Impact of the Maturity of Corn for Use as Silage in the Diets of Dairy Cows on Intake, Digestion, and Milk Production

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ABSTRACT

Whole-plant corn was harvested at early dent, quarter milkline, two-thirds milkline, and black layer stages to evaluate the effects of maturity on intake, digestion, and milk production when corn was fed as silage in the diet. Twenty multiparous Holstein cows were used in a replicated experiment with a 4 × 4 Latin square design with 28-d periods. Diets containing 50% forage (67% corn silage and 33% alfalfa silage) and 50% concentrate (dry matter basis) were fed as total mixed rations. Moisture contents were 69.9, 67.6, 64.9, and 58.0% for silages from corn harvested at early dent, quarter milkline, two-thirds milkline, and black layer stages, respectively. Intakes of dry matter were similar across the four treatments and ranged from 3.73 to 3.79% of body weight. Milk production was highest (33.4 kg/d) for cows fed silage from corn harvested at the two-thirds milkline stage and lowest (32.4 kg/d) for cows fed silage from corn harvested at the early dent stage. Milk protein production was highest for cows fed silage from corn harvested at the two-thirds milkline stage (1.17 vs. 1.12 to 1.13 kg/d). Apparent total tract digestion of dry matter, organic matter, crude protein, acid detergent fiber, and starch was lowest for cows fed silage from corn harvested at the black layer stage. Although starch intake was similar for cows fed silage from corn harvested at the two-thirds milkline stage and for cows fed silage from corn harvested at the black layer stage (9 kg/d), intake of digestible starch was 0.4 kg/d lower for cows fed silage from corn harvested at the black layer stage. The optimum stage for corn that was ensiled was two-thirds milkline with some flexibility between quarter and two-thirds milkline.

(**Key words**: corn silage, intake, digestion, milk production)

Abbreviation key: **BL** = black layer, **ED** = early dent, **LAB** = lactic acid bacteria, **1/4 ML** = quarter milkline, **2/3 ML** = two-thirds milkline, **WPC** = whole-plant corn.

INTRODUCTION

Achieving high DM yield from whole-plant corn (**WPC**) and high milk production from cows fed WPC depends on the harvesting of the corn at the proper stage of maturity. Agronomic trials (7) have shown that DM yields of WPC are maximized by harvesting at two-thirds milkline (**2/3 ML**) to black layer (**BL**) stages.

At an immature stage of harvest, fiber concentrations are highest, which lowers the energy density of WPC (13). At a mature stage of harvest, digestibility of the stover is reduced (26), which may lower the energy density of WPC. Additionally, harvest of WPC at a mature stage may increase whole kernel passage and lower starch digestibility (10), resulting in lower energy density. Neither stover nor starch digestibility is considered in most equations that predict the energy value of silage from WPC from ADF concentration (15).

Moisture content of WPC is inversely related to stage of maturity at harvest (26). Whole-plant corn harvested at an immature or mature stage may be either too wet or too dry, respectively, for good silage preservation. Studies are limited on the feeding value of WPC harvested at varying stages of maturity for use as silage in the diets of lactating dairy cows. Huber et al. (12) reported increases in silage DMI and in milk production of cows as the maturity of WPC at harvest advanced from the soft stage to the hard dough stage. Harrison et al. (10) found higher milk production and total tract starch digestion for cows fed silage from WPC harvested at the one-half milkline stage versus milk production and starch digestion for cows fed silage from WPC harvested at the BL stage.

The objective of this study was to evaluate the effect of harvesting WPC at four stages of maturity for use as silage in the diets of dairy cows on DMI, total tract nutrient digestion, and milk production and composition.

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MATERIALS AND METHODS

At 110 d of relative maturity, a corn hybrid (4277; Cargill, Minneapolis, MN) selected for high grain yield was planted on a 5-ha plot at the University of Wisconsin, Arlington Experimental Station (Arlington). At harvest, the plot was divided into quadrants. Equal quantities of DM were removed from each of the four quadrants during harvest at each of the four stages of maturity. The harvest time was based on visual assessment of kernel milkline positioning. Harvest of WPC was at early dent (approximately half of kernels dented) (**ED**), quarter milkline (**1/4 ML**), 2/3 ML, and BL stages. After harvest at the ED stage in late August 1994, harvest of corn at 1/4 ML, 2/3 ML, and the BL stages was at 13-, 10-, and 20-d intervals, respectively. Whole-plant corn was harvested using a Gehl 8 knife chopper (model 860; Gehl, West Bend, WI) set at a 0.64-cm theoretical length of cut. Approximately 15 tonne of DM from each of the four maturities were stored in individual silo bags. Fermentation was for at least 1 mo before the bags were opened to start the feeding trial.

Twenty multiparous Holstein cows averaging 75 DIM at trial initiation were randomly assigned to treatment in a replicated 4 × 4 Latin square design with 28-d periods. The first 14 d of each experimental period were for diet adaptation; sampling was during d 15 to 28 of each period. Diets containing 50% forage and 50% concentrate (DM basis) were fed as a TMR once daily. The forage portion of the diet consisted of 67% corn silage and 33% alfalfa silage (DM basis). Treatment diets contained silage from corn harvested at the ED, 1/4 ML, 2/3 ML, or BL stages. Corn silages were removed from the silo bags and hauled to the University of Wisconsin, Madison Dairy Cattle Center every 3rd d. Upon delivery, dry buffered propionic acid (Myco Curb®; Kemin Inc., Des Moines, IA) was mixed by hand with each silage at the rate of 0.5% (as-fed basis) to inhibit aerobic deterioration during feedout. All cows received the same grain mix (Table 3), which was formulated to provide 18% CP (DM basis) in the diet and to meet or exceed NRC (19) allowances for minerals and vitamins.

Cows were milked twice daily, and production was recorded at each milking. Milk weights recorded during d 15 to 28 of each period were used for data analysis. Milk fat and protein concentrations were determined on a.m. and p.m. samples obtained on 3 consecutive d during the last week of each period by infrared analysis (Wisconsin DHI Laboratory, Appleton). Mean daily milk composition was an average of a.m. and p.m. samples using the proportion of daily production at each milking as a weighting factor. Body weight was recorded at the same time after the a.m. milking on 3 consecutive d at the start of the trial and on d 26 to 28 of each period. Amounts of feed offered and orts were recorded daily.

Corn silage and alfalfa silage DM were measured weekly using toluene distillation (4) for adjustment of the diet. Alfalfa silage, corn silages, and concentrate were sampled weekly during the last 2 wk of each period and composited by treatment within period for nutrient analyses. Orts were sampled on d 26 to 28 of each period and composited by cow within period. Samples were placed in a 60°C forced-air oven for 48 h and then ground through a Wiley mill (2-mm screen; Arthur H. Thomas, Philadelphia, PA). Feed and ort composites were analyzed for DM, OM, CP (2), ADF (8), sulfuric acid lignin (25), and NDF (25) using α-amylase (Sigma no. A3306; Sigma Chemical Co., St. Louis, MO) and sodium sulfite. Measurement of starch and free glucose on feed and ort samples was by endoamylase and exoglucosidase incubation prior to the use of a glucose oxidase assay (11).

Corn silages were sampled upon delivery to the Dairy Cattle Center during the last 2 wk of each period, composited by period, and then analyzed for pH, lactic acid, VFA, and ethanol. Silage pH was determined as follows: approximately 50 g of duplicate samples were diluted with distilled water to 200 g in a blender jar. Samples were macerated for 30 s, macerated samples were filtered through two layers of cheesecloth, and pH was measured using a glass electrode pH meter (Corning no. 150; Corning Science Products, Corning, NY). Aliquots of the filtered extract (30 ml) were centrifuged at 25,000 × g for 30 min. Collected supernatants were frozen at –20°C until analyzed for organic acids and ethanol by HPLC (Varian Instrument Group, Walnut Creek, CA) as described by Muck and Dickerson (17).

Chopped fresh WPC samples (400 g) were obtained from the second, fourth, and sixth loads of each maturity stage as they were delivered to the bagger. Lactic acid bacteria (**LAB**) counts were determined immediately on 10 g of chopped fresh material taken from a composite of the three samples from each stage of maturity. Test material was placed in a sterilized blender jar, diluted with autoclaved distilled water, and then blended for 30 s. A 0.1% peptone solution was used for duplicate sets of serial dilutions from each sample. A pour-plate technique was used for LAB counts with Rogosa SL agar (Difco no. 0480; Difco Laboratories, Detroit, MI). Duplicate plates were used at each 10× dilution between 10^1 and 10^7 so that there were four plates per dilution from each sample. Plates were incubated in an 85% N_2, 10%

TABLE 1. Chemical composition of corn silages.

Item	Stage of maturity[1]			
	ED	1/4 ML	2/3 ML	BL
	(% of DM)			
Moisture	69.9	67.6	64.9	58.0
CP	7.5	7.3	7.1	7.0
NDF	52.0	44.4	40.5	41.3
ADF	32.0	27.1	23.9	24.2
Lignin	3.3	2.8	2.9	2.7
Starch	18.2	28.7	37.2	37.4

[1]Silages are designated by stage of maturity of whole-plant corn at harvest: ED = early dent, 1/4 ML = quarter milkline, 2/3 ML = two-thirds milkline, and BL = black layer.

CO_2, and 5% H_2 anaerobic environment at 30°C for 48 h.

Apparent total tract digestibilities of DM, OM, CP, ADF, and starch were determined using Yb as an external marker. A Yb solution (23) was sprayed onto wheat middlings. Each cow received 90 g of marked wheat middlings in the diet on d 21 to 28 to provide approximately 35 ppm in the ration DM. Fecal samples were collected daily at 1000 and 2200 h during the last 3 d of each period. Fecal samples were dried in a forced-air oven at 60°C for 72 h and then ground through a Wiley mill (2-mm screen). A fecal composite was made for each cow within period and analyzed for DM, OM, CP, ADF, and starch as previously described. The concentration of Yb in duplicate fecal samples was determined by direct current plasma emission spectroscopy (3) after dry-ashing at 500°C for 16 h. Apparent nutrient digestibilities in the total tract were calculated using Yb and nutrient concentrations in diet, ort, and fecal samples.

Performance and digestibility data were analyzed using the general linear models procedure of SAS (21) for a replicated Latin square design. All mean comparisons were by the least significant difference method after a significant ($P < 0.05$) treatment effect. Significance of effects was designated at $P < 0.05$ unless otherwise noted.

RESULTS AND DISCUSSION

Chemical compositions of treatment silages are presented in Table 1. Moisture content declined from 69.9 to 58.0% as maturity of the corn advanced from the ED stage to the BL stage. This trend was also reported by Hunt et al. (13) and is related to kernel development (1).

Concentrations of NDF and ADF declined from 52.0 to 41.3% and from 32.0 to 24.2%, respectively, as maturity advanced from the ED stage to the BL stage. This decline was related to the increase in the proportion of grain in WPC as it matured (1). The paradox of corn silage is that, although the fiber content of the stover increases as maturity advances, the fiber content of WPC declines because the proportion of grain in WPC increases (6). No further decline in NDF or ADF was detected as maturity increased from the 2/3 ML stage to the BL stage, probably because increased fiber content of the stover offset any increase in the proportion of the grain after the 2/3 ML stage. Similar trends for NDF and ADF have been reported by others (26, 27). Lignin content was highest for silage from corn harvested at the ED stage and was not different for silage from corn harvested at the 1/4 ML, 2/3 ML, or BL stages. Higher lignin content of the silage from corn harvested at the ED stage was likely due to a lower proportion of grain in WPC. Starch content increased as maturity progressed from the ED stage to the 2/3 ML stage, but there was no difference between the 2/3 ML stage and the BL stage. This result agreed with the trends observed for NDF and ADF and was likely related to changes in the proportion of grain in WPC.

Silage pH and organic acid concentrations are presented in Table 2. Silage pH was lower for silage from corn harvested at the ED stage than that for silage from corn harvested at the 2/3 ML or BL stages. Lower pH for high moisture silages was expected because of higher concentrations of water-soluble carbohydrates and more extensive fermentation (5, 16). Lactate concentrations increased as moisture content increased. Lactate concentration was higher for silage from corn harvested at the ED stage than for silage from corn harvested at 2/3 ML or the BL stage. This result reflects silage pH differences and was expected because of higher concentrations of water-soluble carbohydrates (5, 16). Silage pH values and lactate concentrations were indicative of adequate preservation (16, 20). Differences in lac-

TABLE 2. pH and organic acid concentrations of corn silages.

	Stage of maturity[1]			
	ED	1/4 ML	2/3 ML	BL
pH	3.73	3.98	4.11	4.10
Organic acids, % of DM				
Lactate	5.55	4.67	4.15	3.95
Acetate	1.24	0.92	0.85	1.12
Propionate	0.22	0.40	0.44	0.47
Succinate	0.21	0.22	0.21	0.14
Ethanol	0.87	0.23	0.14	0.17

[1]Silages are designated by stage of maturity of whole-plant corn at harvest: ED = early dent, 1/4 ML = quarter milkline, 2/3 ML = two-thirds milkline, and BL = black layer.

TABLE 3. Ingredient and nutrient composition of the diet.

Ingredient				
	(% of DM)			
Forage				
Corn silage	33.5			
Alfalfa silage[1]	16.5			
Concentrate[2]				
Shelled corn	26.5			
Soybean meal (44% CP)	18.6			
Meat meal	1.7			
Urea	0.2			
Dicalcium phosphate	0.4			
Sodium bicarbonate	0.8			
Trace-mineralized salt[3]	0.4			
Limestone	0.8			
Dynamate®[4]	0.2			
Magnesium oxide	0.2			
Vitamin premix[5]	0.2			
	Stage of maturity[6]			
Nutrient	ED	1/4 ML	2/3 ML	BL
	(% of DM)			
OM	91.5	91.6	91.6	91.7
CP	18.2	18.1	18.0	18.0
NDF	29.1	26.5	25.2	25.5
ADF	18.7	17.1	16.1	16.1
Starch and free glucose	28.8	32.3	35.1	35.2

[1]Contained 21.8% CP and 31.1% ADF (DM basis).

[2]Contained 24.0% CP and 5.8% ADF (DM basis).

[3]Contained 0.55% Mn, 0.55% Zn, 0.35% Fe, 0.14% Cu, 0.008% I, 0.006% Se, and 0.002% Co.

[4]Pitman Moore, Inc. (Mundelein, IL).

[5]Contained 2665 IU/g of vitamin A, 900 IU/g of vitamin D, and 3.52 IU/g of vitamin E.

[6]Silages are designated by stage of maturity of whole-plant corn at harvest: ED = early dent, 1/4 ML = quarter milkline, 2/3 ML = two-thirds milkline, and BL = black layer.

tate concentrations between silages were not related to LAB counts in the fresh WPC at ensiling. The LAB counts for silages from corn harvested at the ED, 1/4 ML, 2/3 ML, and BL stages were 5.91, 5.59, 6.57, and 5.94 $\log_{10}$ cfu/g of wet crop, respectively (data not presented).

Silage pH and lactate concentrations varied little across periods for corn harvested at the ED and BL stages. However, a higher pH coinciding with a lower lactate concentration was observed in period 2 for silages from corn harvested at the 1/4 ML and 2/3 ML stages. This increase was particularly apparent for silage from corn harvested at the 2/3 ML stage when pH reached 4.5 as lactate concentration declined to 2.3% of DM, which coincided with a winter warming trend during period 2 that might have affected aerobic stability. Reduced aerobic stability for silage from corn harvested at the 2/3 ML stage might have been caused by the bursting of the silo bag during the 1st wk of the ensiling process. The bag was resealed immediately, but the introduction of oxygen into the bag might possibly have made this silage more prone to aerobic instability (18). This aerobic instability was only apparent during the warming trend of period 2, and pH decreased, and lactate concentrations increased, to their original levels as observed during period 1 levels for periods 3 and 4. Despite problems with aerobic stability during period 2 for silage from corn harvested at the 2/3 milkline stage, DMI for cows fed all treatments were high, averaging 3.76% of BW (Table 4).

The ingredient and nutrient composition of experimental diets is presented in Table 3. Dietary CP concentration was similar across the four diets ranging from 18.0 to 18.2% (DM basis). Dietary NDF and ADF concentrations decreased, and starch concentration increased, as corn maturity advanced from the ED stage to the BL stage. These nutrients followed similar trends in the diets as in the silages. Concentrations reached a plateau at the 2/3 ML stage, and no further changes were detected as maturity advanced to the BL stage. Concentrations of NDF and ADF in the diet containing silage from corn harvested at the ED stage were similar to NRC (19) recommendations, but these concentrations were below NRC (19) recommendations for concentrations of NDF and ADF in diets containing silage from corn harvested at the 1/4 ML, 2/3 ML, and BL stages, which reflected the constant inclusion of corn silage in all diets and decreasing NDF and ADF concentrations as maturity advanced.

Body weight, DMI, and milk production data are presented in Table 4. Body weight and DMI were similar across the four treatments, ranging from 676 to 688 kg and from 3.73 to 3.79% of BW, respectively. Huber et al. (12) reported silage DMI at 1.88, 2.02, and 2.16% of BW for 25.4, 30.3, and 33.3% DM corn silages, respectively. Those results suggest the potential for lower DMI of high moisture corn silages, possibly related to their lower pH (22). However, Shaver et al. (22) reported higher DMI of corn silage that was partially neutralized with sodium bicarbonate prior to feeding. In our trial, the addition of sodium bicarbonate to the diet and the lower inclusion rate of corn silage [33% of dietary DM vs. 60% of dietary DM in the study of Huber et al. (12)] could have possibly alleviated the intake depression associated with the inclusion of high moisture corn silages in the diet.

Milk production was highest for cows fed the silage from corn harvested at the 2/3 ML stage and lowest for cows fed the silage from corn harvested at the ED stage ($P < 0.07$). Milk production was numerically

TABLE 4. Effect of corn maturity for use as silage in the diets of dairy cows on DMI, BW, and milk and milk components.

	Stage of maturity[1]				
Item	ED	1/4 ML	2/3 ML	BL	SEM
DMI					
kg/d	25.5	25.7	25.7	25.6	0.4
% of BW	3.75	3.73	3.77	3.79	0.04
BW, kg	683	688	683	676	3
Production, kg/d					
Milk	32.4[b]	32.6[ab]	33.4[a]	32.7[ab]	0.4
4% FCM	30.5	30.1	30.5	30.4	0.5
Milk fat	1.17	1.14	1.14	1.15	0.02
Milk protein	1.12[d]	1.12[d]	1.17[c]	1.13[d]	0.01
Composition, %					
Milk fat	3.60	3.54	3.43	3.52	0.05
Milk protein	3.49	3.48	3.50	3.48	0.02

[a,b]Means in the same row with different superscripts differ ($P < 0.07$).

[c,d]Means in the same row with different superscripts differ ($P < 0.05$).

[1]Silages are designated by stage of maturity of whole-plant corn at harvest: ED = early dent, 1/4 ML = quarter milkline, 2/3 ML = two-thirds milkline, and BL = black layer.

(0.7 to 0.8 kg/d), but not statistically ($P > 0.10$) higher for cows fed silage from corn harvested at the 2/3 ML stage than for cows fed silage from corn harvested at the 1/4 ML or BL stages. Huber et al. (12) reported increased milk production as maturity of WPC advanced from the soft dough stage to the hard dough stage; silage DM concentrations of 25.4, 30.3, and 33.3% coincided with increases in DMI. Harrison et al. (10) reported higher milk production for cows fed WPC harvested at the one-half ML stage and fed as silage versus WPC harvested at the BL stage and fed as silage. There were no differences in milk fat percentage or production across the four treatments. Milk protein production was highest ($P < 0.05$) for cows fed silage from corn harvested at the 2/3 ML stage, possibly because of higher starch content of this silage than that of silage from corn harvested at the ED and 1/4 ML stages (Table 3) and the higher starch digestibility of silage from corn harvested at the 2/3 ML stage than that of silage from corn harvested at the BL stage (Table 5).

Apparent total tract nutrient digestibilities are presented in Table 5. Digestibilities of DM and OM were similar for cows fed silages from corn harvested at the ED, 1/4 ML, and 2/3 ML stages. This result is somewhat surprising because dietary ADF content decreased, and starch content increased, as corn maturity advanced from the ED stage to the 2/3 ML stage. However, this relationship can be explained by the decline ($P < 0.05$) in ADF and starch digestibilities as corn maturity advanced. The decline in ADF digestibility could be related to negative associative effects of higher starch diets on ruminal fiber digestion (9) or lower digestibility of stover as WPC matured (26). The decline in starch digestibility could be related to lower efficiency of postruminal starch

TABLE 5. Effect of corn maturity for use as silage in the diets of dairy cows on apparent total tract nutrient digestibilities.

	Stage of maturity[1]				
Item	ED	1/4 ML	2/3 ML	BL	SEM
	(%)				
DM	61.8[a]	62.1[a]	61.4[a]	58.5[b]	0.6
OM	65.2[a]	64.9[a]	63.8[a]	60.4[b]	0.7
CP	64.9[a]	63.8[a]	62.5[a]	56.1[b]	1
ADF	45.7[a]	38.3[b]	33.6[c]	29.4[d]	1.4
Starch	94.1[a]	92.9[ab]	92.2[b]	87.7[c]	0.6

[a,b,c,d]Means in the same row with different superscripts differ ($P < 0.05$).

[1]Silages are designated by stage of maturity of whole-plant corn at harvest: ED = early dent, 1/4 ML = quarter milkline, 2/3 ML = two-thirds milkline, and BL = black layer.

digestion for cows fed higher starch diets (24) or more whole kernel passage from the lower moisture corn silages (10). Digestibilities of DM and OM were lowest ($P < 0.05$) for cows fed silage from corn harvested at the BL stage, which was related to lower ($P < 0.05$) digestibilities of CP, ADF, and starch for this treatment. Lower ADF and starch digestibilities for the silage from corn harvested at the BL stage relative to the silage from corn harvested at the 2/3 ML stage might be related to lower stover digestibility (26) and greater whole kernel passage (10), respectively, because dietary ADF and starch concentrations were similar. Dietary starch digestibility declined 6 percentage units between the ED stage and the BL stage. Calculated by difference, this decline represents a 20 percentage unit drop in starch digestibility for silage from corn harvested at the BL stage. Mechanical processing of corn silage prior to ensiling has been shown to increase milk production and reduce whole kernel passage (14) and would likely have improved performance of the silage from corn harvested at the BL stage. Intakes of digestible starch were 6.9, 7.7, 8.3, and 7.9 kg/d for cows fed silages from corn harvested at the ED, 1/4 ML, 2/3 ML, and BL stages, respectively (data not presented). Although starch intakes were similar for silages from corn harvested at the 2/3 ML and BL stages (9 kg/d), intake of digestible starch was 0.4 kg/d lower for cows fed silage from corn harvested at the BL stage.

CONCLUSIONS

Milk and milk protein production were, respectively, 1 and 0.05 kg/d higher for cows fed silage from corn harvested at the 2/3 ML stage than for cows fed silage from corn harvested at the ED stage. There were no differences in milk production among cows fed silages from corn harvested at the 1/4 ML, 2/3 ML, and BL stages. This result suggests that there is some flexibility in harvesting corn between the 1/4 ML and BL stages. However, milk protein production was 0.04 to 0.05 kg/d higher for cows fed silage from corn harvested at the 2/3 ML stage relative to those fed silage from corn harvested at the 1/4 ML and BL stages. Also, apparent total tract starch digestibility and digestible starch intake were lowest for cows fed silage from corn harvested at the BL stage, which could translate into lower milk production or BW gain in a longer term feeding trial or in a trial with higher producing cows. Our data suggest that 2/3 ML (65% moisture) was the optimum maturity stage for harvesting corn for use as silage in the diets of lactating dairy cows when the diets were formulated to have a fixed forage to concentrate ratio. Some flexibility did exist between 1/4 ML and 2/3 ML (65 to 68% moisture).

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