Station (R. F. Eslick, personal communication). Doll and Køie (1978) reported that more than 90% of the reduction in grain yield displayed by the 1508 line was due to a reduction in dimethyl-sulfoxide extractable carbohydrates.

Ingverson (1975) studied protein body formation in the endosperm of Risø mutant 1508 and a wild type barley at 13 and 28 days after fertilization. Little difference was noted between the two types at 13 days whereas at 28 days Risø mutant 1508 displayed a comparative lack of synthesis of the spherical bodies associated with prolamines. Granular bodies associated with the glutelins were synthesized normally, and therefore, were the predominant species in the mutant

endosperm while the spherical bodies dominated in the wild type endosperm. In vitro studies of protein synthesis from polyribosomes of Risø mutant 1508 indicated a relatively low synthesis of hordeins compared to wild type barley (Brandt and Ingverson, 1976).

Brandt (1976) suggested that the high lysine content of Risø mutant 1508 was partially due to a reduction in hordeins and lysine poor glutelins accompanied by an increase in lysine rich glutelins with only minor changes in electrophoretic patterns and amino acid composition of the albumins and globulins. The major contributing factor to the high lysine character of Risø mutant 1508 has been reported to be a reduction in alcohol soluble proteins in contrast to Hiproly in which the major factor is an increase in lysine rich water soluble proteins (Tallberg, 1973). Lysine expressed as g/16g N does not decrease in Risø mutant 1508 as protein increases due to nitrogen fertilizer as it does in Bomi (Anderson and Køie, 1975).

Genetic studies have indicated that the high lysine character of Risø mutant 1508 is due to a single recessive gene (Doll, 1973). Ullrich and Eslick (1977) reported that the high lysine character and shrunken endosperm of Risø mutant 1508 are either pleiotrophic effects of the same gene or that the genes for both characters are very closely linked. Crossing with higher yielding varieties, unlike Hiproly, has failed to correct the problem of decreased yield (Oram et al., 1975). Bomi Risø mutants 9 and 13 appear to have the same

genetic basis of mutation including the inability to segregate the high lysine and shrunken endosperm characters (Doll, 1975). Through linkage studies, Karlsson (1977) located the gene for the high lysine character in Risø mutant 1508 near the centromere on the short arm chromosome 7.

Another barley variety which has resulted in high lysine mutants when mutagenically treated is Carlsberg II. Ethylmethanesulfonate treatment resulted in Risø mutants 29 and 86 with approximately 15% more lysine in the protein than Carlsberg II (Ingverson et al., 1973a). Treatment of Carlsberg II with gamma radiation produced Risø mutant 56 which displays a 20% increase in lysine. Ingverson and Køie (1971) were unable to demonstrate any differences in the hordein composition or in the electrophoretic protein patterns of the albumins and globulins between Carlsberg II and Risø mutants 29 and 86. A change in the regulation of b-protein synthesis similar to that in Hiproly but to a smaller extent may have taken place in these two Risø mutants (Ingverson and Køie, 1973b).

Ingverson et al. (1973a) described a depression in grain yield of the Carlsberg II Risø mutants compared to Carlsberg II with Risø mutant 56 yielding the least of the three. When Risø mutants 29, 56 and 86 were cultivated at locations in Montana, grain yield was lowest in Risø mutant 86, observed at 72% of the yield produced by Carlsberg II (R. F. Eslick, personal communication). Yield depression

was reported to be due to a decreased seed size in all cases. The increase in lysine exhibited by these Risø mutants can be explained by an increase in albumins and globulins, a decrease in hordeins, and an increase in glutelins as a percent of the protein.

Feeding rats with the Carlsberg II Risø mutants has resulted in an improved PER over Carlsberg II (Stobart, 1977). Biological value was highest for Risø mutant 86, however, NPU was not different as the Risø mutants displayed a decreased TPD.

Several other barley cultivars have been developed which show a potential for improved protein quality. Notch-1 and Notch-2 mutants have resulted from ethylmethanesulfonate treatment of the Indian barley NP-113 (Bansal, 1970). Balaravi et al. (1976) reported increases in seed protein content of 34% and 25% in Notch-1 and -2, respectively, compared to NP-113. Lysine as a percent of the protein is increased due to an increase in albumins and globulins and a reduction in hordeins. Seed weight and grain yield were reduced in the Notch mutants due to a dorsal depression in the kernel from which the mutants receive their name. The BV of these mutants was improved over the parent with Notch-2 giving the highest value.

Mortensen et al. (1978) describes another barley cultivar, KVL468, with improved protein and protein quality compared to Emir. Even though protein was 23% higher in KVL468, lysine expressed as g/16g N was similar when the two barleys were compared without nitrogen

fertilizer. As protein increased in Emir due to nitrogen fertilizer, lysine decreased as a percent of the protein, while similar protein increases in KVL468 resulted in very little deviation in lysine content of the protein. The grain yield of this barley (65% and 74% of Emir and Mona, respectively) has prevented its consideration as a feed source this far. Feeding trials comparing KVL468 with Emir have demonstrated improved gains and feed efficiency when the same amount of soybean meal was added to each ration. When rations were balanced on an equal lysine basis 4 to 5% less soybean meal was used in the KVL468 diet. This diet resulted in lower gains and inferior feed conversion from KVL468.

EXPERIMENTAL PROCEDURE

Barleys

Carlsberg II (C II) and Carlsberg II Risø mutant 86 (C II-R86) barleys were grown in 1977 at the Southern Agricultural Research Center at Huntley, Montana. Unitan barley used in biological rat trials was grown in 1977 at the Montana Agricultural Experiment Station (Fort Ellis) east of Bozeman and for identification purposes will be designated Unitan-FE. Unitan barley used in swine trials was grown in 1977 at the Montana State Agricultural Experiment Station (Animal Science Farm) west of Bozeman and will be designated Unitan-Boz.

Proximate analysis was performed on samples of each barley and soybean oil meal by a modification of the method described by A.O.A.C. (1970). Calcium content was determined by the modified Kramer-Tisdall method of Clark and Collip (1925) and phosphorus content by the method of Fiske and Subbarow (1925). Amino acid analysis was carried out on an acid hydrolysate of each sample according to the methods of Spackman et al. (1958). It was necessary to perform separate analysis for tryptophan by the method described by Hulgi and Moore (1972). Cystine/2 was determined as described by Hirs (1967). All amino acid analyses were performed by AAA Laboratories[1]. Fractionation of proteins according to solubility was carried out by the modified Osborne technique described by Ingverson and Køie (1973a).

[1]AAA Laboratories, 6206 89th Avenue Southeast, Mercer Island, Washington 98040.

Diets

Nine isocaloric diets were formulated for the first rat growth and nitrogen balance trials designated trials I and Ia, respectvely, (table 1). Carlsberg II, C II-R86 and Unitan-FE barleys were included in a 3x3 factorial arrangement with each of three protein-amino acid levels represented within each cultivar. Protein level No. 1 was formulated to equal 10% crude protein with no exogenous protein supplementation. Maize starch was added at the expense of barley in these diets to equalize nitrogen content. For protein level No. 2, floured soybean oil meal was added at the expense of barley to formulate 12% crude protein diets. L-lysine·HCl and DL-methionine were added in equal amounts at the expense of barley to otherwise identical 12% crude protein diets to achieve protein level No. 3. Maize oil and purified wood cellulose were added to equalize caloric levels in all diets.

Six isonitrogenous 10% crude protein diets were formulated for use in the second rat growth and nitrogen balance trials designated trials II and IIa, respectively, (table 2). Three of the diets were formulated using either C II, C II-R86 or Unitan-FE as the only source of protein. Two additional diets were formulated using C II or Unitan-FE barleys. The C II diet was supplemented with L-lysine·HCl and DL-methionine. The Unitan-FE diet was supplemented with only L-lysine at the expense of barley to equal the levels of these amino

acids present in the C II-R86 diet. A sixth diet which was fed only in the growth trial, was formulated using casein and maize starch in order to calculate adjusted PER values (Chapman et al., 1959). An equal amount of maize oil was added to each diet in trials II and IIa.

All diets fed in each trial contained equal amounts of calcium carbonate, mineral mixture, vitamin mixture (N.R.C. 1972) and antibiotics. The latter were fed to avoid respiratory infections. All barley fed in rat trials was ground through a Wiley laboratory mill and diets were mixed mechanically in a Hobart food mixer. Diets were maintained under constant refrigeration until fed to avoid rancidity.

Percentage composition of diets used in swine trials is presented in table 3. Barleys used included C II, C II-R86 and Unitan-Boz. Barley was ground through a hammermill having a 6.35 mm screen and diets were mixed in a vertical cone type mixer. Soybean meal (47% crude protein) was added at the expense of barley to balance grower diets to 16% crude protein and finisher diets to 14% crude protein or higher as necessary in the latter to achieve a minimum level of 0.60% lysine. The Unitan-Boz finisher diet was formulated at 14% crude protein and the C II and C II-R86 diets required 14.7 and 14.8% crude protein, respectively, to achieve the desired 0.6% lysine. Equal amounts of salt (sodium chloride) calcium carbonate, dicalcium phosphate, trace mineral premix, vitamin premix and

antibiotic premix were added respectively, to grower and finisher diets to meet or exceed the standards established by the N.R.C. (1973).

Proximate analysis, calcium, phosphorus and amino acid determinations were performed on all swine diets as previously described.

Rat Growth Trials

Female weanling rats of the Holtzman strain were individually caged and assigned according to weight to each diet in both growth trials. Treatments were arranged to minimize variability produced by the position of the cage on the rack. Racks used to hold the cages included six vertical and five horizontal positions on each side. Cages were constructed of woven wire and measured 20 x 24 x 18 cm. Feed and water were offered ad libitum. All rats were maintained in an environmentally controlled room providing 12 hr of light and 12 hr of darkness by means of an automatic flourescent lighting system. Duration of each trial was 28 days with rats being weighed weekly. Feed consumption was recorded each time rats were fed.

In trial I, 15 rats were assigned to each of the nine diet treatments. Individual rat feed consumption and gains were recorded and feed efficiency ratio (feed consumed/gain) and protein efficiency ratio (PER) (gain/protein consumed) were calculated. As the design of the experiment did not facilitate the use of a casein control, PER values were not adjusted as suggested by Chapman et al. (1959).

Ten rats were assigned to each of the six diet treatments in trial II with data collected as in trial I. Adjusted PER's were calculated by the method described by Chapman et al. (1959).

Rat Nitrogen Balance Trials

Female weanling Holtzman rats were assigned according to weight to diets, caged individually and fed for a four day adaptation period after which they were reweighed and placed in individual collection units. Adequate diet was fed to provide 150 mg nitrogen daily during the adjustment and collection periods. Water was made available at all times.

Feces and urine were collected for four days. Urine was collected automatically through a glass wool filter into a flask containing 25 ml of 5% sulfuric acid solution to permit ammonia-nitrogen loss. The total urine collection was diluted with tap water to 200 ml in a volumetric flask. Duplicate 15 ml aliquots were taken from each flask for Kjeldahl analysis. Total urinary nitrogen (gm) was then calculated for the collection period.

Feces were collected in a beaker containing 50 ml of 5% sulfuric acid solution. A homogenous sample was formed by adding 100 ml concentrated sulfuric acid to each fecal collection. After cooling, fecal samples were diluted to 500 ml with tap water in a volumetric flask. Duplicate 100 ml aliquots were analyzed for Kjeldahl nitrogen. Total fecal nitrogen (gm) was calculated for the collection.

Biological value (BV), true protein digestibility (TPD) and net protein utilization (NPU) were calculated for each rat and averaged over each diet (Mitchell, 1924 and Eggum, 1973a). Values used for endogenous urinary nitrogen (16.1 mg N/rat/day) and metabolic fecal nitrogen (1.39 mg N/g DM consumed) were those determined in this laboratory by Stobart (1977) using a nitrogen free diet.

Three rats were assigned to each of the nine diets (table 1) in trial Ia in each of two replications for a total of 54 rats. Two different types of collection units were used. In one type, the feces fell directly into the collection beaker, while in the other type, feces fell onto a metal screen and had to be collected daily into the beaker. Urine collection was identical between units. Rats were assigned in such a manner that each diet treatment was represented equally in both types of units.

Four rats were assigned to each of five diets (table 2) in trial IIa by weight and location on the rack. The casein diet used in trial II was not fed in trial IIa. All collection units were of the first type described above.

Pig Growth Trial

Twenty-three pigs were assigned by weight, sex and genetic background in equal outcome groups to each of three diets (table 3) in six replications. Four pigs were assigned to each pen in each of five replications with three pigs assigned per pen in a sixth

replication for a total of 69 pigs. All animals were fed an 18% barley-soybean meal vitamin-mineral-antibiotic fortified diet while being adjusted to the new environment for three days. Pigs were then reweighed and placed on test diets. Feed and water were provided ad libitum in 3.05 x 1.52 m steel wire pens in an environmentally regulated building having slotted concrete floors throughout. The average initial weight of the pigs was 20.1 kg. Pigs were changed from grower diets to finisher diets at an average pen group weight of 4.5 ± 2.3 kg. Pigs were slaughtered when each pen group reached an average of 100 ± 4.5 kg. All pigs were weighed at 14 day intervals and feed consumption was determined for two week intervals. Average daily feed, average daily gain and feed efficiency ratio were calculated for the grower, finisher and total periods.

Upon slaughter, carcasses were chilled and weighed and the percent carcass yield based on the live weight was determined. Backfat was determined as the average of the backfat measured at the first and last rib and last lumbar vertebrae. Loin eye area was measured at the 10th rib. Fat depth at the 10th rib was measured at a point on the carcass perpendicular to a line drawn through the widest portion of the loin eye. Carcass length was measured as the distance from the anterior edge of the aitch bone to the anterior edge of the first rib. Average backfat, loin eye area and carcass length were adjusted to a 100 kg live weight basis (National Pork Producers

Council, 1976). The actual loin eye area, fat depth of the 10th rib and carcass weight were used in the calculation of the percent carcass muscle as described by Fahey et al. (1975). Trimmed hams, loins and shoulders were weighed to calculate the percent ham, ham and loin and lean cuts (ham, loin and shoulder) based on the chilled carcass weight.

Pig Digestibility Trial

Three genetically similar barrows approximately four months of age were assigned by weight to each of the three grower diets (table 3). The average initial weight of the pigs was 52.9 kg. Pigs were confined in elevated crates of metallic construction with expanded metal floors through which feces dropped into a pan under the rear part of the crate floor. A similar pan was positioned under the front portion of the floor so that urine and wasted water would flow forward and not contaminate the feces. There were two positions which could be occupied by pigs in each of two separate crates. Test barrows were assigned to three of the four positions so that each diet was represented exactly once in each position over three replications. A gilt was placed in the fourth position during each collection period to equalize the location effect. No data was obtained from the gilt.

Test pigs were adjusted to their respective diets and the new environment for five days before collection began. Chromic oxide was added as a marker to the first feeding from which feces would be collected and again after the last feeding from which feces would be

collected. Feed from which feces would be collected was fed twice daily for five days at the rate of 1 kg per feeding to avoid excess feed waste. All feed that was spilled from the feeders was collected, weighed and substracted from the total. Feces were collected twice daily for five days beginning with the first colored feces and ending when colored feces first appeared at the end of the trial. At the end of the collection period, feces were analyzed for Kjeldahl nitrogen and dry matter and apparent digestibilities were calculated from these values (Eggum, 1973a).

Statistical Analysis

Least squares analysis of variance (Harvey, 1960) was applied to all measurements of concern from all rat growth and balance trials and the pig growth trial. Analysis of variance as described by Steel and Torrie (1960) was applied to the data from the pig digestibility trial. Duncan's multiple range test was used to separate significant means in all cases (Snedecor and Cochran, 1967). Analysis of covariance was applied to pig growth data as described by Snedecor and Cochran (1967) to remove the effects of initial weights on grower, finisher and total periods. Covariance was also applied to delete the effect of days on test (an estimate of age at slaughter) on percent ham, percent ham and loin, percent lean cuts, percent muscling and carcass length.

TABLE 1. PERCENTAGE COMPOSITION OF DIETS FED TO RATS IN TRIALS I AND Ia

Barley	Carlsberg II			Carlsberg II Risø 86			Unitan-FE		
Protein level[a]	1	2	3	1	2	3	1	2	3
Ingredients, %									
Barley	87.72	88.17	88.03	81.97	92.80	92.68	91.74	85.83	85.75
Soybean meal	--	4.05	4.08	--	1.41	1.44	--	5.53	5.53
Maize starch	4.63	--	--	11.70	--	--	--	--	--
Alphacel[b]	--	.17	.18	.12	--	--	.87	1.16	1.16
Maize oil	2.60	2.56	2.57	1.16	.74	.74	2.34	2.43	2.42
L-lysine-HCL	--	--	.05	--	--	.05	--	--	.05
DL-methionine	--	--	.04	--	--	.04	--	--	.04
Calcium carbonate	.80	.80	.80	.80	.80	.80	.80	.80	.80
Vitamin mixture[b]	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Mineral mixture[b]	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Antibiotic[c]	.25	.25	.25	.25	.25	.25	.25	.25	.25

[a] Protein level 1 = 10%, 2 = 12% and 3 = 12% with supplemental lysine and methionine.
[b] ICN Nutritional Biochemicals; non-nutritive cellulose, vitamin diet fortification mixture, Bernhardt Tomarelli salt mixtures, modified 1135-B. (Appendix tables 1 and 2).
[c] Chlortetracycline, penicillin, and sulfamethazine, 110.2, 55.1 and 110.2 mg per kg of diet, respectively.

TABLE 2. PERCENTAGE COMPOSITION OF DIETS FED TO RATS IN TRIALS II AND IIa

Diet[a]	C II	C II-R86	Unitan-FE	C II + aa	Unitan-FE + aa	Casein
Ingredient, %						
Barley	84.04	78.13	84.75	84.04	84.75	--
Maize starch	7.41	13.32	6.70	7.34	6.64	80.21
Casein[b]	--	--	--	--	--	11.24
L-lysine-HCL	--	--	--	.0702	.0618	--
DL-methionine	--	--	--	.0038	--	--
Calcium carbonate	.80	.80	.80	.80	.80	.80
Vitamin mixture[b]	2.00	2.00	2.00	2.00	2.00	2.00
Mineral mixture[b]	2.00	2.00	2.00	2.00	2.00	2.00
Maize oil	3.50	3.50	3.50	3.50	3.50	3.50
Antibiotic mixture[c]	.25	.25	.25	.25	.25	.25

[a]C II = Carlbserg II, C II-R86 = Carlsberg II Risø mutant 86, aa = supplemental lysine and/or methionine to equal the amount present in the C II-R86 diet.

[b]ICN Nutritional Biochemicals; vitamin diet fortification mixture, Bernhardt Tomarelli salt mixture, modified 1135-B, casein, purified, high nitrogen. (Appendix tables 1 and 2).

[c]Chlortetracycline, penicillin and sulfamethazine, 110.2, 55.1 and 110.2 mg per kg of diet, respectively.

TABLE 3. PERCENTAGE COMPOSITION OF SWINE DIETS

Barley[a]	IRN[b]	C II-R86		C II		Unitan-Boz	
		Grower	Finisher	Grower	Finisher	Grower	Finisher
Ingredient, %							
Barley (4)		86.60	91.70	82.90	87.75	78.25	84.64
Soybean meal (5)	5-04-604	10.05	5.80	13.75	9.75	18.40	12.86
Dicalcium phosphate (6)	6-01-080	1.45	.95	1.45	.95	1.45	.95
Limestone (6)	6-02-632	.85	.70	.85	.70	.85	.70
Salt		.50	.50	.50	.50	.50	.50
Trace mineral premix[c]		.05	.05	.05	.05	.05	.05
Vitamin premix[d]		.40	.25	.40	.25	.40	.25
Antibiotic premix[e]		.10	.05	.10	.05	.10	.05

[a]C II-R86 = Carlberg II Risø mutant 86, C II = Carlsberg II and Unitan-Boz - Unitan Bozeman.

[b]IRN = International Reference Numbers (Harris et al., 1968).

[c]Furnished the following per kg of premix: 200 g zinc, 100 g iron, 55 g manganese, 11 g copper, and 1 g cobalt.

[d]Furnished the following per kg of premix: 1,102,300 I.U. vitamin A, 220,460 I.U. vitamin D, 2,204 I.U. vitamin E, 99.2 mg menadione sodium bisulfite, 8.82 mg vitamin B_{12}, 1,543 mg riboflavin, 8,818 mg niacin, 4,409 mg d-pantothenic acid and 220, 460 mg choline.

[e]Provided per kg of diet: 110.2 mg chlortetracycline in grower diets, 55.1 mg chlortetracycline in finisher.

RESULTS

Chemical analysis of feedstuffs and diets. Proximate analysis, calcium and phosphorus content of barley cultivars and soybean meal are reported in table 4. Crude protein (as fed basis) in Carlsberg II Risø mutant 86 (C II-R86) was 14% higher than that in Carlsberg II (C II) fed in rat and pig trials, 16% higher than that in Unitan-FE fed in rat trials and 38% higher than Unitan-Boz used in pig trials. Ether extract also ranged from 64 to 157% higher in C II-R86 than in the other cultivars fed in rat and pig trials. Carlsberg II Risø mutant 86 contained less nitrogen-free extract than the other cultivars due to its higher protein content. Other measurements between barley cultivars did not differ greatly.

The results of Osborne protein fractionation of the barley cultivars are presented in table 5. Albumin + globulin content was 11 to 20% higher in C II-R86 than in the other cultivars. Hordein content was 17% lower in C II-R86 compared to C II with only minor differences in this protein component between C II-R86 and the two Unitan barleys. The protein of the Unitan barleys contained a greater percentage of glutelins than the C II-R86. The C II-R86 protein appeared to contain slightly more glutelins than C II protein.

Table 6 shows the amino acid content of the barley cultivars and soybean meal. Lysine expressed as a percent of the whole grain was 21, 31 and 52% higher in C II-R86 compared to C II, Unitan-FE and Unitan-Boz, respectively. Expresssed as a percent of amino acid

nitrogen (g/16 g N), C II-R86 was 11, 20 and 21% higher in lysine than Unitan-Boz, C II and Unitan-FE, respectively. Threonine and methionine were also higher in C II-R86 expressed as a percent of the whole grain and/or as a percent of the amino acid nitrogen.

Proximate composition (table 4) and amino acid composition of soybean meal (table 6) were not remarkably different from that reported in the literature (N.R.C., 1971).

Proximate analysis and calcium and phosphorus content of diets fed in rat trials I, Ia and II, IIa are shown in table 7. Crude protein did not vary to any significant extent within each protein level fed in trials I and Ia or between diets in trials II and IIa.

Proximate analysis and calcium and phosphorus content of swine diets are given in table 8 and amino acid analysis in table 9. All grower diets are formulated at 16% crude protein and by analysis there was little deviation from the level. Although grower diets were formulated to contain .70% lysine, analyzed levels were only .68, 62 and .58 in C II-R86, C II and Unitan-Boz diets, respectively, (table 9). The Unitan-Boz finisher diet contained 14% crude protein and 0.61% lysine while the C II-R86 and C II finisher diets contained 14.7 and 14.8% crude protein and 0.61 and 0.58% lysine, respectively.

Balancing for protein in grower diets and lysine in finisher diets provided adequate levels of the other essential amino acids to meet and exceed the requirements of growing and finishing pigs

(N.R.C., 1973) with the exception of methionine + cystine in grower diets and in the C II-R86 and Unitan-Boz finisher diets. Grower diets were formulated to contain .50% methionine + cystine. Carlsberg II Risø mutant 86, Carlsberg II and Unitan-Boz grower diets contained .48% .44 and .42% methionine + cystine, respectively. Finisher diets were formulated to meet a .44% methionine + cystine requirement. Unitan-Boz and C II-R86 finisher diets contained .41 and .40%, respectively, by analysis.

TABLE 4. PROXIMATE ANALYSIS AND CALCIUM AND PHOSPHORUS CONTENT OF BARLEY CULTIVARS AND SOYBEAN MEAL, AS FED BASIS

	Percentage[a]							
Item	CP	DM	FE	CF	Ash	NFE	Ca	P
Carlsberg II	11.5	92.9	1.4	3.4	2.6	74.0	.04	.39
Carlsberg II Risø mutant 86	13.1	94.5	3.6	3.7	2.7	71.4	.05	.42
Unitan-FE	11.3	92.2	2.2	3.4	2.3	73.0	.04	.36
Unitan-Boz	9.4	90.8	2.0	4.4	2.5	72.5	.02	.41
Soybean meal	48.2	90.6	1.5	2.4	6.2	32.3	.24	.52

[a]CP=crude protein, DM=dry matter, EE=ether extract, CF=crude fiber, NFE=nitrogen-free extract, Ca=calcium and P=phosphorus.

TABLE 5. OSBORNE PROTEIN FRACTIONS OF BARLEYS, PERCENT OF KJELDAHL PROTEIN

Item	Albumin + Globulin	Glutelin	Hordein	Residual
Carlsberg II	31.54	27.36	34.76	6.34
Carlsberg II Risø mutant 86	37.40	28.48	29.00	5.12
Unitan-FE	31.12	31.81	29.70	7.37
Unitan-Boz	33.73	30.59	27.46	8.22

TABLE 6. AMINO ACID CONTENT[a] OF BARLEY CULTIVARS AND SOYBEAN MEAL, AS FED BASIS

Amino Acid	Feedstuff				
	Carlsberg II	Carlsberg II Risø mutant 86	Unitan-FE	Unitan-Boz	Soybean meal
Alanine	.41 (4.08)	.52 (4.73)	.40 (3.93)	.34 (4.20)	1.61 (3.90)
Arginine	.52 (5.17)	.60 (5.45)	.55 (5.41)	.43 (5.32)	3.47 (8.40)
Aspartic acid	.63 (6.26)	.80 (7.27)	.59 (5.80)	.53 (6.55)	4.65(11.25)
Cystine/2	.26 (2.58)	.31 (2.82)	.29 (2.85)	.20 (2.47)	.79 (1.91)
Glutamic acid	2.58(25.65)	2.58(23.45)	2.64(25.96)	1.98(24.47)	7.72(18.68)
Glycine	.35 (3.48)	.44 (4.00)	.37 (3.64)	.30 (3.71)	1.63 (3.95)
Histidine	.23 (2.29)	.28 (2.54)	.23 (2.26)	.19 (2.35)	1.11 (2.69)
Isoleucine	.39 (3.88)	.42 (3.82)	.37 (3.64)	.30 (3.71)	1.88 (4.55)
Leucine	.70 (6.96)	.74 (6.73)	.68 (6.69)	.58 (7.17)	3.08 (7.45)
Lysine	.36 (3.58)	.47 (4.27)	.36 (3.54)	.31 (3.83)	2.71 (6.56)
Methionine	.18 (1.79)	.19 (1.73)	.18 (1.77)	.14 (1.73)	.63 (1.52)
Phenylalanine	.51 (5.07)	.54 (4.91)	.51 (5.01)	.40 (4.94)	2.08 (5.03)
Proline	1.14(11.33)	1.05 (9.55)	1.16(11.41)	.87(10.75)	2.03 (4.91)
Serine	.45 (4.47)	.51 (4.64)	.46 (4.52)	.36 (4.45)	2.14 (5.18)
Threonine	.35 (3.48)	.43 (3.91)	.36 (3.54)	.30 (3.71)	1.66 (4.02)
Tryptophan	.18 (1.79)	.21 (1.91)	.19 (1.87)	.17 (2.10)	.81 (1.96)
Tyrosine	.32 (3.18)	.36 (3.27)	.32 (3.15)	.27 (3.34)	1.36 (3.29)
Valine	.50 (4.96)	.55 (5.00)	.51 (5.01)	.41 (5.07)	1.96 (4.75)
Total	10.06 (100)	11.0 (100)	10.17 (100)	8.09 (100)	41.32 (100)
Kjeldahl protein	11.5	13.1	11.3	9.4	48.2

[a]Values in parenthesis are expressed as a percent of amino acid nitrogen (g/16 g N) and other values are expressed as a percent of the whole grain.

TABLE 7. PROXIMATE ANALYSIS AND CALCIUM AND PHOSPHORUS CONTENT OF DIETS FED IN TRIALS I, Ia AND II, IIa

Diet	Percentage[a]							
	CP	DM	EE	CF	Ash	NFE	Ca	P
Trial I, Ia								
10% protein level								
Carlsberg II	10.0	90.9	3.3	3.4	4.6	69.9	.55	.62
Carlsberg II Risø mutant 86	10.6	90.7	3.1	3.6	4.5	68.9	.60	.61
Unitan-FE	10.3	91.5	3.6	5.2	4.6	67.8	.56	.61
12% protein level								
Carlsberg II	12.0	91.1	3.6	3.4	4.7	57.4	.56	.64
Carlbser II Risø mutant 86	12.7	90.4	3.9	4.9	4.9	64.0	.56	.67
Unitan-FE	12.6	91.8	3.6	4.7	4.6	66.3	.60	.62
12% proteion level + lysine and methionine[b]								
Carlsberg II	12.3	90.9	3.8	3.7	4.7	66.4	.56	.65
Carlsberg II Risø mutant 86	12.7	90.4	4.0	4.9	4.8	64.0	.56	.65
Unitan-FE	12.4	91.7	4.1	4.8	4.8	65.6	.57	.63
Trial II, IIa								
Carlsberg II	10.2	93.0	3.7	2.9	4.3	71.9	.63	.75
Carlsberg II Risø mutant 86	10.4	93.5	4.5	4.0	4.5	70.1	.69	.78
Unitan-FE	10.2	93.5	3.2	4.5	4.5	71.1	.58	.69
Carlsberg II + aa[c]	10.3	93.3	3.6	3.8	4.6	71.0	.52	.62
Unitan-FE + aa[c]	10.1	93.6	3.4	4.3	4.5	71.3	.51	.63
Casein[d]	10.9	94.8	3.6	0.1	2.8	77.4	.53	.61

[a] CP=crude protein, DM=dry matter, EE=ether extract, CF=crude fiber, NFE=nitrogen-free-extract, Ca=calcium, P=phosphorus.

[b] .05% L-lysine·HCl and .04% DL-methionine.

[c] Lysine and/or methionine added to equal the calculated level present in the C II-R86 diet.

[d] Casein diet was not fed in trial IIa.

TABLE 8. PROXIMATE ANALYSIS AND CALCIUM AND PHOSPHORUS CONTENT OF SWINE DIETS

Diet	Percentage[a]							
	CP	DM	EE	CF	Ash	NFE	Ca	P
Carlsberg II Risø mutant 86								
Grower	16.1	93.6	3.3	4.1	5.5	64.6	.63	.75
Finisher	14.7	92.7	3.3	3.9	5.0	65.8	.52	.62
Carlsberg II								
Grower	16.3	92.1	1.7	3.4	5.6	65.1	.69	.78
Finisher	14.8	92.1	1.8	3.6	5.1	66.8	.51	.63
Unitan-Boz								
Grower	16.1	91.4	1.9	3.9	4.9	64.6	.58	.69
Finisher	14.1	91.5	1.9	4.0	4.9	66.6	.53	.61

[a]CP=crude protein,DM=dry matter, EE=ether extract, CF=crude fiber, NFE=nitrogen-free-extract, Ca=calcium and P-phosphorus.

TABLE 9. AMINO ACID CONTENT OF SWINE DIETS, AS FED BASIS

Amino Acid	Diet					
	Carlsberg II Risø mutant 86		Carlsberg II		Unitan-Boz	
	Grower	Finisher	Grower	Finisher	Grower	Finisher
Alanine	.60	.57	.51	.52	.50	.51
Arginine	.83	.78	.78	.67	.70	.71
Aspartic acid	1.24	1.16	1.15	1.15	1.04	1.16
Cystine/2	.25	.19	.22	.24	.23	.22
Glutamic acid	2.96	2.89	2.96	2.80	2.57	2.69
Glycine	.50	.50	.46	.49	.44	.49
Histidine	.32	.32	.30	.32	.28	.31
Isoleucine	.56	.53	.55	.53	.48	.53
Leucine	1.00	.96	.99	.95	.86	.94
Lysine	.68	.61	.62	.58	.56	.61
Methionine	.23	.21	.22	.20	.19	.19
Phenylalanine	.70	.70	.67	.69	.58	.65
Proline	1.11	1.16	1.11	1.10	.95	1.04
Serine	.63	.60	.59	.63	.57	.60
Threonine	.54	.51	.50	.49	.46	.49
Tryptophan	.22	.24	.20	.20	.19	.19
Tyrosine	.43	.46	.44	.45	.37	.45
Valine	.67	.66	.64	.63	.57	.62

Rat growth trial I. The results of the first growth trial are reported in table 10. Data in tables 11 and 12 present the main effects of barley cultivar and protein-amino acid levels, respectively. Most differences noted in table 10 can be reported in terms of the main effects. A significant barley cultivar x protein-amino acid level interaction occurred however, in the feed/gain ratio and protein efficiency ration (PER). These measurements were not significantly different between C II, C II-R86 and Unitan-FE barley diets at the 10% protein level whereas the C II-R86 diets produced inferior feed/gain ratio and PER ($P<.05$) at the 12% protein level with or without supplemental amino acids compared to Unitan-FE and C II diets.

When rat growth and feed consumption are compared according to barley cultivar (table 11), C II-R86 appeared to have promoted superior gains although the differences were not significant. Rats fed C II-R86 diets consumed significantly more feed ($P<.05$) than those fed either of the other two barleys. There was no significant difference in consumption between Unitan-FE and Carlsberg II.

When rat performance is compared according to protein-amino acid level, lower gains occurred at the 10% level compared to the other two protein levels. Rat growth did not differ significantly between the 12% protein level and the 12% protein level with added lysine and methionine. Feed consumption was not significantly affected by protein-amino acid level.

TABLE 10. LEAST SQUARES MEANS OF RAT GROWTH, FEED CONSUMPTION, FEED EFFICIENCY AND PROTEIN EFFICIENCY RATIO DATA OF RATS FED BARLEY DIETS AT THREE PROTEIN-AMINO ACID LEVELS IN TRIAL I

Diet	No. rats	Gain (g)	Feed consumed (g)	Feed/gain ratio	Protein efficiency ratio
10% protein level					
Carlsberg II	15	90.1^{cd}	456.5^{abcd}	5.07^{a}	1.98^{ab}
Carlsberg II Risø mutant 86	15	99.5^{bc}	473.0^{abc}	4.76^{bc}	1.99^{ab}
Unitan-FE	15	86.2^{d}	428.0^{de}	5.01^{ab}	1.98^{ab}
12% protein level					
Carlsberg II	15	107.5^{ab}	439.2^{cde}	4.11^{ef}	2.04^{ab}
Carlsberg II Risø mutant 86	15	107.7^{ab}	493.6^{a}	4.61^{cd}	1.73^{c}
Unitan-FE	15	111.7^{a}	441.3^{bcde}	3.98^{c}	2.00^{ab}
12% protein level + lysine and methionine[g]					
Carlsberg II	15	100.1^{bc}	420.1^{de}	4.20^{e}	1.94^{b}
Carlsberg II Risø mutant 86	15	108.7^{ab}	482.8^{ab}	4.46^{d}	1.78^{c}
Unitan-FE	15	103.5^{ab}	400.3^{e}	3.88^{f}	2.09^{a}

^{abcdef}Means in the same column with different superscript letters are significantly different ($P<.05$).

[g] L-Lysine·HCl and DL-methionine added, .05 and .04%, respectively.

TABLE 11. LEAST SQUARES MEANS OF RAT GROWTH, FEED CONSUMPTION, FEED EFFICIENCY, AND PROTEIN EFFICIENCY RATIO DATA AS INFLUENCED BY BARLEY CULTIVAR IN TRIAL I

Barley	No. rats	Gain (g)	Feed consumed (g)	Feed/gain ratio	Protein efficiency ratio
Carlsberg II	45	99.3	439.5[b]	4.47[b]	1.98[a]
Carlsberg II Risø mutant 86	45	105.4	482.9[a]	4.62[a]	1.83[b]
Unitan-FE	45	100.6	421.7[b]	4.27[c]	2.02[a]

[abc]Means in the same column with different superscript letters are significantly different (P<.05).

TABLE 12. LEAST SQUARES MEANS OF RAT GROWTH, FEED CONSUMPTION, FEED EFFICIENCY, AND PROTEIN EFFICIENCY RATIO DATA AS INFLUENCED BY PROTEIN LEVEL IN TRIAL I

Protein level	No. rats	Gain (g)	Feed consumed (g)	Feed/gain ratio	Protein efficiency ratio
10% protein	45	92.0[c]	451.6	4.93[b]	1.97
12% protein	45	109.0[b]	457.7	4.24[c]	1.92
12% protein + aa[a]	45	104.3[b]	434.8	4.18[c]	1.92

[a]L-Lysine·HCl and DL-methionine, added, .05 and .04%, respectively.

[bc]Means in the same column with different superscript letters are significantly different (P<.05).

Rat nitrogen balance trial Ia. The results of nitrogen balance trial Ia are shown in table 13. Main effects of barley cultivar and protein amino acid level on rat measurements are presented in tables 14 and 15, respectively. Barley cultivar x protein-amino acid level interaction was not signficant for biological value (BV), true protein digestibility (TPD), or net protein utilization (NPU).

The BV of C II-R86 diets was significantly higher ($P<.05$) than that of the Unitan-FE diets and appeared to be somewhat higher than C II diets although the difference was not significant (table 14). Diets containing C II-R86 were significantly lower ($P<.05$) in TPD than those prepared with either Unitan-FE or C II barleys. The latter two diets did not differ significantly from each other in TPD. The NPU of C II diets were significantly higher ($P<.05$) than that of Unitan-FE or C II-R86 diets.

The BV of diets fed at the 10% protein level was significantly higher ($P<.05$) than that of diets fed at the 12% protein level but did not differ significantly from the BV of diets fed at the 12% protein level with supplementary lysine and methionine (table 15). Biological value at the 12% protein level with added lysine and methionine appeared to be higher than that at the 12% protein level but this difference was not significant. True protein digestibility did not differ significantly between the three protein-amino acid levels. Net protein utilization, although not significantly different between protein levels, appeared to follow a pattern similar to BV.

TABLE 13. LEAST SQUARES MEANS OF BIOLOGICAL VALUE, TRUE PROTEIN DIGESTIBILITY AND NET PROTEIN UTILIZATION OF BARLEY DIETS AT THREE PROTEIN AMINO ACID LEVELS IN TRIAL Ia

Diet	No. rats	Biological value	True protein digestibility	Net protein utilization
10% protein level				
Carlsberg II	5	81.4[ab]	85.4[a]	69.5
Carlsberg II Risø mutant 86	6	86.0[a]	73.5[b]	63.1
Unitan-FE	6	75.3[b]	83.0[a]	62.5
12% protein level				
Carlsberg II	6	74.6[b]	85.0[a]	64.1
Carlsberg II Risø mutant 86	6	78.8[ab]	74.4[b]	58.7
Unitan-FE	6	72.8[b]	84.0[a]	61.3
12% protein level + lysine and methionine[c]				
Carlsberg II	6	79.9[ab]	85.9[a]	68.6
Carlsberg II Risø mutant 86	6	80.7[ab]	77.3[b]	62.4
Unitan-FE	6	76.4[b]	86.3[a]	65.8

[ab] Means in the same column with different superscript letters are significantly different ($P<.05$).

[c] L-Lysine·HCl and DL-methionine added, .05 and .04%, respectively.

TABLE 14. LEAST SQUARES MEANS OF BIOLOGICAL VALUE, TRUE PROTEIN DIGESTIBILITY AND NET PROTEIN UTILIZATION AS INFLUENCED BY BARLEY CULTIVAR IN TRIAL Ia

Barley	No. rats	Biological value	True protein digestibility	Net protein utilization
Carlsberg II	17	78.6[ab]	85.4[a]	67.4[a]
Carlsberg II Risø mutant 86	18	81.8[a]	75.1[b]	61.4[b]
Unitan-FE	18	74.8[b]	84.4[a]	63.3[b]

[ab]Means in the same column with different superscript letters are significantly different (P<.05).

TABLE 15. LEAST SQUARES MEANS OF BIOLOGICAL VALUE, TRUE PROTEIN DIGESTIBILITY AND NET PROTEIN UTILIZATION AS INFLUENCED BY PROTEIN AMINO ACID LEVEL IN TRIAL Ia

Protein level	No. rats	Biological value	True protein digestibility	Net protein utilization
10% protein	17	80.9[b]	80.6	65.0
12% protein	18	75.4[c]	81.1	61.4
12% protein + aa[a]	18	79.0[bc]	83.2	65.6

[a] L-Lysine·HCl and DL-methionine added, .05 and .04%, respectively.

[bc]Means in the same column with different superscript letters are significantly different (P<.05).

Rat growth trial II. The results of rat growth trial II are reported in table 16. Gains produced by the C II-R86 diet were significantly higher ($P<.05$) than gains produced by C II and Unitan-FE diets with added amino acids and the Unitan-FE diet without added amino acids but were not different from gains produced by the C II all barley protein and casein diets. Rats consumed larger ($P<.05$) amounts of the C II-R86 diet than any of the other diets with no significant differences in feed consumption between other diets.

The feed/gain ratio and PER obtained from the casein diet were superior ($P<.05$) to those obtained from other diets. The Unitan-FE diet without supplemental lysine and methionine produced PER and feed/gain ratio values that were inferior ($P<.05$) to those obtained from the other diets. Supplementing the Unitan-FE and C II diets with lysine and methionine appeared to improve the feed/gain ratio and PER, although the difference was significant ($P<.05$) between the two Unitan diets only. The PER and feed/gain ration obtained from the C II-R86 diet were statistically different ($P<.05$) only from those obtained from the Unitan-FE diets without supplemental amino acids.

TABLE 16. LEAST SQUARES MEANS OF RAT GROWTH, FEED CONSUMPTION, FEED EFFICIENCY AND PROTEIN EFFICIENCY RATIO DATA OF RATS FED 10% PROTEIN ISONITROGENOUS BARLEY, BARLEY + AMINO ACIDS AND CASEIN DIETS IN TRIAL II

Diet	No. rats	Gain, g	Feed consumed, g	Feed/gain ratio	Adjusted protein efficiency ratio
Carlsberg II	10	86.0^{abc}	414.2^{b}	4.89^{b}	2.17^{b}
Carlsberg II Risø mutant 86	10	101.2^{a}	474.8^{a}	4.71^{b}	2.20^{b}
Unitan-FE	10	72.8^{c}	387.0^{b}	5.41^{a}	1.97^{c}
Carlsberg II + aa^{d}	10	82.6^{bc}	381.7^{b}	4.66^{b}	2.26^{b}
Unitan-FE + aa^{d}	10	84.8^{bc}	391.7^{b}	4.66^{b}	2.30^{b}
Casein	10	93.4^{ba}	367.6^{b}	3.96^{c}	2.50^{a}

^{abc}Means in the same column with different superscript letters are significantly different ($P<.05$).

^{d}aa=supplemental lysine and/or methionine to equal at least the amount present in the Carlsberg II Risø mutant 86 diet.

Rat nitrogen balance trial IIa. Table 17 shows the results of nitrogen balance trial IIa. There were no significant differences in the BV of any of the diets although the C II diet with added lysine and methionine appeared to have the highest value. The TPD of the C II-R86 diet was lower ($P<.05$) than the TPD of the other diets. The two diets containing supplemental amino acids appeared to have higher TPD than the corresponding diets without supplemental amino acids; however, these differences were not significant. The NPU of the C II-R86 diet was lower ($P<.05$) than that of the other diets with the exception of the Unitan-FE diet without added lysine and methionine. The NPU of the Unitan-FE and C II-R86 all barley protein diets was lower ($P<.05$) than that of the other diets but did not differ significantly from each other.

TABLE 17. LEAST SQUARES MEANS OF BIOLOGICAL VALUE, TRUE PROTEIN DIGESTIBILITY AND NET PROTEIN UTILIZATION OF 10% PROTEIN ISONITROGENOUS BARLEY AND BARLEY AMINO ACID DIETS IN TRIAL IIa

Diet	No. rats	Biological value	True protein digestibility	Net protein utilization
Carlsberg II	4	75.3	81.1[a]	61.1[ab]
Carlsberg II Risø mutant 86	4	74.8	73.2[b]	54.4[c]
Unitan-FE	4	74.0	79.4[a]	58.4[c]
Carlsberg II + aa[d]	4	78.5	84.1[a]	66.0[a]
Unitan-FE + aa[d]	4	74.9	83.4[a]	62.5[ab]

[abc]Means in the same column with different superscript letters are significantly different ($P<.05$).

[d] aa=supplemental lysine and/or methionine to equal at least the amounts present in the Carsberg II-Risø mutant 86 diet.

Swine growth trial. The feedlot performance measurements of pigs fed C II, C II-R86 and Unitan-Boz grower diets are given in table 18. Average daily feed intake (ADF) was not influenced significantly by dietary treatment. Average daily gain (ADG) and feed/gain ratio of pigs fed the C II-R86 grower diet were inferior ($P<.01$) to those of pigs fed C II or Unitan-Boz grower diets. Feed/gain ratio and ADG were similar between Unitan-Boz and C II grower diets.

Table 19 shows the feedlot performance performance measurements of pigs fed C II, C II-R86 and Unitan-Boz finisher diets. The C II-R86 finisher diets produced lower ADG and an inferior feed/gain ratio ($P<.01$) compared to C II and Unitan-Boz finisher diets. The finisher diet containing C II produced a lower ADG ($P<.01$) than the Unitan-Boz finisher diet, but the feed/gain ratio did not differ between these diets.

The feedlot performance of pigs fed three barley cultivars through the swine growth trial (20 to 100 kg) are presented in table 20. There was no significant effect of dietary treatment on ADF. Unitan-FE and C II dietary treatments produced faster more efficient gains ($P<.01$) than the C II-R86 dietary treatment and did not differ significantly from each other in these respects.

Also reported in table 20 are the carcass characteristics of pigs fed the three barley cultivars. Pigs fed C II-R86 barley had smaller loin eyes, less backfat and lower carcass yield percentage ($P<.05$) than those receiving C II or Unitan-Boz barleys. Other carcass measurements

were not affected significantly between dietary treatments.

Figures 1 and 2 represent the average accumulative feed and soybean meal intake per pig, respectively, throughout the growth trial. Pigs fed Unitan-Boz and C II diets required 18 and 20% less feed, respectively, to reach market weight than those fed the C II-R86 diet. Total soybean meal consumption, however, was 34 and 80% higher for the average pig fed C II or Unitan-Boz diets, respectively, to reach market weight than for the average pig fed the C II-R86 diet.

TABLE 18. LEAST SQUARES MEANS OF AVERAGE DAILY GAIN, AVERAGE DAILY FEED AND FEED/GAIN RATIO OF PIGS FED THE THREE BARELY CULTIVARS IN GROWER DIETS (20 TO 45 KG)

	Diet		
Item	Carlsberg II	Carlsberg II Risø mutant 86	Unitan-FE
No. pigs	23	23	23
Avg initial wt, kg	20.0	20.0	20.1
Avg final wt, kg	46.9	46.4	46.6
Avg daily gain, kg	.58[a]	.53[b]	.67[a]
Avg daily feed, kg	1.77	1.67	1.73
Feed/gain ratio	2.62[b]	3.17[a]	2.58[b]

[ab]Means in the same row with different superscript letters are significantly different (P<.01).

TABLE 19. LEAST SQUARES MEANS OF AVERAGE DAILY GAIN, AVERAGE DAILY FEED AND FEED/GAIN RATIO OF PIGS FED THE THREE BARLEY CULTIVARS IN FINISHER DIETS (45 TO 100 KG)

	Diet		
Item	Carlsberg II	Carlsberg II Risø mutant 86	Unitan-FE
No. pigs	23	23	23
Avg initial wt, kg	46.9	46.4	46.6
Avg final wt, kg	98.2	98.0	99.1
Avg daily gain, kg	.72[b]	.61[c]	.78[a]
Avg daily feed, kg	2.58	2.73	2.81
Feed/gain ratio	3.56[b]	4.48[a]	3.61[b]

[abc]Means in the same row with different superscript letters are significantly differenty (P<.01).

TABLE 20. LEAST SQUARES MEANS OF AVERAGE DAILY GAIN, AVERAGE DAILY FEED, FEED/GAIN RATIO AND CARCASS DATA OF PIGS FED THE THREE BARLEY CULTIVARS FOR THE TOTAL GROWING-FINISHING PERIOD (20 TO 100 KG)

	Diet		
Item	Carlsberg II	Carlsberg II Risø mutant 86	Unitan-Boz
No. pigs	23	23	23
Avg initial wt, kg	20.0	20.0	20.1
Avg final wt, kg	98.2	98.0	99.1
Avg daily gain, kg	.70[a]	.58[b]	.73[a]
Avg daily feed, kg	2.32	2.33	2.39
Feed/gain ratio	3.23[c]	4.02[b]	3.26[c]
Yield, %	73.01[a]	67.19[b]	72.78[a]
Ham, %	19.99	20.31	19.79
Ham and loin, %	37.66	38.25	37.43
Lean cuts, %	53.09	53.95	52.65
Carcass muscle, %	55.21	54.69	54.71
Loin eye area, cm^2	32.19[a]	28.77[b]	31.48[a]
Avg backfat, cm	2.54[a]	2.26[b]	2.64[a]
Carcass length, cm	78.99	80.65	78.89

[ab]Means in the same row with different superscript letters are significantly different; $P<.05$ for carcass data, $P<.01$ for average daily gain, feed/gain ratio.

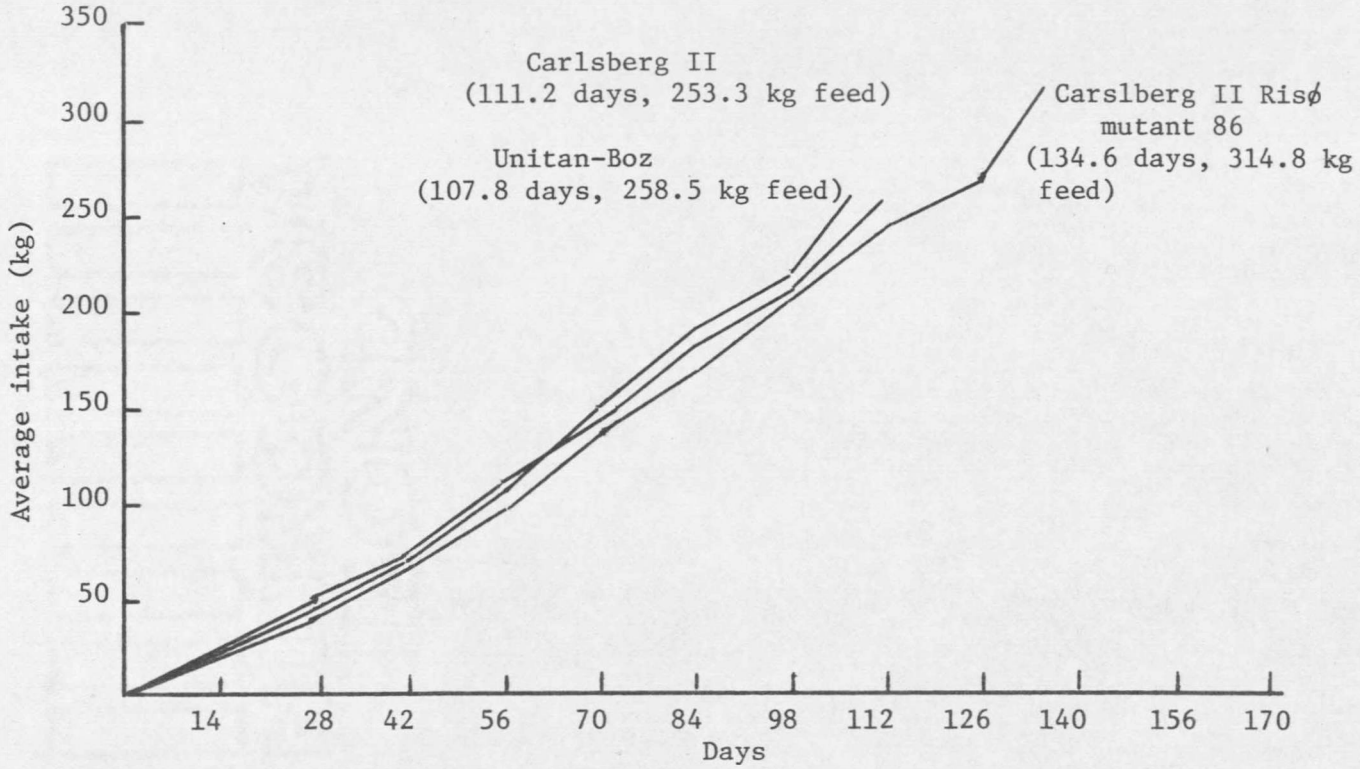


Figure 1. Average accumulative feed intake per pig (20-100 kg).

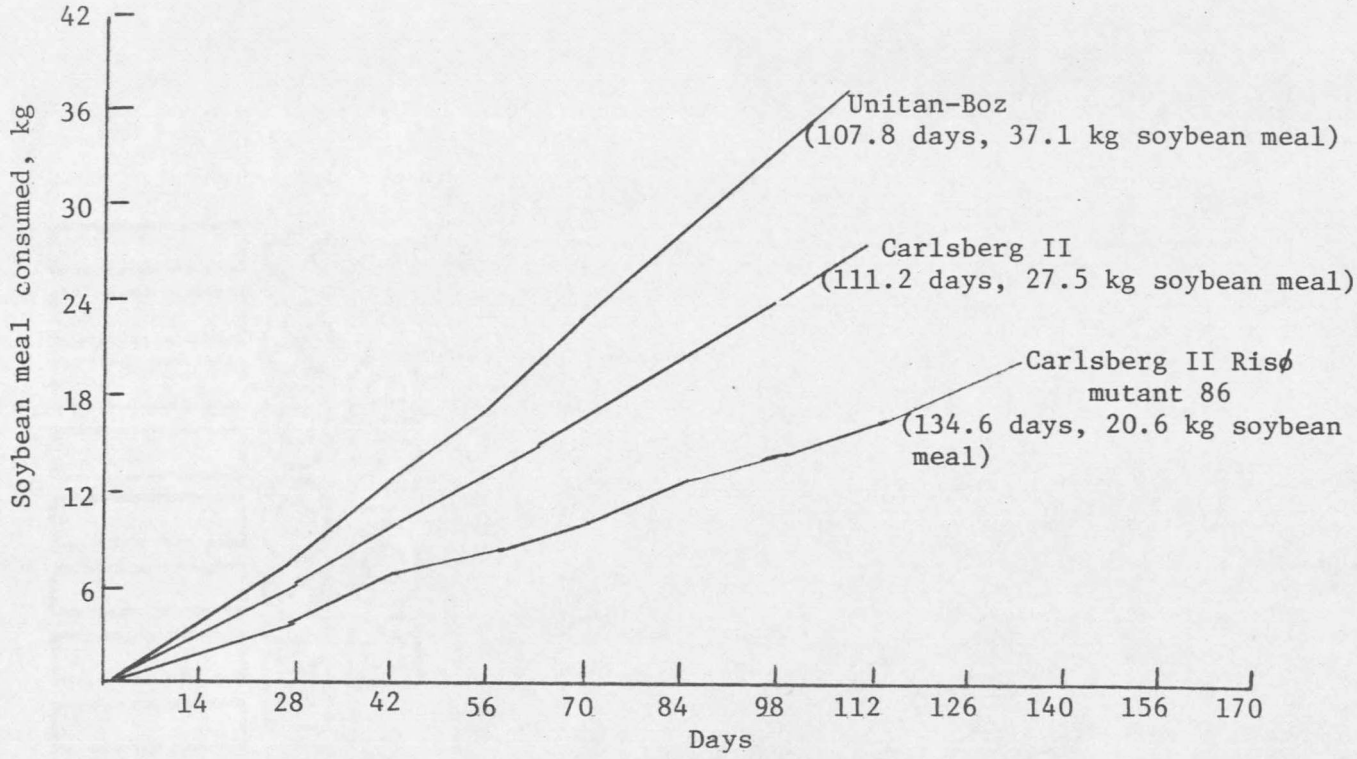


Figure 2. Average accumulative soybean meal intake per pig (20-100 kg).

Swine digestibility trial. Apparent nitrogen digestibility (AND) and dry matter digestibility (DMD) of the three grower diets (table 3) are reported in table 21. The AND and DMD of the C II-R86 diet were significantly lower (P<.01) than those of the C II and Unitan-Boz diets. The AND of the C II diet appeared to be lower than that of the Unitan-Boz diet, but the difference was not significant.

TABLE 21. MEANS OF APPARENT NITROGEN AND DRY MATTER DIGESTIBILITY OF SWINE GROWER DIETS[a]

Barley	Carlsberg II	Carlsberg II Risø mutant 86	Unitan-Boz
Item			
Apparent nitrogen digestibility, %	77.46[b]	64.27[c]	82.56[b]
Dry matter digestibility,%	83.23[b]	77.19[c]	83.38[b]

[a] The pigs weighed an average 52.8 kg at the beginning of the digestibility trial.

[bc] Means in the same row with different superscript letters are significantly different (P<.01).

DISCUSSION

The higher lysine content of the C II-R86 barley used in this project was due to an increase in albumin + globulin content compared to C II and Unitan barleys and a decrease in hordein content compared to C II barley. These findings are supported by the work of Stobart (1977) and Ingversen et al. (1973a). Since lysine is the most limiting amino acid in barley protein (Howe et al., 1965), the higher lysine content of C II-R86 indicated a potential for improved feeding value of that cultivar.

The results of growth trials with rats and pigs in this project failed to support the potential for improved feeding value of C II-R86. Isocaloric, isonitrogenous 10% protein diets containing C II, C II-R86 and Unitan-FE barleys in trial I produced no significant differences in PER. The three all-barley protein diets fed in trial II differed from the 10% protein diets in trial I only in that they were not isocaloric, therefore, the C II-R86 diet contained more ether extract than the C II or Unitan diet (4.5% compared to 3.7 and 3.2% in C II and Unitan-FE diets, respectively) due to the higher endogenous oil content of C II-R86 barley. The PER produed by the C II-R86 diet in trial II was superior to that produced by the Unitan-FE all barley protein diet but did not differ from other diets with or without exogenous amino acid supplementation in trial II. The 12% protein C II-R86 with or without exogenous lysine and methionine produced inferior PERs compared to C II and Unitan-FE diets at those protein-amino acid levels. The C II-R86 diet treatment in the swine growth

trial produced inferior gains and feed efficiency compared to other diets. Pigs fed C II-R86 also had less backfat, smaller loin eye muscle and lower carcass yield. The lower carcass yield was probably due to the decreased backfat and smaller loin eye muscle.

The results of rat nitrogen balance trials Ia and IIa and the swine digestibility trial explain a major portion of the differences noted in the rat and pig growth trials. The TPD of diets containing C II-R86 was lower in both rat nitrogen balance trials as was the AND of the C II-R86 pig grower diet. The BV of C II-R86 diets in trial Ia was higher than that of Unitan-FE, but there were no differences in the BV of diets in trial IIa. The decrease in TPD of C II-R86 diets was sufficient to bring about a decrease in NPU (dietary protein available for body function) compared to all diets containing C II or Unitan-FE in both rat trials although some differences between C II-R86 and Unitan-FE were not significant. This decrease in NPU explains a major portion of the inferior results noted from the C II-R86 diets in growth trials.

A small portion of the decrease in protein availability and inferior growth trial results noted in 12% protein diets in rat growth trial I and in the pig growth trial may be related to the amount of the more easily digested soybean used in the diets (Tables 1 and 3, respectively). Since diets that did not contain soybean meal were also lower in TPD and NPU, it could be assumed that there was a factor or factors in the barley itself that caused a major portion

of the differences. The higher lysine content of C II-R86 as mentioned earlier was due to an increase in the albumin + globulin content of the barley. The albumin + globulin fraction is found in the largest quantity in the aleurone layer and peicarp of the barley seed (Eggum, 1977). Since the proteins of the aleurone layer are more difficult for monogastric animals to digest than those of the endosperm (primarily low lysine hordein) as indicated by Munck et al. (1972), this could well explain the decreased NPU of the C II-R86 diets. Newman et al. (1975b) reported similar results when higher amylose Glacier barley, which has higher lysine content due to increased albumin + globulin and decreased hordein, was compared to Normal Glacier in the diets of rats.

Though the results of this project failed to show improved feeding value of C II-R86 barley, its potential as a feed barley should not be discounted. Although the savings of soybean meal noted was not sufficient to compensate for the inferior gains and feed efficiency of pigs in this project at today's prices in the United States, sufficient changes in the barley/soybean meal price ratio could justify its use. In other areas besides the United States where barley can be cultivated but protein supplements are either too expensive or unavailable, C II-R86 may be feasible as a basal animal feed at the present time.

Further investigation should include feeding trials comparing C II-R86 barley to normal barleys fed alone to pigs as well as a comparison between C II-R86 and normal barley diets having the same level of protein supplement. Other possibilities may include the use of different processing methods of enzymatic treatment to increase the digestibility of C II-R86 barley protein.

SUMMARY

Proximate analysis, Osborne protein fractionation and amino acid analysis were performed on Carlsberg II (C II) barley, its high lysine isogene Carlsberg II Risø mutant 86, and Unitan barley grown at two locations on the Montana Agricultural Experiment Station, Bozeman, Montana (Unitan-FE and Unitan-Boz). Nine isocaloric diets were fed to rats in growth trial I and nitrogen balance trial Ia which consisted of C II, C II-R86 and Unitan-FE barleys represented within each of three protein-amino acid levels including 10 and 12% protein and 12% protein with additional lysine and methionine. Isonitrogenous 10% protein diets fed to rats in growth trial II and nitrogen balance trial IIa included three diets which contained C II, C II-R86 and Unitan-FE barleys as the only protein source and two diets containing C II barley supplemented with lysine and methionine and Unitan-FE barley supplemented with lysine to achieve the levels of those amino acids present in the C II-R86 diet. A casein diet was fed in trial II to permit calculation of adjusted protein efficiency ration (PER). Diets fed in the swine growth trial were vitamin, mineral and antibiotic fortified barley-soybean meal grower and finisher diets containing C II, C II-R86 and Unitan-Boz barleys. Three barrows were fed each of the three grower diets to determine apparent nitrogen (AND) and dry matter digestibility (DMD).

Crude protein and ether extract content of C II-R86 barley were higher than other barleys. Lysine content of C II-R86 was higher compared to other barleys due to an inacrease in albumin + globulin

content at the expense of hordeins.

The C II, C II-R86 and Unitan-FE 10% protein diets produced similar PERs in rat trial I. The PER of C II-R86 diets containing 12% protein or 12% protein + lysine and methionine was inferior to that of C II and Unitan-FE at those protein-amino acid levels. The C II-R86 diet in rat trial II produced superior ($P<.05$) PER compared to the Unitan-FE all barley protein diet but did not differ significantly from other barley or barley-amino acid diets in that trial. Pigs fed C II-R86 gained slower and less efficiently ($P<.01$) than those fed C II or Unitan-Boz diets, but required 34 and 80%, respectively, less soybean meal to reach market weight. Loin eye area, backfat and carcass yield were reduced in pigs fed the C II-R86 diet ($P<.05$).

Biological value (BV) or C II-R86 diets was higher ($P<.05$) than that of Unitan-FE diets and appeared to be higher than that of C II diets in trial Ia, and BV did not differ between diets in trial IIa. The protein digestibility of C II-R86 diets was lower ($P<.05$) than that of other diets in both rat trials as was the ADN ($P<.01$) in the swine digestibility trial. Net protein utilization of C II-R86 diets in both rat trials was consistently lower than that of other diets although some of the differences were not significant.

The higher protein diets in rat trial I and swine diets which contained C II-R86 produced inferior reults compared to C II or Unitan barleys. Differences between Unitan and C II barleys in rat and pig trials were inconsistent and generally nonsignficant.

LITERATURE CITED

Anderson, A. J. and B. Køie. 1975. N fertilization and yield response of high lysine and normal barley. Agron. J. 67:695.

A.O.A.C. 1970. Official Methods of Analysis (11th Ed.). Association of Official Agricultural Chemists, Washington, D. C.

Balaravi, S. P., H. C. Bansal, B. O. Eggum, S. Bhaskaran. 1976. Characterization of induced high protein and high lysine mutants in barley. J. Sci. Food and Agric. 27:545.

Bansal, H. C. 1970. A new mutant induced in barley. Curr. Sci. 34:494.

Brandt, A. 1976. Endosperm protein formation during kernel development of wild type and high lysine barley mutant. Cereal Chem. 53:890.

Brandt, A. and J. Ingverson. 1976. In vitro synthesis of barley endosperm proteins on wild type and mutant templates. Carlsberg Res. Commun. 41:311.

Buchman, N. B. 1977. In vitro digestibility of barley protein. Risø Report No. 351. The Danish Atomic Energy Research Center.

Chapman, D. G., R. Castillo and J. A. Campbell. 1959. Evaluation of protein in foods. I. A method for determination of protein efficiency ratios. Can. J. Biochem. Physiol. 37:679.

Clark and Collip. 1925. Modification of Kramer-Tisdall Method for Calcium Determination. Hawk's Physiological Chemistry. p. 1133. 14th Ed. B. O. Oser, Editor, McGraw-Hill Book Co., New York.

Coulter, J. R. and C. S. Hann. 1971. Gas chromatography of amino acids. In: New Techniques for Amino Acid, Peptide and Protein Analysis. Ann Arbor Science Publishers.

Cromwell, G. L., R. A. Pickett, and W. M. Beeson. 1967. Nutritional value of Opaque-2 corn for swine. J. Anim. Sci. 26:1325.

Danielson, C. E. 1949. Seed globulins of the Graminae and Leguminosae. Biochem. J. 44:387.

Doll, H. 1973. Inheritance of the high lysine character of a barley mutant. Hereditas 74:293.

Doll, H. 1975. Genetic studies of high lysine barley mutants. In: Barley Genetics III, Proc. Third International Barley Genetics Symposium, Garching, p. 542.

Doll, H. and B. Køie. 1978. Influence of the high lysine gene from barley mutant 1508 on grain, carbohydrate and protein yield. In: Seed protein Improvement by Nuclear Techniques, IAEA, Vienna.

Doll, H., B. Køie and B. O. Eggum. 1974. Induced high lysine mutants in barley. Radiation Botany 14:73.

Eggum, B. O. 1969. Evaluation of protein quality and the development of screening techniques. In: New Approaches to Breeding for Improved Plant Protein. Panel Proceedings, Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture. STI/PUB/221. IAEA, Vienna.

Eggum, B. O. 1973a. A study of certain factors influencing protein utilization in rats and pigs. I. Kommission Los Landhusholdningsselskabets forlag, Rolighedsvej 26, 1958 Købehavn V.

Eggum, B. O. 1973b. Biological availability of amino acid constituents in grain protein. In: Nuclear Techniques for Seed Protein Improvement. IAEA, Vienna. 422 pp.

Eggum, B. O. 1977. Amino acid digestibility in cereal grains. In: Proc. 2nd International Symposium on Protein Metabolism and Nutrition, Holland.

Fahey, T. J., D. M. Schaefer, R. G. Kauffman, J. R. Romans, R. J. Epley, D. G. Topel and G. C. Smith. 1975. A comparison of pork carcass evaluation systems. J. Anim. Sci. (Abstr.). 4:290.

Fiske, C. H. and Y. Subbarow. 1925. Phosphorus determination. J. Biol. Sci 66:375.

Food and Agriculture Organization of the United Nations. 1977. FAO Production Yearbook. Rome.

Hagberg, A. and K. E. Karlsson. 1969. Breeding for high protein content and quality in barley. In: New Approaches to Breeding for Improved Plant Protein. IAEA, Vienna, p. 17.

Hagberg, A., K. E. Karlsson and L. Munck. 1970. Use of Hiproly in barley breeding. In: Improving Plant Proteins by Nuclear Techniques. IAEA/FAO, STI/PUB 258, Vienna, p. 121-132.

Hansen, N. G. and B. O. Eggum. 1973. The biological value of proteins estimated from amino acid analysis. Acta Agr. Scandinavia 23:247.

Harris, L. E., J. M. Asplund and E. W. Crampton. 1968. An International Feed Nomenclature and Methods for Summarizing and Using Feed Data to Calculate Diets. Utah State Univ. Agr. Expt. Sta. Bull. 478.

Harvey, W. R. 1960. Least squares analysis of data with unequal subclass numbers. ARS Bull. 20-8, USDA, Washington, D. C.

Hirs, C. H. W. 1967. Determination of cystine as cysteic acid. Meth. in Enzymol. 11:59.

Howe, E. E., G. R. Jansen and E. W. Gilfillan. 1965. Amino acid supplementation of cereal grains as related to the world food supply. Amer. J. Clin. Nutr. 16:315.

Hugli, T. E. and S. Moore. 1972. Determination of the tryptophan chromatography of alkaline hydrolysates. J. Biol. Chem. 247;2828.

Ingverson, J. 1975. Structure and composition of protein bodies from wild type and high lysine barley endosperm. Hereditas 81:69.

Ingverson, J. and B. Køie. 1971. Protein patterns of some high lysine barley lines. Hereditas 69:319.

Ingverson, J. and B. Køie. 1973a. Lysine rich proteins in the salt soluble protein fraction of barley. Phytochemistry 12;73.

Ingverson, J., A. J. Anderson, H. Doll, and B. Køie. 1973a. Selection and properties of high lysine barley. In: Nuclear Techniques for Seed Protein Improvement. IAEA, Vienna, p. 193.

Ingverson, J., B. Køie and H. Doll. 1973b. Induced seed protein mutant of barley. Experientia 29;1151.

Karlsson, K. E. 1972. Linkage studies on a gene for high lysine content in Hiproly barley. Barley Genetics Newsletter 2:34.

Karlsson, K. E. 1977. Linkage studies in a gene for high lysine content in Risø barley mutant 1508. Barley Genetics Newsletter 7;40.

Killen, G. J. 1977. Effect of nitrogen fertilizer on selected barley cultivars. M.S. Thesis, Montana State University, Bozeman.

Lehninger, A. L. 1975. Biolochemistry. Worth Publishers, New York.

Maynard, L. A. and J. K. Loosli. 1969. Animal Nutrition. 6th Ed. McGraw Hill Publ., New York.

Mertz, E. T., L. S. Bates and O. E. Nelson. 1964. Mutant gene that changes protein composition and increases lysine content of maize endosperm. Sci. 145:279.

Mitchell, H. H. 1924. A method of determining the biological value of protein. J. Biol. Chem. 58:873.

Mitchell, H. H. and M. A. Bert. 1954. The determination of metabolic fecal nitrogen. J. Nutr. 52:483.

Mitchell, H. H. and R. J. Block. 1946. Some relationships between the amino acid contents of proteins and their nutritive value for the rat. J. Biol. Chem. 163:599.

Morrison, A. B. and J. A. Campbell. 1960. Evaluation of protein in foods. V. Factors influencing protein efficiency ratio of foods, J. Nutr. 70:112.

Mortenson, H. P., A. Madsen, and A. E. Larsen. 1978. KVL 468 compared with normal barley varieties. Beretning fra Statens Hysdybrugs forsøg Københaven.

Mossberg, R. 1969. Evaluation of protein quality by dye-binding capacity: a tool for plant breeding, In: New Approaches to Breeding for Improved Plant Protein. IAEA/FAO, STI/PUB 212, Vienna, pp. 151-161.

Munck, L. 1964a. The variation of nutritional value in barley. Hereditas 52:1.

Munck, L. 1964b. Plant breeding and nutritional value in cereals. Hereditas 52:152.

Munck, L. 1972a. High lysine barley--a summary of the present research development in Sweden. Barley Genetics Newsletter 2:54.

Munck, L. 1972b. Improvement of nutritional value in cereals. Hereditas 72:1.

Munck, L. 1975. Developing and concept of quality in barley breeding programs for malt and feed. In: Barley Genetics III, Proceedings Third International Barley Genetics Symposium. Garching p. 526.

Munck, L., K. E. Karlsson and A. Hagberg. 1969. Genetics of quality-feeding value: Selection and characterization of a high-protein, high-lysine variety from the World Barley Collection. In: Barley Genetics II, Pullman, WA, pp. 544-558.

Munck, L., K. E. Karlsson, A. Hagberg and B. O. Eggum. 1970. Gene for improved nutritional value in barley seed protein. Sci. 168:985.

N.R.C. 1970. Atlas of Nutritional Data on United States and Canada Feeds. National Academy of Sciences, Washington, D. C.

N.R.C. 1972. Nutrient Requirements of Laboratory Animals, No. 10. Revised 1972. National Academy of Sciences - National Research Council, Washington, D. C.

N.R.C. 1973. Nutrient Requirements of Domestic Animals, No. 2. Revised 1973. National Academy of Sciences - National Research Council, Washington, D. C.

National Pork Producers Council. 1976. Procedures to evaluate market hogs. Des Moines, Iowa.

Newman, C. W., A. M. El-Negoumy and R. F. Eslick. 1978a. Replacing soy protein in swine diets with high protein barley and amino acids. J. Anim. Sci. 46:161.

Newman, C. W., R. F. Eslick and C. C. Calvert, 1978b. Comparative nutritive values of Glacier and high amylose Glacier barleys. J. Anim. Sci. (In press).

Newman, C. W., R. F. Eslick, B. R. Moss, and A. M. El-Negoumy, 1977. Hiproly barley as a source of protein and amino acids for growing-finishing pigs. Nutr. Rep. Int. 15;383.

Newman, C. W., R. F. Eslick and R. C. Rasmuson. 1974. Effect of barley variety on protein quality and nutritional value for rats. J. Anim. Sci. 38:71.

Nielson, H. E., V. W. Hays, V. C. Speer and D. V. Catron. 1963. Lysine supplementation of corn and barley based diets for growing-finishing swine. J. Anim. Sci. 22:454.

Oram, R. N., Doll and B. Køie. 1975. Genetics of two storage protein variants in barley. Hereditas 80:53.

Osborne, T. B. 1895. The proteins of barley. J. Amer. Chem. Soc. 17: 539.

Oser, B. L. 1951. Method for integrating essential amino acid content in the nutritional evaluation of protein. J. Amer. Dietetic Assoc. 27:396.

Pomeranz, Y., R. F. Eslick and G. S. Robbins. 1972. Amino acid composition and malting and brewing performance of high amylose and Hiproly barleys. Cereal Chem. 49:620.

Rose, W. C., M. J. Osterling and M. Womack. 1948. Comparative growth on diets containing ten and nineteen amino acids with further observations upon the role of glutamic and aspartic acids. J. Biol. Chem. 176:753.

Sauer, W. C., P. M. Giovanetti and S. C. Stothers. 1974. Availability of amino acids from barley, triticale and soybean meal for growing pigs. Can. J. Anim. Sci. 54:97.

Saunders, R. M. and G. O. Kohler. 1972. In vitro determination of protein digestibility in wheat mill feeds for monogastric animals. Cereal Chem. 49:98.

Saunders, R. M., H. G. Walker, Jr. and G. O. Kohler. 1969. Aleurone cells and the digestibility of wheat mill feeds. Poultry Sci. 48:1497.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods (6th Ed). Iowa State College Press, Ames.

Spackman, D. H., W. H. Stein and S. Moore. 1958. Automatic recording apparatus for use in chromatography of amino acids. J. Anal. Chem. 30:1190.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Co., New York.

Stobart, J. E. T. 1977. Nutritional evaluation of selected high lysine grains. M.S. Thesis, Montana State University, Bozeman.

Stutz, D. K. 1976. Nutritional evaluation of 2-rowed barleys selected for high lysine. M.S. Thesis, Montana State University, Bozeman.

Tallberg, A. 1973. Ultrastructure and protein composition in high lysine barley mutants. Hereditas 75:195.

Thomke, S., M. Rundgren and K. Elwinger. 1978. Evaluation of Hiproly type barleys fed to rats, pigs, broilers and laying hens. Swedish J. Agric. Res. 8:39.

Thomke, S. and B. Widstromer. 1975. Nutritional evaluation of high lysine barley fed to pigs. In: M. Friedman, Ed. Protein Nutritional Quality of Foods, 2. Quality Factors--Plant Breeding, Composition, Processing and Antinutrients. M. Decker, Inc., pp. 79.

Ullrich, S. E. and R. F. Eslick. 1977. Inheritance of the shrunken endosperm character, sex 3c, of Bomi Risø mutant 1508 and its association with lysine content. Barley Genetics Newsletter 7:66.

United States Department of Agriculture. 1977. Agricultural Statistics. United States Government Printing Office, Washington, D. C.

Waldschmidt-Leitz, E. 1959. Proc. 7th Congr. European Brewing Conven., pp. 37-44. Rome Elsevier Publ. Co., Amsterdam.

APPENDIX TABLE 1. COMPOSITION OF ICN NUTRITIONAL BIOCHEMICALS TOTAL VITAMIN SUPPLEMENT FOR LABORATORY ANIMALS[a]

Ingredients	Amount/45.36 kg diet
Vitamin A	900,000 IU
Vitamin D calciferol	100,000 IU
Alpha-tocopherol	5 g
L-Ascorbic acid	45 g
Inositol	5 g
Choline chloride	75 g
Menadione	2.25 g
p-Aminobenzoic Acid	5 g
Niacin	4.5 g
Riboflavin	1 g
Pyridoxine hydrochloride	1 g
Thiamin hydrochloride	1 g
D-calcium pantothenate	3 g
Biotin	20 mg
Folic Acid	90 mg
Vitamin B_{12}	1.35mg

[a]Vitamins titrated in dextrose to make 1 kg.

APPENDIX TABLE 2. COMPOSITION OF ICN NUTRITIONAL BIOCHEMICALS BERNHARDT TOMARELLI SALT MIXTURE, MODIFIED 1135-B FOR LABORATORY ANIMALS

Ingredints	Percent in premix
Calcium carbonate	2.100
Calcium phosphate	73.500
Citric acid	0.227
Cupric citrate·2.5 H_2O	0.046
Ferrie citrate·5 H_2O	0.558
Magnesium oxide	2.500
Manganese citrate	8.350
Potassium iodide	0.001
Potassium phosphate dibasic	8.100
Potassium sulphate	6.800
Sodium chloride	3.060
Sodium phosphate	2.140
Zinc citrate·2 H_2O	0.133

APPENDIX TABLE 3. LEAST SQUARES ANALYSIS OF RAT GROWTH, FEED CONSUMPTION, FEED EFFICIENCY AND PROTEIN EFFICIENCY RATIO DATA OF RATS FED BARLEY DIETS AT THREE PROTEIN-AMINO ACID LEVELS IN TRIAL I[a]

Source of variation	d.f.	Mean squares			
		Gain	Feed consumed	Feed/gain ratio	PER
Total	135				
Mu-Y	1	7935.0	44416.7	1.780	7.930
Diet	8	1137.0[b]	14267.2[b]	2.780[b]	.210[b]
Error	126	164.4	2756.9	.119	.021

[a]Since the effect of cage level was nonsignficant, this value was pooled in the error term.

[b]P<.01.

APPENDIX TABLE 4. LEAST SQUARES ANALYSIS OF RAT GROWTH, FEED CONSUMPTION, FEED EFFICIENCY AND PROTEIN EFFICIENCY RATIO DATA AS INFLUENCED BY BARLEY CULTIVAR AND PROTEIN LEVEL IN TRIAL I

Source of variation	d.f	Mean squares			
		Gain	Feed consumed	Feed/gain ration	PER
Total	135				
Mu-Y	1	8074.0	48400.0	1.586	8.024
Barley	2	467.0	44628.6[a]	1.348[a]	0.468[a]
Protein level	2	3452.3[a]	6283.1	1.975[a]	0.034
Cage level	4	67.4	3780.4	0.189	0.038
Barley x protein level	4	300.2	3211.8	0.974[a]	0.161[a]
Error	122	167.6	2723.3	0.116	0.020

[a]P<.01.

APPENDIX TABLE 5. LEAST SQUARES ANALYSIS OF BIOLOGICAL VALUE, TRUE PROTEIN DIGESTIBILITY AND NET PROTEIN UTILIZATION OF BARLEY DIETS FED AT THREE PROTEIN-AMINO ACID LEVELS IN TRIAL Ia

Source of variation	d.f.	Mean squares		
		Biological value	True protein digestibility	Net protein utilization
Total	53			
Mu-Y	1	1469.38	793.13	108.15
Diet	8	99.11[a]	155.68[b]	67.73
Error	44	39.64	18.86	32.94

[a]P<.05.
[b]P<.01.

APPENDIX TABLE 6. LEAST SQUARES ANALYSIS OF BIOLOGICAL VALUE, TRUE PROTEIN DIGESTIBILITY AND NET PROTEIN UTILIZATION AS INFLUENCED BY BARLEY CULTIVAR AND PROTEIN-AMINO ACID LEVELS IN TRIAL Ia

Source of variation	d.f.	Mean squares		
		Biological value	True protein digestibility	Net protein utilization
Total	53			
Mu-Y	1	1469.38	793.13	108.15
Barley	2	220.53[a]	579.48[a]	163.85[b]
Protein level	2	136.75[b]	31.61	93.60
Barley x protein level	4	20.10	4.77	10.49
Error	44	39.64	18.86	32.94

[a]P<.01.
[b]P<.05.

APPENDIX TABLE 7. LEAST SQUARES ANALYSIS OF RAT GROWTH, FEED CONSUMPTION, FEED EFFICIENCY AND PROTEIN EFFICIENCY RATIO DATA OF RATS FED ISONITROGENOUS 10% PROTEIN BARLEY, BARLEY + AMINO ACID AND CASEIN DIETS IN TRIAL II

Source of variation	d.f.	Mean squares			
		Gain	Feed consumed	Feed/gain ratio	Adjusted PER
Total	60				
Mu-Y	1	10454.4	287041.6	0.000	0.002
Diet	5	938.4[a]	14742.1[a]	2.169[a]	0.327[a]
Cage level	4	80.1[b]	1461.9	0.627[b]	0.126[b]
Diet x cage level	20	157.8	181.7	0.190	0.042
Error	30	258.3	2888.8	0.198	0.034

[a] $P<.01$.
[b] $P<.05$.

APPENDIX TABLE 8. LEAST SQUARES ANALYSIS OF BIOLOGICAL VALUE, TRUE PROTEIN DIGESTIBILITY AND NET PROTEIN UTILIZATION OF 10% PROTEIN BARLEY AND BARLEY + AMINO ACID DIETS IN TRIAL IIa

variation	d.f.	Mean squares		
		Biological value	True protein digestibility	Net protein utilization
Total	20			
Mu-Y	1	0.184	27.261	19.960
Diet	4	12.897	76.264[a]	76.763[b]
Error	15	17.440	16.996	9.863

[a] $P<.05$.
[b] $P<.01$.

APPENDIX TABLE 9. LEAST SQUARES ANALYSIS OF AVERAGE DAILY GAIN OF PIGS FED THREE BARLEY DIETS, GROWER, FINISHER AND TOTAL PERIODS

Source of variation	d.f.	Mean squares Average daily gain		
		Grower	Finisher	Total
Total	69			
Mu-Y	1	1.232	0.636	0.076
Diet	2	0.720[a]	0.741[a]	0.744[a]
Replication	5	0.078[a]	0.077[a]	0.060[a]
Sex	1	0.056[b]	0.044	0.085[b]
Diet x replication	10	0.031	0.023	0.019
Diet x sex	2	0.003	0.022	0.014
Covariate[c]	1	0.041[a]	0.277[a]	0.119[a]
Error	47	0.017	0.015	0.014

[a] $P<.01$.
[b] $P<.05$.
[c] Covariate for grower and total periods was initial weight, for finisher period covariate was weight at which diets were changed from grower to finisher diet.

APPENDIX TABLE 10. LEAST SQUARES ANALYSIS OF AVERAGE DAILY FEED AND FEED EFFICIENCY RATIOS OF PIGS FED THREE BARLEY GROWER DIETS

Source of variation	d.f.	Mean squares	
		Average daily feed	Feed/gain ratio
Total	18		
Mu-Y	1	0.047	0.794
Replication	5	0.356[a]	0.014
Diet	2	0.065	0.653[b]
Error	10	0.085	0.030

[a] $P<.05$.
[b] $P<.01$.

APPENDIX TABLE 11. LEAST SQUARES ANALYSIS OF AVERAGE DAILY FEED AND FEED EFFICIENCY RATIOS OF PIGS FED THREE BARLEY FINISHER DIETS

Source of variation	d.f.	Mean squares	
		Average daily feed	Feed/gain ration
Total	18		
Mu-Y	1	0.025	0.128
Replication	5	0.372	0.021
Diet	2	0.425	1.591[a]
Error	10	0.218	0.071

[a] $P<.01$.

APPENDIX TABLE 12. LEAST SQUARES ANALYSIS OF AVERAGE DAILY FEED AND FEED EFFICIENCY RATIOS OF PIGS FED THREE BARLEY DIETS FOR THE TOTAL GROWING-FINISHING PERIOD

Source of variation	d.f.	Mean squares: Average daily feed	Mean squares: Feed/gain ratio
Total	18		
Mu-Y	1	0.565	0.207
Replication	5	0.408	0.019
Diet	2	0.046	1.207[a]
Error	10	0.136	0.047

[a] $P<.01$.

APPENDIX TABLE 13. LEAST SQUARES ANALYSIS OF LOIN EYE AREA, AVERAGE BACKFAT AND PERCENT CARCASS YIELD OF PIGS FED THREE BARLEY DIETS

Source of variation	d.f.	Mean squares: Loin eye area	Mean squares: Backfat	Mean squares: Percent yield
Total	69			
Mu-Y	1	1.010	0.762	267.78
Replication	5	0.422	0.014	4.95
Diet	2	1.701[a]	0.141[b]	106.35[b]
Sex	1	1.796[a]	0.107[b]	2.79
Replication x diet	10	0.242	0.010	1.58
Diet x sex	2	0.287	0.003	1.03
Error	48	0.341	0.014	2.07

[a] $P<.05$.
[b] $P<.01$.

APPENDIX TABLE 14. LEAST SQUARES ANALYSIS OF CARCASS LENGTH AND PERCENT CARCASS MUSCLE OF PIGS FED THREE BARLEY DIETS

Source of variation	d.f.	Mean squares	
		Length	Percent carcass muscle
Total	69		
Mu-Y	1	6.295	235.852
Diets	2	0.491	1.675
Sex	1	0.556	99.019[a]
Replication	5	0.762	2.624
Diet x sex	2	0.830	8.455
Covariate[b]	1	0.005	0.017
Error	57	0.583	6.025

[a] $P<.01$.
[b] Covariate used was number of days on test, an estimate of age at slaughter.

APPENDIX TABLE 15. LEAST SQUARES ANALYSIS OF PERCENT HAM, PERCENT HAM AND LOIN AND PERCENT LEAN CUTS OF PIGS FED THREE BARLEY DIETS

Source of variation	d.f.	Mean squares		
		Percent ham	Percent ham and loin	Percent lean cuts
Total	69			
Mu-Y	1	0.061	100.022	39.924
Diets	2	0.313	0.640	1.762
Sex	1	16.122[a]	40.911[a]	50.551[a]
Replication	5	0.487	1.022	0.733
Diet x sex	2	1.982[b]	5.158	6.872
Covariate[c]	1	0.022	0.357	0.451
Error	57	0.564	1.628	2.742

[a] $P<.01$.
[b] $P<.05$.
[c] Covariate used was number of days on test, an estimate of age at slaughter.

APPENDIX TABLE 16. MEAN SQUARES OF APPARENT NITROGEN AND DRY MATTER DIGESTIBILITIES OF THREE BARLEY GROWER DIETS FED TO PIGS

Source of variation	d.f.	Mean squares	
		Nitrogen digestibility	Dry matter digestibility
Total	8		
Diet	2	266.84[a]	37.39[a]
Replication	2	4.48	5.06
Error	4	10.15	1.50

[a] $P<.01$.

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