STARCH AVAILABILITY, MEASUREMENT AND IMPLICATIONS FOR RATION FORMULATION

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SUMMARY

Concentration and ruminal digestibility of starch in rations of lactating cows has important effects on productivity. Starch is more digestible and less filling than forage fiber and provides more glucose precursors than fiber from any source. Ruminal fermentability of starch is affected by grain and endosperm type, processing and conservation method, and diet and animal factors, and affects production of fermentation acids and microbial protein in the rumen. Excessive ruminal fermentability can decrease fiber digestibility, efficiency of microbial protein production, and alter ruminal biohydrogenation, decreasing synthesis of milk fat and increasing energy partitioned to body condition at the expense of milk.

The concentration and ruminal fermentability of starch affects feed intake, and energy partitioning of cows differently as they progress through lactation. High-producing cows in early to mid-lactation thrive on high-starch rations with highly fermentable starch sources while starch concentration and fermentability should decrease as lactation progresses to maintain yield of milk fat and prevent excessive body condition. Highly fermentable starch sources should be limited in rations for the first two weeks following parturition to avoid further depression in feed intake, and decrease risk of ruminal acidosis and displaced abomasum. Grouping cows by physiological state (fresh, early to mid, maintenance) is required to formulate diets for starch to optimize health and production.

INTRODUCTION

Starch is a highly digestible and energy dense feed component that typically ranges from less than 20% to greater than 28% in rations fed to lactating dairy cows. Forages are supplemented with cereal grains to increase energy density, provide glucose precursors, and decrease the filling effects of rations. Starch is composed of polymers of glucose (amylose and amylopectin) with bonds that are readily cleaved by mammalian enzymes. However, starch is packaged in granules that are embedded in a protein matrix in the seed endosperm, which varies in solubility and resistance to digestion (Kotarski *et al.*, 1992). These differences in endosperm type have great effects on ruminal fermentability of starch, which ranges widely; ruminal fermentability of starch from various cereal grains ranges from less than 30% to more than 90% (Nocek and Tamminga, 1991; Firkins *et al.*, 2001). Altering the concentration and ruminal fermentability of starch in rations affects digestibility of starch (Ngonyamo-Majee *et al.*, 2008), ruminal pH and fiber digestibility (Firkins *et al.*, 2001), and the type, amount, and temporal absorption of fuels (e.g. acetate, propionate, lactate, glucose) available to the

cow (Allen, 2000). This has great effects on lactational performance by affecting energy intake and partitioning as well as absorbed protein (Allen *et al.*, 2009). In addition, effects on animal performance depend upon physiological state of cows, which varies greatly through lactation (Allen *et al.*, 2005). Therefore the optimum concentration and ruminal fermentability of starch in rations of lactating cows vary through lactation. The objective of this paper is to discuss what determines site of digestion and total tract digestibility of starch, effects of concentration and ruminal fermentability of starch on animal performance, and considerations related to starch for formulating diets for lactating dairy cows.

STARCH FERMENTABILITY

Ruminal fermentability of starch is highly variable and affected by grain type, vitreousness, processing (e.g. rolling, grinding, steam flaking), conservation method (dry or ensiled), ration composition, and animal characteristics. Starch in wheat, barley and oats is generally more readily fermented than starch in corn, and starch in sorghum is most resistant to fermentation in the rumen and digestion by the animal (Huntington, 1997). These differences are largely because of differences in endosperm type rather than differences in starch composition (amylose vs. amylopectin) per se. Floury endosperm contains proteins that are readily solubilized, allowing greater access of enzymes to starch granules while vitreous endosperm contains prolamin proteins that are insoluble and resistant to digestion, decreasing access of enzymes to starch granules (Hoffman and Shaver, 2010). Starch sources vary in amount and proportion of the two types of endosperm and there is large variation in vitreousness of the endosperm (percent of the total endosperm that is vitreous) among varieties within certain grain types. Endosperm vitreousness in corn harvested dry ranges from 0% to greater than 75% and corn with more vitreous endosperm is more resistant to both particle size reduction by grinding and digestion (Hoffman *et al.*, 2010) than corn with more-floury endosperm. Vitreousness increases with increasing maturity at harvest (Phillipeau and Michalet-Doreau, 1997), so differences among corn hybrids are greatest when field dried. Because corn silage is harvested earlier than high moisture corn, the grain will have less vitreous endosperm and more moisture when harvested from the same field as whole plant silage compared with high-moisture corn. However, there can be large differences in vitreousness within corn silage harvested between 30% and 40% dry matter and within high moisture corn harvested between 60% and 75% dry matter (40 and 25% moisture) from the same field.

When grains are ensiled, ruminal fermentability of starch can be greatly affected by both grain moisture concentration and storage time. This is because ensiling solubilizes endosperm proteins over time, increasing starch fermentability. The increase in protein solubility and starch fermentability over time is greatest for grains with higher moisture concentration (Figure 1; Allen *et al.*, 2003). Therefore, the change is greatest for wetter corn silage and least for drier, high-moisture corn. This change is greatest over the first few months of ensiling and must be anticipated and accounted for when formulating rations. Because of this, it is recommended to wait several months after ensiling before feeding corn silage (Allen, 1998). However, the change continues

for months at a slower rate and corn silage and high moisture corn stored for long periods (one or two years or more) can be difficult to feed in high concentrations because it is so readily fermented.

Processing increases rate of starch digestion and the effects are greater for grains with more vitreous endosperm such as sorghum and corn (Huntington, 1997). Access of enzymes to starch granules is increased by steam flaking, which causes swelling and disruption of kernel structure, and reducing particle size by rolling or grinding whole grains, or processing silage to crush kernels, which greatly increases surface area. Dry grains can be finely ground, greatly decreasing effects of endosperm vitreousness on ruminal fermentability. Processing (rolling) corn silage is not as effective at increasing surface area as fine grinding; processing can reduce, but not eliminate, differences in digestibility of sources varying in vitreousness.

MEASURING STARCH CONCENTRATION AND FERMENTABILITY

Starch concentration is relatively consistent within cereal grain types but varies greatly within forages containing starch such as corn silage and small grain silages. Therefore, book values for starch concentration may be acceptable for cereal grains but starch concentration must be measured for forages from grain crops. For instance, the starch concentration of corn silage varies from less than 20 to over 50% of DM depending upon grain concentration, which, in turn is dependent upon genetics, environment and maturity at harvest. The starch concentration of corn silage is inversely related to concentration of NDF; fibrous stover fraction of the plant is enriched if kernels don't fill.

The non-fiber carbohydrate (NFC) concentration of diets should not be relied upon as a measure of starch concentration. The NFC fraction is calculated by subtracting measured components (NDF, CP, ether extract, ash) from total DM. It contains other carbohydrates such as sugars and pectin and can be underestimated to the extent that non-protein nitrogen is present. While starch, sugars and pectin are generally highly digestible, their effects on rumen microbial populations and fuels available to the animal differ greatly. Starch that is ruminally-fermented increases propionate production in the rumen (Sutton *et al.,* 2003) and starch that escapes ruminal fermentation provides glucose that is absorbed or metabolized to lactate in the small intestine (Reynolds *et al.*, 2003). Sugars are nearly completely fermented in the rumen and generally increase butyrate production (Oba, 2011). Most strains of pectin-degrading rumen bacteria produce acetic and formic acids and relatively little propionic acid (Dehority, 1969). Propionic and lactic acids are glucose precursors while formic, acetic, and butyric acids are not. In addition, propionate can decrease feed intake under some conditions (Allen, 2000) and starch, sugars, and pectin have different effects on microbial populations in the rumen that can affect fiber digestion and ruminal biohydrogenation of fatty acids. Therefore, NFC is not a useful proxy for starch when formulating rations for lactating cows.

Table 1. Effects of dietary treatment on passage rate (kp) of starch from the rumen[1].

Experiment	Treatment	kp, %/h	*P* value
Oba and Allen, 2000b	bm3 corn silage	12.9	0.02
	control corn silage	10.6	
	29% diet NDF	14.5	<0.0001
	38% diet NDF	9.0	
Oba and Allen, 2003a	high-moisture corn	15.4	0.07
	dry ground corn	19.7	
Voelker and Allen, 2003b	high-moisture corn	15.9	0.01
	24% beet pulp	23.5	
Ying and Allen, 2005	high-moisture corn	7.1	<0.0001
	dry ground corn	16.3	
	vitreous endosperm	16.0	<0.001
	floury endosperm	7.5	
Taylor and Allen, 2005	vitreous endosperm	21.2	0.10
	floury endosperm	16.2	
Allen *et al.*, 2008	vitreous endosperm	25.7	<0.001
	floury endosperm	16.0	

[1]Determined by dividing duodenal flux (g/h) by rumen pool size (g) and multiplying by 100.

Relative differences in rate of starch digestion can be determined by *in vitro* starch digestion (IVSD) with ruminal microbes. This can be done by incubating samples over time in rumen fluid with buffered media and evaluating the rate of starch disappearance or, less costly and equally informative, by evaluating starch disappearance over a period of time (e.g. 7 hours). We began using a 7-h incubation time over 20 years ago when our objective was to predict *in vivo* ruminal digestibility of starch because we thought it was a reasonable mean residence time of starch in rumens of lactating cows. However, we subsequently realized that was naïve because ruminal digestibility of starch *in vivo* is highly affected by the enzyme activity of the rumen fluid and particle size of the starch source, and that residence time of starch in the rumen is extremely variable, not only across cows, but also across sources of starch (Table 1). We continue to use IVSD with a 7 h retention time because we think it provides useful information about relative rates of fermentation among starch sources. However, it is very important to know that 7-h IVSD is a relative measure of rate of starch digestion among sources only. Samples must be ground before analysis, which removes important variation for many comparisons (e.g. processed vs. unprocessed corn silage). Comparisons must be done in the same *in vitro* run (at the same time) because IVSD of the same sources is highly variable across runs. This is because enzyme activities (amylases and proteases) of rumen fluid are highly variable from cow to cow, time relative to feeding, and diet consumed. In our laboratory, the coefficient of variation for 7-h IVSD across runs can be as high as 25% even after attempting to minimize variation by taking rumen fluid from several cows fed a specific diet at the same time of day relative to feeding. This is much higher than our coefficient of variation for 30-h *in vitro* NDF digestibility of less than 3%.

Because starch digestion is inhibited by insoluble proteins in the endosperm, the solubility of protein has been measured as an indicator of relative differences in starch digestibility. Like IVSD, determination of protein solubility requires grinding samples, removing variation among sources. Because it is a chemical rather than biological measure, it is less variable across runs than IVSD. Accuracy of ruminal starch digestibility prediction from protein solubility is limited by the relationship between protein solubility and rate of starch digestion as well as limited knowledge of passage rate of starch from the rumen. Therefore, like IVSD, measures of protein solubility provide some information related to ruminal starch digestion but cannot be used to measure ruminal starch digestibility accurately.

Prediction by Models

Although measurement of digestion rate of feed fractions *in vitro* and *in situ* can provide relevant information regarding relative differences among feeds, absolute, not relative, values are required by models to predict ruminal digestibility. Therefore, despite their promise, ration formulation models that include rumen sub-models such as CNCPS do not predict ruminal starch digestibility accurately even if *in vitro* rates of starch digestion are used as inputs (Allen, 2011). Accuracy and precision of prediction of ruminal starch digestibility was poor for several models including CPM and AMTS in a recent evaluation; AMTS and CPM over-predicted ruminal starch digestibility for corn grain by over 25 percentage units (~80% vs. 55%), leading the authors to conclude that the model estimates were not useful (Patton *et al.*, 2012). The primary factors limiting accurate determinations of digestion rate *in vitro* or *in situ* are 1) the inability to mimic the increase in surface area and breakdown of particle size by rumination, 2) variation in enzyme activity and ratio of enzyme to substrate in the rumen over time, and 3) lack of understanding and data on passage rates of starch.

Rates of starch digestion determined *in vitro* are much different than actual rates of digestion because feed particles containing starch that are consumed by cows are larger than what is required for *in vitro* analysis and because enzyme activity in the rumen is extremely variable depending upon diet, time since eating, and the cow. Grinding feeds is necessary to obtain uniform samples for analysis in the laboratory but grinding increases surface area accessible to microbes, increasing rate of digestion compared to intact feeds *in vivo*. On the other hand, not grinding at all will underestimate rate of digestion because feeds are crushed and ground by chewing over time, before they pass from the rumen. This is an unsolvable problem because simulation of the effects of chewing over time of incubation *in vitro* or *in situ* is infeasible.

The high variation in IVSD across runs prompted us to evaluate the effect of rumen fluid sampled before and after feeding on IVSD-7h which was 33% greater after feeding compared to before feeding (41.2 vs. 30.9%, $P < 0.01$; Fickett and Allen, 2002). Enzyme activity related to starch fermentation is also increased with higher starch diets; we reported that the fractional rate of starch digestion determined *in vivo* with the pool and flux method was greater for diets with higher starch concentration and lower NDF from forage (Oba and Allen, 2003a) or beet pulp (Voelker and Allen, 2003b). Therefore,

at least for starch, digestion is a second-order process dependent upon both substrate and enzyme activity. This is a problem for utilization of current data with most existing models in which digestion is modeled as a first-order process dependent on feed characteristics only.

Passage rate of starch was greatly affected by particle size, conservation method, and endosperm type for corn (Table 1; Ying and Allen, 2005; Allen *et al.*, 2008). However, little data exists for passage rates of starch and how it is affected by diet and level of intake. Because passage rate is as important as digestion rate for determining ruminal starch digestibility, accurate predictions by models that use digestion kinetics to predict starch digestibility are not currently possible. In addition, models such as CNCPS that use digestion rates for carbohydrate fractions but passage rates for entire feeds result in even greater inaccuracies for determination of ruminal starch digestion.

PRODUCTION RESPONSE

The filling effects and fermentability of rations are affected by the concentration and ruminal fermentability of starch and can affect DMI, nutrient partitioning, microbial protein production, and total-tract digestibility. Increasing the starch concentration of the ration offered to lactating cows from ~23 to ~34% (~24 to 16% forage NDF, respectively) resulted in variable effects on DMI and FCM yield depending upon the milk yield of cows (range in FCM: ~50 to ~130 lb/d); DMI response to the high-starch, low forage NDF ration increased linearly with increasing milk yield of cows throughout the range while FCM response increased only for cows above ~90 lb/d of FCM (Voelker and Allen, 2003a; Figure 2). Response for DMI was likely because the higher starch diet was less filling (16% forage NDF) and rumen fill is a greater limitation to feed intake as milk yield increases (Allen, 1996), while response for FCM likely depended upon effects of the ration on digestibility and energy partitioning among cows.

The physiological state of animals determines the effects of starch fermentability on DMI (Bradford and Allen, 2007) and production (Bradford and Allen, 2004) responses. High moisture corn compared with dry ground corn had opposite effects on milk yield for cows depending on initial milk yield, with no change for the group overall; high moisture corn increased concentration of milk fat and yield of FCM for cows producing over ~90 lb/day but decreased both for cows producing less than that amount (Bradford and Allen, 2004). Effect of treatment on DMI was not related to milk yield but was affected by physiological state of cows; depression in DMI by the high moisture corn compared with the dry corn treatment was related to plasma insulin concentration and insulin response to a glucose challenge (Bradford and Allen, 2007). Feed intake of cows with greater insulin concentration, and lower insulin response to a glucose challenge, was depressed to a greater extent by high moisture corn compared with dry ground corn. As lactation proceeds and milk yield declines, feed intake is increasingly dominated by metabolic signals. Highly fermentable diets often decrease feed intake in mid to late lactation, likely from stimulation of hepatic oxidation by propionate (Allen *et al.*, 2009). Reducing ruminal fermentability of starch by substituting dry corn for high

moisture corn in rations often increases energy intake and partitioning to milk for these cows.

Several experiments have fed diets differing in starch content in the postpartum period (Andersen et al., 2003; Rabelo et al., 2005; Dann and Nelson, 2011). Increasing diet starch content increased DMI and milk yield in experiments reported by Andersen et al. (2003) and Rabelo et al. (2005) but in those experiments grains were substituted for forage, increasing the forage NDF content of the diet. Forage NDF is very filling (Allen, 2000) and large increases in the forage NDF content of diets in these studies likely contributed to satiety by increasing ruminal distention, especially as lactation progressed and the lipolytic state diminished. Dann and Nelson (2011) substituted corn meal for non-forage fiber sources to increase diet starch content from 21% to 25.5% and the higher starch diet decreased DMI 1.5 kg/d. Non-forage fiber sources are much less filling than forage NDF (Allen, 2000) so the filling effects of the treatment diets were likely much more similar in that experiment than when grains are substituted for forage. To our knowledge, only two previous experiments have evaluated the effects of ruminal fermentability of starch in diets fed to cows in the postpartum period (Dann et al., 1999; Sadri et al., 2009). Increasing ruminal starch fermentability by substituting steam-flaked corn for cracked corn tended to decrease DMI by more than 1 kg/d over the first 63 d postpartum although interactions with time were not reported and greater ruminal fermentability would be expected to have a greater effect in the first few weeks of lactation (Dann et al., 1999). Sadri et al. (2009) compared grains varying in ruminal starch fermentability through the transition period and the more fermentable barley treatment decreased DMI compared with corn during both the prepartum and postpartum periods. These results are consistent with our expectations according to the hepatic oxidation theory of the control of feed intake (Allen et al., 2009).

Energy partitioning between milk production and body condition varies depending upon fuels available and as physiological state changes throughout lactation. Substitution of fiber for starch greatly alters fuels available for intermediary processes and often results in greater partitioning of energy to milk rather than body condition. Substitution of soyhulls for dry ground corn up to 40% of diet DM increased milk fat percent (linearly from 3.60 to 3.91%) and decreased body weight gain (linearly from 1.02 to -0.14 kg/d) with no effect on milk yield (~29 kg/d) and a slight decrease in DMI (tendency, linearly from 23.8 to 22.7 kg/g, Ipharraguerre *et al.*, 2002). We showed that beet pulp decreased BCS without decreasing yields of milk or milk fat when substituted for high-moisture corn up to 12% of diet DM (Voelker and Allen, 2003a). Furthermore, we showed that a 69% forage diet (0% corn grain) containing brown midrib corn silage increased energy partitioned to milk, decreasing body weight gain while numerically increasing FCM yield compared with a 40% forage diet (29 % corn grain) containing control corn silage (Oba and Allen, 2000a). In contrast, DMI and milk yield was reduced when the control corn silage, which had ~20% lower *in vitro* NDF digestibility (46.5% vs. 55.9) than the brown midrib corn silage, was fed in the higher forage diets.

As lactation proceeds, insulin concentration and sensitivity of tissues increase and energy is increasingly partitioned to body condition. Intravenous glucose infusion of

up to 30% of net energy requirement linearly increased plasma insulin, energy balance, body weight and back fat thickness, without affecting DMI or milk yield of mid-lactation cows (Al-Trad *et al.*, 2009). An experiment conducted with cows in the last 2 months of lactation showed that substitution of beet pulp for barley grain linearly decreased body condition score and back fat thickness, maintained milk yield and linearly increased milk fat yield and milk energy output (Mahjoubi *et al.*, 2009). Decreased body condition score and increased milk fat yield might have been because of a linear decrease in plasma insulin concentration which linearly increased plasma NEFA concentration.

High starch diets might result in greater insulin concentration, partitioning energy to adipose at the expense of milk, but they also often result in lower ruminal pH resulting in milk fat depression from altered biohydrogenation of polyunsaturated fatty acids in the rumen reducing milk energy output. While increased energy retention as body condition might be because of increased insulin as observed by Ipharraguerre *et al.* (2002) and Mahjoubi *et al.*, (2009), it might also be a result of altered gene expression in adipose tissue. Harvatine *et al.* (2009) reported that CLA-induced milk fat depression increased gene expression for enzymes and regulators of fat synthesis in adipose tissue. The energy spared from the reduction in milk fat synthesis was likely partitioned toward adipose tissue fat stores. Reducing ration starch concentration by increasing fiber from forages or non-forage fiber sources can maintain milk yield while decreasing gain in body condition.

Increasing ruminal degradability of starch generally increases microbial nitrogen flow to the duodenum but excessive ruminal starch digestion might decrease ruminal fiber digestibility, offsetting its effects (Firkins *et al.*, 2001). In addition, starch sources with faster rates of fermentation might decrease efficiency of microbial protein production; microbial growth can be uncoupled from OM fermentation under some conditions (Russell and Cook, 1995). Greater concentration of starch in rations (32 vs. 21% of DM) increased flow of microbial nitrogen from the rumen with no effect on efficiency of microbial nitrogen production in a study from our laboratory with lactating cows (Oba and Allen, 2003b). However, although ruminal starch digestibility was increased by high moisture corn compared with dry ground in that experiment, high moisture corn decreased efficiency of microbial nitrogen production compared with dry corn and did not affect flow of microbial nitrogen from the rumen. While flow of microbial nitrogen was positively related to true ruminal OM digestibility in that experiment, it was negatively related to rate of starch digestion across all cow period means. Microbial growth might be limited when rate of starch digestion is very fast (Oba and Allen, 2003b). Therefore, increasing ruminal starch degradation by increasing starch concentration of diets might improve flow of microbial nitrogen to the duodenum to a greater extent than increasing ruminal fermentability of starch.

FORMULATING RATIONS FOR STARCH

We know a great deal about what factors affect ruminal digestibility of starch that can be routinely used for ration formulation even if we cannot accurately measure rates of digestion and passage of starch. Starch concentration and ruminal digestibility is so

variable across feeds that we can measure starch concentration and use literature values for ruminal digestibility for initial formulation which can be adjusted using qualitative knowledge of factors that affect ruminal starch digestibility discussed above. Although we should strive to increase accuracy of prediction over time, we are not able to accurately predict animal responses to starch concentration and fermentability because of the many interactions that ultimately affect response such a stocking density, effective fiber concentration, milk yield, physiological state, etc. However, ration formulation should be an iterative process that includes cows in the loop; evaluation of cow response will provide feedback to optimize diets. Cow responses include DMI; yields of milk, fat, and protein; milk urea nitrogen; body condition; manure consistency; ketones; etc. Grains that differ in ruminal starch fermentability, but have high whole tract digestibility (e.g. high moisture corn and ground dry corn), allow evaluation of optimal ruminal starch digestibility without other confounding effects (e.g. effects of changing forage NDF concentration on feed intake) and diet starch concentration can be reduced by substitution of a non-forage fiber source, such as beet pulp, soyhulls, or corn gluten feed, for grains.

Group feeding complicates interpretation of responses for DMI and milk yield. Mean milk yield for the group masks effects of diets because large changes in milk yield of individual cows within the group might occur with no change in milk yield for the group overall. This is most evident when all lactating cows (with great differences in physiological state) are offered the same diet. Individual milk meters provide timely feedback regarding response of individuals within the group and are an important tool for diet formulation and grouping. The same is true for individual DMI response, but this is not feasible economically for group-housed cows. While that limits the usefulness of DMI determination for the group, it is still a very useful measurement, particularly in combination with milk yield to provide important clues for the effects of the diet change. Evaluation of cow response requires more attention by nutritionists and coordination with the management teams on farms. The extent to which nutritionists and the management team interact will vary from farm-to-farm, but this is an important determinant of the success of the nutrition program. The following recommendations for ration starch concentration and ruminal fermentability for cows as they progress through lactation should be adjusted as indicated by cow response.

Fresh Cow Ration (parturition to ~10-14 days postpartum)

Fresh cows are in a lipolytic state, are at increased risk for metabolic disorders, and feed intake is likely controlled by oxidation of fuels in the liver (Allen *et al.*, 2009). These cows require glucose precursors and rations should contain higher starch concentrations to the extent possible. However, they also have lower rumen digesta mass, which increases risk for ruminal acidosis and displaced abomasum. Highly fermentable starch sources increase fermentation acid production including propionate, which can stimulate oxidation of fuels in the liver, suppressing feed intake (Allen *et al.*, 2009). Therefore, highly fermentable starch sources should be limited during this period which lasts up to two weeks for most cows but even longer for cows with excessive body condition at parturition. Highly fermentable starch sources such as wheat, barley,

low-density steam-flaked corn, and aged (greater than 1 year old) high moisture corn and corn silage, should be limited **to allow greater starch concentrations (and glucose precursors)** with less risk of acidosis or displaced abomasum. Supplementing corn silage based diets with dry ground corn works well for this ration with a total starch concentration of up to 28% (DM basis) depending upon the fermentability of starch in the corn silage. Because feed intake is less limited by ruminal distention during this period, and greater rumen digesta mass is desirable, forage NDF concentration should be greater than 23% and use of non-forage fiber sources should be limited to diluting starch concentration, if necessary. Starch concentrations must be decreased when feeding highly fermentable starch sources.

Early to Mid-Lactation Ration

Cows in early to mid-lactation have high glucose requirement for milk production and partition relatively little energy to body reserves. They respond well to rations with lower forage NDF concentration (low fill) and highly fermentable starch. Starch concentration of rations should be in the range of 25 to 30% (DM basis) although the optimum concentration is dependent upon competition for bunk space, forage/effective NDF concentration, and starch fermentability. Higher starch, lower fill rations generally increase peak milk yield and decrease loss of body condition in early lactation. However, once cows replenish body condition lost in early lactation, they should be switched to a maintenance diet with lower starch concentration and ruminal fermentability.

Maintenance Ration (> 150 DIM and BCS of 3)

The maintenance ration is the key component of a ration formulation/ grouping system to increase health and production of cows. The goal of the maintenance ration is to maintain milk yield and body condition through the rest of lactation. Cows should be offered the maintenance ration when they are regaining BCS and reach a BCS of 3. If they continue receiving a high starch diet, BCS will continue to increase and they will be at increased risk for metabolic disease following parturition. Evidence presented above suggests that they are gaining condition because they are being fed rations with greater starch concentrations needed for their current requirement for milk production, increasing plasma glucose and insulin concentrations. Lowering ration starch concentration should limit body condition gain while maintaining and possibly improving feed intake and yields of milk and milk fat. The optimal concentration of starch is dependent upon the milk yield of the herd and physical groups possible but will likely be in the range of 18 to 22% (DM basis). Starch sources that are high fermentable (high-moisture corn, bakery waste, aged corn silage, etc.) should be avoided. Dried ground corn is an excellent starch source because it has lower ruminal digestibility (~60%) but high total tract digestibility (< 90%). The starch concentration of the maintenance ration should contain adequate, but not excessive forage NDF concentration to maintain DMI, and non-forage fiber sources (beet pulp, corn gluten feed, soyhulls, etc.) can be used to dilute starch to the target concentration. Monitoring BCS at dry-off is essential to adjust the starch concentration of the maintenance diet over time.

CONCLUSIONS

Concentration and ruminal fermentability of starch are highly variable among rations fed to lactating cows and have great effects on feed intake, energy partitioning, milk production, and health. The optimal starch concentration and starch source in rations varies by physiological state of cows, which changes through lactation. Cows should be fed different rations through lactation to maximize use of existing knowledge regarding starch nutrition.

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