Why Feed a Molasses-Based Liquid Supplement When Corn is Cheap and Milk Price is Low

Stephen M. Emanuele[1] and Charles J. Sniffen*[§]
**Quality Liquid Feeds*
[§]*Fencrest, LLC*

Introduction

Sugar has been consumed by dairy cattle since the beginning of time. They have come from the pastures which are naturally high in sugars. When we feed fermented forages most of the sugars have been converted to fermentation acids. The rumen and the cow have evolved to use plant sugars. The most prevalent form of added sugar fed to cattle has been molasses. The main sugars in molasses are sucrose (65%), fructose and glucose. Historically, the reason for feeding added sugar has mostly been as a sweetener or to improve palatability of feeds that are being fed. This concept has now changed. There are now research papers showing advantages to feeding sugars. More importantly though is the fact that we now have laboratories analyzing total sugars in forages and byproducts. Sugar addition to rations has had a mixed history. It has only been in recent years that consideration has been given to the addition of sugar to the ration as a nutrient to benefit rumen function as well as the metabolism of the cow. We need to start thinking in terms of individual sugars.

The addition of sugar to dairy cattle diets can be very positive. Trials have reported increased milk yield and milk fat percent or increased NDF digestibility (Broderick and Radloff, 2003, Broderick and Smith 2001, Varga etal. 2001, Oldick etal. 1997). Yet, the addition of sugars to dairy cattle diets has not always improved milk yield, ruminal microbial protein yields or milk components (Hristov and Ropp 2003; McCormick etal. 2001, Morales etal. 1989). The reported variation in response to sugars in dairy cattle diets can be explained by four processes that occur in the rumen. These processes are:

A. A shift in the end products of ruminal sugar fermentation based on bacterial growth rate and rumen pH.
B. Not all sugars are used with the same efficiency by rumen bacteria for growth.
C. Establishment of a viable population of anaerobic fungi in the rumen.
D. Wasting of energy by rumen bacteria (energy spilling) when the supply of fermentable carbohydrates exceeds the needs for microbial growth.

Below is a partial list of sugars found in the feedstuffs that we feed.

Monosaccharaides

[1] Contact at: Quality Liquid Feeds, 3586 Hwy 23 North, P.O. Box 240, Dodgeville, WI 53533. Tel: (608) 935-2345; E-mail: semanuele@qlf.com.

5 carbon sugars – Arabinose, Ribose and Xylose
6 Carbon sugars – diverse across all plants; Glucose, Fructose, Galactose and Mannose

Disaccharides

Sucrose – found in all plants and consists of Glucose + Fructose
Maltose – found in all plants and consists of Glucose + Glucose
Lactose – found in milk and consists of Glucose + Galactose

Trisaccharides

Raffinose – found in cottonseeds and sugar beet pulp and consists of Galactose + Fructose + Glucose
Maltotriose – found in corn distillers grains and consists of Glucose + Glucose + Glucose

Tetrasaccharides

Stachyose - found in soybeans, consists of Galactose + Galactose + Glucose + Fructose

Polysaccharides

Fructans – mainly in grasses and consists of fructose
Galactans – mainly in alfalfa and soybeans and consists of galactose
Pectins – mainly in alfalfa and soybeans and contains arabinose + galactose
Cellulose – all plants and contains long chains of glucose
Hemicellulose – all plants, higher concentration in grasses and contains arabinose, xylose, mannose, galactose, and glucuronic acids
Starch – diverse among plants and contains long chains of glucose
Sugar alcohols – polyol – forage fermentation product - Mannitol – 6 carbon

It would be a mistake to assume that all sugars have the same fermentation rate in the rumen and that all sugars are used with the same efficiency by rumen bacteria. Yet, that is exactly what we do when we formulate dairy cattle diets.

The most common rapidly available sugars in forages and various grains are sucrose and glucose. However when forages are fermented these sugars disappear, leaving residual sugars from the fermentation. These residual sugars are the breakdown products from hemicellulose which are mainly the 5 carbon sugars shown above. There has been some preliminary work that would indicate that the rumen microbes use the different monosaccharide's with different efficiencies. We need to know more about the utilization of the water soluble disaccharides and oligosaccharides in the rumen and by the cow. The sugars found in cane molasses are mainly sucrose, glucose and fructose. Molasses contains 50% sugar on an as fed basis and 70% of the sugar is sucrose. Cellulose, starch and sugars all end up eventually as hexoses. These hexoses then are metabolized to pyruvate which can be metabolized to acetate, propionate, butyrate or lactate. Ruminal conditions must exist where the majority of hexose is fermented to acetate, propionate, and butyrate but not lactate. The energy generated from this fermentation must be used for bacterial growth if sugars are to be used successfully in dairy feeding programs.

Rumen Diversity Influences the Efficiency of Sugar and Starch Utilization

Table 1 provides a global, but simplified view of the rumen ecology. This is a balance that can be disturbed by many factors:

1. Inadequate effective fiber to produce adequate buffering
2. High fermentable starch levels in the ration, which lead to periods of low ruminal pH
3. Ration sorting, which can lead to rumen acidosis and sore feet
4. Excessive rumen degraded protein containing peptides with Histidine
5. Over-crowding or high stocking density, which leads to slug feeding

The bacteria that digest fiber basically need a rumen pH that is over 6.0 for a significant part of the day for good fermentation. There needs to be adequate NH_3 at all times at a concentration high enough that there will be a gradient that will be adequate to bathe the colonies growing within the fiber matrix. There is an absolute requirement for isoacids for continued fermentation of fiber. Note that the bacteria that use protein as their substrate produce the primary source of the isoacids from the branched chain amino acids, leucine, isoleucine and valine. These bacteria have a long doubling time. This is influenced by nutrient supply and then to surface area. However, the down side in chopping or grinding the forages too fine is an increased wash out from the rumen and a depressed digestibility. There is a balance and the balance is to maintain a rumen mat.

The starch and sugar bacteria have very high growth rates. They can drive ruminal pH down very quickly. There is a balance that can be achieved where there first is a balanced nutrient flow to these bacteria that will stimulate a coupled fermentation – one that drives microbial mass and not microbial waste in the form of VFA. Next, there is the importance of enhancing the secondary fermenters which will use the lactic acid moderating the pH drop that occurs after an ingestive episode. This requires a malic acid source. A major organic acid found in molasses is malic acid.

A significant part of the normal rumen ecology is composed by protozoa which, under normal conditions, make up 40-45% of the microbial mass (Table 1). In contrast to the bacterial population, only 10% of this population washes out of the rumen to contribute to the microbial protein supply. This is in contrast to 75 to 85% of the bacterial population washing out of the rumen, with the rest lysing and being predated on by the protozoa. We say that the microbial mass that stays in the rumen contributes to the recycled N pool. It is now suggested that we are under estimating the contribution of this pool to the N needed by the bacteria in the rumen. It should be pointed out that many years ago classic studies conducted by Reis were done in sheep in Australia demonstrating the positive wool growth in sheep resulting from depopulating the rumen of protozoa. These studies pointed out the large pool of bacteria that the protozoa consumed daily in the rumen. The Fungi make up only 3-8% of the microbial mass. It is proposed that they have a key role in opening up the fiber that will enhance colonization by the fiber bacteria. They are stimulated by sugar, which research suggest will result in improved fiber digestion.

It is the understanding of these interactions that will help us in developing better rations going into the future. The balance of the carbohydrates with different fermentation rates and the different protein sources with different fermentation rates must be balanced. Unfortunately we have yet to reach the point where we can effectively do this. It is a dynamic second order system. We have improved our ability to measure and define the amount of each protein and carbohydrate fraction, but in our nutrition models we assume that a cow eats 24 meals a day, the same size and evenly spaced. We know this not to be the case. Does this mean that we should abandon the use of nutrition models? No, but it does require that as nutritionists, we admit that these models do not account for associative feed effects or the impact of ration sorting and meal pattern on nutrient utilization in the rumen.

Impact of Sugar on Animal Performance

There have been several studies over the years that have demonstrated the value of adding sugar to rations. Most of these studies have been with the addition of molasses or sucrose directly. Several of the studies replaced the starch with the sugars, keeping the NFC constant. The results were always positive not only in milk yield but also in components. In studies with fermenters, the work showed increases in fiber digestion. It has been suggested that the fungi which play a role in opening up the fiber, are stimulated by the 6-carbon sugars. This is important because it fits well with the rapidly degraded protein (mostly the soluble) to give an early stimulation to fiber digestibility. Additionally, if we can reduce the starch in the ration, we will have better control of rumen pH, an additional enhancement for fiber digestibility. In the original nutrition models, it was assumed that all of the sugar was broken down in the rumen. This assumption is not correct. This is important because of the positive impact that the digestible sugars can play in the metabolism at the mammary gland. It is important to note that added sugars, in the form of sucrose or sucrose equivalents (glucose + fructose) are about 84% degraded in the rumen.

Figure 1 displays results from some of the work conducted in France by Dr. Rulquin and colleagues at INRA. This suggests that it is important not only to enhance rumen function but also having an optimum amount of digestible sugar that will enhance milk true protein yield. This means that we need to consider the feeding of additional sugars in the rations. Many rations that are fed in this country have silages as their forage base. This usually results in rations with a 3 to 4% total sugar as measured by the 80% ethanol procedure. Unfortunately, this procedure does not identify the individual sugars. A high percentage of these sugars are the 5-carbon sugars discussed earlier. These sugars are not very digestible in the rumen or in the small intestine. It is recommended that we should add about 3 to 5% additional sugar in the form of 6-carbon sugars. This will result in a total sugar in the ration of 6 to 8% of the DM. If we assume that 35% of this sugar will escape then added to the base sugar level plus what we will derive from the escaped starch, we will approach the levels suggested by the work of Rulquin shown above. Research using molasses based liquids shows 84% utilization in the rumen.

Harris and Van Horn (1983) suggested that at 8% or less of the total ration dry matter molasses would contain the same productive energy as ground corn. This would be equal to 4 pounds of molasses on an as fed basis, when DMI was 50 pounds. Feeding 4 pounds of cane molasses would supply 2 pounds of sugar. At dietary concentrations above 8% of ration dry matter, the value of molasses declined relative to corn. Recent trials suggest that Harris and Van Horn were correct. In a recent meta-analysis of 25 published research trials, 3.5% FCM yield, milk protein yield, milk fat yield, were maximized when the diet contained 5 – 7% supplemental sugar (Emanuele et al., 2015). Non-linear analysis of the database indicated that for cows producing 90 to 100 pounds of milk, the ideal dietary sugar content was 7.14% (Emanuele, 2016, Leading Dairy Producer Conference, Wisconsin Dells, WI.). For all cows, the ideal dietary sugar content was 6.75% of diet DM (Emanuele et al., 2015).

Broderick and Smith (2001) replaced high moisture corn with dried molasses. Their diets contained 0, 4, 8, or 12% dried molasses. Their diets contained 60% forage with 67% of the forage from alfalfa silage and 33% from corn silage. When high moisture corn was replaced with dried molasses at 4 or 8% of diet DM, DMI increased ($P = 0.04$) (Table 2). The magnitude of the increase in DMI was 2.4 pounds. At least some of the nutrients from the increased DMI were used for fat synthesis because 3.5% FCM was increased when diets contained 4 or 8% dried molasses. The magnitude of the increase in 3.5% FCM was 4.4 pounds. Fat yield (lb/day) was increased when diets contained 4 or 8% dried molasses but not at 12% dried molasses. Rumen ammonia concentration was decreased when dried molasses replaced high moisture corn ($P = 0.05$). The magnitude of the decrease was 1.4 units (11.3 vs. 9.9 mM).

Based on this trial, dry molasses should not exceed 8% of diet DM. The amount of forage in the diet may influence the amount of sugar or molasses that can be used in the diet. Broderick and Radloff (2003) fed diets to high producing dairy cows that contained 50% forage on a dry matter basis (Table 2). The forage component of the diet was 60% alfalfa silage and 40% corn silage. They replaced high moisture corn with liquid molasses. Diets contained 0, 3, 6, or 9% liquid molasses. Dry matter intake and milk yield were maximized when the diet contained 3% liquid molasses on a dry matter basis ($P < 0.01$). Some of the additional energy derived from the additional DMI appears to be used for fat synthesis because 3.5% FCM was increased 4 pounds compared to the control diet. Yield of all milk components was maximized when the diet contained 3% liquid molasses. Based on the reported dry matter intake, the amount of liquid molasses in the diet was 1.75 – 1.84 pounds on a dry matter basis. This would be equivalent to 2.33 – 2.45 pounds of liquid molasses on an as fed basis. The amount of sugar added to the diet from the molasses would be 1.2 pounds on an as fed basis.

Molasses was compared to molasses and animal fat (Oldick et. al. 1997). The treatments in this trial were control without molasses, molasses only, molasses and animal fat at 2, 4 and 6 pounds of ration dry matter. The molasses and fat liquid supplements were included in the diets at 2.5, 4.9 and 7.4% of the diet dry matter. The molasses only diet contained molasses at 3.4% of diet dry matter. All treatments had similar energy density. Cows on the control diet had an average milk production of 71.6 pounds. Milk response to the molasses only treatment was 2.9 pounds greater than the control diet. Molasses did not increase dry matter or net energy intake but did increase milk yield. There are two possible explanations for the occurrence. One possibility is that the energy from molasses was used with greater efficiency for growth by rumen bacteria than the energy from other dietary carbohydrates. A second possibility is the presence of an associative effect. Adding molasses to the diet may improve the ruminal digestion of NDF. This hypothesis is supported by recent observations from Varga and coworkers (2001). They reported that when starch was replaced with sucrose, NDF digestibility was increased. At the greatest concentration of sucrose, 7.5% of diet DM; NDF digestibility was increased 8.5% compared to the control diet, which did not contain supplemental sucrose.

Growth Rate Dependent Shifts in Fermentation Products Can Explain the Variable Response to Sugar Addition in Dairy Diets

In the trials conducted by Broderick and Smith (2001) and Broderick and Radloff (2003), the response to sugar additions to the diet was not linear (Table 2). The response was quadratic because positive responses were reported at low inclusion levels of sugar addition and negative responses were reported at high inclusion levels. One explanation for the quadratic response to sugar addition is that some ruminal bacteria change their fermentation products based on their growth rate. When the rate of ruminal fermentation is rapid and starches and sugars are readily available in the rumen, *Strep. bovis* and *Selenomonas ruminantium* shift their fermentation from acetate, propionate and formate to lactate (Russell 1998, Russell 2002 pg.71-72). Both *Strep bovis* and *S. ruminantium* can grow very rapidly in the rumen. It is likely that at the higher levels of molasses, these bacteria shifted their fermentation to lactate with a reduction in acetate and propionate production. The shift to lactate fermentation is also influenced by the supply of amino acids in the rumen. When amino acid nitrogen availability is low, these organisms will use ammonia nitrogen as a nitrogen source. When they use ammonia nitrogen as a nitrogen source, the shift to lactate fermentation occurs at a slower growth rate (Russell, 1998). To prevent a shift to lactate production, sugars need to be added to dairy diets in moderate amounts and in combination with protein sources such as soybean meal and canola meal.

When feeding trials have been conducted, it has been assumed that all sugar sources would support the same amount of microbial growth and have similar fermentation rates. We now know that this is not a correct assumption. Bond and coworkers (Bond et. al. 1998) reported that *Streptococcus bovis* cannot utilize pentose (5-carbon sugars) and the growth rate of *Strep. bovis* is 40% slower on lactose than on glucose (Figure 2). *Ruminococcus albus* and *Ruminococcus flavefaciens* are the major species of cellulolytic cocci in the rumen. These cellulose fermenting cocci do not grow on pentose, growth on glucose is slow but they will grow well on cellobiose (Russell, 2002, pg. 19). Cellobiose is a disaccharide made up of glucose units with a beta 1-4 linkage. *Ruminobacter amylophilus*, a starch digesting rumen bacteria will ferment maltose but not glucose (Russell 2002, pg. 21). It appears that certain sugars will stimulate the growth of specific rumen bacteria and that some sugars will not support the growth of major ruminal bacteria species.

All sugars are not equal when it comes to supporting microbial growth in the rumen (Van Kessell and Russell 1995). Strobell and Russell (1986) examined the effect of pH and carbohydrate source on yield of microbial protein from in vitro fermentation. They reported that the yield of microbial protein declined as pH was reduced from 6.7 to 6.0. There was an interaction between pH and carbohydrate source. When pH of the fermentation was 6.0, the yield of microbial protein was lowest on pectin and xylan compared to cellobiose, sucrose, starch or a mixture of carbohydrate sources. When the pH of the fermentation was maintained at 6.7, the yield of microbial protein was greatest on cellobiose, sucrose or a mixture of carbohydrate sources, and intermediate on starch or pectin and least on xylan. This trial suggests that 5-carbon sugars (xylan) will support less microbial growth in the rumen compared to 6-carbon sugars. McCormick and coworkers (2001) reported differences in fermentation between cornstarch, lactose and sucrose. Their diets contained 50% forage and 50% concentrate. They replaced ground corn with either lactose or sucrose at 2.5 and 5.0% of diet DM. Total organic acid production and fermentation pH was not different for any of the diets. Ammonia N concentration in mg/dl was lower on the sucrose supplemented diets compared to the other diets ($P = 0.06$). This would suggest that the rate of fermentation was faster on the sucrose supplemented diets compared to ground corn or lactose diets. The rate of protein fermentation would have been rapid on all diets because the major rumen degradable protein source in these diets was freeze-dried fresh ryegrass. In this study, treatment differences between ground corn and lactose were not significant for the parameters reported.

Impact of Sugar and Molasses on Ruminal pH and Fiber Digestion

If neutral detergent soluble carbohydrates (NDSC) differ in their rate and pattern of fermentation, we can indirectly measure these differences by measuring ruminal pH and volatile fatty acid production. The impact of NDSC on ruminal pH will depend on the amount of NDSC in the diet and the type of forage. When molasses or sucrose were fed at amounts greater than 12% of diet dry matter, rumen pH was depressed within one hour after feeding (Moloney et al. 1994, Khalili and Huhtanen 1991a). The reduction in ruminal pH lasted for up to four hours after feeding. If sodium bicarbonate was fed in the diet along with sucrose, the depression in ruminal pH was prevented (Khalili and Huhtanen 1991a). When molasses-based liquid supplements or dry sugar are used in dairy rations and fed at amounts less than 8% of diet dry matter rumen pH was not depressed compared to the control diet (Table 3; Piwonka and Firkins 1993, Maiga et al. 1995, McCormick et al. 2001, Varga et al. 2001).

The effect of molasses and sugar on fiber digestibility will depend on the composition of the ration and the level of molasses or sugar in the ration. When molasses is used at 12% or greater of diet dry matter, it will decrease dry matter and fiber digestibility (Khalili and Huhtanen 1991b, Moloney et al. 1994, Petit and Veira 1994). When used at less than 8% of diet dry matter, in dairy and beef diets, molasses-based liquid supplements or sugar did not depress fiber digestion compared to control diets (Piwonka and Firkins 1993, Oldick et al. 1997, Varga et al. 2001). These results support the earlier work of Foreman and Herman (1953). They observed that feeding molasses at rates of one or two pounds of dry matter did not decrease cellulose digestibility compared to diets without molasses. The effect of sugar or molasses on fiber digestion will depend on the effective fiber level in the ration, ration particle size and forage form (hay or silage). In dairy rations, which are formulated to meet or exceed the fiber requirements of dairy cows, molasses or sugar should not depress fiber digestion when used at less than 8% of the diet dry matter.

Since 1987, there have been several trials, which have examined the effect of sugar or molasses on microbial protein production in the rumen (Table 4). In all trials, feeding sugar or molasses increased the supply of microbial protein compared to the control treatment (Khalili and Huhtanen 1991a, Huhtanen 1988, Piwonka and Firkins 1993, Rooke and Armstrong 1989).

The increase in microbial protein was greatest when the molasses or sugar was fed in combination with casein, soybean meal or sodium bicarbonate. This is expected because casein and soybean meal would provide amino acids and peptides for the rumen bacteria and increase microbial growth rate. Sodium bicarbonate would increase liquid turnover rate in the rumen and would increase the microbial growth rate. Supplementation of grass silage-based diets with a source of readily available carbohydrate (sugar) has been found to increase the flow of microbial protein and non-ammonia nitrogen to the small intestine (Chamberlain et al. 1985, Huhtanen 1987, Rooke et al. 1987).

Non-ammonia nitrogen (NAN) includes microbial protein and natural protein. It is a measure of the total natural protein reaching the small intestine. In these three trials feed intake was restricted and sugar infused directly into the rumen. The increase in microbial protein production when sugar was infused is not surprising. The grass silage fed in these trials contained significant amounts of rumen degradable protein. The fermentation of this silage in the rumen would lead to elevated concentrations of rumen ammonia. In order for the rumen bacteria to capture this ammonia, they needed a supply of rapidly fermentable carbohydrate. The sugar infused into the rumen supplied the rapidly fermentable carbohydrate and stimulated microbial growth. This increased the microbial protein flow to the small intestine. Direct evidence for increased capture of ruminal ammonia by rumen bacteria was observed in all three trials because ruminal ammonia concentration was decreased when sugar supplements were included in the diet. The amount of non-ammonia nitrogen reaching the small intestine was increased when molasses or sugar replaced starch in the diet. Unfortunately dairy producers do not get paid based on the amount of microbial protein their cows produce each day.

Does an increase in the supply of microbial protein or non-ammonia nitrogen translate into an increase in animal performance?

Summary

Molasses-based liquid supplements and sugar are readily digestible sources of energy for dairy cattle. When added to dairy rations at 6 to 8% of the total ration dry matter, molasses-based liquid supplements and sugar may increase dry matter intake, fat-corrected milk yield, milk protein and milk fat yield and NDF digestibility. The mode of action appears to be through enhancing NDF digestibility, altering the ruminal microbial population and possibly providing an increased supply of nutrients for fat synthesis. Sugar or molasses, when fed at less than 8% of diet dry matter, can be used with the same efficiency as corn for milk production. Physical factors of the ration can influence responses to molasses or sugar. In rations with less than 19% ADF, and small particle size, use of sugar and molasses based liquid supplements may not increase feed intake and milk production. Response to liquid supplements and sugar has been greater when the ration contains adequate amounts of rumen degradable amino acids and peptides. Research trials published since 1983 suggest that molasses and sugar do more than just increase ration palatability, they can play a greater role in dairy rations by altering ruminal microbial populations and possibly increasing microbial growth in the rumen of dairy cattle.

References

Bond D.R., B.M. Tsai and J.B. Russell. 1998. The diversion of lactose carbon through the tagatose pathway reduces the intracellular fructose 1, 6-biphosphate and growth rate of Streptococcus bovis. Applied Microbiology and Biotechnology 49:600.

Broderick, G.A. and W.J. Radloff. 2003. Effects of feeding graded amounts of liquid molasses to high producing dairy cows. J. Dairy Science Vol. 86, Suppl. 1. Pg. 217.

Broderick, G.A. and W.J. Smith. 2001. Effects of replacing dietary high moisture corn with dried molasses on the production of dairy cows. J. Dairy Science Vol. 84, Suppl. 1. Pg. 196

Chamberlain, D.C., P.C. Thomas, W. Wilson, C.J. Newbold and J.C. MacDonald 1985. The effects of carbohydrate supplements on ruminal concentrations of ammonia in animals given diets of grass silage. J. Agric. Sci. Cambridge 104.

Emanuele, S. M., M.B. de Ondarza, and C.J. Sniffen 2015. Meta-analysis to examine the effect of supplemental sugar on dairy cow performance as influenced by diet nutrient content. J. Dairy Sci. ADSA abstract. T448.

Emanuele, S. M. 2016. Management and Feeding for 35,000 pounds of milk. Proceedings of Purina Animal Nutrition, Leading Dairy Producer Conference, Wisconsin Dells, WI.

Foreman, C.F. and H.A. Herman. 1953. Effects of carbohydrate feeding levels on roughage digestion in dairy cattle. Missouri Agr. Exp. Sta., Research Bul. 535.

Hall M.B. and C. Herejk. 2001. Differences among carbohydrates in yields of crude protein from in vitro fermentation with mixed ruminal microbes. J. Dairy Sci. Vol. 84, Suppl. 1. Pg. 200

Harris, B.H. and H.H. Van Horn. 1983. Molasses in dairy nutrition. In: Molasses in Animal Nutrition; National Feed Ingredients Association, West Des Moines, Iowa.

Hristov A.N. and J.K. Ropp. 2003. Effect of dietary carbohydrate composition and availability on utilization of ruminal ammonia nitrogen for milk protein synthesis in dairy cows. J. Dairy Sci. 86:2416

Huhtanen P. 1987. The effects of intraruminal infusions of sucrose and xylose on the nitrogen and fiber digestion in the rumen of cattle receiving diets of grass silage and barley. J. Agric. Sci. Finl. 59:405.

Huhtanen, P. 1988. The effects of barley, unmolassed sugar-beet pulp and molasses supplements on organic matter, nitrogen and fiber digestion in the rumen of cattle given a silage diet. Animal Feed Science and Technology 20:259.

Kellogg, D.W. 1969. Influence of sucrose on rumen fermentation pattern and milk fat content of cows fed a high grain ration. J. Dairy Sci. 52:1601.

Khalili, H. and P Huhtanen. 1991a. Sucrose supplements in cattle given grass silage-based diet. Digestion of organic matter and nitrogen. Animal feed Science and Technology. 33:247

Khalili, H. and P. Huhtanen. 1991b. Sucrose supplements in cattle given grass silage-based diet. 2. Digestion of cell wall carbohydrates. Animal Feed Science and Technology. 33:26.

Maiga, H.A., D.J. Schingoethe and F.D. Ludens. 1995. Evaluation of diets containing supplemental fat with different sources of carbohydrates for lactating dairy cows. J. Dairy Science 78:1122

McCormick, M.E., D.D. Redfearn, J.D. Ward and D.C. Blouin. 2001. Effect of protein source and soluble carbohydrate addition on rumen fermentation and lactation performance of Holstein Cows. J. Dairy Science 84:1686

Mertens, D. R. 1992. Non-structural and Structural Carbohydrates. In: Large Dairy Herd Management. H.H. Van Horn and C.J. Wilcox, eds. American dairy Science Association, Champaign, IL. pg. 219

Moloney, A.P., A.A. Almiladi, M.J. Drennan and P.J. Caffey. 1994. Rumen and blood variables in steers fed grass silage and rolled barley or sugar cane molasses-based supplements. Animal Feed Science and Technology 50:37

Morales, J.L., H.H. Van Horn and J.E. Moore. 1989. Dietary interaction of cane molasses with source of roughage: Intake and lactation effects. J. Dairy Science 72:2331.

Oldick, B.S., J. Pantoja and J.F. Firkins. 1997. Efficacy of fat sources in liquid supplements for dairy cows. J. Dairy Science 80: (Suppl. 1):243.

Piwonka, E.J. and J.L. Firkins. 1993. Rumen and total tract digestion, or forage based diets with starch or dextrose supplements fed to Holstein heifers. Dept. of Dairy Science Research Highlights, 1993. The Ohio State University pg. 9.

Petit, H.V., and D.M. Veira. 1994. Digestion characteristics of beef steers fed silage and different levels of energy with or without protein supplementation. J. Animal Science 72:3213.

Rooke, J.A. and D.G. Armstrong. 1989. The importance of the form of nitrogen on microbial protein synthesis in the rumen of cattle receiving grass silage and continuous intraruminal infusions of sucrose. British J. of Nutrition 61:113.

Rooke, J.A. N.H. Lee and P.G. Armstrong. 1987. The effects of intraruminal of urea. casein, glucose syrup and a mixture of casein and glucose syrup on nitrogen digestion in the rumen of cattle receiving grass-silage diets. British J. of Nutrition 57-89.

Rulquin, H., S. Rigout, S. Lemosquet, and A. Bach. 2004. Infusion of glucose directs circulating amino acids to the mammary gland in well-fed dairy cows. J. Dairy Sci. 87:340–349.

Russell, J.B. 1998. Strategies that ruminal bacteria use to handle excess carbohydrate. J. Animal Science 76:1955

Russell, J.B. 2002. Rumen Microbiology and Its Role in Ruminant Nutrition, Cornell University, Ithaca, NY. Pg. 19.

Russell, J.B. and G.M. Cook. 1995. Energetics of bacterial growth: balance of anabolic and catabolic reactions. Microbiology Review. 59:48

Strobel, H.J. and J.B. Russell. 1986. Effect of pH and energy spilling on bacterial protein synthesis by carbohydrate-limited cultures of mixed rumen bacteria. J. Dairy Science 69:2941

Van Kessell J.S. and J.B. Russell. 1996. The effect of amino nitrogen on the energetics of ruminal bacteria and its impact on energy spilling. J. Dairy Sci. 79:1237

Varga, G.A., T.W. Cassidy, V.A. Ishler, X. Markantonatos, N.D. Luchini and G.A. Broderick. 2001. Effect of replacing dietary starch with sucrose on nutrient utilization by ruminal microorganisms during continuous culture fermentation. J. Dairy Science Vol. 84, Suppl. 1. Pg. 290

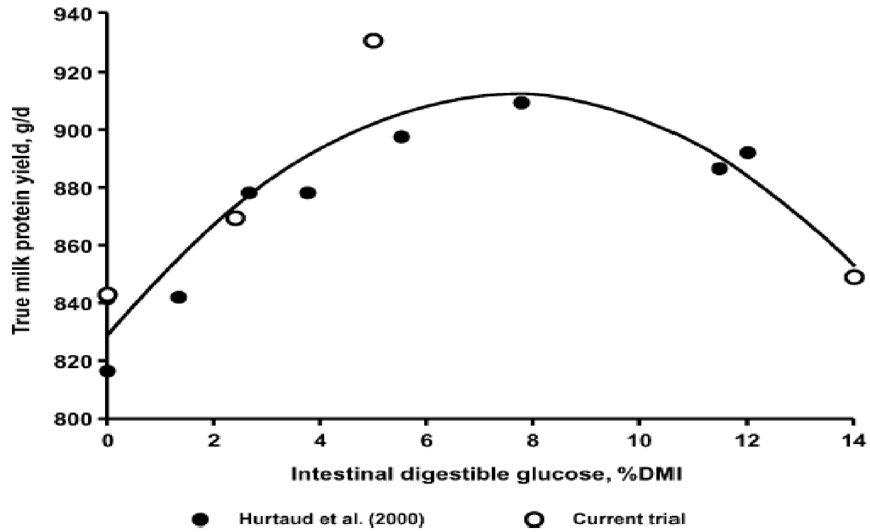

Figure. 1. Adapted from Rulquin et al. (2004).

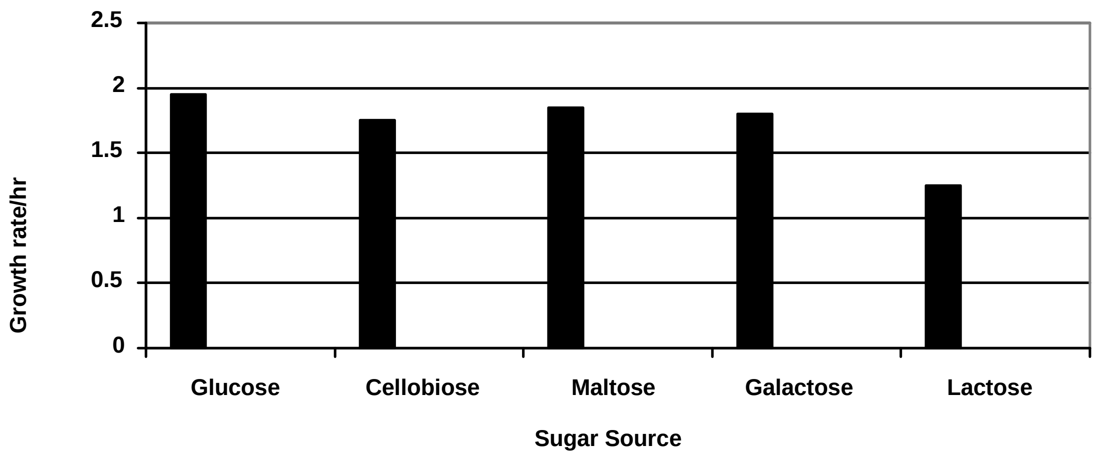

Figure 2. Growth rate of *Streptococcus bovis* on different sugars.

Table 1. Rumen ecology

Microbe	Primary substrate	Optimum rumen pH	Primary requirement	Main fermentation products	Doubling time
Bacteria	About 630 different bacteria (50% of microbial mass)				
Fiber and pectin	Fiber and pectin	6.3 to 6.8	NH_3 , isoacids	Acetate	8 – 10 h
Protein *C. aminophilum*	Protein	6 to 7	Protein, peptides, NH_3	NH_3, Isoacids	4 – 8 h
Allisonella histaminiformans	Histidine	4.5 to 6.5	Histidine, peptides from silage	Histamine	Rapid
Starch, *S. Bovis*	Starch and sugars	5.5 to 6.5	Peptides, AA, NH_3	Propionic, Lactic	15m –30m
Secondary - *M. elsdenii*, Methanogens	Lactic, H_2	6 to 6.8	Peptides, AA, malic	Propionic, CH_4	2 – 4 h
Protozoa	About 30 different protozoa (40 to 45% microbial mass)				
	Starch, sugars	6.3 to 7.0	Peptides, AA, Bacteria	Propionic, H_2	15 – 24 h
Fungi	About 14-15 types of fungi (3 – 8% microbial mass)				
	Fiber	6 to 7	NH_3, AA, sugars	lactic, acetic, H_2,	15 - 24h
Bacterial viruses (5 –7 types and .0000001% TMM); Yeasts (0.1 to 0.2% TMM)					

TMM = total microbial mass.

Table 2. Effect of sugar or molasses on lactating cow performance

Experiment	Forage source	Treatments	Dry matter Intake, lb/d	3.5% FCM yield, lb/d	Treatment effects
Broderick and Radloff (2003)	Alfalfa silage and corn silage, 50% forage diet	HM corn	56.4	97.6	Significant quadratic effects
		Liquid molasses			
		3% diet DM	61.5	100.2	
		6% diet DM	58.2	98.2	
		9% diet DM	57.7	93.0	
Broderick and Smith (2001)	Alfalfa silage and corn silage, 60% forage diet	HM corn	55.3	91.2	Significant quadratic effects
		Dry molasses			
		4% diet DM	56.8	92.5	
		8% diet DM	57.7	95.6	
		12% diet DM	57.3	87.0	
McCormick et al. (2001)	Chopped ryegrass, 50% forage diet	Ground corn	50.2	84.4	No effect on milk yield or DMI
		Sucrose			
		5% diet DM	50.3	83.5	
Oldick et al. (1997)	Corn silage, alfalfa haylage	Ground Corn	47.4	72.0	No effect on DMI
		Molasses	46.5	74.5	Milk yield increased ($P < 0.05$)
		Molasses + Fat	49.2	78.5	
Maiga et al. (1995)	Corn silage and alfalfa hay	Corn	51.0	70.3	Sugar supplements with fat equal to corn + fat
		Molasses + Fat	54.0	74.2	
		Dry Whey + Fat	54.0	74.9	
		Corn + Fat	53.5	74.2	

HM = high moisture.

Table 3. Effect of Sugar and Molasses on Rumen pH When Fed at Less than 8% of Diet Dry Matter

Experiment	Forage Source	Treatments	Rumen pH	Treatment Effects
McCormick 2001 In Vitro Trial	Freeze-dried ryegrass	Ground Corn Lactose Sucrose	6.77 – 6.78	No effect of carbohydrate source
Varga 2001 In Vitro Trial	Alfalfa Silage Corn Silage 2:1 ratio	Starch Starch + Sucrose Sucrose	5.97	No effect of carbohydrate source
McCormick 2001 In Vivo Trial	Chopped Ryegrass	Ground Corn Sucrose	6.19 – 6.21	No effect of carbohydrate source
Maiga 1995 In Vivo trial	Corn Silage Alfalfa Hay	Corn Corn + Molasses Corn + Whey	6.68 – 6.85	No effect of carbohydrate source
Piwonka 1993 In Vivo Trial	Corn Silage Orchardgrass Hay	Barley Barley + Dextrose	6.47	No effect of carbohydrate source
Chamberlain 1985 In Vivo Trial	Grass Silage	Barley Barley + Molasses Beet Pulp Beet Pulp + Molasses	6.33 6.21 6.40 6.45	Within carbohydrate source, Barley or Beet Pulp, pH was not different

Table 4. Effect of Molasses or Sugar on Microbial Protein Production

Experiment	Treatments	Animal	Microbial N g/d	Treatment effects
Rooke and Armstrong 1989	Sucrose Sucrose + Urea Sucrose + Casein Sucrose + Soybean meal	Non-lactating cows	105 108 126 112	Sugar effect significant when fed with casein or soybean meal
Piwonka 1993	Barley Barley , 4.4% of diet DM + Dextrose, 5.6% of diet DM	Holstein heifers	64 74	Sugar effect is significant, microbial N increased 15.6%
Khalili 1991a	Barley Barley + Sucrose Barley + Sucrose + Buffer	Dairy steers	72 90 94	Sugar effect is significant, microbial N increased 25% - 30%
Huhtanen 1988	Barley Barley + Molasses Beet Pulp Beet Pulp + Molasses	Dairy steers	71 74 60 75	No effect with barley diets Effect is significant with beet pulp diets
Hall and Herejk 2001 In Vitro Trial	Bermuda grass (BG) NDF BG NDF + Pectin BG NDF + Sucrose BG NDF + Starch	Rumen microbes	0.014 0.030 0.026 0.034	Sucrose = Pectin Starch effect significant compared to Sucrose

SESSION NOTES