The inclusion of high levels of barley in rations for dairy cows and calves
by Steven George Prier

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

Abstract:
Rations containing high, levels of barley were evaluated in seven experiments (I-VII) with dairy cows and calves. I. Twenty-one Holstein heifer calves and 21 Holstein bull calves were maintained from birth to 84 days on rations containing 1) 100% barley, 2) 50% barley-50% oats or 3) 100% oats as the cereal grain. Grain consumption (kg), gain (kg/day) and feed efficiency (kg feed/kg gain) for the three rations were 1) 54.72, .54 and 1.88, 2) 55.60, .55 and 1.79 and 3) 65.94, .51 and 2.03. II. Twelve eight-week-old Holstein steer calves were used to determine the digestion coefficients for the calf rations. Digestion coefficients (%) of dry matter, crude protein, ether extract, crude fiber and nitrogen free extract for the three rations were 1) 83.15a, 80.71, 47.87a, 47.54 and 88.65a, 2) 81.29a, 81.19, 72.71b, 43.23 and 86.71a and 3) 78.16b, 82.31, 85.13c, 42.46 and 83.35b. Corresponding values with a different superscript differ significantly (P<.05). III. Two trials with 15 12-week-old Holstein calves showed the calves would accept any of the three rations if given no other choice, but the calves preferred the 100% barley over the 100% oats ration if given a choice. IV. Twenty-four lactating Holstein cows were used in two trials to compare rations containing 1) 100% barley, 2) 75% barley-25% oats or 3) 50% barley-50% oats as the ceral grain. Grain consumption (kg), fat corrected milk (kg), milk fat (%), and total volatile fatty acid (mM/1) production for the three rations were 1) 8.2, 18.1, 3.2 and 63.3, 2) 8.5, 19.9, 3.2 and 62.3 and 3) 8.7, 19.6, 3.1 and 59.0. V. Six 15 to 20-month-old Holstein steers were used to determine the digestion coefficients for the rations used in Experiment IV. Digestion coeffif-cients (%) of dry matter, crude protein, and nitrogen free extract for each of the rations, when calculated by difference, were 1) 80.16, 63.02 and 90.28, s) 75.95, 73.58 and 85.93 and 3) 78.32, 71.18 and 85.92. Digestion coefficients of ether extract for the rations plus hay were 1) 1.82a, 2) 45.48ab, and 3) 56.53b. All other digestion coefficients for the complete rations were similar. VI. Two trials with nine dry Holstein cows showed that the cows would accept all of the rations if given no choice, and showed- no preference for any of the three rations when given a choice. VII. In vitro dry matter digestibilities (%) calculated from the grains alone and by difference from grain and hay samples for each of the rations from the lactation trial were 1) 80.60a and 86.18a, 2) 77.97b and 83.02b and 3) 72.10c and 75.92c.

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FOR DAIRY COWS AND CALVES

by

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A thesis submitted in partial fulfillment
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ABSTRACT

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INTRODUCTION

Barley is considered to be the first plant cultivated by man (Bland, 1971). Its early beginnings account for the diverse areas where the plant is found. Barley species have been found from areas above the arctic circle, to the tropics of India, to elevations as high as 15,000 ft. Due to the hardiness of barley, it is well suited for high altitudes, cold weather and short growing seasons. These criteria have made barley ideally suited for growth in Montana and other northern plains states. Barley production in Montana ranks second only to wheat and accounts for 23% of all grains harvested (Anonymous, 1976).

Most of the barely that is produced is used in livestock feeding or malting. Only in the Far East is there a large amount of barley utilized for human consumption. Barley is used extensively for dairy rations in northern Europe (Henry and Morrison, 1923) and in the northwest United States. The total amount of grains in dairy cow rations increased 63% per cow from 1963 to 1973, while the use of barley for ruminants increased 68% over this same time period (Waldo, 1973).

Bath and Bennett (1976) suggested that to be used efficiently and economically, barley should constitute no more than 75% of the ration for lactating cows. Some dairy producers in this state are reluctant to use high levels of barley in their rations, however, other dairy producers are known to use barley as the sole grain at levels higher than 75% without any apparent digestive upsets. Conversely, many dairy producers are reluctant to include high levels of barley in calf starter rations, and often feel that oats are a necessary part of such rations.

The objectives of the experiments described herein are to determine the affects of high levels of barley in rations on the growth of calves to 12 weeks of age and on milk production in lactating cows. In addition, digestibility and palatability studies will be run on both cow and calf rations in order to support results of the growth and lactation trials.

LITERATURE REVIEW

Usage of Barley for Ruminants

Lactating dairy cattle. Early studies (Cunningham, 1928; Darnell and Copeland, 1936; Dice, 1935) indicated that when fed for production of milk, barley was superior to beet pulp, equal to sorghum and corn, and inferior to ground oats. Since that time, much work has centered not only on comparisons of barley and other grains, but also on comparisons of methods of processing these different grains.

Brown et al. (1966 and 1967) extensively studied the use of barley and milo for lactating cows. Using pelleted rations, Brown et al. (1966) compared the following combinations of barley and milo: all barley; 2/3 barley-1/3 milo; 1/3 barley-2/3 milo; and all milo. Dry matter digestibilities of the 2/3 milo-1/3 barley and all milo rations were highest. The 2/3 barley-1/3 milo ration resulted in a depression of milk protein. Overall they concluded that the pelleted milo ration was slightly better than the pelleted barley ration. However, Brown et al. (1967) reported that there were no differences in the ability of barley or milo to support milk production.

In order to compare different forms of barley and milo, Brown et al. (1970) compared steam rolling and pelleting the ration. The barley to milo ratios were 3:1 and 1:3. Their results showed no difference in milk yield, percent butterfat, percent solids-not-fat (SNF), digestibilities, body weight change, or volatile fatty acids (VFAs) as a result of steam rolling or pelleting the rations.

Energy relationships between barley and corn were examined by Tyrrell and Moe (1974). Their results showed the digestible energy of barley (3.24 Mcal/kg DM) was significantly lower than that of corn (3.50 Mcal/kg DM), but the efficiency of using this energy for milk synthesis did not differ between the grains. They obtained net energy for lactation values of 1.83 and 1.99 Mcal/kg DM for barley and corn, respectively. Both of these values are higher than NRC requirements (1.8 Mcal/kg DM) for high producing cows (NRC, 1971).

The value of barley alone and as a component of a concentrate mix has been investigated by several workers. Myers et al. (1968) compared steam rolled barley to a concentrate mix containing ground corn, ground oats and wheat bran. No differences were found in milk production or VFA production. Barley, corn, milo, oats, wheat and a concentrate containing barley, millrun and peas were compared in a lactation trial by Tommervik and Waldern (1969). Even though the proximate analysis of these rations varied, total milk yield and fat corrected milk (FCM) yield did not differ. Crude fiber intake of cows on the barley and mixed rations were significantly lower ($P<.05$) than those on the oats ration and was higher ($P<.05$) than those on milo, wheat and corn. Those animals consuming more fiber had higher milk fat percentages and lower protein and SNF percentages. A comparison of barley, wheat mixed feed and a mixed concentrate containing barley, wheat, peas and cottonseed meal in pelleted and meal forms were compared in a lactation trial by Waldern and Cedeno (1970). Milk fat was lowest from cows on the barley and mixed concentrate rations. The barley ration resulted in the lowest milk protein level. As a result, they concluded that barley or the mixed concentrate is comparable to wheat mixed feed for lactating dairy cattle. In another study, Shirvastova (1973) found that the addition of barley as 40% of the ration to wheat bran and ground nut cake resulted in a depression of milk fat. Edgerly (1963) compared ground barley, steam rolled barley, ground oats, ground oats and maize and a concentrate containing barley, oats and maize. Those cows on all barley rations gave 2 lb less fat corrected milk (FCM) than those on the concentrate ration. Cows on the concentrate ration gave 4.5 and 2.3 lb less FCM than those on oats and maize, and ground oats, respectively. Ground barley proved to be superior to steam rolled barley for milk production.

Khalifa _et al_. (1975) compared three rations with steam rolled barley to pelleted grass ratios of 1:3, 1:1 and 3:1. Their results indicated no difference between treatments for milk yield or milk fat percent.

Marx (1973 and 1974a) studied the use of high moisture barley in dairy rations. The grain was harvested at 71.3% dry matter in an oxygen limiting structure. Even though the differences in milk production were not significant, milk yield tended to increase on diets containing high moisture barley rather than dry barley (Marx, 1973).

A dry grain of barley and oats was compared to high moisture wheat for lactating cows by Marx (1974b). As with high moisture barley, the cows did not refuse the high moisture wheat, and production was comparable to the dry grain mix.

Wapana and Compana, two varieties of barley, were compared in a lactation trial by Miller (1976). No significant differences were found between varieties for milk production or percents of butterfat, SNF or crude protein.

Beef cattle. Early work in Montana indicated that ground barley was superior to crushed wheat and ground oats for gain but inferior to wheat for feed efficiency in beef cattle. A concentrate mix of these three grains was superior to any of the grains individually (Linfield, 1905).

Barley, when ground medium fine or rolled, was worth as much as shelled corn or ensiled ear maize when fed to beef cattle (Peters, 1931; Hoffman et al., 1952; Umoh and Holmes, 1976). However, Morrison (1959) indicated that barley was worth 88% as much as shelled corn for fattening experiments. A disadvantage of having barley as the only grain in the ration is that some cattle tend to bloat on this type of ration (Morrison, 1961).

As with dairy cattle, there is inconsistent evidence concerning the value of barley and milo as feeds. Hale et al. (1962) and Saba et al. (1964) found that barley gave an increase in gain and feed efficiency over milo. Digestion coefficients for protein were 79.3 and 55.2% and those for nitrogen free extract (NFE) were 90.8 and 77.1% for barley and milo, respectively, (Saba et al., 1964). Hale et al. (1966) found no difference in average daily gain but an improvement in feed efficiency for barley over milo. Contrary to this, Garrett et al. (1964) and Garrett (1975) found no difference in gain or feed efficiency for barley and milo rations.

Greater rumen digestibility for barley, as compared to milo, may be a reason for higher and more efficient gains. Using a nylon bag technique, Hale et al. (1962) measured dry matter disappearance from the rumen. After 7 hr, 42% of the barley dry matter was digested, but only 14% of the milo dry matter had been digested. Stockton (1976) found that in vitro dry matter disappearance after 12 hr was 25.65 and 24.33% for Wapana and Compana barley, respectively. Starch fermentation in the rumen for various grains has been reported as follows: barley, flaked corn, steam flaked sorghum, wheat and oats, 94%; ground corn, 74% and untreated milo, 42% (Waldo, 1973).

No differences in growth were obtained by Thomas et al. (1969) and Thomas and Geissler (1968) in a comparison of barley and wheat fed to steers and heifers. Daily gains of 1.16, 1.18 and 1.20 kg, and dry matter intakes of 5.55, 5.19 and 5.20 kg were found for diets of all barley, one-half barley-one-half wheat and all wheat, respectively, (Harvey, 1975). Tartary buckwheat is similar to barley for performance in beef cattle, but has only about 85% of the digestible energy content of barley (Nicholson et al., 1976).

Taylor et al. (1974) found barley equal to pelleted dried grass for growth in Fresian and crossbred bulls, but Boaz et al. (1974) found barley superior to cubed dried grass for growth of young Fresian bulls.

High moisture barley similar to that used by Marx (1974) for dairy cattle, was used for beef cattle in an experiment by Windels (1974). He found that performance of cattle tended to increase with higher levels of high moisture barley in the ration. There was no incidence of bloat among cattle on high moisture barley, but two cases occurred among those cattle on dry barley.

Sheep. Barley is considered to be an acceptable grain for growth and development of sheep (Morrison, 1961). Linfield (1905b) performed the earliest feeding trials with sheep in Montana. In comparing barley, oats and wheat, he found barley and oats gave the best gains, but wheat gave the best feed efficiency when fed to wethers. In lambs, however, the three grains were ranked in the order of oats, barley and wheat for both gain and efficiency. Ørskov et al. (1975) found that fattening lambs required less feed when fed barley rather than oats. The reason for this could be the increased dry matter digestibility of barley over oats (Ørskov et al. 1974b). Blackface lambs, however, did not grow as well on a barley diet as on corn based diets (Sheehan and Lawlor, 1974). Also Newton and Young (1974) found that barley pellets were inferior to grass pellets for growth of lambs.

Stockton (1976) compared the feeding value and energy values for Wapana and Compana varieties of barley fed to Rambouillet and Targhee wether lambs. His results indicated more efficient gains with Compana over Wapana, but no significant differences were found for metabolizable or net energy values between the varieties.

Barley is an acceptable feed for sheep in both processed and unprocessed forms (Morrison, 1961). Since sheep masticate their feeds thoroughly, processing does not improve the quality of the feed.

Young ruminants. Limited work with barley varieties indicate no effect on growth due to variety. Moss et al. (1976) found no difference in feed consumption or growth among calves on Hiproly, Hiproly Normal, Normal Compana or Wapana barley starter diets. No difference in digestion coeffients for dry matter, crude protein or nitrogen free extract was found by Miller (1976) for Wapana and Compana varieties fed to Holstein calves.

Although growth rate and feed efficiency of barley is comparable to other feed grains, it may not be completely acceptable for young ruminants. Tarrago (1973) found that lambs grew poorly when barley was fed as 95% of the ration. After slaughter, he noticed severe destruction of the rumen wall. Fell et al. (1968) noticed the same condition in calves fed barley as 90% of the ration. The destruction of the rumen wall consisted of thickening and hypertrophy of rumen papillae. This condition may be aggravated by pelleting the diet. Ørskov et al. (1974a) found rumen wall destruction in lambs fed pelleted rations, but no destruction in lambs fed whole rations.

Digestibility

Digestive physiology. Digestion of feedstuffs by ruminants can be viewed as containing two separate phases. The first phase consists of digestion by the microbial population of the rumen. The second phase consists of digestion of the microbial population and feedstuffs which bypass ruminal digestion, in the lower gastrointestinal tract of the host.

The microbial species that inhabit the rumen have been studied extensively since Hungate (1950) first developed his anaerobic technique for the isolation of cellulolytic species. Hungate (1966) divided the types of rumen bacteria into the following: 1. cellulose digesters, 2. starch digesters, 3. hemicellulose digesters, 4. fermenters of sugar, 5. bacteria utilizing acids, 6. methanogenic bacteria, 7. proteolytic bacteria and 8. lipolytic bacteria. Due to the high level of carbohydrates in most ruminant diets, the carbolytic species of bacteria predominated.

The cellulolytic species included the rod shaped Bacteroides succinogens, Butyrivibrio fibrisolvens and Clostridium lockheadii, as well as many coccic species. Bryant and Burkey (1952) found that these cellulolytic species compose 15.6% of the total culture count from an animal on an all forage diet.

Bacterial digestion of starch is done by Streptococcus bovis, Bacteroides amylophilus, B. Ruminicola, Succinimonas amylolytica, Selenomonas ruminanticum and many of the cellulolytic species listed above (Hungate, 1966).

Many of these same species also digest hemicellulose. Heald (1953) found that hemicellulose was digested to approximately the same extent as cellulose.

Mono and disaccharides can be fermented by all of the polysaccharide digesting bacteria (Hungate, 1966). Lactobacilli species are important in the fermentation of lactose in young milk-fed ruminants. These species tend to increase as the pH of the rumen decreases (Hungate, 1966).

Methanobacterium ruminantium has been found to be the chief methane producing species (Smith and Hungate, 1968).

Hungate (1966) stated that rumen fermentation is saccharoclastic rather than proteoclastic. Many of the saccharoclastic bacteria contain protease enzymes that break down ingested protein. Over half of the proteolysis of the feed occurs by rumen bacteria. Proteolysis in the ruminant occurs as the breakdown of proteins to peptones to amino acids, followed by deamination (Warner, 1956).

Many of the rumen bacteria also contain lipolytic enzymes necessary to hydrolyse fats into glycerol and fatty acids (Garton et al., 1958, 1961).

As a result of microbial digestion of ingested feed, by-products are released. Acetic acid is produced in the largest quantities. The Selamonas species produce propionic acid, while the Butyrivibrio species are the main producers of butyric acid.

Another by-product is the microbial population itself. Over half of the material digested in the lower gastrointestinal tract comes from microbial cells, which are very important as a protein source for the ruminant (Ørskov, 1969). Experiments have been run to determine the true digestibility and biological value of rumen microorganisms (Johnson et al., 1944; McNaught et al., 1950, 1954; Reed et al., 1949). The true digestibility values range from 62.1 to 91.0%, while biological values range from 66.0 to 88.2%.

The other half of rumen microbiology deals with the protozoan inhabitants. It is necessary for the young ruminant to be in close contact with older animals in order to become innoculated with a protozoal population. A young animal that is only fed liquids will have a lowered rumen pH, which prevents the initiation of a protozoal population (Eadie, 1962). Eadie (1962) found that protozoa free calves showed no difference in weight gain or feed efficiency when compared to normally faunated calves.

The role of protozoa in the normal rumen is still under investigation. Results of earlier *in vitro* studies are inconclusive since digestion may occur by bacteria within the protozoan itself. Purser and Moir (1966) found higher concentrations of protozoa to be associated with higher rumen ammonia levels. They concluded that protozoa may be proteolytic without being proteogenic.

Enzymatic digestion in the abomasum and duodenum compromises the final steps in ruminant digestion. Secretions of the abomasum are similar to those in the nonruminant stomach. These secretions are continuously discharged into the abomasum (Hill, 1965). This is thought to be the case for secretions of the duodenum as well (Church, 1971). The reasoning behind this is that the rumen continuously dumps some of its digested matter (Hill, 1965). Since chyme is always present in the abomasum and duodenum, there is continual enzyme and hormone release. Protease zymogens are released to act on proteins and peptides; amylases act on carbohydrates; and bile and lipase are released to act on fats.

It is thought that there might be some post-ruminal digestion of fiber. Putnam and Davis (1965) found a digestion coefficient of 29% for cellulose given to calves via an abomasal cannula. This crude fiber digestion is most likely caused by microbial degradation in the large intestine. Colonic microbial degradation of crude fiber to less complex carbohydrates may tend to increase the level of NFE in the feces (Schneider and Flatt, 1975). The VFAs produced in this section of the gastrointestinal tract are probably absorbed, but their value has been questioned (Church, 1971).

The digestive system of the young ruminant is greatly different from the adult. At birth, the rumen is undeveloped and correspondingly small. Until 16 weeks of age, the young ruminant is in a period of transition from monogastric to ruminant (Ralston, 1971). Those animals on a liquid diet will have most of the ingested food by-pass the rumen via the esophageal groove. The length of time that this animal is kept on a liquid diet will determine the rate of development of the reticulo-rumen. Kaiser (1976) compared growth rate and reticulo-rumen development of calves raised on milk at levels of 8, 10, 12, or 14% of body weight per day for 12 weeks. Those calves at the 14% level were heavier at weaning than the other groups, but they had poorer postweaning gains. This could be attributed to poor reticulo-rumen development in these high milk calves.

Factors Affecting Digestibility

Digestibility refers to the absorption of compounds from the gastrointestinal tract of the animal. Church (1971) and Schneider and Flatt (1975) have extensively reviewed many of the factors that alter digestibility. These factors depend on the animal, the method of feeding, or the feed. These factors are interrelated and their individual effect on digestibility cannot be easily isolated.

Differences between ruminants due to breed, appetite or palatability will alter digestibility of the feed. Studies with different types of cattle have shown that there may be species differences in rumen fermentation (Hungate _et al_., 1960). Also there is inconclusive evidence concerning the relative digestibility differences between sheep and cattle. Any factor that affects the appetite of the animal will alter intake by the animal. This is closely related to palatability, which will be discussed later in this paper.

An increased plane of nutrition may decrease the digestibility of the feed, however, increased frequency of feeding will increase digestibility (Church, 1971). When higher levels of feed are ingested, the nutrients pass through the gastrointestinal tract quicker. Goshtasbpour-Parsi _et al_. (1977) fed two levels of an isonitrogenous diet to cannulated wethers. They found that as the level of feeding increased, there were greater amounts of nitrogen, non-protein nitrogen and total amino acids in the omasum. Even though these nutrients by-pass ruminal digestion, they may be degraded by intestinal enzymes. An increased plane of nutrition will seriously affect crude fiber digestibility since the rumen is the main organ to digest crude fiber. Postruminal digestion coefficients for crude fiber are 29% compared to 63% for the entire gastrointestinal tract (Putnam and Davies, 1965).

Increases in each of the nutrients fed may also alter digestibility (Schneider and Flatt, 1975). Karr et al. (1966) found that as the amount of starch fed increases so does ruminal by-pass. In such a case the ruminant may receive more starch than he can digest. Increased levels of ingested protein may increase crude fiber digestibility. Nitrogen from this catabolized protein requires a carbon source in order for bacterial protein synthesis. Low fat rations show low and variable fat digestibilities. An increase in the fat content of the ration will increase fat digestibility, but decrease the digestibilities of the other nutrients (Schneider and Flatt, 1975).

It must be remembered that any factor that alters the microbial population of the rumen will also alter digestibility. Hodgson et al. (1976) postulated that there is an association between an increased rate of passage, measured as liquid clearance rate, and the pattern of fermentation.

One of the greatest factors used to alter ruminant digestibility is feed processing. The effect of processing is to make the nutrients of the grain more available to the rumen microbes. Most processing has dealt with the concentrate portion of the ration. Processes that have been utilized include grinding, pelleting, cracking, steam-roasting, steam-flaking, rolling, popping and extrusion of the grain.

Contrary to results shown with sheep, grinding of grains can be effective for cattle (Maynard and Loosli, 1969). Coarsely grinding corn and oats will increase the digestibiltiy for all nutrients except crude fiber (Olson and Wallis, 1938; Wallis et al., 1939). However, finely ground grains will have lower digestibilities than more coarsely ground grain. The finely ground grains are also less palatable (Beardsley, 1964). When roughages are ground, the digestibilities of the nutrients decreases. Campling et al. (1963) found that grinding of hay decreased digestibilities in cows. This was due to the increased rate of passage of the ground hay.

Pelleting of the roughage portion of the diet will decrease crude fiber digestibility (Woods and Rhodes, 1962). Ørskov and Fraser (1972) found that rolling barley before pelleting increased the digestibility of the ration in sheep; but Ørskov et al. (1974a) found that the digestibility of dry and organic matter increased with a pelleted whole barley rather than pelleted rolled barley in lambs. Brown et al. (1970) compared pelleting versus steam processing of two ratios of milo and barley for lactating dairy cows. There were no differences in digestibilities as a result of processing. Barely, wheat mixed feed and a mixed concentrate in meal and pelleted forms were compared by Waldern and Cedeno (1970) in lactating cows. Digestibilities of all nutrients except NFE were lower in the pelleted ration.

Nordin and Campling (1976) compared the digestibility of barley, oats, sorghum and wheat as whole or rolled grains. Rolling of the grains resulted in improved digestibilities with sorghum, wheat and barley. They postulated that there was no improvement with the oats ration due to the higher crude fiber level in this ration, which caused the cows to masticate the oats rations more thoroughly.

Utilizing yearling steers, McNeil et al., 1971) found that starch digestibility increased for a steam-flaked ration compared to the same ration dry ground. Thin-flaking and dry extrusion have also been shown to give improvements over whole grains in beef cattle (Matsushima, 1970).

Changing the forage to concentrate ratio fed to the ruminant will affect the digestibility of nutrients appreciably. Since concentrates usually have smaller particle size, they will increase rate of passage as their proportion in the diet increases. Secondly, increased concentrate levels greatly affect rumen microbial fermentation. The saccharoclastic bacteria preferably attack the more soluble carbohydrates in the concentrate. Concurrently, the pH of the rumen fluid falls, which causes a decrease in the ability to digest cellulose (Donefer et al., 1963). Bryant and Burkey (1953) found that with an increase in the cellulose content of the ration, the ratio of cellulolytic to non-cellulotytic bacteria did change, but the absolute numbers of cellulolytic bacteria did not change. Latham et al. (1974) discovered that low roughage diets caused an unstable microbial population in the rumen.

At low forage to concentrate ratios some of the starch may not be digested (Wheeler et al., 1975). These changes in carbohydrate digestion cause a change in the rumen by-products, namely VFAs. Varying the forage to concentrate ratio is closely related to changes in the molar percent of acetic acid (Bath and Rook, 1963). As the ratio decreases the molar percent of acetic acid increases.

An increase in the percentage of undigestible nutrients in the ration decreases digestibility. Mature forages contain higher levels of undigestible nutrients than young crops. Dry matter digestibility by dairy cows may drop from 75 to 52% in forages harvested early and later in the growing season, respectively, (Reid, 1957).

Even though the microbial population of the rumen produces most of the necessary nutrients for the host, deficiencies of nutrients for the microbes will decrease their ability to digest the ration (Church, 1971).

Abrupt changes in the feeds given to ruminants will cause a disruption of microbial fermentation. Until adaptation to the new ration has occurred, digestibilities may be lowered (Church, 1971). This is one reason why an adequate adjustment period is necessary for ruminants utilized in a digestibility trial.

One diet fed in conjunction with another may exert an effect on the digestibility of that diet. This same effect may not be seen when the diet is fed alone. Associative effects are clearly seen where grain values are calculated by difference. Hay digestibilities are assumed to be the same when hay is fed alone or in conjunction with a grain ration. This effect may be seen qualitatively but cannot be calculated quantitatively (Maynard and Loosli, 1969).

Measuring Digestibility

In order to determine what differences, if any, there are between the digestibility values for two feeds we must have a method of obtaining digestibility data. One common physical method of collection employs the use of metabolism crates. The crates allow for total fecal and urine collection throughout the experimental period. Hobbs *et al.* (1950) described the construction of such a crate. Steel tubing is commonly used to replace the wood in their design. Bouchard (1975) designed a unique metabolism crate for dairy cows. The crate was built with a conveyor belt under the crate angled at 35^{o} from front to back. After urination, urine is allowed to flow cranially to a collection bucket by means of gravity. Upon defecation, the feces are carried up the conveyor belt into a collection pan.

Most ruminant digestibility studies use steers or wethers due to the anatomical ease in separation of feces and urine. Where it is necessary to use female subjects, adequate urine catheters or conduits must be applied to the animals (Hobbs *et al.*, 1950). Urinary or Foley catheters leading directly from the urinary bladder to a collection bucket have been used for urine collection with female subjects. The greatest disadvantage with these catheters is the increased risk of infection and discomfort to the animal (Moss, personal communication).

For some studies it is necessary to allow animals to forage and at the same time obtain fecal and urine collections. Collection bags are strapped to the animal in order to collect fecal and urine samples. Liebenberg and Papenfuss (1975) have designed a light weight, 3.5 kg, metabolism harness for dairy cattle. A similar harness was designed by Owen and Ingleton (1961) for the collection of feces from ewes. These devices allow for collection of urine and feces without interference with feeding or milking.

Various chemical indicators have been used to study digestibility. Fecal grab samples are taken periodically throughout the day and measured for concentration of the indicator. Since there is diurnal variation in the excretion of these indicators, a suitable time for taking grab samples must be established (Kane et al., 1952). Internal indicators are a part of the feed itself. Those utilized include lignin, silica and plant pigments. External indicators are added to the feed and include chromic oxide (Cr_2O_3), various dyes and polyethelene glycol. One problem with external indicators is measuring their rate of passage. CR_2O_3 is passed slowly through the gastrointestinal tract because it is associated with the solid fraction in the reticulo-rumen, whereas polyethelene glycol is passed quickly through the tract because it is associated with the liquid fraction of the digesta (Corbett et al., 1958 and 1959). For an indicator to be useful, it must be insoluble in the gastrointestinal tract, be undigestible, pass through the tract at the same rate as the feed, have no undesirable pharmacological effect and be suitable for chemical analysis (Church, 1971).

The question arises as to how well do indicator methods compare to total collections. Kane et al. (1949) fed alfalfa hay and alfalfa silage to three dairy cows and determined digestibilities by total collection, Cr_2O_3, and lignin. Their results showed no differences between the three methods. Using dairy cows, Kane et al. (1953) compared total collection, Cr_2O_3, lignin and plant pigments. They obtained similar digestion coefficients for all methods whether on a 10-day total collection or on a 3-day collection obtaining grab samples every 12 hr. Putnam et al. (1959) gave dairy cows Cr_2O_3 once daily and took grab samples once every 12 hr. Their digestion coefficients were within $\pm$ 5% of those obtained from total collections.

Digestibility of Rations Fed to Dairy Cattle

Digestibility coefficients for rations fed to dairy cows should be determined from trials with dairy cows, since lactating cows are eating at three times maintenance levels. However, many problems occur where lactating dairy cows are used for digestibility trials.

First and most obvious is the separation of urine and feces. This can be overcome by the use of a metabolism crate and urinary catheters or by a harness attached to the animal. Secondly, the problem arises as to how the stress associated with these collection techniques will affect the digestibility coefficients.

One alternative is to employ a feed marker, such as Cr_2O_3 and take periodic fecal grab samples. With this method the cow can be managed close to normal. Due to partitioning of the marker within the gastrointestinal tract, this method may not be acceptable. Even with these associated problems, both techniques have and can be used quite effectively (Kane et al., 1949, 1952 and 1953).

Digestion coefficients for barley have been found using all of these digestibility methods. Typical digestion coefficients for barley rations fed to cattle are 76.28, 80.10, 90.32, 70.16 and 85.22% for crude protein, dry matter, NFE, ether extract and total digestible nutrients, respectively, (Brown et al., 1970 and 1966; Saba et al., 1964; Schneider 1947; Tommervik and Waldern, 1969; Tyrrell and Moe, 1974; Waldern and Cedeno, 1970).

Palatability

Palatability is too often confused with feed intake. It should be remembered that palatability refers to a preference between two feeds or compounds. Young (1967) describes palatability as being the hedonic response to feedstuffs. This implies that there are psychological as well as taste related factors involved in palatability. Blaxter et al. (1961) suggested discarding the term palatability when referring to ruminants, and recording only the quantitative measurements of feed intake.

An animal may prefer one feed over another when the two feeds are fed simultaneously. However, when fed either of these alone, consumption may be equal (Baumgardt, 1969). Dayton and Morrill (1974) have developed a mathematical model that estimates feed intake when a ration is fed alone rather than in conjunction with another ration.

Palatability may be influenced by both feed related and environmental factors. Feed related factors that alter palatability are kind of feed, texture or form of feed, and temperature of feed. Environmental factors include quantity of feed, position of feed, type of container and degree of contamination of the feed (Young, 1948).

Since cattle and sheep appear to be color blind, taste and smell are the most important senses related to palatability (Church, 1971). The four areas of the tongue related to taste are sweet, sour, salt and bitter. Dilute sucrose, hydrochloric acid, sodium chloride and quinine sulfate solutions are utilized to test responses of each of these areas. Animals fed basal diets are allowed access to distilled water and one of the above solutions. Studies like this have shown that cattle prefer sucrose to molasses, moderately prefer acetic acid and reject sodium chloride and quinine. Sheep appear to have no preference for any of these compounds (Church, 1969; Goatcher and Church, 1970).

Molasses is commonly added to ruminant rations to improve intake and, indirectly, the palatability of the grain in the ration. The effect is mediated through both improved taste and decreased dustiness of the ration. Molasses contains very soluble carbohydrates that are quickly broken down in the rumen. As molasses intake increases, so does microbial production of VFAs. The VFAs act on receptors in the rumen wall or in the hypothalamus to cause satiation and resultant decreased intake (Baile and Forbes, 1974).

It is questionable whether blood glucose plays a role in the control of intake in ruminants (Baile and Forbes, 1974). Kane et al. (1961) examined what would happen if water and a sucrose solution were offered to an animal on a low feed intake. They utilized chickens since it had been found that chickens on a normal ration find water and sucrose to be equally palatable. When food intake was restricted, the birds tried to make up for the caloric loss by drinking greater amounts of the sucrose solution. As shown by these experiments, the effect of molasses in a feed is mediated through both palatability and intake.

There is little evidence in the literature as to the relative palatability of barley compared to other grains. Marks (1974a) indicated that high moisture barley is as palatable as dry barley for lactating dairy cattle. Moss (1976) indicated that calves prefer ($P < .05$) Hiproly barley over Compana and Wapana varieties but not over Hiproly Normal barley.

METHODS AND MATERIALS

Experiment I. Growth Trial

Twenty-one Holstein heifer and twenty-one Holstein bull calves were assigned to one of three experimental rations (table 1) at birth and maintained to 12 weeks of age. The energy sources for these rations were 100% barley, 50% barley-50% oats, or 100% oats. The rations, formulated to give 16% protein, are summarized in table 1. During the first two months of this 10 month experiment, steam rolled barley and whole oats were fed. For the rest of the experiment steam rolled barley and steam rolled oats, purchased locally, were fed.

The calves were housed in individual pens in a covered shed with outside runs at the MSU dairy center. For one month of the experiment, this building was evacuated due to problems associated with a salmenollosis outbreak. For that period, 12 of the calves were housed in a covered shed located south of the MSU farm. Those calves that showed clinical signs of salmenollosis were not included in this experiment.

Milk fed prior to weaning was given according to the following schedule: 10% of body weight from birth to four weeks of age; 8% of body weight during the fifth week of age; and 6% of body weight during the sixth week of age. The calves were weaned at seven weeks of age. Grain, hay and water were offered ad libitum throughout the experimental period to 24 of the calves. However, 18 of the calves only received grain, hay and water ad libitum after weaning.

The amount of grain fed and the amount refused were measured and and recorded twice daily. The amount of hay fed and refused was measured and recorded approximately once every two days. Grain rations were sampled and analyzed when mixed, while the hay was sampled and analyzed periodically throughout the experimental period. The feeds were analyzed for percent dry matter, crude protein, crude fiber, ether extract, ash and NFE by AOAC (1975) methods and neutral detergent fiber (NDF) according to Goering and Van Soest (1970). Weekly measurements of weight, heart girth and height at withers were taken and recorded for each calf.

An analysis of variance (Snedecor and Cochran, 1967) was made between rations for feed consumption and growth parameters.

Experiment II. Digestibility of Calf Rations

Twelve Holstein bull calves approximately one week of age were purchased in the beginning of August for use in this experiment. Within a day of purchase, the calves were castrated using an elastrator. Preweaning milk was given at the same levels as described in Experiment I. At approximately six weeks of age, all 12 calves were moved into one large pen and weaned from milk. For the following two weeks, the calves were offered, *ad libitum*, a ration similar to the D-36 calf ration (table 1). No roughage was offered to these calves from birth to the end of this trial. Starting at eight weeks of age, these calves were utilized to determine the digestibility of rations

TABLE 1. COMPOSITION OF CONENCTRATE RATIONS USED FOR GROWTH, DIGESTIBILITY AND PALATABILITY WITH CALVES, EXPERIMENTS I, II AND III

Ingredient	D-37	D-36	D-37
	%	%	%
Steam rolled barley	79	39.5	--
Steam rolled oats	--	39.5	79
Soybean meal	15	15	15
Dried molasses	4	4	4
Trace mineral salt	1	1	1
Dicalcium phosphate	1	1	1

D-35, D-36 and #-37 (table 1). The digestibility trials were run in the Large Animal Metabolism Lab at the MSU Nutrition Center. Due to the limitations in the number of crates, only six calves were tested during each period. Each calf was tested for two periods, with a two week break between periods. As a result, there were eight calves tested on each ration. The test period for each ration lasted two weeks, with a nine day adjustment period and a five day collection period.

Grain was measured and fed twice daily at 8:00 a.m. and 3:00 p.m. with water offered just prior to feeding. Due to the lack of hay and sunlight, 1,500,000 I.U. of vitamin A and 225,000 USP units of vitamin D were injected IM in each calf at the start of the experiment.

Collection of urine and feces was made daily just prior to the 3:00 p.m. feeding. To prevent the loss of ammonia, 75 ml of 5% sulfuric acid was added to each urine bucket daily. Urine was stirred prior to collection and approximately 100 ml was taken and frozen. Approximately 400 g of feces was taken randomly from the feces pan and frozen.

The five daily collections of urine and feces from each calf during each period was composited for analysis. A 400 g fecal composite was analyzed for percent dry matter, crude protein, crude fiber, ether extract, ash and NFE by AOAC (1975) methods and NDF according to Goering and Van Soest (1970). One 20 ml urine composite was analyzed for nitrogen in order to determine the nitrogen balance