



Nutritive value of Wapana, Compana, high amylose and normal Glacier barleys
by Calvin Rex Miller

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Animal Science

Montana State University

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Abstract:

Two pairs of isogenic barleys, Wapana (waxy Compana, W) and Compana (C), and high amylose Glacier (HAG) and normal Glacier (NG), varying in the ratio of amylose to amylopectin in the starch were tested for feeding value in eight separate experiments using poultry, sheep, and Holstein dairy cattle. In Experiment I, a chromic oxide indicator method with 84 H&N Meat Nick chicks was used to determine the metabolizable energy (ME) of W and C. Respective ME values were 2.80 kcal/g and 2.56 kcal/g ($P > .05$) for W and C. Experiment II used 77 H&N Leghorn chicks to determine the ME of HAG and NG. Data were computed on the basis of total feed consumption and excreta collection. The ME values for HAG and NG, respectively, were 3.06 kcal/g and 3.19 kcal/g ($P > .05$). Experiment III was a second ME determination of W and C, using five non-laying H&N Leghorn hens. Birds were kept in individual cages and ME based on individual feed consumption and total excreta collection data. The ME values for W and C, respectively, were 3.05 kcal/g and 3.09 kcal/g ($P > .05$). Experiment IV compared the relative values of W, C, and wheat in diets with 3% or 5% added fat in layer diets using H&N Leghorn hens in a 31 week layer study. Compana and wheat diets were also fed without fat. Total eggs, total hen days, eggs per day, average egg weight, or beginning body weight (24 weeks of age) did not differ ($P > .05$) for diets. Some differences ($P > .05$) between final body weights (55 weeks of age) occurred. The W group at the low fat level had higher ($P < .05$) body weights (1969 g) compared to the C group (1575 g) at the same fat level. At the high level of fat, the C group tended to have higher body weights than the W group, but not significantly so. Experiment V used four Targhee rams to determine digestibilities of HAG and NG fed as whole grains. Digestibilities of dry matter, crude protein, or nitrogen-free extract did not differ ($P > .05$). Average dry matter digestibilities for HAG and NG, respectively, were 75.3% and 76.1%. Experiment VI utilized Holstein heifer calves to determine digestibilities of concentrate diets containing W or C for dry matter, crude protein, and nitrogen-free extract. No differences ($P > .05$) were noted between barley diets for these nutrients. Average dry matter digestibilities for the W diet and the C diet, respectively, were 70.5% and 75.8%. Experiment VII used five Holstein bull calves fed a W-based concentrate diet and six fed a similar C diet to compare rates of gain for 106 days. Average daily gain was 1.23 kg/day for the W diet and 1.24 kg/day for the C diet ($P > .05$) with no difference in barley consumption. Experiment VIII was a lactation study using 12 Holstein cows in a switchback design to compare diets based on W or C. Daily milk production, percents of butterfat, solids-not-fat, crude protein, or daily grain or hay consumption did not differ ($P > .05$).

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Date August 23, 1976

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AND NORMAL GLACIER BARLEYS

by

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A thesis submitted in partial fulfillment
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Abstract

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INTRODUCTION

Barley is the fourth most widely produced grain in the world, and ranks second only to wheat in Montana. Part of the popularity of barley is due to its ability to grow and produce under a wide variety of environmental conditions. At Montana State University and other research centers around the world, much interest is currently being focused on the improvement of barley feed value through breeding and testing new cultivars. Areas of current interest include barley protein quality and quantity, and the amylose to amylopectin ratio of the barley starch.

Much of the barley produced in the United States is used as animal feed. Common cultivars of barley are typical of plant products in that their protein is usually limiting in lysine, and is low in methionine and tryptophan relative to animal requirements. A cultivar of barley currently being studied, named Hiproly, may be of some help in this respect since it is relatively high in protein, lysine, methionine, and tryptophan.

Ewing (1963) stated that barley can replace corn or oats in layer rations without affecting egg production or feed efficiency but body weights may not be maintained. Barley also is not as palatable as corn, wheat, or oats. Most studies with barley have resulted in poorer performance than with other grains as the major source of energy in high efficiency broiler diets. Water treatment or supplementation with enzymes to rations containing Western U.S. barleys have increased

the efficiency when fed to poultry.

Barley is a major ingredient in dairy concentrate diets in the Northwest United States. Waldern and Cedeno (1970) compared barley, wheat mixed feed, and a mixed concentrate diet containing wheat, peas, barley, and cottonseed meal in a meal or pelleted form for lactating dairy cattle. Barley is equal in acceptability and nutritive value to wheat in mixed concentrate diets and superior to wheat mixed feed in dairy rations.

Advantages in gain and feed efficiency have been shown for waxy (high amylopectin) sorghum and corn in ruminants. In an effort to improve gains and feed efficiencies in barley, therefore, interest has turned to the ratio of amylose to amylopectin in barley starch. Barley cultivars exist that have the amylose to amylopectin ratio in either extreme. Wapana barley, an isogene of Compana, is nearly 100% amylopectin, while high amylose Glacier is about 48% amylose. Most plant starch is about 25% amylose. Evidence to date with rats, swine, poultry, and ruminants does not show a clear-cut feeding advantage of either of these barleys over its respective isogene.

The experiments described in this thesis were designed to further investigate the relative feeding values of Wapana, Compana, high amylose Glacier, and normal Glacier barleys to determine if the ratio of amylose to amylopectin affects the feeding value of barley. Metabolizable energy for poultry and digestibilities for ruminants were

determined for all four barleys. In addition, Wapana and Compana were evaluated in diets for poultry layers, dairy bull growth, and lactation in Holstein cows.

LITERATURE REVIEW

Chemical and Physical Properties of Starch

French (1973), in a review article, describes the molecular structure of starch. The basic chain structure of starch is called amylose, which is a straight chain polymer of D-glucose units linked by alpha-1,4 bonds. In plants, these polymers may be thousands of glucose units long. Most starch occurring in plants is about 25% amylose, with the remainder being amylopectin.

Amylopectin is also a polymer of D-glucose, but in addition to alpha-1,4 linkages has about 4 or 5% alpha 1,6 linkages. These linkages are responsible for the branch points in amylopectin. The average spacing between branch points is 8 glucose units. However, spacing is often as close as 2 glucose units and often much longer than 8 units. The exact structure of amylopectin has not been shown. The classical Meyer and Bernfeld (1940) scheme depicts amylopectin as having more or less evenly spaced branch points, similar to the branching of a tree. French (1972) shows some evidence that the branch points may be in clusters. Such a structure would better explain the fibrous texture observed through the electron microscope, and would better account for the viscosity observed for amylopectin.

According to French (1973), glucose, maltose, and amylose up to 8 units long are soluble in water. At 9 or more units, the amylose molecule becomes non-hygroscopic and progressively less soluble until it is very insoluble at 70-150 units. At about 500 units in length

amylose is again soluble in warm water. Many chemicals, such as NaOH, KOH, certain salts, 6 M urea, many amines or amids, glycerol, ethylene glycol, or dimethyl sulphoxide act as starch solvents in aqueous solution. Also, many chemical modifications that disrupt the regularity of the amylose chain make it more soluble. Examples of such modification are the introduction of a few branch points, substitution of OH groups, or the breakdown of molecular size by oxidation.

In plants, starch is found in the form of granules. These are from less than 1 μm to more than 100 μm in diameter. Although not proven, it is suspected that the linear portions of the starch molecules often form double helices within the starch granule. About half of a typical starch granule is crystalline in nature; the remainder being a gel-like matrix of starch. The gel regions are hygroscopic and can absorb water, causing the entire granule to swell. This process is reversible. The crystalline regions do not change unless enough heat is added to cause them to dissolve or melt. If this happens, the destruction of the crystals is irreversible, and is called gelatinization. With more heating, the starch granules continue to swell. If at least 5% of the starch-water mixture is starch, the starch dispersion can occupy the entire container, thereby increasing the viscosity of the whole mixture. If the starch concentration is sufficient, a starch gel will form when the mixture is cooled.

Swollen, gelatinized, or dissolved starch, when left alone, can return to an aggregated or insoluble form. This is called retrogradation which is caused by the gradual association of starch chains with each other. These aggregates often become large enough to precipitate from the solution. The retrogradation process may be speeded by cooling or partially reversed by heating.

Bathgate and Palmer (1972) found that starch granules in wheat gradually increase in size from 5 μ to 30 μ , but that barley has two classes of starch granules. Small granules, averaging 5 μ in diameter represent 90% of the granules by number, and 10% of the starch by weight. The rest is made up of larger granules averaging 25 μ in diameter. Current evidence (Goering and DeHaas, 1974) shows that in mature barley the small granules are a separate group, and are not immature starch granules.

Variation in the Ratio of Amylose to Amylopectin in Grain Starches

Although most plant starch is about 25% amylose, many cultivars of cereal grains have been discovered or developed which vary radically from this average. These starches, which are called either high amylose or waxy (high amylopectin) have a variety of unique properties, which lead to having a variety of industrial applications. Much interest has also been focused on the potential feed value of these grain cultivars.

Normal corn starch is typical in that it contains about 25% amylose. However, cultivars have been found that vary greatly from this. Borchers (1962) reported three high-amylose cultivars with 50%, 63%, and 77% amylose. At the opposite extreme, Rogols and Meites (1968) reported a waxy corn cultivar containing about 85% amylopectin.

Sorghum grain is a common concentrate for feedlot cattle in many areas. Sorghum starch usually contains about 75% amylopectin. Certain cultivars, however, have been found that contain almost 100% amylopectin (Nisnimuta, et al., 1969).

Glacier, a 6-rowed spring barley (CI 9676) has a mutant isotype (designated Ac 38) discovered in 1967 (Merritt, 1967) which contains starch with about twice as much amylose as the normal cultivar. Banks, et al., (1974) report that the high amylose cultivar has about 45% amylose as compared to the normal with 26% amylose. The average size of the granules is much smaller in the high amylose cultivar. These small granules were observed to gelatinize at a higher temperature than the normal barley granules.

A derivative of Compana barley with starch composed of almost all amylopectin has been developed (Goering, et al., 1957). Starch of the normal cultivar of Compana has 76% amylopectin. The waxy Compana was developed by the introduction of the waxy gene from waxy Oderbrucker and then back-crossing seven times with Compana. The waxy cultivar has since been named Wapana. Goering, et al. (1973) report that there

is some evidence that the amylopectin in Wapana is unique in some way. When compared to waxy sorghum, Wapana has one-third the solubility and about half the swelling power. It has also been shown that there is some affinity for iodine by the waxy starch. Since iodine binding is a property of amylose chains, the amylopectin either has some amylose associated with it or the amylopectin chains are very long. These and other laboratory tests suggest that the amylopectin in Wapana may have some molecular cross-binding or very long amylopectin chains. Long chains may cause the amylopectin to have some of the properties of amylose.

Digestion of Starch

French (1973) describes some of the pathways for digestion of starch. The general group of enzymes that break starch down into glucose are called amylases. Although there are many variations among plants and animals in the pattern for the breakdown of starch, the most common involves the use of an alpha-amylase, an endo enzyme, which can attack the starch molecule at any interior point in a linear starch chain. Alpha-amylase is capable of breaking amylose down completely into glucose, maltose, and maltotriose. Maltose and maltotriose, in turn, can be broken down into glucose by a maltase. The alpha-1,6 linkages of amylopectin are resistant to the action of alpha-amylase. However, plants and many bacteria are capable of breaking these linkages

by means of various debranching enzymes. Amylases act faster on dispersed or cooked starch than on unchanged starch granules. Amylases begin degradation on the surface of the granule, probably at irregularities or fractures, and form pits. Eventually, amylase action can dissolve the entire granule.

In general, the more amylopectin present in the starch, the more readily it is digested. Rogols and Meites (1968) reported that in hog pancreatic alpha-amylase, waxy corn starch (85% amylopectin) is more readily digested than normal corn starch (60% amylopectin), which in turn is more readily digested than high amylose corn starch (20% amylopectin). However, they found that the relative order of digestibility is somewhat different in human saliva, human serum, and human urine. Waxy corn starch is the most digestible in these fluids, followed by high amylose corn starch and then by normal corn starch.

Digestion of starch in monogastrics follows a typical pattern. There is some amylase activity in the saliva, but starch digestion from salivary action is minimal, since its action is halted by the low pH found in the stomach. Nearly all starch digestion takes place in the small intestine by pancreatic alpha-amylases and intestinal enzymes. Glucose is then absorbed into the blood stream by the villi in the small intestine (Sturkie, 1965).

Ewing (1963) describes digestion in poultry. Feed picked up by the beak passes directly to the crop where it is mixed with saliva,

moisture, and other secretions and is thereby softened until the gizzard can accept it. The gizzard takes in feed in small quantities and mixes it with a pepsin-hydrochloric acid mixture while also grinding the feed. From the gizzard, the feed passes into the duodenum, where most starch digestion takes place. Pancreatic amylases and other enzymes break down the starch, and absorption of glucose takes place in the small intestine. Time required for digestion varies from an average of 3 hours and 46 minutes for laying hens to 11 hours and 44 minutes for broody hens. More than 15 hours is sometimes required for digestion of whole grains, while ground grains may only require 2½ hours.

In ruminants, there are two possible pathways of starch digestion (Waldo, 1973). The first is by rumen microorganisms, and the second is in the small intestine. Digestion in the rumen results in production of bacterial cells, and the by-products of fermentation, volatile fatty acids. Digestion in the small intestine results in release and then absorption of glucose.

A summary of experiments (Waldo, 1973) on barley, corn, and sorghum starch showed that whole tract digestion in the ruminant averages 99%. Barley starch was 94% digested before reaching the abomasum or duodenum in several experiments. Different barley cultivars use of cattle or sheep, processing methods, and level of starch made little difference in this value. Corn starch averaged 78% digestion in

the rumen. Variation for corn digestion was much higher than the variation for barley digestion. In the different experiments summarized, this variation was attributed to different lots of corn (having different genetic backgrounds), level of starch in the cultivar, and method of corn processing. Sorghum starch digestibility in the rumen was slightly lower, at 76%, than corn starch, and variation was even greater. The cultivar of sorghum seemed to cause more variation in starch rumen digestibility than for corn digestion. Ruminal digestion of sorghum starch could be increased to the level of barley starch by moist heat treatment.

Digestibility of corn starch in the small intestine can be as high as 93%, but decreases as the amount of starch reaching the intestine increases. Digestibility of barley starch seems to be about 97% to 99% in the small intestine.

Implications of starch digestion in the large intestine are not clear. However, experiments show that corn starch can be digested up to 94%, and sorghum starch up to about 88%, depending on the level of starch reaching the large intestine.

According to Waldo (1973), it is probable that the more efficient concentrate is one that is digested partly in the small intestine, rather than extensively in the rumen. This could partially explain the higher net energy values reported for corn than for barley.

Ørskov (1969), in agreement with Waldo (1973), states that available evidence shows that there may be more energy available to the ruminant animal if some carbohydrate does escape fermentation. Two possible reasons for this are: 1) fermentation is associated with a certain loss of energy; and 2) glucose may be utilized to a greater degree of efficiency than the volatile fatty acid by-products of fermentation. However, in the case of milk production by cows, other factors may change the more desirable location of carbohydrate digestion. Evidence implies that anything that tends to decrease rumen fermentation will also decrease the percent butterfat in the milk, or that increased butterfat may be associated with an increased level of rumen fermentation. There are many questions remaining to be answered in this area of ruminant nutrition.

Performance Studies of High Amylose Grains

Sandstedt, et al. (1962) used rats and chicks for some digestion experiments on high amylose corn. The amylose level in the starch was about 63%. Results showed the digestibility of the high amylose starch to be much lower than for the normal starch. It was estimated that about 60% of the feces was starch in each case. No starch was visible using the microscope in the feces of rats and chicks fed normal corn. The depression in digestibility of high amylose starch seems to be caused by a factor associated with the *ae* gene in corn necessary for

the high amylose content, rather than by the starch itself. Similar experiments by Borchers (1962) on high amylose corn using rats is in agreement with these results.

Calvert (1975) found purified high amylose Glacier starch to be poorer than normal Glacier starch in nutritional value when fed to rats in isonitrogenous diets. Nitrogen balance, energy balance, and gain were measured. In separate trials, rats fed high amylose Glacier barley in diets had a greater rate of gain than rats fed the normal Glacier diet. Diets containing these two barleys were fed to growing-finishing pigs with no significant differences in gain and carcass characteristics except for an increase in percentage of ham for the normal Glacier group in one trial, and an increase in feed utilization for the normal Glacier groups in two trials.

Pomeranz et al. (1972) investigated the value of high amylose Glacier for brewing. They determined that high amylose Glacier is not acceptable for brewing because it resists gelatinization. Without gelatinization, susceptibility to amylases is low.

Wilson and McNab (1975) fed high amylose Glacier, normal Glacier, and feed grade barleys to broilers in diets containing corn and wheat to determine the effect of high amylose Glacier on gain and feed efficiency. High amylose Glacier barley increased feed intake, and consequently weight gains, without affecting the overall efficiency of feed conversion when it replaced the other barleys.

Herstad and McNab (1975) tested the effects of the addition of alpha-amylase to diets containing high amylose and normal Glacier barleys on the digestibility and metabolizable energy (ME) values using broiler chicks. The digestibility and ME of these two barleys fed without enzyme was lower than for a commercial variety also tested. Enzyme additions brought the digestibility and ME of the normal glacier up to the level observed for the commercial barley, but the enzyme addition had little effect on the digestibility and ME content of the high amylose Glacier.

Performance Studies of Waxy Grains

In some cases, waxy corn gives higher gains and feed efficiencies than normal corn. Robinson, et al. (1974) using rats on a 60-day growth trial showed waxy corn at the 15% crude protein level to be slightly higher than normal corn in these respects. However, at the 25% protein level, the relative order was reversed: normal corn was superior in gain and feed efficiency. The same authors showed no significant difference in growth and feed efficiency in a nitrogen balance study using lambs. Separate growth trials using heifers and Holstein steers also showed no significant difference between waxy and normal corn. Braman, et al. (1973) showed that waxy corn increases feed efficiency and gain when fed to finishing lambs and steers.

Many studies have shown a definite advantage in gains and feed efficiency for feedlot cattle by using waxy sorghum rather than normal

sorghum (Sullins and Rooney, 1974). This is due in part to the ease of digestion of waxy starch, and probably in part to an accompanying decrease in the density of the peripheral endosperm. The increased susceptibility of the protein matrix to solubilization also plays a part.

Digestibility studies by Nisnimuta, et al. (1969) using sheep to compare waxy and regular sorghum have given results favorable to the waxy cultivar. Higher digestibilities of organic matter, gross energy, nitrogen-free extract, and crude protein were shown for waxy sorghum. The starch was apparently more readily available in the waxy grain. The structure of the starch granules probably was related to this increase.

Similarly, net energy determinations with finishing steers by Sherrod, et al. (1969) for maintenance and gain showed an advantage for waxy sorghum over regular sorghum. Feed utilization was also better for waxy grain both on a liveweight basis and on a carcass basis. This trial supports claims for a more readily available energy source from waxy sorghum.

Using the nylon bag technique for dry matter digestibility and a fistulated steer, Walker and Lichtenwalner (1974) showed that dry ground or reconstituted waxy sorghum was digested more rapidly in the rumen than dry ground or reconstituted normal sorghum. There was a significant difference in amounts digested at 24 hours, but the values

at 48 and 72 hours were not significantly different. This may be an explanation for the reported higher gains for waxy sorghum over normal sorghum.

From the results observed with waxy corn and waxy sorghum, it might be expected that Wapana would give similar advantages in gain and feed efficiency over Compana for various classes of livestock. However, most evidence does not support this assumption.

Moss, et al. (1974) fed broilers in a growth trial designed to compare the performance of Wapana, Compana, and wheat. In a series of diets, these barleys were substituted for the wheat at levels of 25%, 50%, 75%, and 100%, in a diet based on wheat. In all cases, the diet based on wheat gave the best performance, as expected. However, the diet in which 100% of the wheat was substituted for by Wapana gave the poorest growth ($p < .05$). Unpublished data (Moss, 1975) comparing Wapana and Compana for layers showed no significant difference in egg production using Leghorns 20 weeks of age on a study lasting 20 weeks. Final body weights tended to be lower on the Wapana diet. Preliminary investigations by Newman (unpublished data, 1974) on swine growth have not shown any advantage for Wapana over Compana.

Moss and Newman (1975) studied the nutritional value of Wapana and Compana for Holstein dairy calves. Calves placed on starter diets containing either Wapana or Compana showed no significant difference in weight gains to three months of age.

A feed-gain trial using wether lambs showed a tendency, although not significant, for the normal Compana to give better gains (Stockton, 1976). Net energy values computed in a separate experiment using lambs showed these two barleys to have equal feed potential. In a metabolizable energy trial using yearling rams, there was no significant difference in performance between Wapana and Compana. Also, rumen samples analyzed for the ratios of butyric and acetic acids to propionic acid showed no significant difference. In vitro digestibility of these barleys at 12 hours indicated that Wapana is more rapidly digested, but that the total dry matter digestibility becomes closer to and eventually the same by 96 hours. However, since barley starch is about 94% digested in the rumen, this difference at 12 hours may not be enough to affect the overall production of ruminants.

Studies by Calvert (1975) with rats and pigs using Wapana and Compana gave results similar to those of other authors. These barleys were used in rat studies measuring growth, nitrogen balance, and energy balance. The waxy grain was at least equal in nutritional value, and tended to be slightly better than the normal for rats. Studies with growing and finishing swine also showed no significant differences in gain, feed efficiency, or carcass characteristics although there also was a tendency for the waxy cultivar to be slightly better utilized in these trials than the normal cultivar.

MATERIALS AND METHODS

Experiment I: Wapana and Compana Metabolizable Energy for Chicks.

A total of 84 H&N Meat Nick chicks were used to determine the metabolizable energy (ME) of Wapana and Compana barleys. The basal diet and assay procedures were similar to those described by Sibbald and Slinger (1963).

The chicks were kept in electrically-heated battery brooders and fed a standard starter diet from hatch until they were two weeks of age. The temperature was set at 38 C at hatch and was gradually decreased until at two weeks the electric heaters were turned off and the chicks were kept at room temperature of approximately 24C.

At two weeks, 12 chicks were randomly assigned to each of seven assay groups. Each group was housed in one cage, and feed and water were offered ad libitum throughout the trial. The chicks were allowed to adapt to their respective diets for eight days. On days 9, 10, and 11 excreta were blown free of down and collected for each cage. Samples were pooled over the 3 days for each group for analysis.

Diets used in this assay are described in table 1. All rations were fed as a mash. Since barley alone is not nutritionally adequate for growing chicks, this assay for ME uses barleys mixed in varying proportions with a supplemental basal mix. Vitamins and minerals were added to each diet at a set level after the basal and test portions were combined. When the ME for a series of such diets is known, the ME for the test material (barley) can be calculated by using

simultaneous equations.

Laboratory analysis of feeds and excreta included percent dry matter, Parr oxygen bomb calorimetry, Kjeldahl nitrogen (A.O.A.C. 1970) and chromic oxide ratios (Czarnocki et al., 1961). Kjeldahl nitrogen was determined on wet excreta, since drying of excreta results in substantial loss of ammonia.

Calculation of ME for each diet was according to the equation:

$$\text{ME feed} = \text{GE feed} - \frac{\text{g Cr}_2\text{O}_3/\text{g dry feed}}{(\text{g Cr}_2\text{O}_3/\text{g dry excreta} \times \text{GE excreta})}$$

where ME = metabolizable energy in kcal/g,
GE = gross energy in kcal/g, and
g = grams.

The ME for each diet was corrected for the addition of the mineral-vitamin mix (MVM) by multiplying each diet value by 1.03, since 1000 g diet + 28.25 g (MVM/1000 g diet) = 1.03.

Calculation of ME for the barley in each diet was done by solving pairs of the following equations. Values were obtained by pairing equation number 1 with each of the other equations. The right-hand side is the value calculated as above for each corresponding test diet.

1. 1.00B + 0.00T = ME diet
2. 0.80B + 0.20T = ME diet
3. 0.60B + 0.40T = ME diet
4. 0.40B + 0.60T = ME diet

where B = ME of the basal diet and
T = ME of the barley

Table 1. COMPOSITION OF THE SEVEN ASSAY DIETS FOR THE WAPANA AND COMPANA METABOLIZABLE ENERGY FOR CHICKS, EXPERIMENT I

Diet number	Basal mix ^a to barley ratio in assay diets ^b		Barley tested
	Basal %	Test barley %	
1	100	0	Basal diet
2	80	20	Wapana
3	60	40	Wapana
4	40	60	Wapana
5	80	20	Compana
6	60	40	Compana
7	40	60	Compana

^a The basal mix was formulated as follows in percentage: soybean meal, 55; ground wheat, 17; ground yellow corn, 17; fish meal, 5; dried whey, 4; sun-cured ground alfalfa, 4.

^b Formulation of the seven assay diets was completed by the addition of the mineral-vitamin mix as follows to the combined basal and test mixtures, g/kg of assay diet: dicalcium phosphate, 10.06; ground limestone, 9.63; chromium oxide, 3.21; salt, 2.35; DL-methionine, .43; layer-grower premix^c, 2.57.

^c The layer-grower premix supplied the following per kg assay diet: vitamin A, 6,768 USPU; vitamin D₃, 2,227 ICU; vitamin E, 3.43 IU. The following were supplied as mg/kg diet: vitamin B₁₂, .0056; riboflavin, 3.43; d pantothenic acid, 3.43; choline, 343; menadione sodium bisulfite complex, 1.11; folic acid, .223; ethoxyquin, 64.2; manganese, 51.4; iodine, 1.54; iron, 51.4; copper, 5.14; cobalt, .514; zinc, 51.4.

Experiment II: High Amylose and Normal Glacier Metabolizable Energy for Chicks:

Procedures used for this determination of ME for high amylose Glacier and normal Glacier barleys were very similar to those used in Experiment I. The basal mix and mineral-vitamin mix used were the same. The diets were mixed according to table 2. Each assay group consisted of 11 H&N Leghorn chicks which were the same age and reared in the same way as the chicks in Experiment I.

The major difference between this determination and Experiment I is that feed consumption and excreta weights were recorded in order to provide a cross-check on the chromic oxide indicator method. This cross-check was prompted by the wide variation in ME values observed in Experiment I.

Lab analysis and calculations used in Experiment I also apply to this experiment. However, when the diet ME is calculated on the basis of feed and excreta weights, the expression $\frac{\text{g excreta dry matter/g feed dry matter}}{\frac{\text{g Cr}_2\text{O}_3/\text{g dry feed}}{\text{g Cr}_2\text{O}_3/\text{g dry excreta}}}$ is substituted for the expression

Experiment III: Wapana and Compana Metabolizable Energy for Hens.

Five non-laying H&N Leghorn hens were used in a ME determination for W pana and Compana barleys. This experiment was done to see if the ME values obtained would have less variation than those observed in Experiment I. The procedures used were similar to those used by Sibbald and Price (1975).

Table 2. COMPOSITION OF THE SEVEN ASSAY DIETS, FOR THE HIGH AMYLOSE AND NORMAL GLACIER METABOLIZABLE ENERGY FOR CHICKS, EXPERIMENT II

Diet number	Basal mix ^a to barley ratio in assay diets ^b		Barley tested
	Basal %	Test barley %	
1	100	0	Basal diet
2	80	20	High amylose Glacier
3	60	40	High amylose Glacier
4	40	60	High amylose Glacier
5	80	20	Normal Glacier
6	60	40	Normal Glacier
7	40	60	Normal Glacier

^a The basal mix was formulated as follows in percentage: soybean meal, 55; ground wheat, 17; ground yellow corn, 17; fish meal, 5; dried whey, 4; sun-cured ground alfalfa, 4.

^b Formulation of the seven assay diets was completed by the addition of the mineral-vitamin mix as follows to the combined basal and test mixtures, g/kg of assay diet: dicalcium phosphate, 10.06; ground limestone, 9.63; chromium oxide, 3.21; salt, 2.35; DL-methionine, .43; layer-grower premix^c, 2.57.

^c The layer-grower premix supplied the following per kg assay diet: vitamin A, 6,768 USPU; vitamin D₃, 2,227 ICU; vitamin E, 3.43 IU. The following were supplied as mg/kg diet: vitamin B₁₂, .0056; riboflavin, 3.43; d pantothenic acid, 3.43; choline, 343; menadione sodium bisulfite complex, 1.11; folic acid, .223; ethoxyquin, 64.2; manganese, 51.4; iodine, 1.54; iron, 51.4; copper, 5.14; cobalt, .514; zinc, 51.4.

The five hens were kept in an environmentally-controlled house in individual 8" x 14" cages with an empty cage left between each hen to prevent cross-contamination of excreta. Individual feeders were used, and feed and water were available ad libitum throughout the trial. Sheet metal pans lined with plastic wrap were positioned under each cage to allow for complete collection of excreta. Feed intake and excreta weights were recorded for each bird during three collection periods. Each period consisted of 3 days for adaptation to each diet followed by 4 days of collection. During period 1 a diet consisting of the basal mix plus the mineral-vitamin mix (table 3) was fed. During period two three hens were fed a diet (table 3) of $\frac{1}{2}$ basal plus $\frac{1}{2}$ Wapana, to which the mineral-vitamin mix was added, and two hens were fed a diet of $\frac{1}{2}$ basal mix and $\frac{1}{2}$ Compana plus mineral-vitamin mix (table 3). These barley diets were switched for each hen during period three. All diets were fed as mashes.

Laboratory analysis of feed and excreta was limited to percent dry matter (A.O.A.C., 1970) and Parr oxygen bomb calorimetry. Calculations for diet ME were the same as those used in Experiment II, where calculations were based on the weighed ratios of excreta:feed. Diet values were multiplied by 1.11 to correct for the addition of the mineral-vitamin mix. Calculations of ME values for the barley used the simultaneous equation method of Experiments I and II, but in this case diets and equations were based on 50-50 mixtures of diet and barley.

Statistical analysis was done according to the paired t-test method of Snedecer and Cochran (1967), where each hen was paired with herself to compare the relative values of the two barleys studied.

Table 3. COMPOSITION OF THE BASAL AND BARLEY TEST DIETS FOR THE WAPANA AND COMPANA METABOLIZABLE ENERGY FOR HENS, EXPERIMENT III

Diet number	Basal ^a %	Barley %	Mineral Vitamin mix ^b %	Barley tested
1	90	0	10	Basal
2	45	45	10	Wapana
3	45	45	10	Compana

^a The basal mix contained the following ingredients in percentage: Ground wheat, 40; ground yellow corn, 40; soybean meal, 10; dried whey, 4; dehydrated alfalfa, 4; fat, 2.

^b The mineral-vitamin mix supplied the following per kg of diet ingredients: ground limestone, 72 g; dicalcium phosphate, 20 g; iodized salt, 5 g; DL-methionine, 0.5 g; layer-grower premix^c, 2.5 g.

^c The layer-grower premix supplied the following per kg assay diet: Vitamin A, 6,584 USPU; vitamin D₃, 2,166 ICU; vitamin E, 3.34 IU. The following were supplied as mg/kg diet: vitamin B₁₂, .0054; riboflavin, 3.34; d pantothenic acid, 334; choline, 334; menadione sodium bisulfite complex, 1.08; folic acid, .217; ethoxyquin, 62.5; manganese, 50.0; iodine, 1.50; iron, 50.0; copper, 5.00; cobalt, .500; zinc, 50.0.

Experiment IV: Wapana or Compana with Fat in Diets for Poultry Layers.

Wapana, Compana, and wheat were fed in diets with fat additions of 3% or 5% to H&N Leghorn hens in order to determine their relative effects on egg production. Compana and wheat were also fed in diets without fat. The birds were housed at 20 weeks of age in individual laying cages in an environmentally controlled house and were started on the diets (table 4) at 24 weeks of age. All diets were calculated to 18% crude protein. Feed and water were offered ad libitum throughout the trial. Egg production was recorded daily for each hen, and one egg per week was weighed for each hen. Individual body weights were taken at age 24 weeks and at age 55 weeks, which was the end of the trial period. Diets were analyzed for percents of dry matter, crude protein, ether extract, crude fiber, nitrogen-free extract, and ash (A.O.A.C., 1970). Least squares analysis of variance (Snedecor and Cochran, 1967) was determined on total eggs, total hen days, eggs per day, average egg weight, 24 week body weight, and final (55 week) body weight. Duncan's multiple range test (Snedecor and Cochran, 1967) was done in the event of a significant difference shown by analysis of variance.

Experiment V: High Amylose and Normal Glacier Digestibilities for Sheep.

Four Targhee rams, each weighing approximately 90 kg, were used to determine digestibility of high amylose and normal Glacier barleys.

Table 4. COMPOSITION OF THE DIETS WITH WAPANA OR COMPANA WITH SUPPLEMENTAL FAT FOR POULTRY LAYERS, EXPERIMENT IV

Item	Wheat			Compana			Wapana	
	No fat	Lo fat	Hi fat	No fat	Lo fat	Hi fat	Lo fat	Hi fat
	%	%	%	%	%	%	%	%
Wheat	67.73	63.80	60.63	0	0	0	0	0
Compana	0	0	0	65.71	61.69	59.21	0	0
Wapana	0	0	0	0	0	0	61.69	59.21
Soybean meal	20.98	21.92	22.90	22.99	24.01	24.49	24.01	24.49
Dicalcium phosphate	2.00	2.00	2.02	2.00	2.00	2.00	2.00	2.00
Limestone	8.49	8.49	8.59	8.50	8.50	8.50	8.50	8.50
Salt	.50	.50	.51	.50	.50	.50	.50	.50
Vitamin premix ^a	.25	.25	.25	.25	.25	.25	.25	.25
Methionine	.05	.05	.05	.05	.05	.05	.05	.05
Fat	0	3.00	5.05	0	3.00	5.00	3.00	5.00
Calculated ME, kcal/g	2.49	2.66	2.78	2.24	2.42	2.54	2.42	2.54

^a The vitamin-trace mineral premix provided: vitamin A, 661 USPU; vitamin D₃, 22 ICU; vitamin E, .027 IU; vitamin B₁₂, .055 µg; riboflavin, 33 µg; niacin, 165 µg; pantothenic acid, 33 µg; choline, 3.3 mg; menadione sodium bisulfite complex, 11.0 µg; folic acid, 2.2 µg; ethoxyquin, 624 µg; manganese, 500 mg; iodine, 150 µg; iron, 500 mg; copper, 50 mg and zinc, 500 mg per kg of feed.

The trial consisted of three 14-day periods. For each period the sheep were allowed 9 days to adapt to the diet and the following 5 days were used for collection. During the first two periods, each sheep was offered a daily diet of approximately 900 grams whole grain mixed with 900 grams chopped alfalfa hay. During period 1, two sheep were fed high amylose Glacier and two were fed normal Glacier. These grains were reversed for the sheep during period 2. In order to determine the digestibility of the hay component of the diets, the third period daily diet consisted of approximately 1800 grams of chopped hay, fed alone. The amount fed was adjusted somewhat in each case during the warm-up periods according to the consumption level of each sheep. Half of the daily feed was offered at 8:00 AM and the other half at 4:30 PM. Water was offered before each feeding, and salt blocks were placed in the feed boxes. Grain was separated from the hay for the feed weighbacks by weighing the mixture, blowing the hay away from the whole grain with an electric fan, and in turn weighing the grain. The rams were kept in a temperature-controlled room in metabolism crates in order to measure feed consumption and for quantitative collection of urine and feces. To prevent loss of ammonia, 100 ml. of 5% sulfuric acid was added to each urine bucket daily. Daily collection of urine and feces was immediately after the morning feeding.

Laboratory analysis of the grains, hay, and feces consisted of percents of dry matter, crude protein, ether extract, crude fiber, ash,

and nitrogen-free extract (A.O.A.C., 1970). Fecal crude protein was determined on wet samples, since drying of feces results in loss of ammonia nitrogen. Kjeldahl nitrogen was determined on the urine in order to calculate nitrogen balance for each sheep and diet.

Digestibility for each hay nutrient was calculated according to the equation:

Digestion coefficient hay nutrient = $100\% \times \frac{\text{g nutrient digested}}{\text{nutrient fed}}$,

and for each grain nutrient by using:

D. C. grain nutr =

$$100\% \times \frac{\text{g grain nutr dig} - (\text{D.C. hay nutr})(\text{g hay nutr fed})}{\text{g grain nutr fed}}$$

where D.C. = digestion coefficient expressed as a percent,
nutr = nutrient,
g = grams, and
dig = digested = nutr fed - nutr in feces.

Statistical analysis was done by using a paired t-test (Snedecor and Cochran, 1967). Each sheep was paired with itself for each grain nutrient to compare the digestibilities of the barleys.

Experiment VI: Wapana and Compana Digestibilities for Calves.

Four Holstein heifer calves ranging in age from 103 days to 143 days were used to determine the digestibility of Wapana- and Compana-based concentrate diets. The trial was divided into three 14-day periods. Ten days were allowed for adaptation to each diet, followed

by four days of collection. Each calf was fed, in turn, a diet of chopped alfalfa hay only, four parts hay to three parts Wapana diet, and finally four parts hay to three parts Compana diet (table 5). The order of feeding these diets was staggered among the calves for the different periods. The calves were fed according to individual consumption levels. Water was offered before each feeding at 9:00 AM and 4:30 PM. Calves were placed in metabolism crates in order to measure feed intake and to quantitatively collect urine and feces. The calves were removed from the crates during the adaptation periods and maintained in individual pens. In order to facilitate separation of urine and feces, retaining bladder catheters were used. Plastic tubing was used to drain the urine into the collection bucket. To prevent loss of ammonia, 100 ml. of 5% sulfuric acid was added to each urine bucket daily. Collections of urine and feces were taken immediately after the morning feeding.

Laboratory analysis, digestibility calculations, and statistical analysis were done the same as in Experiment II. Since the barleys were studied within concentrate diets, the value of this determination is in comparing the relative feeding values of the two barleys studied, rather than determining their absolute digestibilities.

Experiment VII: Wapana or Compana in Diets for Dairy Bull Growth.

Eleven Holstein bull calves ranging in age from 107 days to 169 days were randomly divided into two lots to compare rate of gain while

Table 5. CONCENTRATE DIETS USED FOR THE COMPARISON OF WAPANA AND COMPANA BARLEYS IN THE WAPANA OR COMPANA DIGESTIBILITIES FOR CALVES, EXPERIMENT VI

Ingredient	Wapana diet	Compana diet
	%	%
Ground Wapana	67	0
Ground Compana	0	64
Rolled oats	18	18
Soybean meal	8	11
Dried molasses	4	4
Trace mineral salt	1	1
Dicalcium phosphate	1	1
Vitamin-trace mineral premix ^a	1	1

^a Supplied 55 mg Terramycin, 6600 units Vitamin A, and 1100 units Vitamin D per kg diet.

being fed a Wapana or a Compana based concentrate diet (table 6). The concentrate diets were adjusted slightly during days 58 through 106 (table 6). The concentrate diets and alfalfa hay were fed free choice, and group consumption was measured. The calves were weighed individually at the beginning of the trial and once every two weeks thereafter. Weights were taken three days consecutively just before the diet change and at the end of the experimental period, in order to provide more accurate final weights. The concentrate diets and the hay were analyzed for percents of dry matter, crude protein, ether extract, crude fiber, nitrogen-free extract, ash, calcium, and phosphorus (A.O.A.C., 1970).

Table 6. CONCENTRATE DIETS USED FOR THE COMPARISON OF WAPANA AND COMPANA BARLEYS IN THE WAPANA OR COMPANA FOR DAIRY BULL GROWTH. EXPERIMENT VII

Ingredient	Days 0-57		Days 58-106	
	Wapana %	Compana %	Wapana %	Compana %
Ground Wapana	65.0	0	70.35	0
Ground Compana	0	65.0	0	70.35
Ground oats	23.0	23.0	17.5	17.5
Soybean meal	5.0	5.0	5.0	5.0
Dried molasses	5.0	5.0	5.0	5.0
Dicalcium phosphate	0	0	1.0	1.0
Monosodium phosphate	1.0	1.0	0	0
Trace mineral salt	1.0	1.0	1.0	1.0
Vit. A, D, E Suppl.	0	0	0.15	0.15

Experiment VIII. Wapana or Compana in Diets for Lactating Holsteins.

Wapana and Compana were compared for value in lactation diets by using 12 Holstein cows in their second, third, or fourth lactation. The cows were randomly divided into two equal groups, but were all kept in the same dry lot. A switchback design consisting of three 43-day periods was used. Eight days were allowed for adaptation to each change in diet followed by 35 days of data collection. Group 1 was fed a Wapana diet during periods 1 and 3, and a Compana diet during period 2. Group 2 was fed the Compana diet during periods 1 and 3 and the Wapana diet during period 2. Concentrate diets were the same as those formulated for days 0-57 in Experiment VII (table 6).

The cows were fed individually three times daily at the rate of 1 kg concentrate diet for 2½ kg of milk corrected to 4% butterfat, and was recalculated weekly for each cow. No grain was fed in the milking parlor, and alfalfa hay was fed free choice. The cows were fed individually three times daily after morning and night milking and at mid-point between AM and PM milkings with individual consumption determined. Daily records of individual milk production were kept and composite AM-PM milk samples were taken weekly to be analyzed for percents of butterfat (Babcock method), solids-not-fat (Golding beads test), and Kjeldahl protein (A.O.A.C., 1970). Analysis of variance for the switchback design was patterned after the method of Lucas (1956).

RESULTS AND CONCLUSIONS

Experiment I: Wapana and Compana Metabolizable Energy for Chicks.

Calculations of the ME resulted in values (table 7) of $2.80 \pm .36$ kcal/gram for Wapana and $2.56 \pm .53$ kcal/gram for Compana. These values are not significantly different ($P > .05$). The standard deviations of these values were fairly large. This variation was probably due in part to some separation of the chromic oxide, and in part to the fact that the chicks had a tendency to select and eat the larger granules from the mash and leave the fines and the hulls. However, these values are only slightly lower than the ME value of 2.99 kcal/gram (dry matter basis) for barley reported by McNab and Shannon (1974) using colostomized hens.

The correction for nitrogen balance is of questionable value (Vohra, 1972) and was not included in table 7. However, it was calculated and found to be of little significance in this case.

Sibbald (1976) has taken a critical look at the problems associated with the determination of Apparent (classical) metabolizable energy, as used in these trials, and has offered a possible alternative. The major problem with apparent ME is it does not account for metabolic and endogenous loss of energy. At low levels of feed intake, these losses may affect the results significantly. True Metabolizable Energy (TME) values exclude metabolic and endogenous energy losses. Values for TME are also independent of the level of feed intake. The assay devised by Sibbald utilizes two roosters paired by body weight for each replication.

Both are starved for 21 hours. At this time, one is force fed (using a funnel) a weighed amount of test material, and the other is not fed. Total fecal collections are then made for each bird. The unfed bird is used to provide an estimate of metabolic and endogenous energy voided in the excreta. There are several advantages to this assay. The correction for metabolic and endogenous energy losses seems to take out variation between types of assay birds. The low palatability of some feedstuffs is not a problem using this technique. There is some evidence that TME is more predictable using analysis of the grains than is ME. Also, a limited study by Sibbald (1976) suggests that TME values may be additive. However, Vohra (1972) states that ME is additive, but only for a limited number of ingredients. Sibbald (1976) suggests that the probable advantages of TME over ME warrant wide-scale testing of the technique.

Table 7. METABOLIZABLE ENERGY VALUES CALCULATED FOR DIETS AND FOR BARLEYS ON THE BASIS OF CHROMIC OXIDE RATIOS FOR THE WAPANA AND COMPANA METABOLIZABLE ENERGY FOR CHICKS, EXPERIMENT I

Diet number	ME, kcal/gram			Barley used
	Diet	Barley	Ave. ± Std. Dev.	
1	2.53	Basal		Basal
2	2.57	2.74		Wapana
3	2.50	2.47	2.80 ± .36	Wapana
4	2.92	3.18		Wapana
5	2.64	3.10		Compana
6	2.32	2.03	2.56 ± .53	Compana
7	2.54	2.55		Compana

Experiment II: High Amylose and Normal Glacier Metabolizable Energy for Chicks.

Calculations for this trial resulted in two separate sets of values for each barley (table 8). On the basis of chromic oxide ratios, as used in Experiment I, the ME values were 2.93 \pm .36 for high amylose Glacier and 3.73 \pm .73 for normal Glacier. When calculations were based on feed consumption and excreta weight data, values were 3.06 \pm .16 for high amylose Glacier and 3.19 \pm .16 for normal Glacier. There were no significant differences ($P > .05$) between the ME values for the barleys shown by either method.

A certain amount of separation of the fines from the mash was observed during the trial, as noted in Experiment I. This was probably a major cause of the variation noted in the results, especially in the case of values calculated according to the chromic oxide method. There was less variation among the values obtained when ME was calculated according to feed consumption and feces collection data. This experiment shows no advantage for either high amylose or normal Glacier over the other when fed to chicks.

Values were similar to the ME value reported for barley by McNab and Shannon (1974) of 2.99 kcal/gram (dry matter basis). Wilson and McNab (1975) found that high amylose Glacier increased food intake and body weights, without affecting food conversion efficiency, when fed to broilers as compared to normal Glacier. Enzyme additions by Herstad

and McNab (1975) to diets fed to broilers raised the digestibility and ME of the normal Glacier diets but had little effect on values for the high amylose diets. Their nitrogen corrected ME values for high amylose and normal Glacier, respectively, were 2.71 kcal/g and 2.80 kcal/g (dry matter basis).

Table 8. METABOLIZABLE ENERGY VALUES CALCULATED FOR DIETS AND FOR BARLEYS ON THE BASIS OF CHROMIC OXIDE RATIOS AND ON THE BASIS OF FEED:EXCRETA RATIOS FOR THE HIGH AMYLOSE AND NORMAL GLACIER METABOLIZABLE ENERGY FOR CHICKS, EXPERIMENT II

Diet number	ME, kcal/gram, chromic oxide basis			Barley used
	Diet ^a	Barley ^b	Ave. ± std. dev.	
1	2.10	Basal		Basal
2	2.33	3.27		High amylose Glacier
3	2.27	2.54	2.93 ± .36	High amylose Glacier
4	2.63	2.97		High amylose Glacier
5	2.60	4.58		Normal Glacier
6	2.58	3.32	3.73 ± .73	Normal Glacier
7	2.82	3.30		Normal Glacier

Diet number	ME, kcal/gram, feed:excreta basis			Barley used
	Diet	Barley	Ave. ± std. dev.	
1	3.10	Basal		Basal
2	3.09	3.06		High amylose Glacier
3	3.15	3.23	3.06 ± .16	High amylose Glacier
4	2.97	2.88		High amylose Glacier
5	3.16	3.38		Normal Glacier
6	3.08	3.07	3.19 ± .16	Normal Glacier
7	3.10	3.10		Normal Glacier

^a ME kcal/gram for total diets

^b ME kcal/grams calculated for the barley in the total diet.

Experiment III: Wapana and Compana Metabolizable Energy for Hens.

Considerably less variation occurred in the values obtained for each barley in this trial than was noted in Experiment I. The average ME values (table 9) of $3.5 \pm .11$ kcal/gram for Wapana and $3.09 \pm .09$ kcal/gram for Compana were not different ($P > .05$) and were somewhat higher than the respective average values of $2.80 \pm .36$ and $2.56 \pm .53$ calculated in Experiment I. These values of $3.05 \pm .11$ and $3.09 \pm .09$ were also in the range of the values of $3.06 \pm .16$ and $3.19 \pm .16$ found for high amylose and normal Glacier, respectively, in Experiment II where ME was calculated on the basis of feed and excreta weights. The ME values found in this trial for these barleys compare favorably with the value for barley found by McNab and Shannon (1974) of 2.99 kcal/g (dry matter basis). A similar value of 2.91 kcal/g was reported by Herstad and McNab (1975).

When Experiments I and III are considered together, no difference in metabolizable energy is shown between the ME of Wapana and Compana for poultry. It would appear that either barley could replace the other in practical rations with no net effect.

Experiment IV: Wapana or Compana with Fat in Diets for Poultry Layers.

There were no differences ($P > .05$) between the diets tested for total eggs, total hen days, eggs per day, average egg weight, or 24 week (beginning) body weight (table 10). However, there were some

Table 9. METABOLIZABLE ENERGY VALUES FOR THE BASAL MIX, WAPANA, AND COMPANA BARLEYS FOR THE WAPANA AND COMPANA METABOLIZABLE ENERGY FOR HENS, EXPERIMENT III

Hen number	ME, kcal/gram		
	Basal mix	Wapana	Compana
1	3.14	2.90	3.21
2	3.27	3.13	3.13
3	3.09	3.18	3.10
4	3.22	2.99	3.02
5	3.19	3.04	2.97
Average	3.18	3.05	3.09
Standard deviation	±.08	±.11	±.09

differences ($P < .05$) between 55 weeks (final) body weights for different diets. There was also a tendency for the group with the highest final body weights to correspond to the highest eggs per day and highest average egg weight, and the group with the lowest final body weight to have the lowest eggs per day and lowest average egg weight. The group with the highest final body weight was on the Wapana low fat diet, and the lowest was on the Compana low fat diet. However, there was not a significant difference between final body weights for the Wapana group and the Compana group at the high fat levels. The Compana group tended to have higher final body weights at high fat levels than the Wapana group. It is interesting to note that the Compana low fat group had significantly ($P < .05$) lower final body weights than the Compana high fat group, while the results for the Wapana diets were reversed: the Wapana low fat group had significantly ($P < .05$) higher body weights than the Wapana high fat group. There were no significant differences between the wheat diets due to fat levels, including no additional fat. The final body weight values for the wheat were somewhat interspersed among the barley values, but were not significantly lower than any of the barley diets. Results of feed analysis are shown in table 11.

The favorable results for Wapana over Compana for final body weights at the low fat level is contrary to most other evidence comparing the two barleys. In a separate trial comparing Wapana and Compana

for layers (Moss, 1975, unpublished data), no significant differences were noted for egg production, but final body weights tended to be lower on the Wapana diet. Similarly, in a growth trial using broilers (Moss et al., 1974) to compare Compana, Wapana, and wheat, the best growth was noted on a wheat-based diet, and the poorest on a Wapana-based diet. Significantly better growth was shown for Compana-based diets than for Wapana-based diets in two cases. In a third case there was no significant difference in growth rates for the two barleys. Considering the results of the present study and the two studies mentioned, there is no clear-cut advantage for either Wapana or Compana in poultry feeds.

Table 10. EFFECT OF WAPANA, COMPANA, OR WHEAT WITH OR WITHOUT ADDITIONAL FAT ON PRODUCTION AND WEIGHTS IN LAYERS, EXPERIMENT IV

Diet	31-week averages				Ave body wt(g)	
	Total Eggs	Total Hen days	Eggs Per day	Egg Wt.,g.	24 weeks	55 weeks
Wheat no fat	168.1	215.0	.7808	54.72	1622	1785 bcd
Wheat low fat	174.0	214.7	.8105	56.00	1587	1828 cd
Wheat high fat	170.1	215.5	.7878	55.54	1543	1735 bcd
Compana no fat	168.7	215.0	.7845	55.37	1572	1662 ab
Compana low fat	163.1	216.3	.7540	54.34	1579	1575 a
Compana high fat	173.8	215.2	.8087	55.39	1590	1822 bcd
Wapana low fat	176.3	212.4	.8307	56.80	1621	1869 d
Wapana high fat	177.5	215.2	.8249	56.13	1542	1695 abc

abcd Values with unlike subscripts within a column are significantly different (P <.05).

Table 11. PROXIMATE ANALYSIS OF DIETS USED IN THE WAPANA OR COMPANA WITH FAT IN DIETS FOR POULTRY LAYERS, EXPERIMENT IV

Diet, Fat added	Dry matter basis					
	D.M. %	C.D. %	E.E. %	C.F. %	N.F.E. %	ASH %
Wheat no fat	93.8	19.7	1.9	2.5	60.2	15.7
Wheat low fat	93.7	19.9	4.4	2.5	58.3	14.9
Wheat high fat	94.0	19.7	5.7	2.3	57.4	14.9
Compana no fat	94.3	20.0	2.8	3.6	57.7	15.9
Compana low fat	94.8	19.7	4.1	3.5	57.1	15.6
Compana high fat	94.7	19.7	6.2	3.2	55.4	15.5
Wapana low fat	94.5	19.1	1.8	3.5	58.2	17.4
Wapana high fat	94.9	19.7	6.4	3.7	54.1	16.1

Experiment V: High Amylose and Normal Glacier Digestibilities for Sheep.

Proximate analysis of the hay and barleys used is shown on table 12. There were no differences ($P > .05$) between the digestibilities of high amylose and normal Glacier barleys for any of the nutrients studied (table 13). The average dry matter, crude protein, and nitrogen-free extract digestibilities, respectively, were 75.3 ± 4.1 , 71.7 ± 11.7 , and 83.6 ± 2.9 for high amylose Glacier and 76.1 ± 2.9 , 66.2 ± 7.4 , and 84.2 ± 2.2 for normal Glacier. These are somewhat lower than values reported for barley by other workers. Dry matter, crude protein, and nitrogen-free extract digestibilities for rolled barley using lactating cows reported by Waldern and Cedeno (1970) were 83.8, 86.5, and 89.4, respectively. Morrison (1961) reported average digestibilities of 85, 79, and 92 for these three nutrient groups. Morrison's values were averaged from 16 trials, but barley varieties were not listed.

In a digestibility trial where the digestion coefficients for grain are determined by difference, using a roughage in part of the diet, the digestion coefficients for ether extract and crude fiber have little meaning (Mitchell, 1942). In fact, impossible values (greater than 100% or less than 0%) have often been encountered. Many of the materials extracted by ether in the feces are actually fecal metabolic products. It has also been noted on numerous occasions that digestibility of crude fiber is depressed in the presence of more soluble

carbohydrates since rumen microorganisms tend to use the more readily available carbohydrates first. The results of this experiment have more value, therefore, in comparing the relative values of the two barleys studied, rather than establishing the absolute digestibility of each nutrient discussed.

Table 12. PROXIMATE ANALYSIS OF FEEDS USED IN THE HIGH AMYLOSE AND NORMAL GLACIER DIGESTIBILITIES FOR SHEEP, EXPERIMENT V.

Feed	Dry matter basis ^a					
	D.M. %	C.P. %	E.E. %	C.F. %	H.F.E. %	ASH %
Alfalfa	86.9	18.6	2.0	22.7	44.2	12.5
High amylose Glacier	95.1	12.6	3.6	4.8	76.1	2.9
Normal Glacier	94.2	11.0	2.3	4.7	79.1	2.9

a Abbreviations used in table 12 are:

D.M. = dry matter; C.P. = crude protein; E.E. = ether extract;
C.F. = crude fiber; N.F.E. = nitrogen-free extract.

Table 13. DIGESTION COEFFICIENTS AND NITROGEN RETENTION FOR THE HIGH AMYLOSE AND NORMAL GLACIER DIGESTIBILITIES FOR SHEEP, EXPERIMENT V

Sheep Number	Feed	Digestion coefficients ^a					N Retained ^b
		D.M. %	C.P. %	E.E. %	C.F. %	N.F.E. %	
1	Hay	66.0	71.8	33.3	55.4	78.0	3.2
1	HAG	76.5	59.2	96.8	-14.8	86.1	4.1
1	NG	78.9	76.6	80.8	-13.5	85.1	20.7
2	Hay	71.3	77.9	34.4	62.0	81.8	3.9
2	HAG	69.3	63.1	99.4	-57.0	79.5	1.0
2	NG	72.1	66.5	84.5	-35.7	81.0	21.1
3	Hay	72.4	79.4	41.4	62.9	82.2	13.4
3	HAG	77.1	79.4	41.4	-15.4	83.5	25.4
3	NG	77.6	61.1	99.8	7.9	85.0	24.3
4	Hay	69.6	76.9	33.3	59.0	80.9	12.0
4	HAG	78.4	84.9	87.7	-27.5	85.3	19.8
4	NG	75.7	60.5	94.8	-31.9	85.8	8.9

Average ± Standard deviation

Hay	69.8 ±2.8	76.5 ±3.3		80.7 ±1.9
HAG	75.3 ±4.1	71.7 ±11.7		83.6 ±2.9
NG	76.1 ±2.9	66.2 ±7.4		84.2 ±2.2

^a Abbreviations used in table 13 are: HAG = High amylose Glacier; NG = normal Glacier; D.M. = dry matter; C.P. = crude protein; E.E. = ether extract; C.F. = crude fiber; N.F.E. = nitrogen-free extract.

^b % N retained is for a hay diet or a hay + barley diet in each case.

Experiment VI: Wapana and Compana Digestibilities for Calves.

There were no significant differences ($p > .05$) between the digestibilities of the Wapana and Compana diets for any of the nutrients studied (table 15). The average dry matter, crude protein, and nitrogen-free extract digestibilities, respectively, were 70.5 ± 4.5 , 67.6 ± 5.1 , and 79.4 ± 4.7 for the Wapana diet and 75.8 ± 5.0 , 69.4 ± 4.4 , and 82.6 ± 2.3 for the Compana diet. Proximate analysis of the hay and barley diets used is shown on table 14. Since the barleys being studied were included in concentrate diets, comparison of these values with other reported values would be of questionable value. The same problems associated with the determination of concentrate digestibilities by difference, as discussed in Experiment V, also hold true for this trial.

During the trial, there were some mechanical problems encountered with the catheters and with the crates. One calf escaped after two days of collection, but was returned to the crate the next day. Data were computed on the basis of the last two days of collection for that calf. The calves were less comfortable in the crates than were the sheep and had more trouble adapting to the confinement. This, coupled with the trauma of having catheters in place may have led to the negative nitrogen retentions observed in two cases (table 15). However, all of the calves gained weight over the trial as a whole.

Walker and Lichtenwalner (1974) using a nylon bag technique showed that dry ground or waxy sorghum was digested more rapidly in the

rumen than similarly prepared normal sorghum. Nisnimuta *et al.* (1969) showed higher digestibilities of organic matter, gross energy, nitrogen-free extract, and crude protein for waxy sorghum. Stockton (1976) showed that Wapana is more rapidly digested *in vitro* than Compana, but the total digestibilities are the same by 96 hours. Since most barley starch is digested in the rumen (Waldo, 1973), any differences in *in vitro* digestibilities may be masked.

Table 14. PROXIMATE ANALYSIS OF FEEDS USED IN THE WAPANA AND COMPANA DIGESTIBILITIES FOR CALVES, EXPERIMENT VI

Feed	D.M. %	Dry matter basis ^a				ASH %
		C.P. %	E.E. %	C.F. %	N.F.E. %	
Alfalfa hay	94.4	14.1	1.3	36.5	38.6	9.5
Wapana diet	94.3	14.2	2.0	5.9	72.5	5.4
Compana diet	94.1	14.7	1.9	6.0	72.3	5.1

^a Abbreviations used in table 14 are:

D.M. = dry matter; C.P. = crude protein; E.E. = ether extract;
C.F. = crude fiber; N.F.E. = nitrogen-free extract.

Table 15. DIGESTION COEFFICIENTS AND NITROGEN RETENTION FOR THE WAPANA AND COMPANA DIGESTIBILITIES FOR CALVES, EXPERIMENT VI

Calf Number	Feed	Digestion coefficients ^a					N Retained ^b
		D.M. %	C.P. %	E.E. %	C.F. %	N.F.E. %	
1	Hay	61.1	57.4	11.8	55.9	70.8	-17.0
1	W.D.	71.2	67.5	90.8	-33.3	80.9	8.4
1	C.D.	80.1	71.9	116.1	42.2	85.0	10.3
2	Hay	58.7	61.7	34.5	48.3	68.8	3.0
2	W.D.	64.8	63.0	72.9	22.3	72.4	-1.1
2	C.D.	68.7	63.0	61.6	-18.1	79.4	10.8
3	Hay	56.8	56.3	22.6	47.9	68.3	3.7
3	W.D.	70.2	65.2	83.9	-59.8	81.2	17.6
3	C.D.	78.1	70.1	76.8	46.8	83.0	21.0
4	Hay	62.5	61.2	40.4	55.7	71.2	.1
4	W.D.	75.8	74.7	77.4	2.7	82.9	23.6
4	C.D.	76.1	72.5	63.5	16.6	83.1	12.3
<u>Average ± Standard deviation</u>							
	Hay	59.8 ±2.5	59.2 ±2.7			69.8 ±1.4	
	W.D.	70.5 ±4.5	67.6 ±5.1			79.4 ±4.7	
	C.D.	75.8 ±5.0	69.4 ±4.4			82.6 ±2.3	

^a Abbreviations used in Table 15 are: W.D. = Wapana diet; C.D. = Compama diet; D.M. = dry matter; C.P. = crude protein; E.E. = ether extract; C.F. = crude fiber; N.F.E. = nitrogen-free extract.

^b % N retained is for a hay diet or a hay - barley diet in each case.

Experiment VII: Wapana or Compana in Diets for Dairy Bull Growth.

Proximate analysis of the concentrate diets and alfalfa hay is shown on table 16. There were no significant differences in weight gains between the lot of bulls receiving the Wapana diet and the lot receiving the Compana diet. The average kg/day gain was $1.23 \pm .18$ and $1.24 \pm .10$ for the Wapana group and the Compana group, respectively. Average grain diet consumption per bull per day was 4.70 kg for both lots. Hay consumption per bull per day was 3.53 kg for the Wapana lot and 2.94 kg for the Compana lot (table 17). No statistical analysis could be made on the feed consumption data since the bulls were fed as groups, not individually.

No apparent advantage for Wapana or Compana in feed-gain applications for ruminants has been shown by these results. Similarly, there were no significant differences in gain for dairy calves (Moss and Newman, 1975), for wether lambs (Stockton, 1976), or for gain in rats and pigs (Calvert, 1975). Robinson et al. (1974) showed no differences in gains when heifers and Holstein steers were fed waxy corn over normal corn, but Braman et al. (1973) showed an increase in gain and feed efficiency for the waxy corn when fed to finishing lambs and steers. Several workers (Sullins and Rooney, 1974, Sherrod, et al., 1969) have shown advantages in gain and feed efficiency for waxy sorghum over normal sorghum. A possible explanation of the lack of differences between Wapana and Compana may lie in the high percentages of barley

starch digested in the rumen (94%) as compared to other grains (76-78%) (Waldo, 1973). Differences in the barleys may be masked by rumen fermentation, since rumen bacteria adapt well to different types of diets.

Table 16. PROXIMATE ANALYSIS OF FEEDS USED IN THE WAPANA OR COMPANA IN DIETS FOR DAIRY BULL GROWTH, EXPERIMENT VII

Diet	Days	D.M. %	Dry matter basis ^a						Ca %	P %
			C.P. %	E.E. %	C.F. %	N.F.E. %	ASH %			
Wapana	0-57	93.1	13.9	2.9	5.0	72.5	5.7	.12	.73	
Compana	0-57	93.3	13.1	2.1	5.4	73.7	5.7	.09	.73	
Wapana	58-106	91.9	14.0	2.0	4.7	73.9	5.4	.38	.62	
Compana	58-106	90.6	14.2	1.8	4.3	73.3	6.4	.49	.75	
Alfalfa Hay, Ave.		90.7	16.3	1.9	28.8	42.7	10.3	1.59	.24	

^a Abbreviations used in table 16 are:

D.M. - dry matter; C.P. - crude protein; E.E. - ether extract;
C.F. - crude fiber; N.F.E. - nitrogen-free extract;

Table 17. WEIGHT GAINS IN THE WAPANA OR COMPANA IN DIETS FOR DAIRY
BULLS GROWTH, EXPERIMENT VII

Bull Number	Age, days At day 0	Wt, kg At day 0	Ave Wt, kg At day 106	kg/day gain Days 0-106
Wapana				
1	169	157	303	1.38
2	137	125	271	1.38
3	134	110	242	1.26
4	127	111	240	1.21
5	117	111	210	.93
Average	137	123	253	1.23 ± .18
Compana				
6	119	109	254	1.37
7	114	123	240	1.10
8	107	123	261	1.30
9	128	141	271	1.22
10	117	112	246	1.26
11	114	119	243	1.17
Average	117	121	253	1.24 ± .10

Experiment VIII: Wapana or Compana in Diets for Lactating Holsteins.

Average feed analysis is shown on table 18. One cow developed a severe case of mastitis during the first period and was dropped from the trial, leaving 5 cows in group 1 and 6 cows in group 2. There were no significant differences ($P > .05$) in milk production or percents of butterfat, solids-not-fat, and crude protein attributed to whether the cows were on a Wapana diet or a Compana diet. Averages of these values and feed consumption are given on table 19.

The probable reason for no differences between barleys in this trial is the tendency for nearly all (about 94%) of the starch of barley to be digested in the rumen (Waldo, 1973). Rate of digestion in the rumen between these barleys is probably not different enough (Stockton, 1976) to affect the production of ruminants.

Table 18. PROXIMATE ANALYSIS OF FEEDS USED IN THE WAPANA OR COMPANA IN DIETS FOR LACTATING HOLSTEINS, EXPERIMENT VIII

Diet	Dry matter basis ^a							
	D.M. %	C.P. %	E.E. %	C.F. %	N.F.E. %	ASH %	Ca %	P %
Wapana	91.4	14.6	2.3	5.9	70.6	6.6	.11	.81
Compana	90.1	14.2	2.0	5.9	71.2	6.7	.10	.87
Alfalfa hay	90.8	17.0	2.4	25.9	43.8	10.9	1.41	.29

^a Abbreviations used in table 18 are:

D.M. - dry matter; C.P. - crude protein; E.E. - ether extract;
C.F. - crude fiber; N.F.E. - nitrogen-free extract;

Table 19. MILK PRODUCTION, MILK COMPOSITION, AND FEED CONSUMPTION FOR THE WAPANA OR COMPANA IN DIETS FOR LACTATING HOLSTEINS, EXPERIMENT VIII

Period	Diet	Averages per cow ^a					
		kg milk day	B.F. %	S.N.F. %	C.P. %	Consumption/day (kg) Grain Hay	
<u>Group 1, 5 cows</u>							
1	Wapana	27.2	3.5	8.46	3.2	10.3	12.8
2	Compana	23.8	3.6	8.40	3.2	8.9	13.7
3	Wapana	21.2	3.6	8.40	3.3	8.4	13.2
<u>Group 2, 6 cows</u>							
1	Compana	29.1	3.1	8.25	3.2	10.4	13.3
2	Wapana	25.0	3.3	8.25	3.1	8.9	13.8
3	Compana	22.6	3.4	8.21	3.1	8.7	13.4

^a Abbreviations for table 19 are:

B.F. - butterfat; S.N.F. - solids-not-fat; C.P. - crude protein.

SUMMARY AND CONCLUSION

In an effort to improve the nutritive value of barley, interest has been recently focused on barley cultivars that vary from the average ratio of amylose to amylopectin of 25:75 found in plant starch. Wapana, the name given to the waxy cultivar of Compana, has starch that is nearly 100% amylopectin, while high amylose Glacier starch is about 45% amylose. The eight experiments described in this thesis were designed to further investigate the nutritional value of these barleys for poultry, ruminants, and dairy cattle.

In Experiment I, a chromic oxide indicator method with 84 H&N Meat Nick chicks was used to determine the metabolizable energy (ME) of Wapana and Compana. Respective ME values of 2.80 kcal/g and 2.56 kcal/g were not different ($P > .05$).

Experiment II used 77 H&N Leghorn chicks to determine the ME of high amylose and normal Glacier barleys. Data were computed on the basis of total feed consumption and excreta collection. The ME values for high amylose and normal Glacier, respectively, of 3.06 kcal/g and 3.19 kcal/g did not differ ($P > .05$).

Experiment III was a second ME determination of Wapana and Compana using five non-laying H&N Leghorn hens. Birds were kept in individual cages and ME based on individual feed consumption and total excreta collection data. The ME values for Wapana and Compana, respectively, of 3.05 kcal/g and 3.09 kcal/g, were not different ($P > .05$).

Experiment IV compared the relative values of Wapana, Compana, and

wheat in diets with 3% or 5% added fat in layer diets using H&N Leghorn hens in a 31 week layer study. Compans and wheat diets were also fed without fat. Total eggs, total hen days, eggs per day, average egg weight, or beginning body weight (24 weeks of age) did not differ ($P > .05$) for diets. Some differences ($P < .05$) between final body weights (55 weeks of age) occurred. The Wapana group at the low fat level had higher ($P < .05$) body weights (1969 g) compared to the Compans group (1575 g) at the same fat level. At the high level of fat, however, the Compans group tended to have higher body weights than the Wapana group, but not significantly so.

Experiment V used four Targhee rams to determine digestibilities of high amylose and normal Glacier fed as whole grains. Digestibilities of dry matter, crude protein, or nitrogen-free extract did not differ ($P > .05$) between the barleys. Average dry matter digestibilities for high amylose and normal Glacier, respectively, were 75.3% and 76.1%.

Experiment VI utilized Holstein heifer calves to determine digestibilities of concentrate diets containing Wapana or Compans for dry matter, crude protein, and nitrogen-free extract. No differences ($P > .05$) were noted between barley diets for these nutrients. Average dry matter digestibilities for the Wapana diet and the Compans diet, respectively, were 70.5% and 75.8%.

Experiment VII used five Holstein bull calves fed a Wapana-based concentrate diet and six fed a similar Compans diet to compare rates

of gain for 106 days. Average daily gains of 1.23 kg/day for the Wapana diet and 1.24 kg/day for the Compana diet were not different ($P > .05$).

Experiment VIII was a lactation study using 12 Holstein cows in a switchback design to compare diets based on Wapana or Compana. Daily milk production, percents of butterfat, solids-not-fat, crude protein, or daily grain or hay consumption did not differ ($P > .05$).

Very few significant differences were noted in these experiments between the feeding values of the barleys studied. The few differences observed, such as differences in final body weights of hens in the Wapana and Compana layer trial, were inconclusive in the light of data from other experiments. However, advantages for other waxy grains, such as corn and sorghum, have been shown. My observations that the ratio of amylose to amylopectin in barley starch seems to make no real difference in nutritional value implies that barley must be different in some way from other grains. One possible difference is there may be one or more factors associated with the gene or genes involved in changes in starch composition that also affect the overall availability of barley starch. Another possibility is that the differences are so small that they are masked during the digestion process (especially in the case of ruminants) and therefore may be unimportant in the kinds of diets that were fed in these trials. However, if there are some small but real differences, they might be more obvious in diets for ruminants that include a source of non-protein nitrogen (NPN), since the rate of starch

digestion in the rumen has an effect on the utilization of NPN. In general, though, the work reported herein as well as previous reports gives no conclusive evidence that the amylose to amylopectin ratio in barley starch has a significant effect on the nutritional value of barley.

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Nutritive value of
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