Feeding Low Starch Diets

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Abstract

A common recommendation for dietary starch content for lactating dairy cows is between 23 and 26%. However, some of the most productive herds in the U.S. feed diets that contain between 15 and 30% starch. High corn prices have increased interest in feeding lower-starch diets. Corn grain can be replaced with byproduct feeds high in digestible fiber in lactating dairy cow diets, resulting in a low-starch diet without adversely affecting lactational performance and ruminal fermentation. Dietary starch content between 18 and 21% appears to be acceptable when high quality forages are fed and the dietary starch is highly fermentable in the rumen.

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 produce more than 28,000 lb of milk per cow per year found that dietary starch content ranged between 15 and 30% (Table 1; 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 during the past 2 years. Consequently, lower-starch feeding strategies that minimize the amount of corn may be more profitable than higher-starch diets, particularly if lactation 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 more high-quality forage and using more byproduct feeds to provide highly digestible neutral detergent fiber **(NDF)** and nonfiber carbohydrates (Chase, 2007; Knapp, 2007, Staples, 2007; Shaver, 2008). These strategies can result in a lower dietary starch content.

Summarized in Table 2 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. Most of the studies were conducted as either Latin square or crossover designs with the period typically $\leq$ 4 weeks, except for of a few studies that used either a completely randomized design (Ranathunga et al., 2008) or a randomized complete block design (Broderick et al., 2002; Broderick and Radloff, 2004; Broderick et al., 2008) with the treatment period typically $\leq$ 8 wk. In general, mid-lactation Holstein cows were used.

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Replacement of corn starch with nonforage fiber sources

Many NFFS, such as soybean hulls **(SH)**, beet pulp **(BP)**, citrus pulp, corn gluten feed **(CGF)**, and dried distillers grains with solubles **(DDGS)** are characterized by low-starch content, high-fiber digestibility, and variable content of soluble fiber and sugar. 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 10%), dried brewers grains (3 to 20%), and SH (0 to 9%) to provide alfalfa silage-based diets (48:52 forage:concentrate, **(F:C)**) 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 (46:54 F:C) for mid-lactation cows. Estimated starch content ranged from 38% on the 0% SH diet to 9% on the 40% SH diet. There tended to be a linear decrease in DMI as SH replaced corn and the starch content decreased, 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. Milk fat content increased linearly with more SH and less starch. Thus, cows can be successfully fed a 19% starch diet containing up to 30% SH.

Voelker and Allen (2003abc) replaced high moisture corn with 0 to 24% BP to formulate alfalfa/corn silage-based diets (40:60 F:C) 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 **(OM)** 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 (33:67 F:C) 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 (60:40 F:C) and partially replaced high moisture ear corn or cracked corn with citrus pulp (19%). Inclusion of citrus pulp reduced the dietary starch content from 31 to 20%. Dry matter intake and milk yield were reduced when the citrus pulp was fed. However, feed efficiency and body condition were unchanged.

Boddugari et al. (2001) replaced corn and soybean meal with wet CGF (0 to 40%) in alfalfa/corn silage based diets (54:46) fed to lactating cows. Estimated starch content decreased from 30 to 15% as the amount of wet CGF increased. Dry matter intake tended to be lower for the diets containing the wet CGF. Diet did not affect milk yield or milk composition. However, feed efficiency improved with the inclusion of wet CGF in the lower-starch diets. In another study, lactating cows were fed diets containing 49:51 F:C and 21% forage NDF with a starch content ranging from 28 to 17.5% (Ranathunga et al., 2008). As corn starch was partially replaced with DDGS (0 to 21%), DMI linearly decreased and feed efficiency tended to linearly increase. There was no effect of diet on milk yield or composition.

Replacement of corn starch with sugar sources

Replacing corn starch with sugar sources in high forage (60:40 F:C) 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, OM, and NDF but had no effect on milk yield and ruminal fermentation. However, there was a quadratic effect on milk fat content and yield. 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.

Replacement of corn starch with forage sources

Another feasible strategy to reduce the dietary starch content is to replace corn with high-quality forage. Valadares Filho et al. (2000) varied the F:C from 35:65 to 80:20 and the starch content from 38.3 to 12.3% of diets for lactating cows by substituting 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 concentration (12.3%; 80:20 F:C). There were linear and quadratic responses in milk fat content and yield. Reducing the dietary starch content to less than 20.7% (65:35 F:C) should be avoided when substituting alfalfa silage for high corn starch. Oba and Allen (2003ab) fed lactating cows diets containing either ground high moisture corn or dry ground corn at 2 dietary starch contents (32 and 21%). The high-starch diets (43:57 F:C) contained 22% alfalfa silage and 21% corn silage and the low-starch diets (66:34 F:C) contained 34% alfalfa silage and 32% corn silage. 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 concentrationt. Interestingly, the ground corn treatment increased productivity of cows fed the high-starch diets because of greater DMI. However, the corn grain treatment did not affect the productivity of cows fed the low-starch diets. Oba and Allen (2003b) suggested that the optimal ruminal starch digestibility is dependent on the starch content and fermentability of the diets.

Research at Miner Institute with Low-Starch Diets

We (Dann et al., 2008) used 12 multiparous cows (118 ± 5 days in milk; 3 ruminally fistulated) in a replicated 3×3 Latin square design study with 21-day periods (7-day collection) to determine the effect of feeding diets (Table 3) containing low-starch (18%), medium-starch (21%), or high-starch (25%) on lactational performance, ruminal fermentation, and total tract nutrient digestibility (Table 4). Diets were formulated to have a range in starch content to encompass the range from little supplemental corn grain to an amount of corn grain typically fed. All diets contained similar amounts of corn silage (30%), grass silage (19%), and alfalfa hay (5%). Dietary starch was manipulated by reducing the amount of corn grain and increasing the amount of beet pulp, wheat middlings, and DDGS. Consequently, NDF content, sugar content, and in vitro 6-hour starch digestibility increased with increasing byproduct incorporation, reflecting the differences in chemical composition between the corn grain and the byproducts. As dietary starch decreased in this study, 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).

Cows were able to maintain high productivity on all diets. Dry matter intake (58.4 lb/day), milk yield (95.6 lb/day), milk fat content (3.54%), milk true protein content (3.14%), and efficiency of milk production (1.65 lb milk/lb DMI) were unaffected by diet. There was a significant increase in milk urea nitrogen as dietary starch content decreased, although the difference in milk urea nitrogen (13.3 to 14.6 mg/dL) was small and biologically insignificant.

All diets contained the same amount of forage NDF (24.7%) processed in the same manner and so we expected no difference in chewing response among the diets. Total chewing and ruminating averaged 815 and 530 min/day, respectively. Diet also had no effect on ruminal pH averaged over 24 hours (6.06), total volatile fatty acids (150 mM), acetate:propionate (2.4), or microbial nitrogen yield (1.29 lb/day). Total tract digestibility of OM 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. Digestibilities of crude protein, NDF, and starch were 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, the digestibility of that starch increased simultaneously in our study. 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. Ultimately, the cow needs a certain amount of rumen fermentable starch, or fermentable carbohydrate, which will be a function of the amount and the digestibility of the starch and other carbohydrate fractions.

Previous research has not addressed how little forage can be fed with a low-starch diet. We (Myers et al., 2009) used 16 lactating Holstein cows (116 ± 5 days in milk; 8 ruminally fistulated) in a replicated 4×4 Latin square design study with 21-day periods (9-day collection) to determine the effect of feeding diets (Table 5) containing low-starch (formulated at 19% of DM) and different amounts of forage (52, 47, 43, and 39% of DM) on lactational performance, ruminal characteristics, and total tract digestibility (Table 6). The forage portion (corn silage, alfalfa-grass silage, and wheat straw) of all diets consisted of 72% corn silage. As the forage content of the diets decreased, the amount of wheat straw increased and the amount of alfalfa-grass silage decreased. The concentrate portion of the diets was adjusted to maintain as similar as possible amounts of starch, other carbohydrate fractions, and protein fractions.

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. Diet did not affect milk yield (93.7 lb/day), 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 lb milk/lb DMI) when cows were fed the 52% forage diet and lowest (1.77) when cows were fed the 39% forage diet. Interestingly, efficiency of milk production was good for all diets (≥ 1.77) with minimal body weight and body condition change. The concentration of urea nitrogen in milk was lowest for the 52 and 47% forage diets and highest for the 43 and 39% forage diets. The higher milk urea nitrogen concentration indicated less efficient use of dietary nitrogen. The 39% forage diet had the highest crude protein content (18.1%) and the 43% forage diet had the lowest crude protein content (17.3%). Soluble protein was lower for the lower forage diets, which does not explain the finding of higher milk urea nitrogen. Possibly, the rate and amount of fermentable carbohydrate was not appropriate to capture the available nitrogen on the lower forage diets.

Time spent chewing (777 min/day; 42 min/lb NDF), eating (263 min/day; 14 min/lb NDF) and ruminating (515 min/day; 28 min/lb NDF) expressed as minutes per day or minutes per pound of NDF were not affected by diet. All diets resulted in at least 70 min of total chewing activity per pound of physically effective NDF, which is above the minimum of 68 min of total chewing activity per pound of physically effective NDF to maintain optimal ruminal function (Mertens, 1997). As expected, mean ruminal pH (6.07) and microbial nitrogen yield (0.99 lb/day) were not affected by diet. As the forage content of the diets decreased from 52 to 39%, the total tract OM digestibility decreased from 65 to 61% and the total tract NDF digestibility decreased from 39 to 29%.

Overall, the diet containing the highest level of straw and lowest amount of forage compromised lactation performance and reduced efficiency of milk production. 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 grains and forages, but the limit appears to be between 39 and 43% forage with these types of diets when high productivity is expected.

The optimal dietary starch content during the dry period and fresh period is unclear and requires more research. It is questionable whether a low-starch diet that contains large amounts of fibrous byproduct feeds, such as that fed by Dann et al. (2008) and Myers et al. (2009), can support the energy needs of cows during early to peak lactation. In our next low-starch study, we will feed cows a low-energy, high-straw diet during a 40-day dry period, then feed either: 1) a low-starch (~18%) diet for the first 91 days of lactation, 2) a medium-starch (~24%) diet for the first 91 days of lactation, or 3) a low-starch diet for 21 days of lactation and a medium-starch diet for the next 70 days of lactation. Lactational performance will be evaluated. If feeding dairy cows a low-energy diet during a short dry period and a low-starch diet in early to peak lactation can be successfully implemented without compromising production and animal health, herd profitability of dairy farms may be improved.

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 weeks) 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 digestibilities. 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.

Conclusion

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. Dietary starch content (dry matter basis) of high producing herds surveyed in the U.S.

Reference	Region	RHA[1], lb	Herds	Starch, %	
				Minimum	Maximum
Hall and Van Horn, 2001	U.S.	-	-	15	27
Johnson et al., 2002	WA	28,000	7	17	25
Shaver and Kaiser, 2004	WI	29,000	6	25	30
Chase, 2006	U.S. (East, Midwest)	29,000	25	21	30

[1]RHA = rolling herd average.

Table 2. 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	Treatment	F:C	Forage	NDF	Forage NDF	Starch	DMI, lb/day	Milk, lb/day
	Dietary content, % of dry matter[1]							
	Replacement of Corn Starch with Nonforage Fiber Sources							
Batajoo and Shaver, 1994; shelled corn	0, 3, 0	48:52	48 AS	28.2	20.5	32.9	60.7[L]	88.4
and soybean meal replaced with wheat	7, 7, 0	48:52	48 AS	32.9	20.5	28.5	59.8[L]	87.3
middlings (0 to 10%), dried brewers grains	10, 9, 7	48:52	48 AS	37.4	20.5	24.0	58.7[L]	87.3
(3 to 20%), and soybean hulls (0 to 9%)	9, 20, 9	48:52	48 AS	42.9	20.5	17.6	56.8[L]	86.9
Leiva et al., 2000, Study 1; corn hominy (CH)	CH	33:67	6 AH, 27 CS	35.9	-	26.5	47.1	72.2
replaced with dried citrus pulp (24%)	Citrus pulp	33:67	6 AH, 27 CS	36.5	-	15.1	46.0	68.9
Leiva et al., 2000, Study 2; corn meal	Corn meal	46:54	16 AH, 30 CS	33.8	-	19.1	-	70.0[a]
replaced with dried citrus pulp (21%)	Citrus pulp	45:55	16 AH, 29 CS	34.4	-	12.9	-	61.4[b]
Boddugari et al., 2001, Study 1; corn and	0	54:46	27 AS, 27 CS	28.2	22.8	30E	54.3[a]	66.9
soybean meal replaced with wet corn gluten	22	54:46	27 AS, 27 CS	35.4	22.8	23E	49.5[b]	67.1
feed (0 to 45%)	34	54:46	27 AS, 27 CS	38.2	22.8	18E	50.8[ab]	67.8
	45	54:46	27 AS, 27 CS	41.6	22.8	15E	48.0[b]	64.9
Ipharraguerre et al., 2002; corn replaced	0	46:54	23 AS, 23 CS	29.4	19.0	38E	52.4	64.9
with soybean hulls (0 to 40%)	10	46:54	23 AS, 23 CS	34.4	19.0	31E	54.6	64.5
	20	46:54	23 AS, 23 CS	39.9	19.0	24E	53.7	65.8
	30	46:54	23 AS, 23 CS	44.8	19.0	17E	50.4	64.5
	40	46:54	23 AS, 23 CS	49.4	19.0	9E	49.9	62.3
Broderick et al., 2002, Study 1; high moisture	HMEC	60:40	50 AS, 10 GS	27.4	22.0	30.6	44.0	75.9[A]
ear corn (HMEC) or cracked corn (CC)	CC	60:40	50 AS, 10 GS	26.2	22.0	31.0	46.0[a]	73.9[a]
replaced with dried citrus pulp (19%)	Citrus pulp	60:40	50 AS, 10 GS	28.4	22.0	20.0	42.2[b]	65.8[Bb]

Table 2. continued. Summary of selected research where corn starch was replaced with nonforage fiber sources or other carbohydrate sources resulting in low-starch (< 23%) diets.

	Dietary content, % of dry matter[1]							
Reference; Treatment information	Treatment	F:C	Forage	NDF	Forage NDF	Starch	DMI, lb/day	Milk, lb/day
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	54.6[L]	80.1
	6	40:60	20 AS, 20 CS	26.2	17.1	30.5	55.0[L]	80.5
	12	40:60	20 AS, 20 CS	28.0	17.1	26.5	55.2[L]	79.0
	24	40:60	20 AS, 20 CS	31.6	17.1	18.4	50.4[L]	77.9
Ranathunga et al., 2008; corn replaced with dried distillers grains with solubles (0 to 21%)	0	49:51	-	-	21.0	28.0	56.3[L]	86.7
	7	49:51	-	-	21.0	24.5	55.0[L]	82.3
	14	49:51	-	-	21.0	21.0	51.5[L]	82.9
	21	49:51	-	-	21.0	17.5	50.4[L]	84.3
Replacement of Corn Start 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	48.6[LQ]	68.6[L]
	31	65:35	65 AS	38.2	31.1	20.7	55.4[LQ]	79.2[L]
	44	50:50	50 AS	32.6	23.9	29.5	58.1[LQ]	87.6[L]
	56	35:65	35 AS	27.7	16.8	38.3	56.3[LQ]	95.5[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	43.3[b]	73.5[b]
	DGC, 21	66:34	34 AS, 32 CS	30.5	25.4	21.3	43.1[b]	75.5[b]
	HMC, 32	43:57	22 AS, 21 CS	23.1	16.5	31.1	45.8[b]	85.4[a]
	DGC, 32	43:57	22 AS, 21 CS	24.2	16.5	32.2	49.5[a]	84.5[a]
Broderick and Radloff, 2004, Study 1; high moisture corn replaced with dried molasses (0 to 12%)	0	61:39	40 AS, 21 CS	28.2	22.9	31.5	55.7[Lb]	83.6[Cab]
	4	61:39	40 AS, 21 CS	29.1	22.9	28.4	56.5[Lab]	82.5[Cab]
	8	61:39	40 AS, 21 CS	29.2	22.9	25.2	57.9[La]	85.6[Ca]
	12	61:39	40 AS, 21 CS	29.3	22.9	23.2	57.2[Lab]	80.7[Cb]

Table 2 continued. Summary of selected research where corn starch was replaced with nonforage fiber sources or other carbohydrate sources resulting in low-starch (< 23%) diets.

		Dietary content, % of dry matter[1]						
Reference; Treatment information	Treatment	F:C	Forage	NDF	Forage NDF	Starch	DMI, lb/day	Milk, lb/day
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	49.9[c]	74.8[c]
	GC	45:55	45 AS	27.1	18.8	28.8	53.5[b]	82.3[ab]
	GC + WS	45:55	45 AS	25.1	18.8	33.3	53.7[b]	82.7[a]
	GC + WP	45:55	45 AS	24.9	18.8	21.6	56.5[a]	78.8[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	53.9[La]	85.4
	2.5	60:40	39 AS, 21 CS	29.2	25.6	27.4	55.9[Lab]	89.3
	5.0	60:40	39 AS 21 CS	29.6	25.6	24.5	57.2[La]	86.5
Gozho and Mutsvangawa, 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	57.6	88.4
	Corn	48:52	18 AH, 30 BS	32.9	-	21.8	57.2	85.6
	Wheat	52:48	20 AH, 32 BS	33.0	-	22.4	52.8	81.0
	Oats	48:52	18 AH, 30 BS	35.7	-	15.2	55.4	84.5
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	24.0	61.8[Q]	82.1[Q]
	7	55:45	25 AH, 30 CS	28.8	23.5	23.3	64.0[Q]	83.6[Q]
	14	55:45	25 AH, 30 CS	29.8	23.5	21.6	63.4[Q]	84.0[Q]
	21	55:45	25 AH, 30 CS	30.7	23.5	19.3	60.1[Q]	79.9[Q]

[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, and E = starch content estimated with CPM-Dairy v.3.

[L]= Linear effect with $P < 0.05$

[Q] =quadratic effect with $P < 0.05$

[C]= cubic effect with $P < 0.05$

[abc or AB] Least squares means within the same column and study without a common superscript differ with $P < 0.05$.

Table 3. Ingredient and chemical composition (dry matter basis) of diets containing 18, 21, or 25% starch fed to lactating Holstein cows (Dann et al., 2008).

	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% CP), %	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 (ethanol soluble carbohydrate), %	4.8	3.9	3.6
Starch, %	17.7	21.0	24.6
Starch 6-hour digestibility, % of starch	82.5	77.3	73.6
Rumen fermentable starch, %	14.6	16.2	18.1

Table 4. Lactational performance, ruminal fermentation, and total tract digestibility data of lactating Holstein cows fed diets containing 18, 21, or 25% starch (Dann et al., 2008)[1].

	Diet				
Item	18% starch	21% starch	25% starch	SEM	*P*-value
Lactational performance					
DMI, lb/day	58.1	59.2	57.9	1.8	0.51
DMI, % of BW/day	3.68	3.72	3.65	0.10	0.60
BW, lb	1580	1595	1588	35	0.27
BW change, lb/21 days	13	24	15	9	0.66
BCS	2.90	2.83	2.95	0.13	0.12
BCS change, unit/21 days	-0.04	-0.12	0.00	0.06	0.34
Milk, lb/d	94.4	95.5	97.0	4.2	0.60
3.5 % FCM, lb/day	94.8	95.5	96.4	4.0	0.86
Milk fat, %	3.57	3.57	3.48	0.15	0.45
Milk fat, lb/day	3.30	3.30	3.23	0.18	0.90
Milk true protein, %	3.09	3.18	3.14	0.07	0.19
Milk true protein, lb/day	2.88	2.97	2.93	0.13	0.75
Milk urea nitrogen, mg/dL	14.6[a]	14.8[a]	13.3[b]	0.7	0.04
Milk/DMI, lb/lb	1.64	1.62	1.68	0.08	0.32
3.5 % FCM/DMI, lb/lb	1.64	1.61	1.67	0.05	0.48
Ruminal fermentation					
Ruminal pH	6.10	6.01	6.07	0.12	0.76
Area < 5.8 pH	1.29	1.61	1.75	0.52	0.74
Total VFA, m*M*	151.8	153.4	145.2	6.0	0.21
Acetate, m*M*	87.0	85.8	87.1	3.5	0.94
Propionate, m*M*	38.6	38.3	34.5	2.9	0.51
Butyrate, m*M*	19.5[a]	18.9[ab]	17.4[b]	1.1	0.01
Acetate: propionate	2.3	2.3	2.6	0.3	0.70
Microbial nitrogen, lb/day	1.28	1.30	1.28	0.05	0.75
Total tract digestibility					
Dry matter, %	64.5[b]	64.8[b]	67.1[a]	0.6	0.004
Organic matter, %	67.0[b]	67.3[b]	69.2[a]	0.5	0.009
Crude protein, %	66.8	66.4	68.1	0.9	0.21
Acid detergent fiber, %	42.4	40.6	42.2	1.4	0.60
Neutral detergent fiber, %	43.7	43.4	42.3	1.2	0.62
Starch, %	98.2	98.3	98.5	0.1	0.25

[1]DMI = Dry matter intake, BW = body weight, BCS = body condition score, FCM = fat-corrected milk, Area < 5.8 pH = ruminal pH units below 5.8 by hour, VFA = volatile fatty acids, and SEM = standard error of mean.

[ab]Least squares means within a row without a common superscript differ ($P < 0.05$).

Table 5. 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 (Myers et al., 2009).

	Diet			
Item	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% CP), %	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
Physically effective NDF, %	21.5	20.2	19.2	18.9
Starch, %	20.2	20.8	21.2	21.6
Sugar, %	4.6	4.8	5.1	5.2

Table 6. Lactational performance, ruminal fermentation, and total tract digestibility data of lactating Holstein cows fed low-starch diets varying in forage content (52, 47, 43, and 39% forage) (Myers et al., 2009)[1].

Item	Diet: 52% forage	47% forage	43% forage	39% forage	SEM	*P*-value
Lactational performance						
DMI, lb/day	50.2	51.5	51.5	53.0	1.1	0.07
DMI, % of BW/day	3.47[b]	3.55[ab]	3.54[ab]	3.67[a]	0.1	0.03
BW, lb	1459	1463	1465	1456	31	0.74
BW change, lb/19 days	0	9	13	-11	9	0.22
BCS	2.97	2.94	2.98	3.01	0.10	0.49
BCS change, unit/19 days	-0.08	-0.08	-0.08	-0.07	0.04	0.99
Milk, lb/day	93.5	93.7	94.2	93.7	2.9	0.99
3.5 % FCM, lb/day	94.8	93.9	96.6	94.8	2.6	0.59
Milk fat, %	3.62	3.52	3.68	3.59	0.09	0.24
Milk fat, lb/day	3.37	3.32	3.45	3.37	0.11	0.55
Milk true protein, %	2.99	3.01	3.04	3.02	0.04	0.32
Milk true protein, lb/day	2.79	2.82	2.84	2.84	0.09	0.74
Milk urea nitrogen, mg/dL	15.5[b]	15.3[b]	17.3[a]	18.4[a]	0.8	<0.001
Milk/DMI, lb/lb	1.87[a]	1.82[ab]	1.84[ab]	1.77[b]	0.04	0.02
3.5 % FCM/DMI, lb/lb	1.90[a]	1.83[ab]	1.89[ab]	1.80[b]	0.04	0.02
Ruminal fermentation						
Ruminal pH	6.06	6.02	6.06	6.13	0.07	0.15
Area < 5.8 pH	1.0	1.3	1.3	0.2	0.6	0.20
Microbial nitrogen, lb/day	0.98	0.98	1.00	1.00	0.04	0.73
Total tract digestibility						
Dry matter, %	62.2[a]	60.9[ab]	59.8[bc]	58.6[c]	0.7	<0.001
Organic matter, %	64.5[a]	63.3[ab]	62.0[bc]	61.0[c]	0.7	<0.001
Crude protein, %	67.7	67.8	66.1	67.9	0.7	0.09
Acid detergent fiber, %	34.1[a]	31.4[ab]	28.5[b]	23.1[c]	1.3	<0.001
Neutral detergent fiber, %	39.4[a]	35.9[ab]	34.0[b]	29.1[c]	1.3	<0.001
Starch, %	97.1	97.3	97.4	97.3	0.2	0.69

[1]DMI = Dry matter intake, BW = body weight, BCS = body condition score, FCM = fat-corrected milk, Area < 5.8 = ruminal pH units below 5.8 by hour, and SEM = standard error of mean.
[abc]Least squares means within a row without a common superscript differ ($P < 0.05$).