HOW TO GET MORE OUT OF DIETARY STARCH AND LOW STARCH DIETS

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INTRODUCTION

Starch is an energy dense nutrient made up of glucose units linked by an α-1,4 glycosidic bond. Typically, most dietary starch is fermented ruminally by dairy cows, likely ranging from 50 to 90% of starch intake. Starch fermented in the rumen generates propionate, used both as an energy source and to support lactose synthesis, a primary osmoregulator of milk yield. Furthermore, starch fermented in the rumen supports increased microbial protein synthesis, increased flow of metabolizable protein to the small intestine, and greater milk protein yield. Starch that is not ruminally fermented will be primarily digested in the small intestine, supplying glucose for use as an energy source. The remaining starch not digested in the rumen or small intestine will be available for fermentation in the large intestine. Increases in ruminal starch digestion will decrease starch digestion in the small intestine, but increase total tract starch digestion (**TTSD**). Several factors can influence TTSD of starch sources including grain particle size, moisture content, length of fermentation, vitreousness or prolamin content, and exogenous enzyme application. Dairy producers and nutritionists should monitor starch digestion to ensure starch sources are adequately processed.

The amount of dietary starch is quite variable in rations for lactating dairy cows but typically ranges from 20 to 30% of DM. There has been considerable interest in decreasing dietary starch content over the past 5 to 7 years. Much of this interest has been due, until recently, the relatively high cost of corn compared to historic prices. More recently, dairy producers and nutritionists have witnessed benefits in lowering dietary starch content beyond cost, particularly when starch content is 28% or greater. These benefits include improved NDF digestibility, increased bulk tank milk fat percent, and improved ruminal health. Partial replacement of high starch feeds with alternative feed ingredients can have profoundly different effects on lactational performance. Understanding those differences may lead to improved knowledge on ideal feeding strategies to replace dietary starch.

Monitoring Starch Digestion

Starch digestibility should be routinely monitored to determine if adequate digestion is occurring. Starch digestibility can be monitored as little as one or two times per year or as routinely as desired. Historically, starch digestion has been monitored by qualitatively assessing the amount of whole grain kernels or pieces in manure. Excessive grain in manure suggested poor starch digestion, requiring changes in the diets or improved grain processing. More recently, total tract starch digestion has been quantitatively measured by submitting fecal samples for starch analysis.

Several equations have been developed to estimate TTSD from fecal starch. In a review of the literature, Owens and Zinn (2005) reported that TTSD % = 98.2 – (0.93 × fecal starch %) for dairy cows. In 2006, Ferguson (*personal communication*) found that TTSD % = 98.7 – (1.76 × fecal starch %) in dairy cows.

More recently, Fredin et al. (2014) reported that TTSD % = 100.0 – (1.25 × fecal starch %). It should be expected that the intercept is 100.0 since the maximum amount of digestible starch is 100%. Fecal starch accounted for almost all of the variation in TTSD (R^2 = 0.94), strongly suggesting that measuring fecal starch alone is adequate to predict TTSD. Therefore, additional measurements, such as starch content of the diet or marker concentrations of the feces or diet, should not be needed. Several labs now offer near-infrared reflectance spectroscopy equations to predict fecal starch, allowing for more rapid and inexpensive monitoring of TTSD.

I recently updated the equation published in Fredin et al. (2014). I included individual cow data from the University of Wisconsin (Madison, WI) and Miner Institute (Chazy, NY) that I had direct access too (Dann et al., 2014; Farmer et al., 2014; Fredin et al., 2015a; Fredin et al., 2015b). These studies were added to the original equation (Fredin et al., 2014). The updated equation is presented in Figure 1. Due to the presence of heteroscedasticity in the updated regression model for TTSD and fecal starch, a default heteroscedasticity-consistent matrix estimator was included to properly estimate standard error around the intercept and slope. The updated equation is: TTSD % = 99.8 – 1.23 × fecal starch. The updated equation is remarkably similar to the original equation and serves to support the precision of the original equation. Due to the simplicity of the original equation (TTSD = 100.0 – 1.25 × fecal starch), I would advocate for its continued adoption to estimate TTSD.

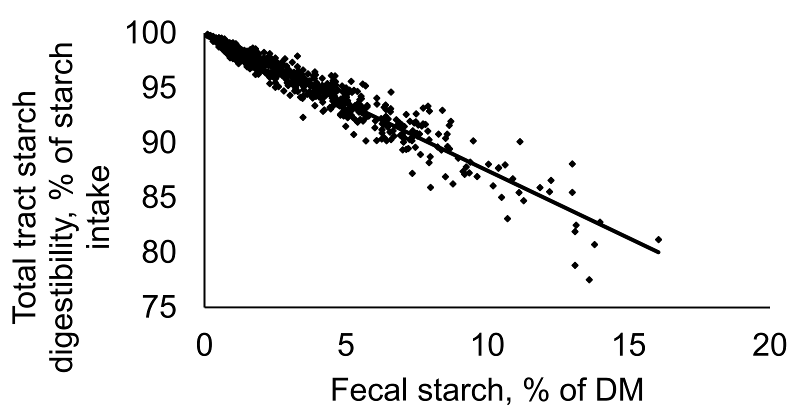

Figure 1. Regression plot of fecal starch (% DM) and total tract starch digestibility (% starch intake). Total tract starch digestibility % = 99.8 (± 0.06) – 1.23 (± 0.02) × fecal starch %; RMSE = 0.90; R^2 = 0.93; P < 0.001; n = 726.

Average TTSD from the data set used in the updated equation was 95.7%. This dataset contained several treatments that were designed to depress starch digestibility, such as diets that included unprocessed corn silage or coarsely ground corn grain and suggests that excellent TTSD can occur in dairy cows. Total tract starch digestibility greater than 98% are considered good and are consistently achievable. Starch digestibility greater than 95% is considered adequate. If TTSD is below 95%, consider replacing starch sources. Researchers at the University of Pennsylvania found that a decrease of 1%-unit in total tract starch digestibility is estimated to result in a 0.33 kg/d decrease in milk yield. By monitoring TTSD and adjusting starch sources when necessary, milk yield can be improved, especially when energy is limiting in the diet.

The most effective methods to improve starch digestibility of grains when TTSD is below 95% and grain type is unchanged is to grind grain more finely, add steam-flaked grain, or to include grain fermented at a higher moisture content. Total tract starch digestibility improved from 93 to 98% as the particle size of dry ground corn grain was decreased from 1270 to 552 μm (Fredin et al., 2015b). In a meta-analysis describing the effects of cereal grain type and processing methods on nutrient digestion by dairy cows, TTSD was 93% for corn ground to ≤ 1.5 mm, 90% for corn ground to ≤ 3.5 mm, and 78% for corn ground to > 3.5 mm (Ferraretto et al., 2013). In a review, Firkins et al. (2001) reported that TTSD for dry ground corn was 90.7%, steam-flaked corn was 94.2%, and high-moisture ground corn was 98.8%. Ferraretto et al. (2013) reported that TTSD was increased for ensiled (94.2%) and steam-flaked corn (93.9%) compared with dry ground or rolled corn (92%). Proper processing can have profound impacts on TTSD, leading to greater milk yield.

Effect of Feeding Reduced-Starch Diets

Fluctuations in grain costs have led to the partial replacement of grains such as corn and barley in lactating dairy cow diets with less expensive feeds. Common strategies for replacing grain in diets include the use of non-forage fiber sources (**NFFS**) such as citrus pulp, dried distillers grains plus solubles, soyhulls, or wheat middlings; forages such as corn silage or grass and legume hays and grass and legume silages; or sugars and sugar byproducts including molasses or glycerol. However, reduced-starch diets have resulted in reduced DMI (Ferraretto et al., 2013) due to increases in NDF content causing rumen fill. Furthermore, reduced-starch diets decrease the amount of rumen fermentable organic matter in the diet, potentially limiting microbial protein synthesis (NRC, 2001) and a reduction in the production of the glucogenic precursor, propionate (Allen et al., 1997) decreasing milk and milk protein yields. However, reduced-starch diets have the potential to improve rumen function by increasing rumen pH when excessive amounts of ruminally fermentable starch are fed (Allen, 1997), thereby increasing DMI and lactational performance. Often, TTSD increases when feeding a reduced-starch diet since less digestible grain sources are typically the first starch sources replaced.

Recently, I conducted a meta-analysis to determine the effect of reduced-starch diets on DMI and lactational performance, as well as to identify feedings strategies that can mitigate potential negative effects of feeding reduced-starch diets. The data set for the meta-analysis contained 223 treatment means from 53 peer-review papers and 4 scientific abstracts published from September 1993 through January 2014 in the *Journal* *of Dairy Science*, *Animal*, or *Animal Feed Science and Technology*[1]. Studies included in the data set measured lactational performance of dairy cows fed TMR.

Studies that did not report dietary starch content were not included in the data set. Dietary starch content (% of DM) of the high-starch diet was included as a covariate effect because high dietary starch content can result in excessive amounts of ruminally-fermentable carbohydrate, increased risk for subacute or acute ruminal acidosis, and reduced DMI and lactational performance. The primary strategies to reduce dietary starch content included the partial replacement of grain or starch with NFFS, forage, or sugar or sugar byproducts.

The dependent variables evaluated were DMI and milk, fat, protein, and lactose yield, and MUN content. To determine the effects of reduced-starch diets on the dependent variables, the dependent variables were transformed as follows: Dependent variables = [Dependent variable mean on the high-starch treatment – dependent variable mean on the reduced-starch treatment]. Treatment included the decrease in dietary starch content (as a % of DM) and were calculated from the following equation: Decrease in dietary starch content = [Starch content (% of DM) on the high-starch diet – starch content (% of DM) on the reduced-starch diet.

Descriptive statistics of selected diet nutrient composition of experiments used in the meta-analysis are listed in Table 1. Dry matter intake averaged 24.2 kg/d across all diets and was 0.4 kg/d greater for reduced-starch diets than high-starch diets. Diet CP content averaged 17.8% across all diets and was similar for high-starch and reduced-starch diets.

Diet NDF content averaged 31.8% across all diets and mean NDF content was 3.1% greater for reduced-starch compared with high-starch diets. Dietary starch content averaged 24.6% across all diets and averaged 28.7% for high-starch and 21.9% for reduced-starch diets. Suggested levels of dietary starch for lactating cows are not well defined. Kaiser and Shaver (2006) reported that dietary starch content ranged from 25 to 30% for high producing herds and Staples (2006) suggested an optimal dietary starch content of 24 to 26% from a literature review. Dietary forage content averaged 48.0% for all diets and was 2.7% greater for the reduced-starch compared to the high-starch diets due to the partial replacement of grains with forages in 25 of the studies. Standard deviations and minimum and maximum values for the reported diet nutrient compositions suggest that a wide range of diets are represented in the meta-analysis.

Descriptive statistics for lactational performance data are provided in Table 2. Milk yield averaged 36.2 kg/d across all trials and was 0.7 kg/d greater for high-starch compared to reduced-starch diets. Milk fat and protein yield averaged 1.30 and 1.13 kg/d across all diets, respectively. On average, fat and protein yields were similar between high-starch and reduced-starch diets. Milk urea-N averaged 13.53 mg/dL across all diets and was decreased on the high-starch compared to the low starch diets. The large SD

[1] A complete list of published papers and abstracts are available upon request.

and minimum and maximum values suggest a wide range in lactational performance among experiments included in the meta-analysis

Table 1. Descriptive statistics and select diet nutrient composition of experiments used in the meta-analysis[1]

Item	Average	SD[2]	Minimum	Maximum
<u>All diets</u>				
DMI, kg/d	24.2	2.6	17.5	31.6
CP, % of DM	17.8	2.3	13.2	31.9
NDF, % of DM	31.8	5.5	19.5	48.4
Starch, % of DM	24.6	6.1	5.2	41.5
Forage, % of DM	48.0	11.6	10.3	79.6
<u>High-starch diets</u>				
DMI, kg/d	24.0	2.4	18.1	28.9
CP, % of DM	17.5	2.2	13.2	28.8
NDF, % of DM	30.0	4.8	19.5	42.1
Starch, % of DM	28.7	4.6	16.9	41.5
Forage, % of DM	46.5	10.1	10.3	67.0
<u>Reduced-starch diets</u>				
DMI, kg/d	24.4	2.8	17.5	31.6
CP, % of DM	17.9	2.3	13.2	31.9
NDF, % of DM	33.1	5.4	19.9	51.8
Starch, % of DM	21.9	5.1	5.2	34.3
Forage, % of DM	49.2	12.3	10.3	79.6

[1]Number of treatment means were 218, 83, and 135 for all, high-starch, and reduced-starch diets, respectively.
[2]Standard deviation.

The adjusted effect of reduced dietary starch on DMI (kg/d) is listed in Figure 2A. Dry matter intake was decreased 0.10 kg/d per %-unit decrease in dietary starch (P = 0.001; RMSE = 0.80). Dry matter intake tended to decrease 0.07 kg/d per %-unit decrease in dietary starch when starch was replaced by NFFS (P = 0.06) and decreased 0.12 kg/d per %-unit decrease in dietary starch when starch was replaced with forage (P < 0.01; Table 3). Ferraretto et al., (2013) reported that DMI was unaffected by dietary starch content which may be caused by the opposing effects of low DMI when excessive rumen fill occurs as dietary starch is replaced by forage NDF or increased meal size due to reduced ruminal propionate concentrations on reduced-starch diets (Allen et al., 2009). The more pronounced effect on DMI when forage replaces dietary starch is likely due to the greater amount of physically effective NDF in forages compared with NFFS (Mertens, 1997). The relatively large RMSE for the effect of reduced-starch diets on DMI indicates that the response on DMI is quite variable and dependent on the ingredients used to displace high starch feeds. Including low digestible forages in diets will reduce DMI due to effects on rumen fill, whereas highly digestible NFFS or forage such as BMR corn silage may increase DMI. Unexpectedly, the y-intercept for DMI is not zero. This is true for all other dependent variables. Theoretically, this would suggest that when dietary starch is unchanged from the high-starch diet, DMI would increase. Biologically, this cannot happen and in all cases, the y-intercept is not statistically different from zero (P > 0.10).

Table 2. Descriptive statistics of lactational performance of experiments used in the meta-analysis[1]

Item	Average	SD[2]	Minimum	Maximum
All diets				
Milk yield, kg/d	36.2	5.69	17.4	52.1
Fat yield, kg/d	1.30	0.20	0.76	1.74
Protein yield, kg/d	1.13	0.17	0.59	1.57
Lactose yield, kg/d	1.76	0.29	0.66	2.60
MUN, mg/dL	13.53	3.03	6.94	25.7
High-starch diets				
Milk yield, kg/d	36.6	5.98	17.9	52.1
Fat yield, kg/d	1.28	0.21	0.78	1.71
Protein yield, kg/d	1.15	0.17	0.60	1.57
Lactose yield, kg/d	1.80	0.30	0.72	2.60
MUN, mg/dL	13.07	2.54	6.94	20.60
Reduced-starch diets				
Milk yield, kg/d	35.9	5.51	17.4	50.9
Fat yield, kg/d	1.32	0.20	0.76	1.74
Protein yield, kg/d	1.11	0.16	0.59	1.52
Lactose yield, kg/d	1.74	0.28	0.66	2.51
MUN, mg/dL	13.80	3.27	8.01	25.70

[1]Number of treatment means were 218, 83, and 135 for all, high-starch, and reduced-starch diets, respectively.
[2]Standard deviation.

The effect of reduced starch diets on milk yield (kg/d) is listed in Figure 2B. Milk yield was decreased 0.19 kg/d per %-unit decrease in dietary starch ($P < 0.001$; RMSE = 0.63). The negative effect on milk yield may be due to the reduction in DMI. Ferraretto et al., (2013) reported a tendency for milk yield to decrease by 0.09 kg/d per %-unit decrease in dietary starch. A potential difference between the two estimates for the effect of dietary starch content on milk yield is the meta-analysis by Ferraretto et al., (2013) was more expansive (n = 320) as it was not restricted to only trials that evaluated dietary starch concentrations. Partially replacing starch by forage NDF will also decrease the rate and extent of rumen fermentable OM and decrease production of propionate (Allen et al., 1997), a primary source of blood glucose and milk lactose. Twenty four treatment means for milk yield were greater for reduced-starch compared to high-starch diets, suggesting that positive lactational performance can be achieved when feeding reduced-starch diets. Milk yield tended to decrease by 0.16 kg/d per %-unit decrease in dietary starch when NFFS replaced grain ($P = 0.06$) and 0.32 kg/d when forage replaced grain ($P < 0.01$; Table 3). The greater reduction in milk yield when dietary starch was replaced by forage is likely due to reduced DMI and decreased ruminal degradation of forage NDF compared to non-forage NDF (Allen, 1997).

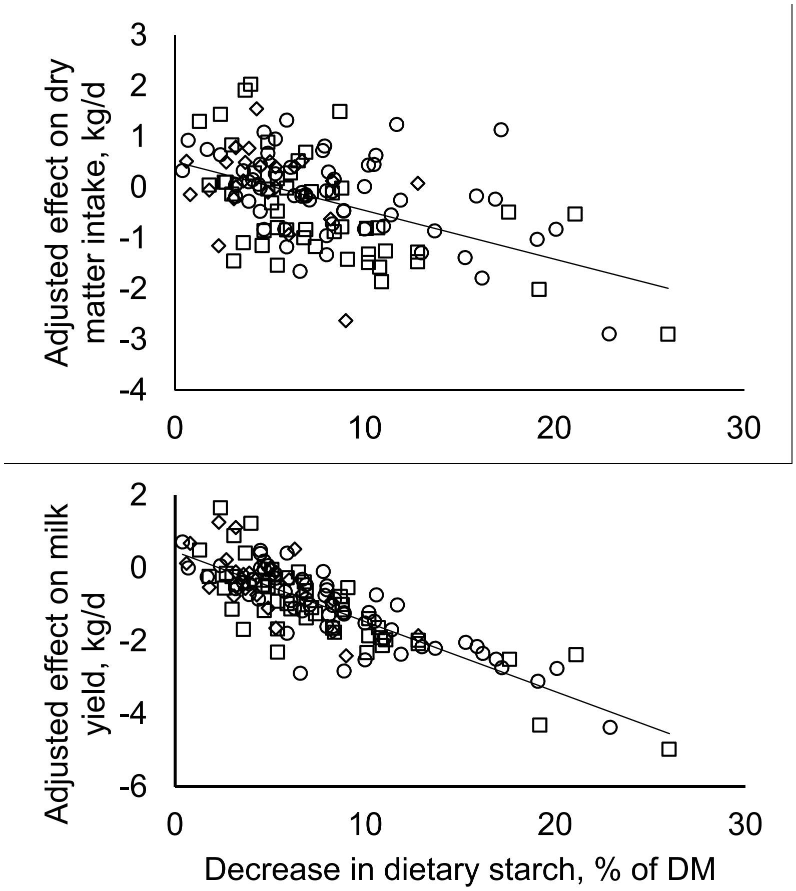

Figure 2. Effect of decreased dietary starch (% of DM; panel A) on DMI (kg/d; panel A) and milk yield (kg/d; panel B) adjusted for the random effect of trial. A) Effect on DMI = 0.52 + (–0.10 × decrease in % starch) + (–0.08 ± 0.79); RMSE = 0.80; P = 0.001; n = 135. B) Effect on milk yield = 0.44 + (–0.19 × decrease in % starch) + (0.00 ± 0.63); RMSE = 0.63; P < 0.001; n = 135. Strategies for decreasing dietary starch included partial replacement of grain with non-forage fiber source (○), forage (□), or sugar (◊).

The effect of reduced-starch diets on milk fat yield (g/d) is listed in Table 3. Milk fat yield decreased 6.9 g/d per %-unit decrease in dietary starch (P < 0.001). The decrease in milk fat yield is partly caused by the decrease in milk yield (Figure 2B). Milk fat yield decreased 5.4 g/d or 8.1 g/d when starch was replaced by NFFS (P = 0.05) or by forage (P = 0.01), respectively. Firkins et al. (2001) reported that increased amounts of grain intake reduced milk fat percent, whereas Ferraretto et al. (2013) reported a negative relationship between increased dietary starch content and milk fat percent, likely due to lower NDF intake, leading to milk fat depression. Both the composition and amount of unsaturated fatty acids influence the ruminal load of bioactive conjugated fatty acids that can cause milk fat depression and some NFFS such as barley distillers or corn distillers grains contain greater content of fat than grains, resulting in an increased ruminal unsaturated fatty acid load. Furthermore, barley or corn silages will have a similar fat content and fatty acid profiles to barley or corn grain, leading to similar ruminal unsaturated fatty acid loads, negating potential increases in milk fat percent when replacing grain with forage.

Table 3. Effect of replacing dietary starch content (% of DM) on lactation performance[1]

Item	n[2]	Intercept	Slope	Cov[3]	*P*-value	RMSE[4]
All diets						
Fat yield, g/d	135	–181.1	–6.9	9.1	<0.001	72.7
Protein yield, g/d	135	16.7	–8.3	–0.1	0.001	28.5
Lactose yield, g/d	111	13.8	–11.5	-	<0.001	38.5
MUN, mg/dL	93	0.3	0.0	-	0.26	0.7
Non-forage fiber sources only						
DMI, kg/d	61	0.8	–0.07	-	0.06	0.8
Milk yield, kg/d	61	0.7	–0.16	-	0.01	0.6
Fat yield, g/d	61	–143.2	–5.4	7.6	0.05	65.3
Protein yield, g/d	61	31.6	–8.8	-	<0.01	23.9
Lactose yield, g/d	48	46.5	–14.7	-	<0.01	38.1
MUN, mg/dL	41	–2.8	0.0	0.1	0.68	0.9
Forage sources only						
DMI, kg/d	49	0.2	–0.12	-	0.01	1.6
Milk yield, kg/d	49	0.6	–0.32	-	0.01	0.8
Fat yield, g/d	49	–326.9	–8.1	13.7	0.01	123.3
Protein yield, g/d	49	–9.5	–11.1	0.7	<0.001	30.7
Lactose yield, g/d	46	5.3	–12.0	-	<0.01	90.0
MUN, mg/dL	34	–0.1	0.2	-	0.01	0.8

[1]Adjusted for the random effect of experiment.
[2]Number of treatment means.
[3]Cov = Covariate; Highest dietary starch content (% of DM) within study.
[4]Root mean square error.

Milk protein yield was reduced 8.3 g/d per %-unit decrease in dietary starch content ($P < 0.001$; RMSE = 28.65; Table 3). Milk protein yield was reduced 8.8 g/d per %-unit decrease in dietary starch content when starch was replaced by NFFS ($P < 0.01$) and 11.1 g/d when starch was replaced by forage ($P < 0.001$). There was actually a slight numerical increase in protein yield when starch was replaced with sugar (1.9 g/d). Nocek and Tamminga (1991) reported a positive correlation coefficient between starch intake (kg/d) and milk protein yield. Increased grain intake (Firkins et al., 2001) and dietary starch concentration (Ferraretto et al., 2013) also increased milk protein content. Furthermore, increased starch intake results in an increased amount (kg/d) of ruminal starch digestion (Nocek and Tamminga, 1991), leading to increased microbial protein synthesis and flow to the small intestine, increased amounts of metabolizable protein, and improved milk protein synthesis (NRC, 2001). Increased starch intake also increases the amount of starch flowing to the small intestine (Nocek and Tamminga, 1991). Greater starch flow and digestion (as kg/d) in the small intestine will result in greater utilization of glucose by small intestinal enterocytes as an energy source and reduced reliance on glucogenic AA. Sparing amino acids from metabolism by enterocytes will lead to increased uptake of amino acids into the portal vein and greater amounts of metabolizable protein for tissue and milk protein synthesis (Nocek and Tamminga, 1991). Increased starch flow to the small intestine can also increases arterial concentrations of glucose and insulin, further resulting in improved milk protein content.

Milk lactose yield was decreased by 11.5 g/d per %-unit decrease in dietary starch content (P < 0.001; RMSE = 35.5). Milk lactose yield decreased 14.7 g/d per %-unit decrease in dietary starch when starch was replaced by NFFS (P < 0.01) and 12.0 g/d when starch was replaced by forage (P < 0.01). Lactose is a primary osmoregulator in mammary uptake of water and increased lactose synthesis increases milk yield. Increases in dietary starch increase the proportion of propionate in absorbed VFA (Allen et al., 2009). Up to 59% of absorbed propionate is converted to glucose in the liver of lactating dairy cows, 80% of glucose supply is utilized by the mammary gland, and 74% of the glucose extracted by the mammary gland is used for lactose synthesis (Hanigan et al., 2001). Greater supply of absorbed propionate from high-starch diets likely results in increased lactose synthesis. Increased amounts of dietary starch may also increase the amount of starch flow to the small intestine. Owens et al. (1986) reported that starch digested in the small intestine provides 42% more energy than starch digested in the rumen due to losses through methane, heat of fermentation, and futile energy cycling by microbes. The results from the meta-analysis suggest that increased dietary starch content increases both lactose yield and milk yield. This may be due to greater starch intake and potential increased flow of starch to the small intestine, leading to greater glucose absorption.

Unexpectedly, MUN was unaffected by dietary starch content (P = 0.26). Ferraretto et al., (2013) found that increased dietary starch content reduced MUN. Typically, highly fermentable, high starch diets will decrease MUN by increasing NH_3 utilization by rumen microbes to synthesize microbial protein.

CONCLUSIONS

Total tract starch digestibility can be effectively monitored by measuring fecal starch. Total tract starch digestibility greater than 98% is achievable and digestibility lower than 95% will result in the need to re-evaluate dietary ingredients or processing. Based on results of a meta-analysis, reduced starch diets result in decreased DMI and milk, fat, protein, and lactose yields. Milk urea-N content was unaffected by dietary starch content. More pronounced decreases in lactational performance were observed when starch was replaced with forage compared with NFFS. These data suggest that when lowering dietary starch content, consider replacing starch with NFFS. If forage is the only available ingredient, replace starch with a highly digestible forages to minimize production losses.

REFERENCES

Allen, M. S. 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. J. Dairy Sci. 80:1447-1462.

Allen, M. S., B. J. Bradford, and M. Oba. 2009. Board-invited review: The hepatic oxidation theory of the control of feed intake and its application to ruminants. J. Anim. Sci. 87:3317-3334.
Dann, H. M., H. A. Tucker, K. W. Cotanch, P. D. Krawczel, C. S. Mooney, R. J. Grant, and T. Eguchi. 2014. Evaluation of lower-starch diets for lactating dairy cows. J. Dairy Sci. 97:7151-7161.
Farmer, E. R., H. A. Tucker, H. M. Dann, K. W. Cotanch, C. S. Mooney, A. L. Lock, K. Yagi, and R. J. Grant. 2014. Effect of reducing dietary forage in lower starch diets on performance, ruminal characteristics, and nutrient digestibility in lactating Holstein cows. J. Dairy Sci. 97:5742-5753.
Ferraretto, L. F., P. M. Crump, and R. D. Shaver. 2013. Effect of cereal grain type and corn grain harvesting and processing methods on intake, digestion, and milk production by dairy cows through a meta-analysis. J. Dairy Sci. 96:533-550.
Firkins, J. L., M. L. Eastridge, N. R. St-Pierre, and S. M. Noftsger. 2001. Effects of grain variability and processing on starch utilization by lactating dairy cattle. J. Anim. Sci. 79(E-Suppl.):E218-E38.
Fredin, S. M., M. S. Akins, L. F. Ferraretto, and R. D. Shaver. 2015a. Effects of corn-based diet starch content and neutral detergent fiber source on lactation performance, digestibility, and bacterial protein flow in dairy cows. J. Dairy Sci. 98:554-565.
Fredin, S. M., L. F. Ferraretto, M. S. Akins, S. J. Bertics, and R. D. Shaver. 2015b. Effects of corn-based diet starch content and corn particle size on lactation performance, digestibility, and bacterial protein flow in dairy cows. J. Dairy Sci. 98:541-553.
Fredin, S. M., L. F. Ferraretto, M. S. Akins, P. C. Hoffman, and R. D. Shaver. 2014. Fecal starch as an indicator of total-tract starch digestibility by lactating dairy cows. J. Dairy Sci. 97:1862-1871.
Hanigan, M. D., L. A. Crompton, J. A. Metcalf, and J. France. 2001. Modeling mammary metabolism in the dairy cow to predict mik constituent yield, wth emphasis on amino acid metabolism and milk protein production: Model construction. J. Theor. Biol. 213:223-239.
Kaiser, R., and R. D. Shaver. 2006. Benchmarking high-producing herds. Pages 179-190 in Proc. Western Canadian Dairy Seminar, Red Deer, Alberta, Canada. University of Alberta, Edmonton, Alberta, Canada
Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80:1463-1481.
Nocek, J. E., and S. Tamminga. 1991. Site of digestion of starch in the gastrointestinal tract of dairy cows and its effects on milk yield and composition. J. Dairy Sci. 74:3598-3629.
NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, D. C.
Owens, F. N., R. A. Zinn, and Y. K. Kim. 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63:1634-1648.
Owens, F. N., and R. A. Zinn. 2005. Corn grain for cattle: Influence of processing on site and extent of digestion. Pages 86-112 in Proc. Southwest Nutr. Conf., Tempe, AZ. University of Arizona, Tucson, and New Mexico State University, Las Cruces.

Staples, C. R. 2007. Feeding dairy cows when corn prices are high. Pages 722 in Proc. 44th Florida Dairy Production Conference, Gainesville, FL. University of Florida Extension, Gainesville.