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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AND NORMAL GLACIER BARLEYS

by

CALVIN REX MILLER

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

of

MASTER OF SCIENCE

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Approved:

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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).

INTRODUCTION

Barley is the fourth most widely produced gain 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 branch-
ing 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 cuase 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 ruminent 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, susceptability 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 metaboliz-
able energy trial using yearling rams, there was no significant differ-
ence 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:

$$ME\ feed = GE\ feed - \frac{g\ Cr_2O_3/g\ dry\ feed}{(g\ Cr_2O_3/g\ dry\ excreta \times GE\ excreta)}$$

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 D_3, 2,227 ICU; vitamin E, 3.43 IU. The following were supplied as mg/kg diet: vitamin B_{12}, .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 g excreta dry matter/g

feed dry matter is substituted for the expression $\dfrac{g\ Cr_2O_3/g\ dry\ feed}{g\ Cr_2O_3/g\ dry\ excreta}$.

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 D_3, 2,227 ICU; vitamin E, 3.43 IU.
The following were supplied as mg/kg diet: vitamin B_{12}, .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 ½ basal plus ½ Wapana, to which the mineral-vitamin mix was added, and two hens were fed a diet of ½ basal mix and ½ 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 D_3, 2,166 ICU; vitamin E, 3.34 IU.
The following were supplied as mg/kg diet: vitamin B_{12}, .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 through-
out 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 D_3, 22 ICU; vitamin E, .027 IU; vitamin B_{12}, .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% x g nutrient digested/g
    nutrient fed,

and for each grain nutrient by using:

D. C. grain nutr =

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

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 Terramyacin, 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 individ-

ually 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 devia-

tions 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 gran-

ules 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 calcu-

lated 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. $\pm$ Std. Dev.	
1	2.53	Basal		Basal
2	2.57	2.74		Wapana
3	2.50	2.47	2.80 $\pm$ .36	Wapana
4	2.92	3.18		Wapana
5	2.64	3.10		Compana
6	2.32	2.03	2.56 $\pm$ .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