Feeding Low-Starch Diets to Lactating Dairy Cows

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Introduction

Common recommendations for dietary starch content (dry matter (DM) basis) for lactating cows are 23 to 30% (Grant, 2005), 24 to 26% (Staples, 2007), and greater than 24% (Shaver, 2008). Surveys of dairy herds that produced more than 12,700 kg of milk per cow per year found that dietary starch content ranged between 15 and 30% (Hall and Van Horn, 2001; Johnson et al., 2002; Shaver and Kaiser, 2004; Chase, 2006). The major source of dietary starch for lactating cows is corn according to the Dairy 2007 survey (USDA, 2008). Corn, oats, barley, and wheat were fed to lactating cows in 94, 18, 14, and 7% of herds, respectively. The price for corn grain as a livestock feed has increased substantially in recent years. Consequently, lower-starch feeding strategies that minimize the amount of corn may be more profitable than higher-starch diets particularly if lactational performance and ruminal fermentation are not compromised.

Strategies to Lower the Dietary Starch Content

Recently, strategies for formulating lactating cow diets with high corn prices have been suggested and include using less corn grain and using more high-quality forage and byproduct feeds to provide highly digestible neutral detergent fiber (NDF) and nonfiber carbohydrates (Chase, 2007; Knapp, 2007; Staples, 2007; Shaver, 2008). Summarized in Table 1 are the dietary conditions and dry matter intake (DMI) and milk yield results of studies on replacement of corn starch with nonforage fiber sources (NFFS) and other carbohydrate sources to yield lower-starch (≤ 23%) diets.

Use of NFFS is a practical way to reduce the dietary starch content while maintaining lactational performance. Batajoo and Shaver (1994) replaced shelled corn and soybean meal with wheat middlings (0 to 9%), dried brewers grains (3 to 20%), and soyhulls (SH; 0 to 9%) to provide alfalfa silage-based diets ranging in starch content from 32.9 to 17.6% to lactating cows. Decreasing the dietary starch content linearly decreased DMI, milk protein content, and milk protein yield, linearly increased milk fat content, ruminal pH, ruminal acetate concentration, ruminal acetate:propionate, and total tract digestibility of NDF and starch, and had no effect on milk yield. In another study (Ipharraguerre et al., 2002), SH (0 to 40%) were used to replace corn grain in alfalfa/corn silage-based diets for mid-lactation cows. There tended to be a linear decrease in DMI as SH replaced corn, but the major decrease in DMI occurred at the 30 and 40% inclusion level of SH. Milk yield tended to decrease at the 40% inclusion level.

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Milk fat content increased linearly with more SH and less starch. Thus, cows can be fed successfully a 19% starch diet containing up to 30% SH.

Voelker and Allen (2003abc) replaced high moisture corn with 0 to 24% beet pulp to formulate alfalfa/corn silage-based diets with decreasing starch content (34.6 to 18.4%) for lactating cows. Decreasing starch content linearly decreased DMI and microbial nitrogen yield, tended to linearly increase feed efficiency, and had no effect on milk yield and milk composition. Ruminal passage rate of starch, ruminal digestion rate of potentially digestible NDF, and total tract digestibility of organic matter and NDF increased linearly, while ruminal digestion rate of starch decreased linearly with decreasing starch content. Corn hominy was partially replaced with citrus pulp (24%) in corn silage-based diets to provide diets containing 26.5 and 15.1% starch to mid-lactation cows (Leiva et al., 2000). There was no effect of diet on DMI, milk yield, or milk composition. Broderick et al. (2002) used alfalfa silage-based diets and partially replaced high moisture ear corn or cracked corn with citrus pulp (19%). Dry matter intake and milk yield were reduced when the citrus pulp was fed. Boddugari et al. (2001) replaced corn and soybean meal with wet corn gluten feed (CGF; 0 to 40%) in alfalfa/corn silage based diets fed to lactating cows. Dry matter intake tended to be lower for the diets containing the wet CGF. Diet did not affect milk yield or milk composition. Ranathunga et al. (2008) partially replaced corn starch with dried distillers grains with solubles (0 to 21%) in diets for lactating cows. As the starch content decreased from 28.0 to 17.5%, DMI linearly decreased and feed efficiency tended to linearly increase. There was no effect of diet on milk yield or composition.

Replacing corn starch with sugar sources in high forage diets containing alfalfa silage and corn silage is a viable strategy for reducing dietary starch content while maintaining milk yield. Broderick and Radloff (2004) replaced high moisture shelled corn with 0 to 12% dried molasses in diets for mid-lactation cows. Decreasing the starch content from 31.5 to 23.2% linearly increased DMI and total tract digestibility of DM, organic matter, and NDF, but had no effect on milk yield and ruminal fermentation. Broderick et al. (2008) fed lactating cows diets containing 21.5, 24.5, 27.4, and 28.2% starch; corn starch was replaced with 0 to 7.5% sucrose. Decreasing starch content linearly increased DMI, milk fat content, and milk fat yield, linearly decreased feed efficiency, ruminal acetate concentration, and ruminal acetate:propionate, and had no effect on milk yield and ruminal pH.

Another feasible strategy to reduce the dietary starch content is to replace corn with high-quality forage. Valadares Filho et al. (2000) substituted alfalfa silage for high moisture ear corn and soybean meal. As the starch content decreased, there was a linear decrease in DMI and milk yield with the majority of the decrease in DMI occurring at the lowest starch level. There were linear and quadratic responses in milk fat content and yield. Reducing the dietary starch content to less than 20.7% should be avoided when substituting alfalfa silage for corn starch. Oba and Allen (2003ab) fed lactating cows diets containing either ground high moisture corn or dry ground corn at two dietary starch contents (32 and 21%). Dry matter intake, milk yield, and milk protein content were lower for the low-starch diets. Milk fat content, body condition loss, ruminal pH, and acetate:propionate were higher for the low-starch diets. Total tract digestibility (%) of starch was lower for the low-starch diets, but ruminal digestion (%) of starch was not affected by starch content.

Research at Miner Institute with Low-Starch Diets

We (Dann et al., 2008) used 12 multiparous, mid-lactation cows in a replicated 3×3 Latin square design study with 21-d periods (7-d collection) to determine the effect of feeding diets containing 18, 21, and 25% starch (Table 2) on lactational performance, ruminal fermentation, and total tract nutrient digestibility (Table 3). Dietary starch was reduced by decreasing the amount of corn grain and increasing the amount of beet pulp, wheat middlings, and distiller's grains. Cows were able to maintain high productivity on all diets. Dry matter intake (26.5 kg/d), milk yield (43.5 kg/d), milk fat content (3.54%), milk true protein content (3.14%), and efficiency of milk production (1.65 kg milk/kg DMI) were unaffected by diet. Diet also had no effect on ruminal pH averaged over 24 h (6.06), total volatile fatty acids (150 m*M*), acetate:propionate ratio (2.4), or microbial nitrogen yield (584 g/d). Total tract digestibility of organic matter was higher for the 25% starch diet (69.2%) compared with the 21% (67.3%) and 18% (67.0%) starch diets but was of little biological relevance. Digestibility of NDF and starch was not affected by diet.

In summary, with the sources of corn grain, corn silage, and byproducts fed in this study, we observed no effect on feed intake, milk component production, ruminal metabolism, or microbial protein yield when dietary starch was varied between 18 and 25%. It is important to note that, as dietary starch decreased, ruminal fermentability increased and consequently the range between the 25 and 18% starch diets in rumen fermentable starch (3.5%-units) was less than the range in starch content (6.9%-units). When predicting the potential impact of starch content of the diet on animal response, we need to consider not only the amount, but the digestibility of the starch.

A low-starch, low-forage dietary strategy may be advantageous when corn starch and forages are either expensive or availability is limited. We (Myers et al., 2009) used 16 mid-lactation Holstein cows in a replicated 4×4 Latin square design study with 21-d periods (9-d collection) to determine the effect of feeding diets containing low-starch (formulated at 19% of DM) and different amounts of forage (52, 47, 43, and 39% of DM; Table 4) on lactational performance, ruminal characteristics, and total tract digestibility. Dry matter intake was lowest (3.47% of body weight) when cows were fed the 52% forage diet and highest (3.67% of body weight) when cows were fed the 39% forage diet ($P = 0.03$). Diet did not affect ($P > 0.10$) milk yield (42.6 kg/d), milk fat content (3.60%), or milk true protein content (3.02%). Because there was an effect of diet on DMI, but not milk yield, efficiency was highest (1.87 kg milk/kg DMI) when cows were fed the 52% forage diet and lowest (1.77) when cows were fed the 39% forage diet ($P = 0.02$). Mean ruminal pH (6.07) and microbial nitrogen yield (450 g/d) were not affected ($P > 0.10$) by diet. As the forage content of the diets decreased from 52 to 39%, the total tract OM digestibility decreased from 65 to 61% ($P < 0.01$) and the total tract NDF digestibility decreased from 39 to 29% ($P < 0.01$). Lower forage diets with low-starch content are a good strategy for feeding high-producing dairy cows under conditions of expensive or limited supplies of corn and forages, but the limit appears to be between 39 and 43% forage with these types of diets when high productivity is expected.

Watch the Cows when Feeding Low-Starch Diets

Most of the research conducted with low-starch diets has been short-term (i.e. less than 8 wk) and focused on mid-lactation cows. The long-term effect of feeding low-starch diets to cows in all stages of lactation is unknown. Therefore, when implementing low-starch diets on an entire herd basis, the nutritionist and dairy producer should watch for signs that may indicate that the dietary starch content is too low. Signs include decreased milk production, decreased milk protein content and yield, decreased body condition and weight, increased milk urea nitrogen, and stiffer manure (Staples, 2007). In addition to watching the cows, feed ingredients should be monitored for changes in NDF and starch digestibility. Providing the proper amounts of ruminally fermentable carbohydrates are critical to optimizing ruminal fermentation and generating volatile fatty acids and microbial protein for energy and amino acid use by the cow.

Conclusions

Corn grain can be replaced with byproduct feeds in lactating cow diets resulting in low-starch (18 to 21%) diets without adverse effects on ruminal fermentation and lactational performance. In particular, diets containing NFFS that provide digestible NDF can support excellent production and feed efficiency with lower than commonly recommended amounts of starch. When a low-starch diet strategy is implemented on a herd, be sure to include feed ingredients that provide highly digestible starch and NDF, monitor the cow’s performance, and analyze feed ingredients for NDF and starch digestibility.

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Table 1. Summary of selected research where corn starch was replaced with nonforage fiber sources or other carbohydrate sources resulting in low-starch (< 23%) diets

Reference; Treatment information	Dietary content, % of dry matter[1]						DMI, kg/d	Milk, kg/d
	Treatment	F:C	Forage	NDF	Forage NDF	Starch		
Replacement of Corn Starch with Nonforage Fiber Sources								
Batajoo and Shaver, 1994; shelled corn and soybean meal replaced with wheat middlings (0 to 9%), dried brewers grains (3 to 20%), and soybean hulls (0 to 9%)	0, 3, 0	48:52	48 AS	28.2	20.5	32.9	27.6[L]	40.2
	7, 7, 0	48:52	48 AS	32.9	20.5	28.5	27.2[L]	39.7
	10, 9, 7	48:52	48 AS	37.4	20.5	24.0	26.7[L]	39.7
	9, 20, 9	48:52	48 AS	42.9	20.5	17.6	25.8[L]	39.5
Leiva et al., 2000, study 1; corn hominy (CH) replaced with dried citrus pulp (24%)	CH	33:67	7 AH, 27 CS	35.9	-	26.5	21.4	32.8
	Citrus pulp	33:67	7 AH, 27 CS	36.5	-	15.1	20.9	31.3
Leiva et al., 2000, study 2; corn meal replaced with dried citrus pulp (21%)	Corn meal	46:54	16 AH, 30 CS	33.8	-	19.1	-	31.8[a]
	Citrus pulp	45:55	16 AH, 29 CS	34.4	-	12.9	-	27.9[b]
Boddugari et al., 2001, study 1; corn and soybean meal replaced with wet corn gluten feed (0 to 45%)	0	54:46	27 AS, 27 CS	28.2	22.8	30E	24.7[a]	30.4
	22	54:46	27 AS, 27 CS	35.4	22.8	23E	22.5[b]	30.5
	34	54:46	27 AS, 27 CS	38.2	22.8	18E	23.1[ab]	30.8
	45	54:46	27 AS, 27 CS	41.6	22.8	15E	21.8[b]	29.5
Ipharraguerre et al., 2002; corn replaced with soybean hulls (0 to 40%)	0	46:54	23 AS, 23 CS	29.4	19.0	38E	23.8	29.5
	10	46:54	23 AS, 23 CS	34.4	19.0	31E	24.8	29.3
	20	46:54	23 AS, 23 CS	39.9	19.0	24E	24.4	29.9
	30	46:54	23 AS, 23 CS	44.8	19.0	17E	22.9	29.3
	40	46:54	23 AS, 23 CS	49.4	19.0	9E	22.7	28.3
Broderick et al., 2002, study 1; high moisture ear corn (HMEC) or cracked corn (CC) replaced with dried citrus pulp (19%)	HMEC	60:40	50 AS, 10 GS	27.4	22.0	30.6	20.0	34.5[A]
	CC	60:40	50 AS, 10 GS	26.2	22.0	31.0	20.9[a]	33.6[a]
	Citrus pulp	60:40	50 AS, 10 GS	28.4	22.0	20.0	19.2[b]	29.9[Bb]

Table 1 continued.

Reference; Treatment information	Treatment	F:C	Forage	NDF	Forage NDF	Starch	DMI, kg/d	Milk, kg/d
	Dietary content, % of dry matter[1]							
Voelker and Allen, 2003a; high moisture corn replaced with pelleted beet pulp (0 to 24%)	0	40:60	20 AS, 20 CS	24.3	17.1	34.6	24.8^{L}	36.4
	6	40:60	20 AS, 20 CS	26.2	17.1	30.5	25.0^{L}	36.6
	12	40:60	20 AS, 20 CS	28.0	17.1	26.5	25.1^{L}	35.9
	24	40:60	20 AS, 20 CS	31.6	17.1	18.4	22.9^{L}	35.4
Ranathunga et al., 2008; corn replaced with dried distillers grains with solubles (0 to 21%)	0	49:51	-	-	21.0	28.0	25.6^{L}	39.4
	7	49:51	-	-	21.0	24.5	25.0^{L}	37.4
	14	49:51	-	-	21.0	21.0	23.4^{L}	37.7
	21	49:51	-	-	21.0	17.5	22.9^{L}	38.3
Replacement of Corn Starch with Other Carbohydrate Sources								
Valadares Filho et al., 2000; alfalfa silage replaced with high moisture corn (19 to 56%)	19	80:20	80 AS	42.9	37.9	12.3	22.1^{LQ}	31.2^{L}
	31	65:35	65 AS	38.2	31.1	20.7	25.2^{LQ}	36.0^{L}
	44	50:50	50 AS	32.6	23.9	29.5	26.4^{LQ}	39.8^{L}
	56	35:65	35 AS	27.7	16.8	38.3	25.6^{LQ}	43.4^{L}
Oba and Allen, 2003a; ground high moisture corn (HMC) or dry ground corn (DGC) at 32 or 21% starch	HMC, 21	66:34	34 AS, 32 CS	30.1	25.3	21.0	19.7^{b}	33.4^{b}
	DGC, 21	66:34	34 AS, 32 CS	30.5	25.4	21.3	19.6^{b}	34.3^{b}
	HMC, 32	43:57	22 AS, 21 CS	23.1	16.5	31.1	20.8^{a}	38.8^{a}
	DGC, 32	43:57	22 AS, 21 CS	24.2	16.5	32.2	22.5^{a}	38.4^{a}
Broderick and Radloff, 2004, study 1; high moisture corn replaced with dried molasses (0 to 12%)	0	60:40	40 AS, 21 CS	28.2	22.9	31.5	25.3^{Lb}	38.0^{Cab}
	4	60:40	40 AS, 21 CS	29.1	22.9	28.4	25.7^{Lab}	37.5^{Cab}
	8	60:40	40 AS, 21 CS	29.2	22.9	25.2	26.3^{La}	38.9^{Ca}
	12	60:40	40 AS, 21 CS	29.3	22.9	23.2	26.0^{Lab}	36.7^{Cb}

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Table 1 continued.

Reference; Treatment information	Treatment	F:C	Forage	NDF	Forage NDF	Starch	DMI, kg/d	Milk, kg/d
	Dietary content, % of dry matter[1]							
Charbonneau et al., 2006; cracked corn (CC, 47%), ground corn (GC, 47%), GC (35%) + wheat starch (WS, 11%), GC (35%) + dried whey permeate (WP, 11%)	CC	45:55	45 AS	28.9	18.8	26.7	22.7[c]	34.0[c]
	GC	45:55	45 AS	27.1	18.8	28.8	24.3[b]	37.4[ab]
	GC + WS	45:55	45 AS	25.1	18.8	33.3	24.4[b]	37.6[a]
	GC + WP	45:55	45 AS	24.9	18.8	21.6	25.7[a]	35.8[b]
Broderick et al., 2008; corn starch replaced with sucrose (0 to 7.5%)	0	60:40	39 AS, 21 CS	30.0	25.6	28.2	24.5[Lb]	38.8
	2.5	60:40	39 AS, 21 CS	29.2	25.6	27.4	25.4[Lab]	40.6
	5.0	60:40	39 AS, 21 CS	29.6	25.6	24.5	26.0[La]	39.4
	7.5	60:40	39 AS, 21 CS	29.6	25.6	21.5	26.0[La]	39.3
Gozho and Mutsvangwa, 2008; barley (31%), corn (29%), wheat (33%), and oats (31%) as primary starch source	Barley	48:52	18 AH, 30 BS	32.7	-	19.2	26.2	40.2
	Corn	48:52	18 AH, 30 BS	32.9	-	21.8	26.0	38.9
	Wheat	52:48	20 AH, 32 BS	33.0	-	22.4	24.0	36.8
	Oats	48:52	18 AH, 30 BS	35.7	-	15.2	25.2	38.4
Abdelqader et al., 2009; corn and soybean meal replaced with corn germ (0 to 21%)	0	55:45	25 AH, 30 CS	28.3	23.5	24	28.1[Q]	37.3[Q]
	7	55:45	25 AH, 30 CS	28.8	23.5	23.3	29.1[Q]	38.0[Q]
	14	55:45	25 AH, 30 CS	29.8	23.5	21.6	28.8[Q]	38.2[Q]
	21	55:45	25 AH, 30 CS	30.7	23.5	19.3	27.3[Q]	36.3[Q]
Arndt et al., 2009; corn (C) replaced with corn bran (CB;19, 38%) in high forage (HF, 64%) and low forage (LF, 38%) diets	HFC	64:36	29 AS, 36 CS	29.7	18.1	25.6	24.8[bc]	42.0[b]
	HFCB	64:36	29 AS, 36 CS	42.6	18.1	14.8	24.3[c]	38.7[c]
	LFC	38:62	17 AS, 21 CS	23.1	10.9	34.0	26.7[a]	46.7[a]
	LFCB	38:62	17 AS, 21 CS	48.4	10.8	12.5	25.9[ab]	40.5[bc]

[1] F:C = forage to concentrate ratio, NDF = neutral detergent fiber, DMI = dry matter intake, AS = alfalfa silage, AH = alfalfa hay, CS = corn silage, GS = grass silage, BS = barley silage, E = starch content estimated with CPM-Dairy v.3.
[L] = linear effect with $P \leq 0.05$, [Q] = quadratic effect with $P \leq 0.05$, [C] = cubic effect with $P \leq 0.05$, [abc or AB] Least squares means within the same column and study without a common superscript differ with $P \leq 0.05$.

Table 2. Ingredient and chemical composition (dry matter basis) of diets containing 18, 21, or 25% starch fed to lactating Holstein cows

	Diet		
Item	18% starch	21% starch	25% starch
Ingredient composition			
Corn silage, %	30.2	30.2	30.4
Grass silage, %	18.5	18.4	18.6
Alfalfa hay, %	5.0	5.0	5.1
Soybean meal (48%), %	7.1	8.0	8.4
Corn, finely ground, %	3.4	10.1	16.9
Beet pulp, %	6.7	3.4	-
Wheat middlings, %	13.4	10.1	6.8
Distillers grains, %	9.7	8.7	7.8
Other, %	6.0	6.1	6.0
Chemical composition			
Crude protein, %	17.4	17.6	17.2
Acid detergent fiber, %	22.2	20.8	20.0
Neutral detergent fiber, %	38.0	36.5	34.2
Forage neutral detergent fiber, %	24.7	24.7	24.8
Sugar, %	4.8	3.9	3.6
Starch, %	17.7	21.0	24.6
Starch 6-h digestibility, % starch	82.5	77.3	73.6
Rumen fermentable starch, %	14.6	16.2	18.1

Table 3. Lactational performance, ruminal fermentation, and total tract digestibility data of lactating Holstein cows fed diets containing 18, 21, or 25% starch

	Diet				
Item[1]	18% starch	21% starch	25% starch	SEM	*P*-value
DMI, kg/d	26.4	26.9	26.3	0.8	0.51
DMI, % of BW/d	3.68	3.72	3.65	0.10	0.60
Milk, kg/d	42.9	43.4	44.1	1.9	0.60
3.5 % FCM, kg/d	43.1	43.4	43.8	1.8	0.86
Milk fat, %	3.57	3.57	3.48	0.15	0.45
Milk true protein, %	3.09	3.18	3.14	0.07	0.19
Milk/DMI, kg/kg	1.64	1.62	1.68	0.08	0.32
Ruminal pH	6.10	6.01	6.07	0.12	0.76
Total VFA, m*M*	151.8	153.4	145.2	6.0	0.21
Acetate: propionate	2.3	2.3	2.6	0.3	0.70
Microbial nitrogen, g/d	579	590	583	24	0.75
Organic matter TTD, %	67.0[b]	67.3[b]	69.2[a]	0.5	0.009
NDF TTD, %	43.7	43.4	42.3	1.2	0.62
Starch TTD, %	98.2	98.3	98.5	0.1	0.25

[1] DMI = dry matter intake, BW = body weight, FCM = fat-corrected milk, VFA = volatile fatty acids, TTD = total tract digestibility, NDF = neutral detergent fiber.
[ab] Least squares means within a row without a common superscript differ ($P \leq 0.05$).

Table 4. Ingredient and chemical composition (dry matter basis) of low-starch diets varying in forage content (52, 47, 43, and 39% forage) fed to lactating Holstein cows

Item	Diet			
	52% forage	47% forage	43% forage	39% forage
Ingredient composition				
Corn silage, %	37.3	34.0	31.0	27.9
Alfalfa-grass silage, %	14.5	11.1	5.9	0.6
Wheat straw, %	-	2.1	6.2	10.3
Distillers grains, %	11.1	10.3	9.5	8.8
Soybean meal (48%), %	11.0	11.0	11.4	12.2
Wheat middlings, %	7.4	12.5	16.1	19.3
Corn, finely ground, %	5.6	5.4	6.4	7.3
Beet pulp, %	6.2	6.2	6.2	6.2
Other, %	6.9	7.4	7.3	7.4
Chemical composition				
Crude protein, %	17.3	17.7	17.3	18.1
Acid detergent fiber, %	20.5	20.6	19.9	19.1
Neutral detergent fiber (NDF), %	37.4	37.5	37.0	36.0
Forage NDF, %	25.0	23.1	21.7	20.3
Starch, %	20.2	20.8	21.2	21.6
Sugar, %	4.6	4.8	5.1	5.2

SESSION NOTES