Evaluation of Wapana and Compana barley for sheep
by Gilles Stockton

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

Abstract:
Wapana barley, a high amylopectin barley produced from seven backcrosses of Compana on waxy Oderbrook, was compared to Compana in five separate experiments to ascertain the relative feed value for sheep. In experiment I, 96 Rambouillet and Targhee wether lambs were in a 2x2x2 factorial design feed gain trial. Factors were Wapana vs. Compana, high rate of gain vs. low rate of gain and small lambs vs. large lambs. Metabolizable energy intake/kg W.75/kg gain values were 3.94 and 3.13 for large, high gain Wapana and Compana pens; 2.97 and 2.68 for small, high gain Wapana and Compana pens; -4.06 and -16.78 for large, low gain Wapana and Compana pens; and 5.00 and 30.60 for small low gain Wapana and Compana pens. Net energy (NEm and NEG) of the two barleys were determined in experiment II with the same lambs stratified in the same 2x2x2 factorial design as described above. Net energy maintenance (NEm) values computed for the barleys from six lambs on each of the eight treatments were 1.26 Mcal/kg and 1.45 Mcal/kg for large and small lambs, respectively, for Wapana and 1.37 Mcal/kg and 1.42 Mcal/kg for large and small lambs, respectively, for Compana. Corresponding net energy gain (NEg) values were .31 Mcal/kg, .77 Mcal/kg, .77 Mcal/kg and .766 Mcal/kg. Experiment III utilized four Targhee rams in a complete block design to determine the metabolizable energy (ME) and nitrogen retention of the two barleys. Factors were Wapana and Compana barley at 40 and 60% barley diets. Results showed no difference (P>.05) in ME or in nitrogen retention. Metabolizable energy values were 3.02 Mcal/kg for the barleys and 2.52 Mcal/kg for the hay. Rumen fluid analysis showed no difference (P>.05) in proprionic to acetic and butyric acid ratios. Experiment IV measured ruminal and total tract starch digestion by using a sheep fitted with rumen and abomasal cannulae. Rumen fluid analysis gave a proprionic to acetic and butyric acid ratio of 1:2.5 for the Wapana diet and 1:1.6 for the Compana diet. Analysis showed 1.1 and 2.1% starch in the abomasal fluid and .2 and .9% starch in the feces on the Wapana and Compana diet, respectively. In vitro total dry matter (DM) disappearance and the rate of digestion was determined in experiment V. Total DM digestion was 80.79 and 81.78% for Wapana and Compana barley which was not significantly different (P>.05) . Digestion was 59.70% for hay; 71.70 and 68.09% for Wapana in 60% and 40% barley rations, respectively, and 72.46 and 67.95% for Compana in 60% and 40% barley rations, respectively. In vitro digestion after 12 hrs was 25.65 and 24.33% (P<.01) for Wapana and Compana. From 12 hrs, extent of digestion converged until digested to the same extent at 96 hrs.

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by

GILLES STOCKTON

3'1

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

of

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ABSTRACT

Wapana barley, a high amylopectin barley produced from seven backcrosses of Compana on waxy Oderbrook, was compared to Compana in five separate experiments to ascertain the relative feed value for sheep. In experiment I, 96 Rambouillet and Targhee wether lambs were in a 2x2x2 factorial design feed gain trial. Factors were Wapana _vs._ Compana, high rate of gain _vs._ low rate of gain and small lambs _vs._ large lambs. Metabolizable energy intake/kg $W^{.75}$/kg gain values were 3.94 and 3.13 for large, high gain Wapana and Compana pens; 2.97 and 2.68 for small, high gain Wapana and Compana pens; -4.06 and -16.78 for large, low gain Wapana and Compana pens; and 5.00 and 30.60 for small low gain Wapana and Compana pens. Net energy (NE_m and NE_g) of the two barleys were determined in experiment II with the same lambs stratified in the same 2x2x2 factorial design as described above. Net energy maintenance (NE_m) values computed for the barleys from six lambs on each of the eight treatments were 1.26 Mcal/kg and 1.45 Mcal/kg for large and small lambs, respectively, for Wapana and 1.37 Mcal/kg and 1.42 Mcal/kg for large and small lambs, respectively, for Compana. Corresponding net energy gain (NE_g) values were .31 Mcal/kg, .77 Mcal/kg, .77 Mcal/kg and .766 Mcal/kg. Experiment III utilized four Targhee rams in a complete block design to determine the metabolizable energy (ME) and nitrogen retention of the two barleys. Factors were Wapana and Compana barley at 40 and 60% barley diets. Results showed no difference ($P>.05$) in ME or in nitrogen retention. Metabolizable energy values were 3.02 Mcal/kg for the barleys and 2.52 Mcal/kg for the hay. Rumen fluid analysis showed no difference ($P>.05$) in proprionic to acetic and butyric acid ratios. Experiment IV measured ruminal and total tract starch digestion by using a sheep fitted with rumen and abomasal cannulae. Rumen fluid analysis gave a proprionic to acetic and butyric acid ratio of 1:2.5 for the Wapana diet and 1:1.6 for the Compana diet. Analysis showed 1.1 and 2.1% starch in the abomasal fluid and .2 and .9% starch in the feces on the Wapana and Compana diet, respectively. _In vitro_ total dry matter (DM) disappearance and the rate of digestion was determined in experiment V. Total DM digestion was 80.79 and 81.78% for Wapana and Compana barley which was not significantly different ($P>.05$). Digestion was 59.70% for hay; 71.70 and 68.09% for Wapana in 60% and 40% barley rations, respectively, and 72.46 and 67.95% for Compana in 60% and 40% barley rations, respectively. _In vitro_ digestion after 12 hrs was 25.65 and 24.33% ($P<.01$) for Wapana and Compana. From 12 hrs, extent of digestion converged until digested to the same extent at 96 hrs.

INTRODUCTION

World barley production ranks fourth after wheat, rice, and corn making it an extremely important grain for animal and human consumption. Contributing to its popularity is the ability to grow in more northern latitudes, at higher elevations and under dryer conditions than any other cereal grain. Barley yield per acre also exceeds that of other spring planted grains such as wheat, oats and rye. In addition, barley tends to have a higher protein potential than any other grain. Montana State University is currently conducting a major research effort to improve the quality of barley beyond that which it already possesses. One aspect of this effort is to determine whether a high amylopectin content in barley is of nutritive value.

In the last few years, interest has focused on corn and sorghum varieties that had a waxy texture in its starch fraction. Chemical evaluation has shown that waxy starches consist of nearly 100% amylopectin. Amylopectin differs from amylose in that it has a branched molecular structure. Glucose molecules in amylose are united in alpha-1,4 linkages whereas amylopectin has a majority of alpha-1,4 linkages but also contain alpha-1,6 linkages which give the branched structure. Corn and sorghum grains considered normal have a starch fraction of 75% amylopectin and 25% amylose. Animal feeding trials have sometimes shown superior results for waxy starch grains. Montana State University has developed a barley variety, Wapana, whose starch is virtually 100% amylopectin.

Wapana resulted from seven backcrosses of waxy Oderbrook with Compana and therefore shares most of the same genes as Compana. Gross energy content of Compana and Wapana are very similar as are crude protein, moisture, crude fiber and ether extract. The only consistently different analytical value is the Van Soest neutral detergent fiber with Wapana having higher fiber content. The starch fraction of corn, sorghum and barley are 99 to 100% digested in the digestive tract of ruminant animals. However, barley starch is more easily digested in the rumen than either corn or sorghum starch. Barley starch is 94% $\pm$ 2.4 digested in the rumen whereas corn starch is 78% $\pm$ 12.5 and sorghum is 76% $\pm$ 22.4 digested. Rumen fermentation results in a loss of available energy as heat and methane. In addition, volatile fatty acids are not as efficiently metabolized as is glucose. This implies that a feed grain that is less digestible in the rumen could cause greater growth than one that is very easily digested. It further implies that careful experimentation is required to show any differentiation in the energy metabolism of any two barleys. The purpose of this research effort was to compare Wapana and Compana as feeds for ruminant animals.

LITERATURE REVIEW

Starch and its Properties

Most vertebrates are well suited to digest starch which is a major source of food energy produced by plants. Cereal chemists in the last few years have been seriously working on identifying the factors that cause some starch types and sources to be more digestible than others. French (1973) in a review article explains the chemical nature of starch. Starch has two basic varieties: amylose and amylopectin. Amylose is a linear molecule consisting of a large number of glucose molecues hooked in an alpha-1,4 linkage. Amylopectin is a branched molecule of 1,000 to 500,000 glucose molecules. The majority of the bonds between amylopectin glucose units are alpha-1,4. Approximately 5% of the bonds are alpha-1,6 linkages thereby causing the branched structure. A few alpha-1,2 and alpha-1,3 linkages may occur but in minor numbers. The classical model for the structure of an amylopectin molecule is somewhat reminiscent of a tree. In this model the branches are considered to be regularly apaced. French (1973) feels that this model does not adequately describe amylopectin's high solution viscosity or that electron microscopy has been unable to discern globular amylopectin molecules. Micrographs instead show a fibrous structure. He postulates another model in which the alpha-1,6 linkages are clustered, thereby enabling the branches to be longer and allowing the separate amylopectin molecules to aggregate in fibrous units. This type of structure would show a fibrous structure in electron micrographs and have a high solution viscosity.

Normal cereal grains contain starch that is 75% amylopectin and 25% amylose (French, 1973; Calvert, 1975). Interest has focused on genetic varieties in which the starch fraction varies from the norm. One such group are those whose starch fraction contains nearly 100% amylopectin. These high amylopectin grains are often referred to as waxy grains. Part of the interest in high amylopectin starch comes from results of *in vitro* starch digestion research which indicates that it is more digestible than normal starch and thus may be more completely used by animals. Leach and Schoch (1961) treated starches from a number of different sources with bacterial alpha-amylase. He found that starches varied considerably in their susceptibility to the enzyme. The starches studied, listed from least resistant to most resistant, were waxy maize, tapioca, waxy sorghum, sorghum, corn, wheat, sago, arrow-root, potato, heat-moisture-treated potato, and high-linear corn. This study indicates that waxy starches tend to be more susceptible to alpha-amylase than the normal varieties. Sandstedt *et al.* (1968) subjected corn varieties that had uniform genetic backgrounds, but various combinations of the genes responsible for starch type, to a number of physical examinations. They had homozygous varieties of starch types for amylose extender, $sugar_1$, $sugary_2$, dull and waxy. In addition, varieties that had all of the double and triple combinations of these genes were isolated. Corn carrying the waxy gene had one of the maximum values for water absorption and susceptibility to enzymatic hydrolysis. Corn containing the sugary$_2$ and waxy gene had the highest raw-starch digestibility.

Why high amylopectin content causes starch to be more easily digested is not known for certain. Sandstedt (1965) indicated that the differences between starch granules which cause wide differences in susceptibility to enzyme attack is not directly related to amylose content, density, gelatinization temperature, or ability of the granule to absorb cold water. Sandstedt and Mattern (1960) studied _in vitro_ digestibility of damaged and natural starch. They concluded that physically damaged starch, such as flour where the milling process breaks the starch granules, is more readily digested by amylase than native undamaged starch. In this vein, Goering _et al_. (1973) reported fissures in Wapana barley starch granules that may allow the entrance of digestive enzymes. Roguls and Meites (1968) offer another possibility that may account for some of the variability in starch digestibility. In a study using human fluids containing alpha-amylase, high amylopectin starch was more easily digested. They postulated that some of the variation may be due to small quantities of protein in the starch which can interfere with the alpha-amylase, keeping it from complexing with the starch. French (1973) theorized another possibility. He discussed the fact that the alpha-1,6 linkages cause problems in digestion because special enzymes are needed to break those bonds.

Yet, the branching may increase the starch solubility, making it easier for the alpha-amylase to digest the starch granule.

The waxy starch extracted from Wapana barley has some unique characteristics. Goering et al. (1973) reported a Brabender cooking curve for Wapana that is nearly identical to waxy sorghum but has half the swelling power and one-third the solubility of the waxy sorghum starch. The solubility of the waxy barley starch is even less than values reported for high amylose corn, which is considerably less soluble than waxy or normal corn. A hypothesis put forward by Goering et al. (1973) for this behavior is that the amylopectin of Wapana barley has unusually long branches or is naturally cross-linked.

Starch Digestion of Various Segments of the Gastrointestinal Tract of Ruminants

Using fistulas placed in the rumen, abomasum, duodenum and terminal ileum, considerable work has been accomplished on defining the extent of starch digestion at various segments of the ruminants' digestive tract. The rumen is the major site of carbohydrate digestion. The small intestine and the cecum are of lesser importance but the exact extent of their carbohydrate digestive capacity has not been accurately measured (Waldo, 1973).

Although the rumen is the major site of carbohydrate digestion, the fermentation process results in a considerable energy loss to the animal (Hungate 1968, Ørskov et al. 1968). Besides the losses incured from the heat of fermentation and methane production, there is an additional loss because the volatile fatty acids (VFA) were less efficiently utilized for body growth than glucose (Armstrong et al., 1960). Blaxter (1962) indicated that 143 kcal of glucose are required to produce 100 kcal of body fat on a sheep fed an otherwise maintenance diet whereas 300 kcal of acetic acid are required to produce 100 kcal of body fat. Ørskov (1969) calculated that the total energy loss because of the fermentation process amounted to 20 to 30%. Theoretically, the more starch that will bypass rumen digestion, the more energy that will be available to the animal for production. One exception to this rule is milk fat production (Van Soest 1963, Ørskov et al., 1969). Milk fat production is a function of the ratio of energy absorbed as gluconeogenic to energy absorbed as non-gluconeogenic substances. Diets conducive to production of high levels of glucose and proprionic acid as compared to acetic and butyric acids depressed milk fat production. Flatt et al. (1967) found that high concentrate rations lower milk fat and raised the energy retained in body fat.

Corn, sorghum, and barley are important starch sources for ruminant animals. Work with these grains indicate wide variations in digestibility. Waldo (1973) collected and organized data from a large number of feeding studies. He reported total tract digestion of 99% $\pm$ 1.2 for all three starch sources combined. This indicated that starch from these grains are very efficiently digested by ruminants. When he compared the rumen digestibility of each of the three grains, a very different picture emerged. Ruminal barley starch digestion was 94% $\pm$ 2.4 in 23 observations. Corn starch was 78% $\pm$ 12.5 digested in 30 observations, whereas sorghum starch was 76% $\pm$ 22.4 digested in eight observations. These values indicated that although all starch is very efficiently digested by ruminants, considerably more starch was available for postruminal digestion when corn or sorghum was fed than when barley was fed.

Other factors affect starch passage from the rumen to the abomasum besides grain type. Some of these factors included the amount of dry matter ingested, particle size, feed processing and amount of bulk included in the diet.

There was some controversy as to whether increased levels of feeding causes more starch to bypass the rumen because not all research efforts have ended with the same results. Wright et al. (1966), Karr et al. (1966), Ørskov et al. (1968) and Ørskov et al. (1969) concluded from their research that total intake can influence the extent of carbohydrate digestion in the rumen. Ørskov et al. (1969) used much higher feed levels in a study which showed increased starch bypass than did Sutton and Nichelson (1968) who showed little starch bypass. The maximum amount given mature sheep by Sutton and Nichelson (1968) was 1230 g of dry matter (DM) while Ørskov et al. (1969) gave growing 40 kg lambs a maximum of 1438 g of DM.

Ørskov *et al*. (1968) comparing ground *vs*. pelleted corn rations found that finer particles resulting from grinding had decreased rumen retention time. This same effect was seen by Thomson *et al*. (1969) and Beever *et al*. (1969) in studies with lucerne. Beever *et al*. (1970) specifically studied the ruminal bypass of ground and flaked maize starch in sheep. They found that 78% of the ground maize starch was digested in the rumen *vs*. 95.7% of the flaked maize starch. Total tract digestion was near 100% for both processing methods.

The high ruminal digestibility of the flaked maize starch observed by Beever *et al*. (1970) may also be indicative of the greater digestibility imparted to the corn by the flaking process. Sunde (1972) felt that heating partially gelatinized the starch in cereal grains thereby increasing ruminal digestibility. Flaking, grinding and pelleting in addition to causing increased heating, caused a physical disruption of the cells and thus improved the availability of energy. Steam-processing, flaking, roasting, micronization, gelatinization and extrusion all seemed to improve digestibility to the same relative degree (Beeson, 1972). Popping also increased the digestibility but also lowered particle density and the animals could not eat as much. Hinman and Johnson (1974) fed dry-rolled, low micronized, medium micronized and high micronized sorghum to beef cattle. They found that the degree of micronization increased rumen digestibility. Micronization also dramatically increased the total tract digestion.

Dry-rolled was 81.4% digested in the total tract while low micronized sorghum starch was 98% digested. They also noted digestion of 51 and 95.4% for dry-rolled starch and low micronized starch in the intestines. Williamson (1972) felt that heat processing of feeds could be overdone since severe heat treatment could depress butterfat production in milk cows. This would suggest that a considerable amount of starch bypassed the rumen and was digested postruminally. In this vein, it is apparent that processing methods are not universally effective. McNeil et al. (1971) fed steers dry-ground micronized, steam-flaked and reconstituted sorghum. They found that relative to the steam-flaked and reconstituted, the dry-ground and micronized sorghum had impaired ruminal starch digestion. The postruminal digestion failed to completely compensate for the reduced ruminal starch fermentation.

Topps et al. (1968) and Ørskov et al. (1969) observed a curious phenomena during starch digestion experiments. Ørskov et al. (1969) fed lambs diets consisting of 100% barley or 60% barley-40% roughage. More of the starch was observed to bypass the rumen on the diets containing the roughage, causing the lambs to gain more on the roughage diets. Ørskov et al. (1969) felt that the roughage accelerated the rate of passage of the smaller particles out of the reticulo-rumen. This is perhaps a partial explanation for Dinius's (1970) observation that the inclusion of 10% of an indigestible substance such as sawdust, baggass, or kaolin in a high concentrate diet can increase the concentrates digestibility of 5 percent.

Barley has unique properties relative to corn and sorghum. Processing does not have significant effects on digestibility or site of digestion. Ørskov et al. (1974) found that whole barley fed to sheep was retained in the rumen longer than ground barley, but they were both nearly completely digested in the rumen. Feeding whole barley had the added benefit of causing more stable rumen conditions, harder fat, and less damage to the rumen wall.

An accurate measurement of the starch digestion in the small intestine of ruminants has yet to be determined. Researchers are unsure if the small intestines have a limited ability to secrete alpha-amylase and therefore a limited capacity to digest starch, or whether with adequate adaptation time alpha-amylase secretion increases. Walker (1959) compared the development of pancreatic amylase in young lambs and young pigs. He found that amylase activity in lambs did not increase with age, but stayed at a relatively low concentration. The pig, however, rapidly increased its amylase activity. Henshael (1963) infused 10 g doses of various carbohydrates into a cannula at the proximal end of the intestines of four to six month steers. Collections of 0% of the glucose, 62% of the sucrose, 14% of the lactose, 30% of the maltose, 28% of the starch and 59% of the raw wheat starch were obtained from a cannula near the terminal end of the small intestine. Karr et al. (1966) found that as the amount of corn starch entering the small intestine of steers increased from 4.3 to 12 $g/kg^{.75}$, the percent digested decreased from 93% to 64 percent.

However, the total amount of starch digested increased from 4.0 to 7.7 $g/kg^{.75}$. Tucker et al. (1966) observed a low level of corn starch in feces of sheep regardless of the amount of starch entering the small intestine. Grams of starch entering the small intestine, recovered in the feces, and digestion coefficients were 38 g, 21 g, and 45% for a 20% corn diet; 120 g, 30 g, and 75% for a 40% corn diet; 144 g, 32 g, and 77.8% for a 60% corn diet; and 130 g, 43 g, and 67% for an 80% corn diet. Tucker et al. (1968) found the postruminal digestive system to be highly efficient; 96 to 99% of the starch escaping fermentation in the rumen of sheep were digested. They concluded that the fermentation capacity of the rumen can be exceeded but that the overall digestive ability is not overcome with 583 g/day of starch. Recent work by Mayes and Ørskov (1974) indicated that the alpha-amylase activity might be higher than thought and the factors that might be limiting starch digestion in the small intestine was utilization of maltose and maltotriose by intestinal alpha-glucosidase or the absorption of maltose and glucose into the brush border cells.

Very little is known of the role of the cecum on starch digestion. Ørskov and Foote (1969) infused starch into the cecum of sheep and found that most of the starch in excess of 150 g/day was recovered in the feces. Data from Karr et al. (1966) indicated that steers fed corn had 4.3 $g/kg^{.75}$ of starch enter the cecum and digested 83% of it. Sorghum fed to steers by McNeil et al. (1971) had 88% of

6.5 g/kg$^{.75}$ of starch digested in the cecum. These studies show that considerable amounts of starch can be fermented in the large intestine of ruminants even though the exact limits are not yet known. Ørskov (1969) indicates that the factors that limit digestion in the large intestine are not known but are likely to include retention time and availability of nitrogen for microbial fermentation of carbohydrates.

Feeding Trials with Waxy Grain

Through the years a number of feeding and digestibility trials have been conducted to determine the value of waxy cereal grains. Some of these show waxy varieties to be superior feeds and others have been inconclusive. One of the first reported studies on waxy grain was conducted by Hanson (1946) who studied waxy corn as a feed for swine. He fed one pen waxy corn, another pen normal corn and the third pen had free access to both waxy and normal corn. The response to feeds were similar for all three pens. Pigs who had their choice of waxy and normal ate 2.6 times more normal corn, indicating that waxy was unpalatable to the pigs. Jensen et al. (1973) fed waxy and regular corn to five-week-old pigs. Rates of gain were similar for the two diets but the gain per unit of feed was about 5% higher for the pigs fed waxy corn. The waxy corn produced 455 lbs of gain per 1,000 lbs of feed while the regular produced 443 lbs of gain per 1,000 lbs of feed.

Cohen and Tanksley (1973) studied the energy and protein digestibility of four different varieties of sorghum as a feed for pigs. The four sorghum varieties were characterized by the texture of their endosperm and by starch type. Studied were floury endosperm-normal starch, intermediate endosperm-normal starch, corneous endosperm-normal starch, and intermediate endosperm-waxy starch. The grain containing intermediate endosperm had greater digestibility than the floury or corneous textured endosperm. There was a slight but non-significant advantage in the performance of pigs eating waxy starch.

Waxy corn was fed to lambs and steers in a study by Braman et al. (1973). Waxy corn resulted in increased plasma urea-nitrogen concentrations, increased daily gains, increased feed efficiencies, decreased fecal nitrogen, and decreased retention of absorbed nitrogen. It was felt that the protein in the waxy corn was less susceptible to utilization in the rumen thereby causing the lower nitrogen retention. Although the lambs gained more on waxy corn than on normal corn, they had better gains when urea was added to the waxy corn diet. The results of steer feeding trials showed that waxy corn produced greater and more efficient gains than normal corn. Waxy corn resulted in more gain than normal corn when both were supplemented with soybean meal. A series of feed trials conducted by Robinson et al. (1974) compared the response of rats, lambs, heifers and steers to waxy and normal corn. On a 15% protein diet, the rats fed waxy corn had greater gains and better feed efficiencies. At 25% protein diets, the reverse was true. Lambs showed no significant difference on nitrogen balance. Heifer calves fed 35% corn and 65% haylage showed no significant difference as to growth. No differences were observed between waxy or normal corn as to protein levels or with inclusion of the hormones Synovex or Ralgro in a group of Holstein steers. McCormick and Farlin (1974) studied average daily gains, dry matter consumption, and feed per gain ratios of lambs fed a number of corn varieties. Corn varieties studied consisted of Opaque-2 high moisture, Opaque-2 dry, waxy high moisture, waxy dry, the gentic equivalent of waxy dry, average maturity high moisture, average maturity dry, and high moisture silage corn. There were no significant differences in growth. In another trial with steers, no significant differences existed between waxy high moisture, waxy dry, the genetic counterpart of waxy high moisture, and the genetic counterpart of waxy dry.

McGinty and Riggs (1968) tested a number of sorghum varieties. Coefficients of digestibility were obtained with steers using the total collection technique. Waxy Feterita was among four sorghum varieties with higher dry matter and protein digestibilities, but waxy Feterita did not differ significantly from the other three varieties with high digestibilities. Nishimuta et al. (1969) studied the effect of waxy sorghum (3758) and white sorghum (G-766) in 45 kg wethers. In the course of this digestibility trial they compared these two sorghums to a locally grown red sorghum. Waxy sorghum had virtually 100% amylopectin in its starch fraction while the white and regular consisted of approximately 75% amylopectin and 25% amylose. The white variety had more uniform starch than the regular. Waxy and white sorghum had greater organic matter and non-protein organic matter digestibilities than the regular. In addition crude and true protein digestibilities and nitrogen retention were better than for the regular. Waxy and white sorghum did not differ significantly in response. A net energy determination of waxy sorghum (3758) was conducted by Sherrod et al. (1969). Net energy values for waxy and regular sorghums were measured by the comparative slaughter technique with 48 Angus and Angus-Hereford steers. Waxy sorghum had a net energy for maintenance (NE_m) value of 1.50 Mcal/kg while regular had 1.43 Mcal/kg; net energy for gain (NE_g) values were 1.24 Mcal/kg and .95 Mcal/kg for waxy and regular sorghum. It is interesting to note that the daily gain for the regular was greater than that of the waxy, and that the feed per gain ratio tended to indicate that the waxy was more efficient although efficiency was not significant ($P>.10$). Carcass evaluation revealed that the animals fed waxy sorghum had a greater carcass fat percentage. Hinders and Eng (1970) showed a waxy sorghum to have feed per gain ratios of 2.10 compared to two normal sorghum varieties which had ratios of 2.49 and 2.34.

Walker and Lichtenwalner (1974) studied the ruminal digestibility of two nearly isogenic sorghum varieties, one of which had waxy starch. They found that the waxy grain, after being suspended in nylon bags in the rumen of steers for 24 hours, was more digested than the normal sorghum. After 48 and 72 hours in the rumen there was no significant difference in the degree of digestion of the two sorghums.

Very little work has been published on the nutritional quality of waxy barley. Moss and Newman (1973) reported on calf feeding trials with starter rations using Hiproly, Hiproly normal, normal Compana, and Wapana (waxy Compana). Wapana tended to have a higher average daily gain but differences were not significant ($P > .05$). Moss et al. (1973) in a study with broilers compared Wapana and Compana to wheat. There was a significantly lower growth rate for Wapana as compared to Compana and wheat and the feed conversion tended to be lower also. Calvert (1973) did extensive studies on Compana and Wapana in feed trials with rats and swine. To provide isonitrogenous diets for the rats the starches were extracted from the barleys and used to dilute ground barley diets. These diets resulted in no significantly greater rates of gain, feed efficiencies, protein efficiency ratios, nitrogen balance, or energy balance. Pigs receiving Wapana had lower feed per gain ratios in both supplemented and unsupplemented diets, unsupplemented Wapana diets caused higher average daily gains ($P \leq .01$), but carcass characteristics did not differ between Wapana and Compana diets. In a third trial using Wapana and Compana grown in a different locality, the unsupplemented Compana caused a slightly better ($P<.05$) average daily gain than the unsupplemented Wapana. Pigs eating the Wapana barley had a slightly better feed gain ratio. Loin eye and percent ham did not differ between barley types.

MATERIALS AND METHODS

Experiment I: Feed Gain Trial

Ninety-six Rambouillet and Targhee wether lambs were used in a 2 x 2 x 2 factorial design to compare Wapana *vs*. Compana barley at a low and high rate of gain in heavy and light lambs. The lambs were housed in a covered shed at the Fort Ellis Research Station. The experiment was terminated after 48 days.

In order to accustom the lambs to a concentrate diet, 20% barley was given the first week with the barley increment increased by 10% each week thereafter until the lambs were consuming 70% barley and 30% hay. Whole barley was fed three times a day in a trough with 50, 30 and 20% of daily allowance given at evening, morning and midday. Long hay was fed in equal amounts evening and morning. Analysis of the barleys and hay are given in table 1. Free access was given to warm water, trace mineral salt, and a calcium-phosphorus supplement with vitamins A, D and E added.

All lambs were weighed weekly and amount of diet readjusted for for weight gains according to a formula published by Ørskov *et al*. (1969) which estimates the maximum intake, on an as fed basis, that a lamb will eat (feed/day as percent of body wt = 5 -.0353 (wt in kg)). High-gain groups received 100% of this amount while the low-gain groups initially received 70% of this amount. After 4 weeks the low-gain groups received 80% of full feed in order to offset weight losses.

Weighback of barley was taken daily while hay weighback was taken bi-weekly. During the fourth week when lambs were on 60% barley diets, digestive upsets began to appear and the lambs failed to finish all of the feed which was allowed. It became necessary to reaccustom certain pens to high concentrate diets. In order that the pens which were off feed did not receive less feed than their corresponding pens. (For example, the pen of larger lambs receiving high gain diets of Compana compared to the similar pen receiving Wapana), both pens were reduced to lower grain/hay ratios. They were then reaccustomed to 60% barley diets over a two week period. For the last week of the experiment, 1% bicarbonate of soda was included in their diet.

Experiment II: Net Energy Determination

The net energy determination experimental design was the same 2 x 2 x 2 factorial as the design for the feed-gain trial. The same lambs were used and maintained in the same facilities. Since the lambs that had received the high gain diets during the feed-gain trial had grown considerably more than the ones receiving low gain diets, the feed levels were reversed. Each pen still received the same type of barley as before.

A new method of calculating the amount of feed to be given each pen of lambs was introduced for this experiment. According to theoretical data using the equations published in the N.R.C. "Nutrient Requirements of Sheep" (1968), the feed levels dictated by Ørskov's equation begin to deviate from producing equal weight gains in larger lambs. One-hundred percent of feed intake calculated for large lambs resulted in a smaller weight gain than similar calculations for smaller lambs. Research conducted by Brody (1945) and Kleiber (1960) indicate that metabolism varies proportionately to the metabolic size of the animals, with metabolic size defined as the weight of an animal raised to the 3/4 power ($wt^{.75}$). If two animals of unequal weight are given the same amount of food, the larger animal will use more of that food to maintain his body function than the smaller animal. The effect would be for the smaller animal to gain more than the larger until they were both the same size, causing erroneous conclusions as to the value of a feed. If two animals were fed as a function of their body weight alone, the larger animal would always receive more food and gain more. Therefore all animals, (pens of animals) were fed as a relative function of their metabolic size.

The eight pens of lambs were paired such that the high gain large lambs receiving Wapana and the high gain large lambs receiving Compana constituted a pair, etc. Using the Ørskov formula, 100% intake was calculated for lambs in the pen with the greater average weight. Dry matter intake indicated by the equation was divided by the metabolic size to determine the amount of dry matter per unit of metabolic size. The same amount of feed per unit of metabolic size was given to the corresponding pen of small lambs ($DM_1 wt^{.75}1 = DM_2/wt^{.75}{}_2$).

Paired pens would receive approximately equivalent amounts of feed by use of these calculations, and the true value of the barleys could be ascertained.

Net energy values of the barleys were computed by the methods described by Garrett et al. (1959), Harris (197) and Sherwood (1970). Lambs were left without food or water during the first night of the experiment and weighed the next morning in order to determine the initial shrunk weight. Two lambs from each pen were randomly selected for slaughter from the lambs with weights which fell within one standard deviation of the mean weight for the pen. Lambs selected were immediately sheared, transported to the Montana State University Meats Laboratory, and slaughtered using standard commercial slaughtering techniques. Carcasses were cooled overnight to 2°C. The water bath in which the specific gravity was to be measured was also cooled to 2°C in order to reduce the accumulation of air bubbles on the carcass when emersed in water. During emersion and weighing, care was taken to insure that large air bubbles were not entrapped under skin and fat flaps. A limited number of lambs could be processed each day so the lambs slaughtered at the end of the experiment were slaughtered in two groups. Twenty-eight days after initiation of the experiment, the four pens of large lambs were kept overnight without food and water. The next day four lambs from each pen were randomly selected to be slaughtered adhering to the procedures described above. Four lambs from each of the four pens of small lambs were handled in the same manner 35 days after initiation of the experiment.

A formula converting shrunk body weight to wool free empty body weight (WFEB) was derived from data published by Mitchell _et al_. (1926), Mitchell _et al_. (1928a) and Mitchell _et al_. (1928b) (WFEB=.19 (WF live wt) -1.42 - (WF live wt)).

Experiment III: Metabolizable Energy Determination

A metabolizable energy (ME) and nitrogen retention trial was conducted to 1) evaluate the digestibility of Wapana and Compana barley and to 2) determine the ME value of the two barleys since an ME value was needed for the calculations for the net energy experiment. In addition, nitrogen retention of the barley diets was measured to gain information of the protein quality of the two barleys.

Four yearling Targhee rams were accustomed to metabolism crates for use in a complete block design to compare (1) 40% Wapana - 60% chopped hay (2) 40% Compana - 60% chopped hay (3) 60% Wapana - 40% chopped hay or (4) 60% Compana - 40% chopped hay. The experiment was divided into four periods consisting of five days preparation and five days collection for each period. Each sheep received each diet once during the experiment. Separation of the ME value of the barleys from that of the hay was accomplished by solving simultaneous equations.

The barley was fed whole, mixed in the chopped hay each morning and evening. Feed allowed in each period was calculated according to body weights taken at the start of each phase. Water was available in the morning and in the afternoon before feeding. The amount of dry matter presented to each sheep was a function of metabolic size. The largest sheep (80 kg) was assigned an amount of dry matter suggested by N.R.C. (1968) as being a good amount for a sheep weighing 80 kg. For the first period, this was 1.8 kg DM. Because this was a little more than he could eat, it was reduced to 1.75 kg DM for the last three phases. An equation was then used to calculate how much dry matter each of the other sheep should receive ($DM_1/wt^{.75}{}_1 = DM_2/wt^{.75}{}_2$). This amount of feed allowed for a small but steady weight increase in all four sheep.

During the collection periods a strict procedure was followed. Feces and urine were collected, stirred, weighed and sampled, starting at 8:00 a.m. each day. Immediately thereafter the sheep were fed and the area around the metabolism crates was thoroughly cleaned. This procedure insured that collection was accurate by minimizing feed contamination of feces and urine. Urine was collected in 100 ml of 5% sulfuric acid to prevent nigrogen loss. One hundred-fifty gram samples of feces and urine were taken each day and frozen. Feed weighback was taken at the end of the five day collection phase. The barley in the weighback was settled out in water, dried and weighed.

Rumen samples were pumped via an oral tube at 1:00 and 3:00 p.m. from each sheep during one day of each collection period. Samples were filtered, acidified, centrifuged and frozen according to the method described by Baumgardt (1964) and Erwin et al. (1961) for subsequent volatile fatty acid analysis (VFA). The VFAs were analyzed in a Varion Aerograph 1400 gas chromatograph using a 10% FFAP 100/200 chromsorb G column. The ratio of the amounts of acetic plus buty ic acids to proponic acids was computed to evaluate differences in rumen digestion.

Experiment IV: Ruminal and Total Tract Starch Digestion

In order to measure the extent of Wapana and Compana starch digestion in the rumen and in the intestine, cannulae were introduced into the rumen and abomasum of sheep. The percentages of VFAs produced in the rumen give an indication of the relative amounts of rumen fermentation. Starch analysis of the material collected in the abomasum and in the feces give direct measurements of the extent of starch utilized in the rumen fermentation and in the total tract.

Inserting the cannulae was a two stage operation. The first stage involved placing the sheep under a general anesthetic using intravenous injections of sodium pentabarbitol. The area in which the cannula were to be placed was shaved and thoroughly washed. Lidocaine was used as a local anesthetic. The incision for the rumen cannula was made at a position approximately eight cm ventral to the transverse process of the vertabrae and eight cm posterior to the last rib of the left side. A circular portion of skin and musculature slightly larger than the diameter of the cannula was removed so that the wall of the rumen was exposed. The rumen wall was then sutured to the musculature with one line of suture and to the skin with another. This incision was allowed to heal for four to six days at which time the portion of exposed rumen wall was cut out and the cannula maneuvered into place. The abomasum fistula was placed approximately 10 cm posterior to the sternum and three cm to the right of the midline. The same surgical procedure was used as that described for the rumen fistula.

The cannulae utilized were 2.75 inches long, hard plastic tubes threaded for two inches on the outside and flanged at the bottom end. The abomasal cannula had an inside diameter of one-half inch and an outside diameter of three-fourths inch. The rumen cannula had an inside diameter of seven-eighths inch and an outside diameter of one and one-fourth inch. A plastic oval washer kept the cannula inside the animal and a plastic nut screwed down from the outside. A cap screwed over the end.[1]

[1]Purchased from Precision Machine Company, 2933 No. 36 St. Lincoln, Nebraska 68504.

Six wether lambs were fitted with cannulae but only one survived a sufficient time to be utilized in the experiment. Most of the deaths involved errors in the placement of the abomasal cannula. Two sheep had a twist in the abomasum due to suturing the stomach wall on the left side of its dorsal midline. One fistula was too close to the pylorus, whereas one was placed on the duodenal side of the pylorus. All of these sheep apparently died of mechanical blockage of the digestive system. As an experiment, the cannula was placed on the left side of the midline instead of the right on one sheep but this animal also died. This cannula was well placed with no evidence of infection according to the pathalogist's autopsy. No sign of infection was seen in any of the lambs.

Considerable problems were encountered in maintaining the cannula in place. Abomasal cannula was sometimes kicked or scraped out. The rumen fistula would often dilate and the cannula would either pop out from inside pressure or be scraped out.

The remaining sheep was placed in a metabolism crate and maintained along with the four sheep on the metabolizable energy determination. The same procedures described for that group of sheep applied for the feeding and daily collection of this sheep. The lamb was given 1.25 kg DM of feed consisting of Wapana and Compana at a level of 60% whole barley and 40% chopped hay.

Rumen samples for analysis of VFAs were taken at 8:00 a.m., 11:00 a.m., 1:00 p.m. and 5:00 p.m. on the second and fourth days of each collection period. Samples were prepared by the methods described by Erwin et al. (1961) and analyzed by the method described by Baumgardt (1964). Abomasal samples to be analyzed for starch taken and frozen each morning at 8:00 a.m. of the collection periods and at 11:00 a.m., 1:00 p.m. and 5:00 p.m. of the second and fourth day of each collection period. Starch analysis was conducted by the Montana State University Chemistry Station according to a procedure published by Banks et al. (1975).

Experiment V: In Vitro Digestion

Two in vitro digestion trials were run to determine Wapana and Compana barley dry matter disappearance. The in vitro digestion procedure was adapted from Tilley and Terry (1963) which assumes that the amount of dry matter that disappears during the course of the in vitro digestion is an accurate measurement of the in vivo digestibility. The procedure consists of a phase in which the feed is digested in rumen fluid and a phase in which it is digested in HCl pepsin solution.

Trial 1 consisted of three tubes each of Wapana, Compana, hay, 60% mixures of each barley and hay, and 40% mixtures of each barley and hay. The barley-hay tubes were included at the same levels that were fed the rams in Experiment III in order to see if there was any difference in the digestibility of barley when included with hay.

Twenty ml of McDougall's artificial saliva buffer solution adjusted to a pH of 6.8 to 7.0 was added to .25 g of the samples which was in tared 100 ml tubes. Five ml of strained rumen fluid was then added to each tube. The rumen fluid was collected, using a stomach pump introduced orally, a few minutes before the start of the digestion so that it did not lose its activity. To further protect the rumen fluid it was kept in a thermos bottle. Repeatability of the results of the assay was insured by collecting rumen fluid from the same animal kept on a constant diet. The tubes were flooded with CO_2, corked with rubber stoppers that have holes punched in them to release gas pressure and incubated at 39°C for 48 hours. Tubes were gently rotated at 2, 4, 20 and 28 hrs after initiation of incubation. Blank tubes were run that contained no sample because a small but constant amount of organic matter was present in the rumen fluid. This amount must be subtracted from the amount of dry matter left in the tubes after digestion.

After 48 hrs the tubes were emersed in ice cold water to stop bacterial activity and centrifuged for 10 minutes. The supernate was poured off and 25 ml of HCl pepsin added. The tubes were incubated for an additional 48 hrs, with stirring 2, 4, 20 and 28 hrs after initiation of this second incubation. Ninety-six hours following original incubation, the tubes were centrifuged and the supernate poured off. The tubes were dried overnight at 60°C and weighed. Percent dry matter disappearance was calculated by subtracting the weight of the sample left at the end of the assay from the weight of the original sample minus the residual rumen dry matter and dividing by the weight of the original sample.

Trial 2 was run in order to determine the rate of digestion of Wapana and Compana barley at various intervals following incubation. Eighteen tubes each of Compana and Wapana were tested. The procedure was essentially the same as described above, but three tubes of each barley were removed at 6, 12, 24, 48, 72 and 96 (full term) hrs from the water bath, centrifuged and dried. The purpose of this procedure was to determine if digestion rate was different for the two barleys. In addition to the blank tubes to measure residual matter in the rumen fluid at the end of the digestion, blank tubes were prepared, centrifuged and dried at the beginning of the digestion period. It was assumed that a linear function described the disappearance of dry matter from the blank tubes over the 96 hrs of digestion. Therefore, that amount of rumen matter assumed to have disappeared was subtracted from the tubes taken off before full term.

RESULTS AND DISCUSSION

Experiment I: Feed-Gain Trial

Gains per day varied considerably from pen to pen (table 1). Feed per day is calculated as ME per day (table 2) because some of the pens went off feed making it impossible to control their feed intake. This caused barley to hay ratios to vary considerably making kg of DM consumed per day a meaningless statistic. Table 2 also shows ME per mean metabolic size (ME/mean wt$^{.75}$), and ME per gain (ME/gain kg). The data indicates that for the pens of large, high gain; small, high gain; and large, low gain lambs, the Compana barley ration caused slightly better feed efficiencies. When expressed as ME per metabolic size per gain (ME/mean wt$^{.75}$/gain kg) (table 2) the same three pens appeared to be the more efficient. In the case of the two pens of small, low gain lambs, the Wapana barley resulted in a gain and efficiency ratio out of proportion to the feed intake.

Feed-gain trials are not considered the most accurate measurement of feed value because of variation in rumen-intestinal fill and potential differences in body protein to fat ratios. Sherrod et al. (1969) observed that there was no difference in the gain between two groups of steers fed regular and waxy sorghum but that there was a significant difference in the net energy for gain (NE_g) and net energy for maintenance (NE_m) of the two sorghums. Waxy sorghum caused a greater deposition of fat than regular sorghum resulting in greater energy retention. A net energy determination was therefore considered essential to the accurate evaluation of Compana and Wapana barley.

TABLE 1. FEED ANALYSIS FOR BARLEY AND HAY USED IN THE FEED GAIN AND NET ENERGY STUDY[a]

	Wapana	Compana	Hay
Crude protein, %	11.2	11.0	16.3
Moisture, %	9.3	11.8	10.4
Ash, %	2.9	3.0	10.1
Ether extract, %	2.2	1.6	1.9
Crude fiber, %	4.5	3.9	24.9
Calcium, %	.06	.05	1.61
Phosphorus, %	.42	.40	.25
Van Soest neutral detergent fiber, %	15.4	12.8	--
Gross energy C/g	3890.0	3799.8	3848.2

[a] The same lots of barley were used for all studies.

TABLE 2. GAIN AND ENERGY CONSUMPTION OF TWO SIZES OF LAMBS FED WAPANA OR COMPANA BARLEY FOR HIGH OR LOW GAIN

Lambs	Wapana				Compana			
	Large		Small		Large		Small	
Gain	High	Low	High	Low	High	Low	High	Low
Gain/day, g	49	-36	74	32	62	-9	84	5
ME mcal/day	3.54	2.58	3.52	2.64	3.52	2.67	3.87	2.54
ME mcal/kgW$^{.75}$	.193	.146	.211	.160	.194	.155	.225	.153
ME mcal/gain, kg	72.24	-71.67	47.57	82.5	56.77	-297.0	46.07	508.0
ME mcal/kgW$^{.75}$ per gain, kg	3.94	-4.06	2.97	5.00	3.13	-16.78	2.08	30.60