Sugar In Diets For Dairy Cows

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It would be great if the decision to add sugar to dairy cattle diets was a black and white issue. Unfortunately it is not a simple decision because the rumen is a complex ecosystem. This complex ecosystem will respond positively or negatively to the addition of sugar to dairy diets based upon the ruminal environment. 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). In contrast, other 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). The reported variation in response to sugar 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 sugar fermentation in the rumen 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.

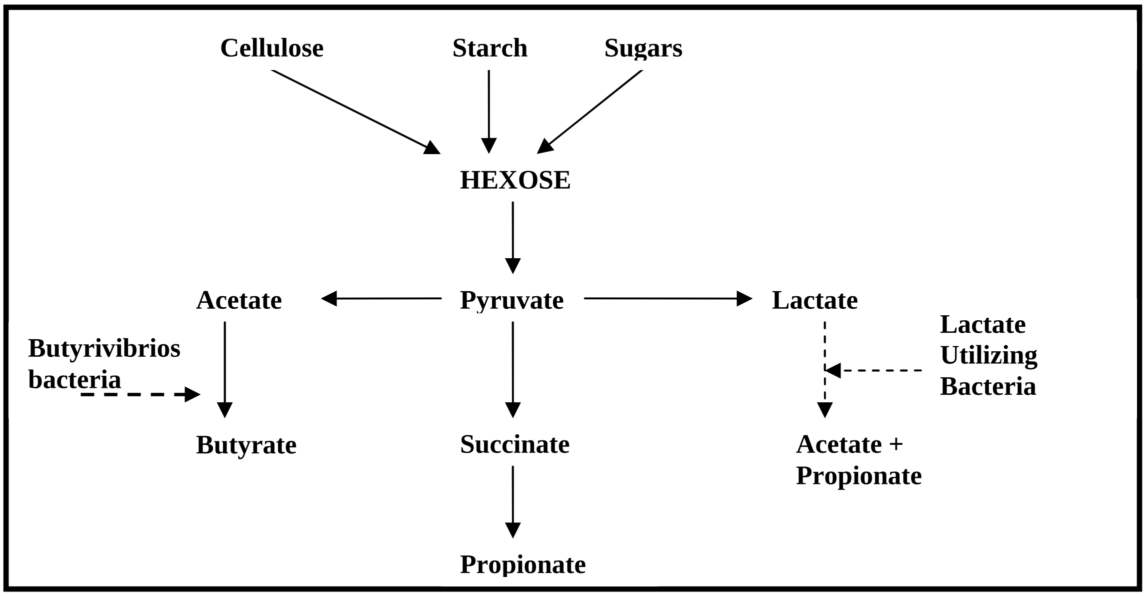
Let's begin by examining how carbohydrates containing 6-carbon subunits (Hexoses) are metabolized in the rumen. The most common hexose is glucose. The number of hexose units, linked in a polymer chain, is how we classify carbohydrates. (Table 1).

Table 1. The Classification of Carbohydrates

Carbohydrate Class	Example	Number of Hexose Units
Monosaccharides	Glucose	1 Glucose
	Galactose	1 Galactose
	Fructose	1 Fructose
Disaccharides	Lactose	1 Glucose + 1 Galactose
	Sucrose	1 Glucose + 1 Fructose
	Cellobiose	2 Glucose
Oligosaccharides	Dextrin	5 Glucose
	Cellotriose	3 Glucose
Polysaccharides	Starch	20 Glucose
	Cellulose	20 Glucose

The hexoses 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 (fig. 1.). These hexoses then are metabolized to pyruvate which can be metabolized to acetate, propionate, butyrate or lactate. You can influence the end-products of hexose fermentation by manipulating the ruminal environment. Acetate can be generated from the fermentation of both cellulose and sugars when conditions in the rumen favor the growth of acetate producing bacterial species. Lactate can be formed in the rumen from the fermentation of sugars when conditions are favorable in the rumen for the rapid growth of *Streptococcus bovis*.

Figure 1: Hexose metabolism in the rumen



Ruminal conditions must exist where the majority of hexose is fermented to acetate, propionate, butyrate and 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.

IMPACT OF SUGAR OR MOLASSES ON ANIMAL PERFORMANCE

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 when sugars are added to high forage diets. 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 was 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. Milk yield and DMI were depressed when 12% dried molasses was added to the diet. 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. All performance parameters were decreased compared to the control diet when the diet contained 9% liquid molasses. Dry matter intake and milk yield was 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 1.15 – 1.2 pounds on an as fed basis.

Table 2: Effect of Sugar or Molasses on Lactating Cow Performance

Trial	Forage Source	Treatments	Dry Matter Intake lbs./day	3.5% FCM Yield lbs/day	Treatment Effects
Broderick and Radloff 2003	Alfalfa silage Corn silage 50% forage diet	HM corn liquid molasses 3% diet DM 6% diet DM 9% diet DM	56.4 61.5 58.2 57.7	97.6 100.2 98.2 93.0	Significant Quadratic Effects
Broderick and Smith 2001	Alfalfa silage Corn silage 60% forage diet	HM corn dry molasses 4% diet DM 8% diet DM 12% diet DM	55.3 56.8 57.7 57.3	91.2 92.5 95.6 87.0	Significant Quadratic Effects
McCormick 2001	Chopped Ryegrass 50% forage diet	Ground corn Sucrose 5% diet DM	50.2 50.3	84.4 83.5	No effect on milk yield or DMI
Oldick 1997	Corn Silage Alfalfa Haylage	Ground Corn Molasses Molasses + Fat	47.4 46.5 49.2	72.0 74.5 78.5	No effect on DMI Milk Yield increased **(*p*< .05)**
Maiga 1995	Corn Silage Alfalfa Hay	Corn Molasses + Fat Dry Whey + Fat Corn + Fat	51.0 54.0 54.0 53.5	70.3 74.2 74.9 74.2	Sugar supplements with fat equal to corn + fat

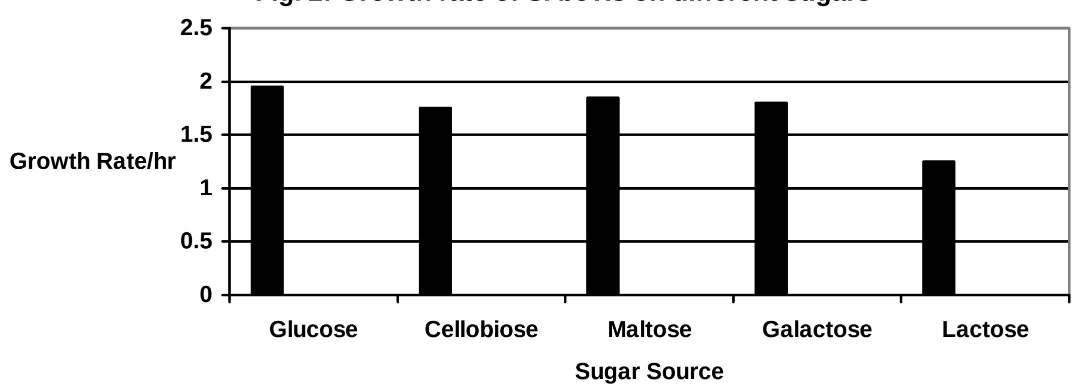
A trial from the Ohio State University (Oldick et. al. 1997) supports the recent trials of Broderick and coworkers (Table 2.). In this trial, liquid supplements containing molasses and fat were mixed into the grain mix of a TMR. The liquid supplements were 5.1% of the ration dry matter and fed in combination with roasted soybeans (8.3% of ration DM). The control treatment did not contain supplemental fat. Supplemental fat sources in the other treatments were roasted soybeans only, roasted soybeans plus tallow, and roasted soybeans plus liquid supplement. The energy density of all treatments with supplemental fat was similar. Dry matter intake was not different among treatments. This was expected because the liquid supplements were added to the grain mix prior to mixing into the TMR. Milk production was similar on all treatments with supplemental fat. There was a trend for 4% fat-corrected-milk to be higher on the diets containing tallow or liquid supplements compared to the roasted soybean treatment. Cows receiving liquid supplements had an average milk production of 82 pounds and cows on the control diet had an average milk production of 78.6 pounds. The magnitude of the milk response to supplemental fat was an increase of 3.45 pounds. Milk fat percent was not different among the treatments. Milk protein percent was lower on the treatments containing supplemental animal fat compared to the control treatment. The reduction in milk protein percent was due to the addition of animal fat rather than molasses because milk protein percent was decreased on the roasted soybean and tallow treatment, which did not contain molasses. This trial demonstrated that a molasses-based liquid supplement when fed at less than 6% ration dry matter can replace corn and tallow in the ration of high producing dairy cattle. In a second trial, (Oldick et. al. 1997) molasses was compared to molasses and animal fat. 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* can not utilize pentoses (5-carbon sugars) and the growth rate of *Strep. bovis* is 40% slower on lactose than on glucose (Fig. 2). *Ruminococcus albus* and *Ruminococcus flavefaciens* are the major species of cellulolytic cocci in the rumen. These cellulose fermenting cocci do not grow on pentoses, 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.

Fig. 2: Growth rate of S. bovis on different sugars



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. Bond and coworkers (Bond et. al. 1998) found that lactose supported less microbial growth than other hexose sugars (Fig. 2). 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. One explanation for similar responses on lactose and corn diets is that the rate and extent of fermentation must have been similar between these two carbohydrates.

Excess Rumen Fermentable Carbohydrate Can Lead to Wasting of Energy and a Lack of Response to Sugar Supplementation

When sugars are added to dairy cattle diets, sometimes we do not observe the expected response. When we do not get the expected response, we conclude that adding sugar did not work. What really occurred is that rumen fermentation became uncoupled. The fermentation of sugar generated more ATP than was needed by the bacteria for growth and maintenance. Another way to express this idea is that the rate of catabolism exceeded the rate of anabolism and microbial protein synthesis declines per gram of carbohydrate fermented (Russell and Cook 1995, Van Kessel and Russell 1996, Bond and Russell, 1998). A good analogy would be a car stopped at a red light and you step on the gas while stepping on the brake. You are burning up plenty of fuel but going nowhere. You are generating heat and smoke (assuming you are spinning the tires) which is wasted energy. In the same way, the bacteria ferment glucose to lactose but don't increase in cell number or increase the amount of microbial protein. They produce ATP but this ATP is wasted or "spilled". Microbiologists call this "energy spilling". This is likely to occur when sugars are added to diets which already contain highly fermentable starch sources. It can also occur if the ruminal degradable protein supply is not adequate for the amount of fermentable carbohydrate. If ruminal ammonia concentration is elevated, adding sugar may not lower the ammonia concentration because fermentation becomes uncoupled due to a lack of amino acid nitrogen and an increase in fermentation rate. The trial of Maiga and co-workers (Table 2), (Maiga et al. 1995) is an example of energy wastage or spilling by rumen bacteria. Maiga and co-workers replaced corn in the ration with a molasses-based liquid supplement continuing 20% fat (Maiga et al. 1995). They compared the liquid supplement to dried whey plus fat and corn plus fat. All the treatments containing fat had the same calculated net energy. The molasses-based liquid supplement was fed at 4.5/lb of dry matter per day. This represented 8.33% of the ration dry matter. On a dry matter basis the liquid supplement was 30.8% fat. It provided 3.1 pounds of dry matter from molasses and 1.4 pounds of fat. Under these circumstances, the molasses-based liquid supplement should be able to replace corn and fat in the ration. The average milk response across the fat treatments was an increase of 4.13 pounds. There was no difference between the treatments containing the molasses-based liquid supplement with fat, dried whey with fat or corn plus fat for dry matter intake or milk production. Replacing corn with a molasses-based liquid supplement did not depress milk protein or milk fat percent. In this trial, 4.5 pounds of dry matter from liquid supplement replaced 3.1 pounds of dry matter from corn and 1 pound of dry matter from tallow. Based on TDN values for tallow and corn, the liquid supplement replaced 4.5 pounds of TDN. Since the extent of molasses fermentation in the rumen is greater than the extent of corn fermentation in the rumen, we would have expected the molasses supplement to yield more milk than the corn supplement. Since this did not happen, we can conclude that any extra energy from the fermentation of the molasses was wasted by rumen bacteria.

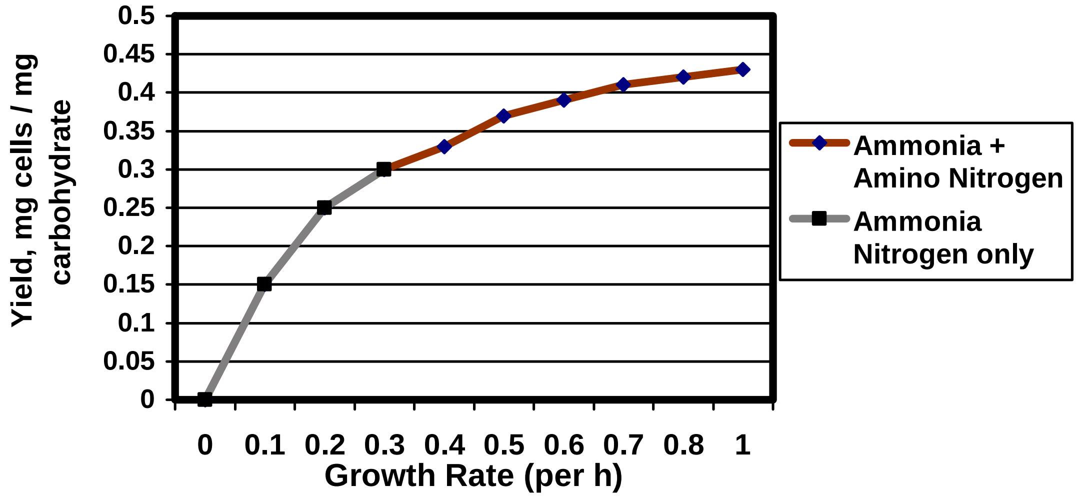
Enhanced NDF digestibility may be due to a greater population of rumen fungi

Anaerobic fungi can account for as much as 8% of the microbial biomass in the rumen. These ruminal fungi have potent cellulase enzymes. They can penetrate deep into feed particles because of their mycelium and break fibers apart. This enables their enzymes to attack the fiber because of a greater surface area. Ruminal fungi are attracted to simple sugars and they can differentiate among the sugars (Russell, 2002 pg. 27). They can ferment sucrose, glucose and cellobiose. It is possible that when you add sugar to a dairy diet, you are increasing the population of anaerobic fungi. This could lead to increased NDF digestibility. Enhanced NDF digestibility could explain the increase in milk yield when molasses replaced starch in the diet (Oldick et al. 1997). Adding the liquid supplement with molasses and fat to the TMR did increase dry matter intake compared to the control. Dry matter intake was increased 1.76 and 1.98 pounds when liquid supplements were incorporated into the TMR at 2.5 and 4.9% of diet dry matter. This would suggest greater NDF digestibility and less rumen fill. Milk response was greatest (7.5 lbs.) when liquid supplement was fed at 4.9% of diet dry matter. When the liquid supplement was fed at 2.5% of diet dry matter, the milk response was 6.4 pounds. Based on milk production there was no advantage to feeding the liquid supplement at 7.4% of diet dry matter. Milk fat and milk protein percent were not different among the 5 treatments. Based on these recent trials, molasses-based liquid supplements and dry sugar work best when fed at 3 – 6 % of the diet dry matter.

Do Not Add Sugar to Diets Which Are Low in Effective Fiber

Morales and coworkers reported variable results to the addition of molasses to dairy cattle diets (Morales et al. 1989). This could be the result of a lack of effective fiber and rumen degradable amino acids and peptides. When molasses was added to cottonseed hull based diets, dry matter intake was increased 1.87 pounds and milk production was increased 2.2 pounds. These cottonseed hull based diets contained 22.6 to 25.1% acid detergent fiber and 36.6% neutral detergent fiber. This is adequate fiber for lactating dairy cows. These diets also contained 9 to 10.5% soybean meal on a dry matter basis. Given the reported dry matter intake of 54 pounds these cows would be receiving 4.9 to 5.5 pounds of dry matter from soybean meal. This would provide sufficient supply of rumen degradable amino acids and peptides to the rumen. When molasses was added to the other nine diets in this trial, dry matter intake and production were not increased. Three of the diets contained 35% alfalfa haylage and 65% grain. Lack of response on these diets could be due to a lack of effective fiber. These diets (35% alfalfa haylage) contained 17.1 to 17.9% ADF and 26.0 to 26.4% NDF. This is below the current NRC recommendation for fiber in the diet. Adding molasses to these diets at 8% of diet DM depressed both milk fat and milk protein percent, which suggests the diets were low in effective fiber. Three diets in this trial contained adequate fiber but probably were deficient in rumen degradable amino acids and peptides. These diets contained 65% alfalfa haylage and less than 1.9% soybean meal on a dry matter basis. The cows on these three diets received 1 pound or less of soybean meal dry matter per day. It is likely that microbial growth on these diets was limited by a lack of peptides and amino acid nitrogen. Van Kessel and Russell (1996) reported that the microbial yield of mixed ruminal bacteria was increased 30% when they received a combination of amino acid nitrogen and ammonia nitrogen compared to ammonia nitrogen only (Fig. 3).

Fig. 3. Yield of mixed ruminal bacteria supplied with ammonia nitrogen only or amino acid nitrogen



Source: Redrawn from Russell (1998)

The remaining three diets contained 4.7 to 5.9% soybean meal on a dry basis. The dry matter intake reported for these diets was 52.2 pounds. Soybean meal dry matter intake on these diets was 2.4 to 3.1 pounds. This is 44 to 51% below the intake on the cottonseed hull diets. When molasses is added to a dairy diet replacing starch, it will speed up the microbial growth rate. When this occurs, it increases the microbial requirement for amino acids and peptides. It is possible that these diets were adequate in amino acids and peptides prior to molasses addition. Following the addition of molasses they would not contain enough amino acids and peptides to support rapid microbial growth. Animal performance supports this supposition. Both dry matter intake and milk production declined when molasses was added to these diets.

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). When sucrose or dried whey is added to lactating dairy rations, it is fed at rates of 3 – 6% of diet dry matter. At these amounts, sucrose or dried whey should not depress ruminal pH in diets with adequate effective fiber.

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

Trial	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

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 that 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.

Impact of Sugar or Molasses on Microbial Protein Production

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).

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

Trial	Treatments	Animal	Microbial Nitrogen grams/day	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	Bermudagrass (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

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. 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 3 to 7% of the total ration dry matter, molasses-based liquid supplements and sugar may increase dry matter intake and fat-corrected milk yield. 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 7% 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.

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 can 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.

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 ScienceVol. 84, Suppl. 1. Pg. 290