J. Dairy Sci. 86:287–308

Corn Silage Management: Effects of Hybrid, Maturity, Inoculation, and Mechanical Processing on Fermentation Characteristics

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ABSTRACT

Two experiments were conducted to evaluate the effects of hybrid, maturity, mechanical processing, and inoculation of corn silage on fermentation characteristics. In experiment 1, Pioneer hybrid 3845 corn silage was harvested at three maturities (hard dough, one-third milkline, two-thirds milkline). In experiment 2, Pioneer hybrids 3845 and Quanta were harvested at three maturities (one-third milkline, two-thirds milkline, and blackline). In both experiments, corn silage was harvested at each maturity with and without mechanical processing and with and without inoculation. In experiments 1 and 2, corn silage was harvested at a theoretical length-of-cut of 6.4 and 12.7 mm, respectively. Maturity at harvest tended to have a greater impact on silage fermentation characteristics of corn silage than mechanical processing and inoculation. In experiments 1 and 2, corn silage harvested at the earliest maturity tended to have decreased dry matter content and increased water-soluble carbohydrate concentrations during the ensiling process than corn silage harvested at advanced maturities. In experiment 2, pH levels were lower for corn silage harvested at the early maturity (one-third milkline) compared with advanced maturities (two-thirds milkline and blackline) by 57 d after ensiling. The difference in pH can be explained by the greater concentration of water-soluble carbohydrates at the early maturity (one-third ML) soon after ensiling (2, 3, 6 and 10 d after ensiling) compared with advanced maturities (two-thirds ML and BL). The increased water-soluble carbohydrate concentrations in the less mature corn silage provided nutrients for bacteria to grow and produce primarily lactic acid (6, 10, and 57 d after ensiling) and some acetic acid (2, 3, 6, and 10 d after ensiling) which reduced the pH of corn silage more than at the advanced maturities. There was a slight change in silage fermentation characteristics when corn silage was inoculated with Pioneer 1132 inoculant in experiment 1. The inoculated corn silage had increased temperature, lactate and acetate concentrations, and lower water-soluble carbohydrate and pH levels compared with uninoculated corn silage. Dry matter recovery tended to be greater for processed corn silage in experiment 1, and greater for unprocessed corn silage in experiment 2. It appears that when fermentation was greater (increased temperature and lactate concentration 57 d after ensiling) the dry matter recovery was lower.
(**Key words:** corn silage, inoculation, mechanical processing, maturity)

Abbreviation key: BL = blackline, **ML** = milkline, **WSC** = water-soluble carbohydrates.

INTRODUCTION

Many factors of corn silage management can influence silage fermentation characteristics. Studies have demonstrated some of the chemical changes that occur in the corn plant as it matures that leads to less fermentable substrates being available for lactic acid producing bacteria (McDonald et al., 1991). As the corn plant matures, water-soluble carbohydrate (**WSC**) levels decrease and the starch levels increase in whole-plant corn. Therefore, there is less fermentable substrate available for lactic acid producing bacteria to consume. This has the potential of delaying fermentation. Several studies have demonstrated the effects of inoculation of corn silage on silage fermentation characteristics (Harrison et al., 1996; Higginbotham et al., 1998; Cai et al., 1999; Ranjit and Kung et al., 2000). A summary of 17 studies that used corn silage inoculants demonstrated a numerical increase in lactic acid levels, and a significant reduction in pH of fermented corn silage that utilized an inoculant (Harrison et al., 1996).

Received February 11, 2001.
Accepted July 18, 2002.
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Other studies have reported that chop length and degree of crop maceration can influence silage fermentation characteristics (personal communication with Richard Muck). Short chop length or increased maceration has increased the rate of lactic acid bacteria proliferation, increased the rate of pH reduction, and lowered final pH (personal communication with Richard Muck). However, only one study has been published on the effects of mechanical processing of corn silage on silage fermentation characteristics (Johnson et al., 1997). Because there has been rapid adoption of mechanical processing of corn silage prior to ensiling in the US over the last 5 yr, it is important to characterize changes that occur in the silo due to processing, and to interactions of processing with maturity, inoculation, and corn silage hybrid.

The objective of this study was to evaluate the effects of hybrid, maturity, mechanical processing, and inoculation of corn silage on silage fermentation characteristics and DM recovery.

MATERIALS AND METHODS

Experimental Design

Two experiments were conducted using mini-silos to evaluate the effects of hybrid, stage of maturity, mechanical processing, and inoculation of corn silage on silage fermentation characteristics and DM recovery. Experiment 1 was a $2 \times 2 \times 3$ factorial arrangement; experiment 2 was a $2 \times 2 \times 2 \times 3$ factorial. In experiment 1, there was one hybrid of corn silage (Pioneer hybrid 3845), and in experiment 2 there were two hybrids of corn silage (Pioneer hybrids 3845 and Quanta). In both experiments, corn silage was harvested at three maturities. Within each maturity, corn silage was harvested with and without mechanical processing and with and without inoculation. In experiment 1, each treatment (maturity by processing by inoculation) was ensiled in triplicate, and in experiment 2, each treatment (hybrid $\times$ maturity $\times$ processing $\times$ inoculation) was ensiled in duplicate.

Two hybrids of corn silage were chosen in experiment 2 to evaluate the effects of maturity, processing, and inoculation on silage fermentation of corn silage that differed in silage characteristics. Hybrid Quanta is a flint corn and hybrid 3845 is a dent corn. Hybrid Quanta tends to have higher DM and starch content at the same maturity as hybrid 3845. Flint corn also tends to have a greater percentage of vitreous starch than dent corn. This starch tends to be less digestible because it contains starch that is embedded in a protein matrix (Kortarski et al., 1992).

In all experiments, corn silage was harvested with a self-propelled John Deere 5830 harvester (with a kernel processing unit) at a ground speed between 3.2 and 4.0 km/h. The processing equipment was fully active (two counter-rotating rolls positioned between the cutterhead and blower with their axis of rotation parallel to the cutterhead). The harvester consisted of four knives per row, and there were 10 tangential rows. At each stage of maturity, corn silage was harvested with the kernel processing rolls set 1 mm apart (processed), and with the kernel processing rolls set 15.9 mm apart (unprocessed). In experiments 1 and 2, the inoculated treatments were treated with Pioneer 1132 corn silage inoculant (Pioneer Hi-Bred Intl., Des Moines, IA). In experiments 1 and 2, inoculant was applied as a fine mist at a standard rate of 1.0×10^5 cfu of fresh forage. During inoculant application, the corn silage was mixed manually. In experiments 1 and 2, an equal amount of water was sprayed onto the forage treatments that did not require inoculation.

Experiments 1 and 2. In experiment 1, hybrid 3845 corn silage was harvested during the 1996 growing season in western Washington. Corn silage was harvested at hard dough (23.5% DM), one-third milkline [**ML**; 25.0% DM], and two-thirds ML (29.3% DM-with two light frosts and one killing frost) stages of maturity (experiment 1). The TLC for the corn silage was 6.4 mm (harvester set with 10 rows of knives and a 12-tooth sprocket; experiment 1). In experiment 2, hybrid 3845 corn silage was harvested in western Washington during the 1997 growing season at one-third ML (25.3% DM), two-thirds ML (31.3% DM), and blackline [**BL**; 33.4% DM] stages of maturity. In experiment 2, hybrid Quanta corn silage was harvested during the 1997 growing season in western Washington. Corn silage was harvested at one-third ML (26.8% DM), two-thirds ML (34.0% DM), and BL (41.3% DM) stages of maturity. The TLC for the corn silage in experiment 2 was 12.7 mm (chopper set with 10 rows of knives and a 24-tooth sprocket). Corn silage was stored in 20-L pails (29 cm $\times$ 35 cm, height $\times$ diameter) with double-lined plastic liner to ensure anaerobic conditions. Each silo held approximately 5 to 6 kg of wet corn silage.

Sample Collection, Preparation, and Analysis

In experiments 1 and 2, a pre-ensiled sample of the whole corn plant for each treatment was dried at 55°C in a forced-air oven and analyzed for DM (Tables 1 through 3). Dried, pre-ensiled, whole-plant corn was ground through a 1-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA) and analyzed for WSC (Dubois et al., 1956; Tables 1 through 3). In experiments 1 and 2, a composited sample of wet, pre-ensiled, whole-plant corn, was analyzed for pH for each treat-

Table 1. Chemical composition of pre-ensiled corn silage in experiment 1 (DM Basis).

	Hard dough				1/3 Milkline				2/3 Milkline			
	Proc[1]		Unproc[2]		Proc		Unproc		Proc		Unproc	
Item	Inoc[3]	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc
DM, %	25.7	25.9	23.0	24.1	26.2	27.1	26.2	27.6	28.0	29.8	31.3	31.6
pH	5.93	5.94	6.06	6.12	5.91	6.04	5.93	5.89	5.96	5.95	6.04	6.02
WSC, mg/g DM	122.8	134.9	106.3	109.1	55.3	63.1	84.1	86.5	30.6	23.2	87.6	99.9

[1]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[2]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[3]Inoc = inoculated.

ment, using a portable pH meter (Digital Mini-pH-meter, model 55, VWR Scientific, Inc.; Tables 1 through 3).

The mini-silos in experiments 1 and 2 were opened 2, 3, 6, 10, and 57 d after ensiling. Whole-plant corn ensiled for 2, 3, 6, 10, and 57 d was dried at 55°C in a forced-air oven and analyzed for DM concentration. A dried-corn silage sample for each mini-silo was ground through a 1-mm screen with a Wiley mill and analyzed for WSC. The temperature of the corn silage was measured with a temperature probe (Model #: HH-25KF, OMEGA Engineering, Inc., Stamford, CT) and recorded at the time of ensiling, and when the silo was opened (2, 3, 6, 10, and 57 d after ensiling). Wet samples of corn silage from each mini-silo were extracted and analyzed for VFA (Bulletin 749C, GC separation of VFA C2-C5. Supelco, Inc., Bellefonte, PA), lactate, and ethanol by gas chromatography (80/20 Carbopack B-DA/4% Carbowax 20M, Supelco, Inc., Bellefonte, PA). Wet samples of pre-ensiled whole-plant corn (experiment 2) and post-ensiled corn silage from each mini-silo were also analyzed for pH, using a portable pH meter. Corn silage was composited by treatment, and a dried corn silage sample was ground through a 1-mm screen using a Wiley mill and analyzed for absolute DM and ash (AOAC, 1990). The composited corn silage samples were analyzed for CP (AOAC, 1990), NDF with sulfite (Van Soest et al., 1991), ADF (Goering and Van Soest, 1970), and starch (modified starch procedure of Holm et al., 1986; Tables 4 through 6). Modifications to the starch procedure were described in Johnson et al. (2002a). Total corn silage DM recovered (silage + spoilage) from each mini-silo was estimated. The gross weight of corn put into the silo, spoilage removed, and end weight after fermentation was complete were recorded on a dry basis.

Statistical Analysis

The model to test for treatment differences in experiments 1 and 2 was:

$$Y_i = \mu + T_i + E$$

where μ = overall mean, T_i = treatment effect (experiment 1: i = 1 to 12; experiment 2: i = 1 to 24), and E_i = error term. Treatment means are reported in Tables 7 through 13.

The model to test for main effects and interaction differences in experiment 1 was:

$$Y_{ijkl} = \mu + R_i + M_j + K_k + I_l + (M \times K)_{jk} + (M \times I)_{jl} + (K \times I)_{kl} + E_{ijkl}$$

where μ = overall mean; R_i = replication (i = 1 to 3); M_j = maturity effect (j = 1 to 3); K_k = kernel processing effect (k = 1 to 2); I_l = inoculation effect (l = 1 to 2);

Table 2. Chemical composition of pre-ensiled corn silage for hybrid 3845 in experiment 2 (DM Basis).

	1/3 Milkline				2/3 Milkline				Blackline			
	Proc[1]		Unproc[2]		Proc		Unproc		Proc		Unproc	
Item	Inoc[3]	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc
DM, %	27.4	28.2	28.3	27.8	32.5	33.2	32.9	34.6	30.9	33.0	38.2	35.7
pH	5.58	5.66	5.68	5.66	5.67	5.69	5.63	5.78	5.60	5.47	5.48	5.39
WSC, mg/g DM	112.5	146.8	107.5	101.8	61.5	87.4	60.1	39.5	57.0	75.3	50.1	77.3

[1]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[2]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[3]Inoc = inoculated.

Table 3. Chemical composition of pre-ensiled corn silage for hybrid Quanta in experiment 2 (DM Basis).

	1/3 Milkline				2/3 Milkline				Blackline			
	Proc[1]		Unproc[2]		Proc		Unproc		Proc		Unproc	
Item	Inoc[3]	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc
DM, %	27.7	28.2	28.9	28.5	33.1	34.4	36.8	38.1	41.8	42.2	41.2	46.0
pH	5.48	5.53	5.56	5.60	5.76	5.65	5.70	5.73	5.35	5.39	5.52	5.73
WSC, mg/g DM	97.6	116.1	99.0	74.4	76.3	69.6	73.1	76.7	75.5	50.6	48.4	35.0

[1]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[2]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[3]Inoc = inoculated.

$(M \times K)_{jk}$ = interaction effect of M_j and K_k; $(M \times I)_{jl}$ = interaction effect of M_j and I_l; $(K \times I)_{kl}$ = interaction effect of K_k and I_l; and E_{ijkl} = error term. The *P* values for the main effects and interaction terms are reported in Tables 7 through 13.

The model for analyzing repeated measures in experiment 1 was:

$$Y_{ijklm} = \mu + R_i + M_j + K_k + I_l + (M \times K)_{jk} + (M \times I)_{jl} + (K \times I)_{kl} + D_m + (M \times D)_{jm} + (K \times D)_{km} + (I \times D)_{lm} + (M \times K \times D)_{jkm} + (M \times I \times D)_{jlm} + (K \times I \times D)_{klm} + E_{ijklm}$$

where μ = overall mean; R_i = replication (i = 1 to 3); M_j = maturity effect (j = 1 to 3); K_k = kernel processing effect (k = 1 to 2); I_l = inoculation effect (l = 1 to 2); $(M \times K)_{jk}$ = interaction effect of M_j and K_k; $(M \times I)_{jl}$ = interaction effect of M_j and I_l; $(K \times I)_{kl}$ = interaction effect of K_k and I_l; $(R \times M \times K \times I)_{ijkl}$ error term for all whole-plot sources of variation; D_m = day after ensiling (m = 1 to 5); $(M \times D)_{jm}$ = interaction effect of M_j and D_m; $(K \times D)_{km}$ = interaction effect of K_k and D_m; $(I \times D)_{lm}$ = interaction effect of I_l and D_m; $(M \times K \times D)_{jkm}$ = interaction of M_j, K_k, and D_m; $(M \times I \times D)_{jlm}$ = interaction of M_j, I_l, and D_m; $(K \times I \times D)_{klm}$ = interaction of K_k, I_l, and D_m; and E_{ijklm} = error term for sub-plot (time) sources of variation.

The model to test for main effect and interaction differences in experiment 2 was:

$$Y_{ijklm} = \mu + R_i + H_j + M_k + K_l + I_m + (H \times M)_{jk} + (H \times K)_{jl} + (H \times I)_{jm} + (M \times K)_{kl} + (M \times I)_{km} + (K \times I)_{lm} + E_{ijklm}$$

where μ = overall mean; R_i = replication (i = 1 to 2); H_j = hybrid effect (j = 1 to 2); M_k = maturity effect (k = 1 to 3); K_l = kernel processing effect (l = 1 to 2); I_m = inoculation effect (m = 1 to 2); $(H \times M)_{jk}$ = interaction effect of H_j and M_k; $(H \times K)_{jl}$ = interaction effect of H_j and K_l; $(H \times I)_{jm}$ = interaction effect of H_j and I_m; $(M \times K)_{kl}$ = interaction effect of M_k and K_l; $(M \times I)_{km}$ = interaction effect of M_k and I_m; $(K \times I)_{lm}$ = interaction effect of K_l and I_m; and E_{ijklm} = error term. The *P* values for the main effects and interaction terms are reported in Tables 7 through 13.

The model for analyzing repeated measures in experiment 2 was:

$$Y_{ijklmn} = \mu + R_i + H_j + M_k + K_l + I_m + (H \times M)_{jk} + (H \times K)_{jl} + (H \times I)_{jm} + (M \times K)_{kl} + (M \times I)_{km} +$$

Table 4. Chemical composition of post-ensiled corn silage in experiment 1 (DM Basis).

	Hard Dough				1/3 Milkline				2/3 Milkline			
	Proc[1]		Unproc[2]		Proc		Unproc		Proc		Unproc	
Item	Inoc[3]	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc
	(%)											
Ash	5.0	5.0	4.3	4.6	4.2	4.4	4.4	4.2	4.2	4.8	5.1	5.3
NDF	53.6	53.8	55.8	56.2	52.6	55.7	56.7	56.7	48.9	48.8	57.3	58.8
ADF	33.9	33.3	35.5	36.8	33.0	35.4	36.6	36.4	29.6	28.8	34.2	35.5
CP	8.2	8.5	8.3	8.3	8.2	8.2	8.1	8.2	8.6	8.6	8.8	10.8
Starch	14.8	16.0	15.9	14.8	23.0	21.8	18.2	18.1	28.7	28.3	18.3	14.3

[1]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[2]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[3]Inoc = inoculated.

Table 5. Chemical composition of post-ensiled corn silage for hybrid 3845 in experiment 2 (DM Basis).

	1/3 Milkline				2/3 Milkline				Blackline			
	Proc[1]		Unproc[2]		Proc		Unproc		Proc		Unproc	
Item	Inoc[3]	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc
	(%)											
Ash	4.4	4.3	4.2	4.1	4.6	4.7	4.3	4.0	4.2	3.6	3.7	3.6
NDF	44.1	40.5	42.5	44.7	38.9	40.1	38.3	41.2	48.8	45.3	39.3	37.5
ADF	31.4	29.3	29.9	30.6	28.6	30.4	27.8	29.5	34.9	32.4	26.6	27.1
CP	8.2	8.5	8.7	8.8	8.1	8.2	8.0	7.8	9.0	7.1	7.7	8.1
Starch	17.6	21.8	17.7	17.6	36.2	32.4	30.4	28.6	21.1	24.5	32.5	40.2

[1]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[2]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[3]Inoc = inoculated.

$$(K \times I)_{lm} + D_n + (H \times D)_{jn} + (M \times D)_{kn} + (K \times D)_{ln} + (I \times D)_{mn} + (H \times M \times D)_{jkn} + (H \times K \times D)_{jln} + (H \times I \times D)_{jmn} + (M \times K \times D)_{kln} + (M \times I \times D)_{kmn} + (K \times I \times D)_{lmn} + E_{ijklmn}$$

where μ = overall mean; R_i = replication (i = 1 to 2); H_j = hybrid effect (j = 1 to 2); M_k = maturity effect (k = 1 to 3); K_l = kernel processing effect (l = 1 to 2); I_m = inoculation effect (m = 1 to 2); $(H \times M)_{jk}$ = interaction effect of H_j and M_k; $(H \times K)_{jl}$ = interaction effect of H_j and K_l; $(H \times I)_{jm}$ = interaction effect of H_j and I_m; $(M \times K)_{kl}$ = interaction effect of M_k and K_l; $(M \times I)_{km}$ = interaction effect of M_k and I_m; $(K \times I)_{lm}$ = interaction effect of K_l and I_m; $(R \times H \times M \times K \times I)_{ijklm}$ error term for all whole-plot sources of variation; D_n = day after ensiling (n = 1 to 5); $(H \times D)_{jn}$ = interaction effect of H_j and D_n; $(M \times D)_{kn}$ = interaction effect of M_k and D_n; $(K \times D)_{ln}$ = interaction effect of K_l and D_n; $(I \times D)_{mn}$ = interaction effect of I_m and D_n; $(H \times M \times D)_{jkn}$ = interaction effect of H_j, M_k, and D_n; $(H \times K \times D)_{jln}$ = interaction effect of H_j, K_l, and D_n; $(H \times I \times D)_{jmn}$ = interaction effect of H_j, I_m, and D_n; $(M \times K \times D)_{kln}$ = interaction of M_k, K_l, and D_n; $(M \times I \times D)_{kmn}$ = interaction of M_k, I_m, and D_n; $(K \times I \times D)_{lmn}$ = interaction of K_l, I_m, and D_n; and E_{ijklmn} = error term for sub-plot (time) sources of variation.

The model for regression analyses in experiments 1 and 2 was:

$$Y_i = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \beta_3 \cdot X_3 + \ldots (\beta_x{*}X_x + E_i$$

where β_0 = intercept on the Y axis; $\beta_1, \beta_2, \beta_3, \ldots, \beta_x$ = regression coefficients for multiple variables; X_1, X_2, X_3, …, X_x = prediction variables; and E_i = error term. Significance was declared at $P < 0.05$ and trends were observed at $P < 0.10$ for all statistical models in this paper (SAS, 1988).

RESULTS AND DISCUSSION

Maturity

In experiments 1 and 2, the pre-ensiled DM concentration increased and the WSC concentration tended to decrease as maturity of pre-ensiled whole-plant corn advanced (Tables 1 through 3). This was similar to other published data where the whole-plant corn DM

Table 6. Chemical composition of post-ensiled corn silage in experiment 2 (DM Basis).

	1/3 Milkline				2/3 Milkline				Blackline			
	Proc[1]		Unproc[2]		Proc		Unproc		Proc		Unproc	
Item	Inoc[3]	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc	Inoc	No Inoc
	(%)											
Ash	4.0	4.8	4.3	4.6	4.1	4.4	4.2	4.4	4.0	3.6	4.1	3.7
NDF	40.6	38.1	40.6	38.7	37.8	38.0	36.3	36.5	38.8	40.4	38.9	40.1
ADF	27.4	26.6	27.7	26.9	24.6	25.3	24.9	23.7	26.0	26.6	27.0	26.8
CP	8.6	9.2	8.0	8.4	8.1	8.2	8.4	8.6	8.5	8.3	8.4	8.0
Starch	20.3	23.9	27.7	29.8	38.9	37.7	35.8	36.3	35.7	37.5	37.7	38.0

[1]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[2]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[3]Inoc = inoculated.

Table 7. Dry matter concentration and DM recovery of post-ensiled corn silage in experiments 1 and 2.

Treatment	DM Concentration Day[1] 57	DM Recovery Day 57
	(%)	(%)
Experiment 1		
Hard dough		
Proc[2] w/inoculant	24.9	94.7
Proc w/o inoculant	24.8	96.3
Unproc[3] w/inoculant	21.6	95.4
Unproc w/o inoculant	22.6	91.4
1/3 Milkline		
Proc w/inoculant	25.6	95.8
Proc w/o inoculant	25.9	93.4
Unproc w/inoculant	24.1	89.2
Unproc w/o inoculant	24.4	90.3
2/3 Milkline		
Proc w/inoculant	29.7	97.0
Proc w/o inoculant	27.6	97.7
Unproc w/inoculant	29.5	92.4
Unproc w/o inoculant	30.2	93.9
SE	0.17	0.75
Treatment	0.0001	0.0001
Maturity	0.0001	0.0004
Processing	0.0001	0.0001
Inoculation	NS[4]	NS
Maturity × processing	0.0001	NS
Maturity × inoculation	0.01	NS
Processing × inoculation	0.0001	NS
Experiment 2—Hybrid 3845		
1/3 Milkline		
Proc w/inoculant	25.0	89.7
Proc w/o inoculant	24.7	87.9
Unproc w/inoculant	25.2	89.2
Unproc w/o inoculant	26.4	89.0
2/3 Milkline		
Proc w/inoculant	30.1	91.7
Proc w/o inoculant	30.2	90.2
Unproc w/inoculant	31.1	93.7
Unproc w/o inoculant	33.7	97.3
Black layer		
Proc w/inoculant	29.5	93.2
Proc w/o inoculant	30.8	93.5
Unproc w/inoculant	36.2	94.6
Unproc w/o inoculant	37.0	97.4
Experiment 2—Hybrid Quanta		
1/3 Milkline		
Proc w/inoculant	25.7	88.8
Proc w/o inoculant	25.8	91.6
Unproc w/inoculant	27.6	99.9
Unproc w/o inoculant	28.2	99.1
2/3 Milkline		
Proc w/inoculant	31.4	92.2
Proc w/o inoculant	32.1	91.5
Unproc w/inoculant	35.5	94.5
Unproc w/o inoculant	35.5	91.4
Black layer		
Proc w/inoculant	40.3	95.1
Proc w/o inoculant	40.7	95.9
Unproc w/inoculant	39.6	94.4
Unproc w/o inoculant	44.7	96.3
SE	0.80	1.62
Treatment	0.0001	0.0004
Hybrid	0.0001	0.02
Maturity	0.0001	0.01
Processing	0.0001	0.0009
Inoculation	0.02	NS
Hybrid × maturity	0.0001	0.005
Hybrid × processing	NS	NS
Hybrid × inoculation	NS	NS
Maturity × processing	0.07	NS
Maturity × inoculation	NS	NS
Processing × inoculation	NS	NS

[1]Day = Day corresponds to the day silos were opened (57 d after ensiling).

[2]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[3]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[4]NS = Not significant ($P > 0.05$).

concentration increased and sugar concentration decreased as maturity advanced (Xu et al., 1995; Hunt et al., 1989). In experiments 1 ($P < 0.0001$) and 2 (Quanta, $P < 0.0001$ and 3845, $P < 0.006$), as maturity advanced, the DM concentration of postensiled corn silage increased (Table 7).

Final temperature of the different treatments of corn silage varied from 11 to 19°C (Table 8). These temperatures were within the range in which respiration occurs at a rapid rate (Muck and Pitt, 1993). Muck and Pitt (1993) reported that respiration slows as temperature increases from 24 to 46°C and stops at 54°C. Corn silage harvested at two-thirds ML in both experiments tended to have temperatures that stayed elevated through 57 d after ensiling (15.5 to 18°C; Figures 1a through 1c). Corn silage harvested at the earliest maturity in both experiments (hard dough-experiment 1 and one-third ML-experiment 2) had temperatures that stayed elevated (16 to 19°C) through 10 d after ensiling, and then declined by 57 d after ensiling (14 to 15°C; Figures 1a through 1c).

In experiment 2, corn silage harvested at earlier maturities (one-third ML and two-thirds ML) tended to have a higher temperature than corn silage harvested at physiological maturity in the first 10 d following ensiling [d 2 ($P < 0.0003$), d 3 ($P < 0.0001$), d 6 ($P < 0.0003$), and d 10 ($P < 0.0001$) d after ensiling; Table 8]. This indicates that there was more WSC available for lactic acid-producing bacteria to use as a substrate (Table 9). Therefore, microbial activity soon after ensiling was high for the less mature corn silage compared with the mature corn silage. Also, the corn silage harvested at an early maturity contained a greater percentage of moisture than corn silage harvested at advanced maturity (Table 7). Water serves as a heat sink, there-

Table 8. Temperature of post-ensiled corn silage in experiments 1 and 2.

Treatment	Day[1] 2	Day 3	Day 6	Day 10	Day 57
	(°C)				
Experiment 1					
Hard dough					
Proc[2] w/inoculant	16.0	15.7	17.0	17.3	12.3
Proc w/o inoculant	15.7	15.3	16.7	17.0	11.0
Unproc[3] w/inoculant	16.0	16.0	17.3	16.3	16.3
Unproc w/o inoculant	16.0	16.0	17.0	16.3	16.0
1/3 Milkline					
Proc w/inoculant	15.0	15.3	15.3	14.7	16.3
Proc w/o inoculant	15.7	15.3	14.7	13.7	13.0
Unproc w/inoculant	16.0	15.3	15.7	14.7	16.7
Unproc w/o inoculant	15.3	14.7	15.0	13.0	12.7
2/3 Milkline					
Proc w/inoculant	16.7	14.0	15.7	16.0	16.3
Proc w/o inoculant	14.0	17.3	18.3	14.0	14.7
Unproc w/inoculant	16.7	15.3	17.7	17.3	18.7
Unproc w/o inoculant	14.0	15.7	16.0	14.3	18.0
SE	0.40	0.69	0.32	0.27	0.74
Treatment	0.0006	NS[4]	0.0001	0.0001	0.0001
Maturity	NS[9]	NS	0.0001	0.0001	0.0001
Processing	NS	NS	NS	NS	0.0001
Inoculation	0.0004	NS	NS	0.0001	0.0001
Maturity × processing	NS	NS	NS	0.0008	0.0006
Maturity × inoculation	0.0001	0.07	NS	0.0001	0.02
Processing × inoculation	NS	NS	0.01	NS	NS
Experiment 2—Hybrid 3845					
1/3 Milkline					
Proc w/inoculant	18.0	17.5	17.5	19.0	14.5
Proc w/o inoculant	17.0	17.0	17.0	18.0	14.0
Unproc w/inoculant	16.5	18.0	19.0	18.5	15.0
Unproc w/o inoculant	17.0	18.0	17.5	19.0	14.5
2/3 Milkline					
Proc w/inoculant	17.5	18.0	15.0	16.0	18.5
Proc w/o inoculant	17.0	18.0	15.0	16.0	19.0
Unproc w/inoculant	17.5	16.5	16.5	16.5	18.0
Unproc w/o inoculant	18.0	17.5	17.0	16.5	18.0
Black layer					
Proc w/inoculant	16.0	16.0	15.0	14.0	14.0
Proc w/o inoculant	17.0	17.0	14.0	13.0	14.0
Unproc w/inoculant	17.0	16.5	14.5	13.0	14.0
Unproc w/o inoculant	17.0	16.5	14.5	13.0	14.0
Experiment 2—Hybrid Quanta					
1/3 Milkline					
Proc w/inoculant	18.0	17.0	17.0	17.5	16.0
Proc w/o inoculant	18.0	17.0	17.0	17.0	16.0
Unproc w/inoculant	17.0	17.5	17.0	18.0	14.5
Unproc w/o inoculant	17.0	18.0	17.0	17.0	13.0
2/3 Milkline					
Proc w/inoculant	16.5	17.5	17.0	18.0	18.0
Proc w/o inoculant	16.0	16.0	18.0	17.0	18.5
Unproc w/inoculant	17.5	18.5	17.0	16.0	18.0
Unproc w/o inoculant	17.5	17.5	17.0	16.0	17.0
Black layer					
Proc w/inoculant	16.5	15.5	14.5	16.0	14.0
Proc w/o inoculant	16.5	15.0	14.0	16.5	14.5
Unproc w/inoculant	16.0	15.0	12.5	16.5	14.0
Unproc w/o inoculant	16.0	15.0	13.0	16.5	15.0
SE	0.29	0.32	0.40	0.34	0.38
Treatment	0.0001	0.0001	0.0001	0.0001	0.0001
Hybrid	0.08	0.002	NS	0.0001	NS
Maturity	0.0001	0.0001	0.0001	0.0001	0.0001
Processing	NS	NS	NS	NS	0.02
Inoculation	NS	NS	NS	NS	NS
Hybrid × maturity	0.01	0.01	0.0001	0.0001	NS
Hybrid × processing	NS	0.07	0.0001	NS	0.04
Hybrid × inoculation	NS	0.07	0.09	NS	NS
Maturity × processing	0.0001	NS	0.003	NS	0.09
Maturity × inoculation	NS	NS	NS	NS	NS
Processing × inoculation	NS	NS	NS	NS	NS

[1]Day = Day corresponds to the day silos were opened (2, 3, 6, 10, or 57 d after ensiling).

[2]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[3]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[4]NS = Not significant ($P > 0.05$).

Table 9. Water-soluble carbohydrates of post-ensiled corn silage in experiments 1 and 2.

Treatment	Day[1] 2	Day 3	Day 6	Day 10	Day 57
	(mg/g of DM)				
Experiment 1					
Hard dough					
Proc[2] w/inoculant	74.8	65.4	62.3	35.0	19.8
Proc w/o inoculant	81.0	62.6	42.3	50.5	28.2
Unproc[3] w/inoculant	73.6	47.7	33.1	22.4	15.5
Unproc w/o inoculant	68.4	53.1	46.2	31.5	17.9
1/3 Milkline					
Proc w/inoculant	23.0	20.8	21.4	16.0	11.9
Proc w/o inoculant	31.4	30.1	24.7	12.7	19.7
Unproc w/inoculant	34.2	24.3	19.4	21.0	13.8
Unproc wo/inoculant	43.5	37.1	23.5	22.6	14.8
2/3 Milkline					
Proc w/inoculant	26.4	22.0	13.7	10.7	8.8
Proc w/o inoculant	21.3	18.0	21.2	15.7	11.9
Unproc w/inoculant	73.2	53.5	22.8	22.0	25.8
Unproc w/o inoculant	73.1	48.4	24.9	12.1	11.9
SE	1.50	1.10	1.11	0.85	. . .
Treatment	0.0001	0.0001	0.0001	0.0001	. . .
Maturity	0.0001	0.0001	0.0001	0.0001	. . .
Processing	0.0001	0.0001	NS[4]	NS	. . .
Inoculation	0.05	0.001	NS	0.003	. . .
Maturity × processing	0.0001	0.0001	0.0007	0.0001	. . .
Maturity × inoculation	0.0006	0.0001	NS	0.0001	. . .
Processing × inoculation	NS	0.02	0.01	0.007	. . .
Experiment 2—Hybrid 3845					
1/3 Milkline					
Proc w/inoculant	71.7	52.1	22.3	18.6	21.5
Proc w/o inoculant	73.8	57.0	22.5	16.8	14.6
Unproc w/inoculant	106.5	84.6	40.3	19.5	15.8
Unproc w/o inoculant	84.9	76.0	25.4	19.6	16.9
2/3 Milkline					
Proc w/inoculant	15.3	7.8	7.6	7.0	7.1
Proc w/o inoculant	16.5	16.6	16.1	13.0	12.3
Unproc w/inoculant	13.9	11.1	9.2	8.6	10.0
Unproc w/o inoculant	27.1	21.0	25.8	19.8	10.2
Black layer					
Proc w/inoculant	33.8	21.2	22.8	9.8	7.2
Proc w/o inoculant	15.6	11.9	11.5	9.1	8.0
Unproc w/inoculant	33.7	17.5	11.7	8.2	8.5
Unproc w/o inoculant	36.2	20.0	20.2	20.0	12.5
Experiment 2—Hybrid Quanta					
1/3 Milkline					
Proc w/inoculant	50.3	49.6	32.7	28.7	15.3
Proc w/o inoculant	79.9	71.1	33.3	31.0	13.0
Unproc w/inoculant	44.4	29.9	17.5	14.3	13.1
Unproc w/o inoculant	42.8	33.2	15.7	13.8	12.0
2/3 Milkline					
Proc w/inoculant	19.9	16.0	12.6	15.6	10.9
Proc w/o inoculant	15.0	14.3	14.7	12.1	6.6
Unproc w/inoculant	27.9	20.5	22.0	8.4	9.4
Unproc w/o inoculant	20.8	13.7	11.3	13.8	12.6
Black layer					
Proc w/inoculant	20.4	24.7	17.1	9.2	9.6
Proc w/o inoculant	35.6	11.6	11.0	9.7	9.5
Unproc w/inoculant	16.8	11.5	10.3	9.8	10.4
Unproc w/o inoculant	27.7	15.3	14.0	14.6	9.9
SE	1.13	1.32	0.61	0.49	0.53
Treatment	0.0001	0.0001	0.0001	0.0001	0.0001
Hybrid	0.0005	0.01	NS	NS	0.05
Maturity	0.0001	0.0001	0.0001	0.0001	0.0001
Processing	NS	NS	NS	NS	NS
Inoculation	NS	NS	NS	0.0008	NS
Hybrid × maturity	0.0001	0.002	NS	NS	0.001
Hybrid × processing	0.001	0.0003	0.007	0.0001	NS
Hybrid × inoculation	0.06	NS	NS	0.08	NS
Maturity × processing	NS	NS	NS	0.0001	0.02
Maturity × inoculation	NS	NS	NS	0.05	0.01
Processing × inoculation	NS	NS	NS	0.004	0.02

[1]Day = Day corresponds to the day silos were opened (2, 3, 6, 10, or 57 d after ensiling).

[2]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[3]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[4]NS = Not significant ($P > 0.05$).

Table 10. Lactate of post-ensiled corn silage in experiments 1 and 2.

Treatment	Day[1] 2	Day 3	Day 6	Day 10	Day 57
	(% of DM)				
Experiment 1					
Hard dough					
Proc[2] w/inoculant	1.17	1.26	1.72	2.79	6.30
Proc w/o inoculant	1.08	1.38	1.71	1.58	5.39
Unproc[3] w/inoculant	1.44	1.82	2.62	2.96	6.90
Unproc w/o inoculant	1.26	1.34	1.69	2.51	5.22
1/3 Milkline					
Proc w/inoculant	1.29	1.71	2.30	3.30	4.79
Proc w/o inoculant	1.45	1.73	2.13	3.17	4.67
Unproc w/inoculant	1.60	2.42	2.42	2.70	5.50
Unproc w/o inoculant	1.56	1.79	2.83	2.78	5.29
2/3 Milkline					
Proc w/inoculant	1.18	1.71	2.35	2.80	4.08
Proc w/o inoculant	1.03	1.86	1.96	2.56	4.39
Unproc w/inoculant	1.17	1.63	2.37	3.24	4.93
Unproc w/o inoculant	1.00	1.73	2.47	2.75	5.02
SE	0.113	0.117	0.171	0.178	0.249
Treatment	0.001	0.0001	0.0007	0.0001	0.0001
Maturity	0.0001	0.0001	0.007	0.001	0.0001
Processing	0.02	0.02	0.004	NS	0.0008
Inoculation	NS	NS	NS	0.0008	0.006
Maturity × processing	NS	0.02	NS	0.001	NS
Maturity × inoculation	NS	0.05	NS	0.02	0.0005
Processing × inoculation	NS	0.005	NS	NS	NS
Experiment 2—Hybrid 3845					
1/3 Milkline					
Proc w/inoculant	2.02	3.14	3.25	4.44	4.39
Proc w/o inoculant	1.85	2.08	3.73	4.55	4.37
Unproc w/inoculant	1.48	5.93	2.99	5.10	4.40
Unproc w/o inoculant	1.83	2.11	3.30	4.65	4.04
2/3 Milkline					
Proc w/inoculant	2.21	1.94	2.53	2.62	3.44
Proc w/o inoculant	1.82	2.39	2.48	2.92	3.51
Unproc w/inoculant	2.07	2.42	2.84	3.18	3.52
Unproc w/o inoculant	1.78	2.43	2.85	3.52	3.51
Black layer					
Proc w/inoculant	1.70	2.31	2.67	3.26	3.46
Proc w/o inoculant	1.38	1.81	2.98	2.67	3.41
Unproc w/inoculant	1.46	1.79	2.13	2.64	3.27
Unproc w/o inoculant	1.56	2.44	2.89	2.77	3.03
Experiment 2—Hybrid Quanta					
1/3 Milkline					
Proc w/inoculant	2.09	3.05	3.60	3.45	5.31
Proc w/o inoculant	2.34	2.64	3.09	3.13	5.46
Unproc w/inoculant	2.19	2.07	2.84	3.78	3.26
Unproc w/o inoculant	2.15	2.25	2.57	3.10	3.95
2/3 Milkline					
Proc w/inoculant	1.49	2.61	2.56	3.09	3.58
Proc w/o inoculant	2.21	2.25	2.52	2.81	3.22
Unproc w/inoculant	1.87	2.45	3.11	3.14	3.75
Unproc w/o inoculant	2.02	2.35	2.71	2.81	3.86
Black layer					
Proc w/inoculant	1.75	1.74	1.74	2.25	3.00
Proc w/o inoculant	2.50	2.38	2.28	2.27	2.87
Unproc w/inoculant	1.69	1.83	1.93	2.45	2.33
Unproc w/o inoculant	1.33	1.44	1.90	1.84	2.31
SE	0.198	0.247	0.241	0.247	0.188
Treatment	0.0003	0.0001	0.0001	0.0001	0.0001
Hybrid	0.02	NS	0.0002	0.0001	NS
Maturity	0.005	0.001	0.0001	0.0001	0.0001
Processing	0.04	NS	0.08	NS	0.001
Inoculation	NS	0.04	NS	0.02	NS
Hybrid × maturity	NS	NS	0.002	0.0001	0.001
Hybrid × processing	NS	0.01	NS	NS	0.03
Hybrid × inoculation	0.05	0.09	0.004	0.05	NS
Maturity × processing	NS	NS	0.0001	0.03	0.0005
Maturity × inoculation	NS	0.006	0.03	NS	NS
Processing × inoculation	NS	NS	NS	NS	NS

[1]Day = Day corresponds to the day silos were opened (2, 3, 6, 10, or 57 d after ensiling).

[2]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[3]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[4]NS = Not significant ($P > 0.05$).

Table 11. Acetate of post-ensiled corn silage in experiments 1 and 2.

Treatment	Day[1] 2	Day 3	Day 6	Day 10	Day 57
	(% of DM)				
Experiment 1					
Hard dough					
Proc[2] w/inoculant	0.77	0.90	1.34	1.81	1.93
Proc w/o inoculant	0.77	0.77	1.29	1.08	1.56
Unproc[3] w/inoculant	0.81	0.95	1.06	1.39	1.74
Unproc w/o inoculant	0.88	0.82	1.09	1.02	1.84
1/3 Milkline					
Proc w/inoculant	0.63	0.63	0.98	1.21	2.87
Proc w/o inoculant	0.61	0.65	0.82	1.25	3.22
Unproc w/inoculant	0.55	0.72	0.74	0.82	2.75
Unproc w/o inoculant	0.57	0.80	0.75	0.98	2.49
2/3 Milkline					
Proc w/inoculant	0.45	0.71	0.72	0.96	1.68
Proc w/o inoculant	0.35	0.59	0.74	1.06	2.17
Unproc w/inoculant	0.47	0.48	0.50	0.65	2.01
Unproc w/o inoculant	0.27	0.62	0.50	0.57	1.80
SE	0.059	0.075	0.092	0.125	0.123
Treatment	0.0001	0.007	0.0001	0.0001	0.0001
Maturity	0.0001	0.0001	0.0001	0.0001	0.0001
Processing	NS[4]	NS	0.0004	0.0001	NS
Inoculation	NS	NS	NS	0.05	NS
Maturity × processing	NS	NS	NS	NS	0.08
Maturity × inoculation	0.04	NS	NS	0.002	NS
Processing × inoculation	NS	NS	NS	NS	NS
Experiment 2—Hybrid 3845					
1/3 Milkline					
Proc w/inoculant	0.74	0.72	0.55	0.95	1.57
Proc w/o inoculant	0.70	0.67	1.07	0.73	1.66
Unproc w/inoculant	0.56	1.12	0.82	1.86	2.27
Unproc w/o inoculant	0.71	0.65	1.18	1.92	1.88
2/3 Milkline					
Proc w/inoculant	0.90	0.62	0.75	0.94	2.39
Proc w/o inoculant	0.44	0.85	0.68	0.93	2.49
Unproc w/inoculant	0.79	0.64	0.78	0.92	1.93
Unproc w/o inoculant	0.51	0.61	0.64	0.93	1.63
Black layer					
Proc w/inoculant	0.52	0.60	0.78	1.08	2.11
Proc w/o inoculant	0.61	0.64	0.73	0.87	1.89
Unproc w/inoculant	0.51	0.57	0.71	0.92	1.62
Unproc w/o inoculant	0.62	0.69	0.84	0.90	1.63
Experiment 2—Hybrid Quanta					
1/3 Milkline					
Proc w/inoculant	0.80	0.87	1.10	0.81	1.71
Proc w/o inoculant	0.92	1.06	1.08	0.84	1.89
Unproc w/inoculant	0.58	0.64	0.66	0.92	0.87
Unproc w/o inoculant	0.67	0.58	0.53	0.76	0.90
2/3 Milkline					
Proc w/inoculant	0.39	0.93	0.71	0.93	1.98
Proc w/o inoculant	0.90	0.58	0.72	0.85	1.84
Unproc w/inoculant	0.71	0.53	0.69	0.69	1.42
Unproc w/o inoculant	0.80	0.62	0.52	0.71	1.46
Black layer					
Proc w/inoculant	0.42	0.43	0.48	0.69	0.98
Proc w/o inoculant	0.85	0.67	0.64	0.66	1.54
Unproc w/inoculant	0.44	0.47	0.60	0.75	2.40
Unproc w/o inoculant	0.39	0.38	0.52	0.57	1.78
SE	0.047	0.058	0.058	0.064	0.130
Treatment	0.0001	0.0001	0.0001	0.0001	0.0001
Hybrid	NS	NS	0.008	0.0001	0.005
Maturity	0.001	0.0003	0.0002	0.0001	NS
Processing	0.02	0.03	0.03	0.003	NS
Inoculation	NS	NS	NS	NS	NS
Hybrid × maturity	NS	NS	NS	0.02	NS
Hybrid × processing	NS	0.005	0.003	0.001	NS
Hybrid × inoculation	0.003	NS	0.05	NS	NS
Maturity × processing	NS	NS	NS	0.0001	0.02
Maturity × inoculation	0.04	NS	0.06	NS	NS
Processing × inoculation	NS	NS	NS	NS	NS

[1]Day = Day corresponds to the day silos were opened (2, 3, 6, 10, or 57 d after ensiling).

[2]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[3]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[4]NS = Not significant ($P > 0.05$).

Table 12. Ethanol of post-ensiled corn silage in experiments 1 and 2.

Treatment	Day[1] 2	Day 3	Day 6	Day 10	Day 57
	(% of DM)				
Experiment 1					
Hard dough					
Proc[2] w/inoculant	0.21	0.18	0.18	0.28	. . .
Proc w/o inoculant	0.25	0.15	0.16	0.15	. . .
Unproc[3] w/inoculant	0.24	0.12	0.33	0.27	. . .
Unproc w/o inoculant	0.26	0.17	0.34	0.53	. . .
1/3 Milkline					
Proc w/inoculant	0.40	1.57	0.90	0.82	. . .
Proc w/o inoculant	0.30	2.12	1.14	1.14	. . .
Unproc w/inoculant	0.42	2.21	1.19	1.41	. . .
Unproc w/o inoculant	0.26	1.48	1.29	1.11	. . .
2/3 Milkline					
Proc w/inoculant	0.13	0.62	0.62	0.61	. . .
Proc w/o inoculant	0.18	0.78	0.28	0.36	. . .
Unproc w/inoculant	0.41	1.77	2.00	2.29	. . .
Unproc w/o inoculant	0.12	0.44	1.82	1.81	. . .
SE	0.072	0.362	0.065	0.127	. . .
Treatment	0.01	0.0001	0.0001	0.0001	
Maturity	0.01	0.0001	0.0001	0.0001	. . .
Processing	NS[4]	NS	0.0001	0.0001	. . .
Inoculation	0.04	NS	NS	NS	. . .
Maturity × processing	NS	NS	0.0001	0.0001	. . .
Maturity × inoculation	NS	NS	0.0003	0.08	. . .
Processing × inoculation	0.09	0.02	NS	NS	. . .
Experiment 2—Hybrid 3845					
1/3 Milkline					
Proc w/inoculant	0.44	1.13	0.65	1.70	1.76
Proc w/o inoculant	0.38	0.64	1.29	1.59	1.65
Unproc w/inoculant	0.21	1.11	1.29	1.82	1.78
Unproc w/o inoculant	0.31	0.34	1.19	1.46	1.86
2/3 Milkline					
Proc w/inoculant	0.85	0.81	0.79	0.96	0.99
Proc w/o inoculant	0.49	0.83	0.69	1.01	0.86
Unproc w/inoculant	0.76	0.77	0.77	0.78	0.65
Unproc w/o inoculant	0.88	1.07	1.03	0.92	0.70
Black layer					
Proc w/inoculant	0.71	1.49	1.65	1.60	1.47
Proc w/o inoculant	0.54	0.69	0.61	0.91	1.38
Unproc w/inoculant	0.47	0.50	0.71	1.07	1.19
Unproc w/o inoculant	0.83	1.24	1.05	0.82	0.73
Experiment 2—Hybrid Quanta					
1/3 Milkline					
Proc w/inoculant	0.27	0.31	1.09	0.41	1.45
Proc w/o inoculant	0.24	0.25	0.52	1.49	1.32
Unproc w/inoculant	0.46	1.71	0.91	0.12	0.92
Unproc w/o inoculant	0.53	0.51	1.04	0.91	0.91
2/3 Milkline					
Proc w/inoculant	0.60	1.48	1.52	1.70	1.41
Proc w/o inoculant	1.43	1.29	1.54	1.51	1.36
Unproc w/inoculant	0.98	1.20	1.14	0.99	1.01
Unproc w/o inoculant	0.69	1.09	1.08	1.10	1.05
Black layer					
Proc w/inoculant	1.08	1.09	0.93	1.00	1.02
Proc w/o inoculant	0.79	0.73	0.86	0.96	1.01
Unproc w/inoculant	1.27	1.05	0.95	1.06	0.95
Unproc w/o inoculant	0.73	0.72	0.84	0.80	0.79
SE	0.149	0.116	0.146	0.098	0.213
Treatment	0.0002	0.0001	0.0001	0.0001	0.0001
Hybrid	0.03	NS	NS	0.004	0.03
Maturity	0.0001	0.03	NS	NS	0.0001
Processing	NS	NS	NS	0.001	0.0004
Inoculation	NS	0.007	NS	NS	NS
Hybrid × maturity	NS	0.06	0.001	0.0001	0.0001
Hybrid × processing	NS	NS	NS	NS	NS
Hybrid × inoculation	NS	NS	NS	0.003	NS
Maturity × processing	NS	NS	NS	NS	NS
Maturity × inoculation	NS	0.03	NS	0.002	NS
Processing × inoculation	NS	NS	NS	NS	NS

[1]Day = Day corresponds to the day silos were opened (2, 3, 6, 10, or 57 d after ensiling).

[2]Proc = Corn silage was harvested with a 5830 John Deere harvester with kernel processing rolls set 1 mm apart.

[3]Unproc = Corn silage was harvested with a 5830 John Deere harvester with kernel processing rolls set 15.9 mm apart.

[4]NS = Not significant ($P > 0.05$).

Table 13. pH of post-ensiled corn silage in experiments 1 and 2.

Treatment	Day[1] 2	Day 3	Day 6	Day 10	Day 57
Experiment 1					
Hard dough					
Proc[2] w/inoculant	4.30	4.21	4.08	3.84	3.70
Proc w/o inoculant	4.32	4.23	4.18	4.15	3.83
Unproc[3] w/inoculant	4.32	4.30	3.95	3.71	3.74
Unproc w/o inoculant	4.40	4.30	4.19	4.14	3.84
1/3 Milkline					
Proc w/inoculant	4.18	4.10	3.82	3.81	3.38
Proc w/o inoculant	4.26	4.12	3.82	3.84	3.38
Unproc w/inoculant	4.13	4.02	3.74	3.73	3.29
Unproc w/o inoculant	4.19	4.04	3.76	3.74	3.34
2/3 Milkline					
Proc w/inoculant	4.40	4.26	4.06	3.85	3.84
Proc w/o inoculant	4.58	4.20	3.98	3.94	3.85
Unproc w/inoculant	4.28	4.28	4.06	3.97	3.91
Unproc w/o inoculant	4.54	4.44	4.20	4.09	3.92
SE	0.018	0.017	0.015	0.017	0.013
Treatment	0.0001	0.0001	0.0001	0.0001	0.0001
Maturity	0.0001	0.0001	0.0001	0.0001	0.0001
Processing	0.007	0.003	NS[4]	NS	NS
Inoculation	0.0001	0.06	0.0001	0.0001	0.0001
Maturity × processing	0.0001	0.0001	0.0001	0.0001	0.0001
Maturity × inoculation	0.0001	NS	0.0001	0.0001	0.0001
Processing × inoculation	0.07	0.02	0.0001	0.07	NS
Experiment 2—Hybrid 3845					
1/3 Milkline					
Proc w/inoculant	3.93	3.83	3.69	4.03	3.55
Proc w/o inoculant	3.95	3.85	3.68	4.02	3.55
Unproc w/inoculant	4.09	3.91	3.78	3.72	3.64
Unproc w/o inoculant	4.08	3.91	3.78	3.72	3.64
2/3 Milkline					
Proc w/inoculant	4.18	4.11	4.07	3.98	3.97
Proc w/o inoculant	4.18	4.10	4.08	3.96	3.92
Unproc w/inoculant	4.11	4.01	3.89	3.83	3.84
Unproc w/o inoculant	4.11	3.96	3.87	3.83	3.78
Black layer					
Proc w/inoculant	4.06	3.87	3.91	3.75	3.90
Proc w/o inoculant	4.05	3.94	3.96	3.80	3.86
Unproc w/inoculant	4.16	4.07	3.99	3.86	3.89
Unproc w/o inoculant	4.06	3.96	3.90	3.89	3.91
Experiment 2—Hybrid Quanta					
1/3 Milkline					
Proc w/inoculant	3.97	3.84	3.60	3.65	3.67
Proc w/o inoculant	4.01	3.93	3.67	3.66	3.70
Unproc w/inoculant	4.00	3.82	3.69	3.69	3.68
Unproc w/o inoculant	4.01	3.83	3.71	3.70	3.72
2/3 Milkline					
Proc w/inoculant	4.26	4.13	4.03	3.98	3.92
Proc w/o inoculant	4.25	4.12	4.04	3.98	3.89
Unproc w/inoculant	4.14	4.07	3.95	3.92	3.84
Unproc w/o inoculant	4.13	4.08	3.95	3.94	3.84
Black layer					
Proc w/inoculant	4.27	4.14	3.94	3.90	4.04
Proc w/o inoculant	4.31	4.20	3.93	3.94	4.05
Unproc w/inoculant	4.20	4.15	3.93	3.98	4.17
Unproc w/o inoculant	4.29	4.21	3.94	3.94	4.10
SE	0.013	0.011	0.009	0.011	0.017
Treatment	0.0001	0.0001	0.0001	0.0001	0.0001
Hybrid	0.0001	0.0001	0.02	NS	0.0001
Maturity	0.0001	0.0001	0.0001	0.0001	0.0001
Processing	NS	NS	0.04	0.002	NS
Inoculation	NS	NS	NS	NS	NS
Hybrid × maturity	0.0001	0.0001	0.0005	0.0001	0.0001
Hybrid × processing	0.0001	0.005	NS	0.0003	NS
Hybrid × inoculation	0.01	0.01	NS	NS	NS
Maturity × processing	0.0001	0.0001	0.0001	0.0001	0.0001
Maturity × inoculation	NS	NS	NS	NS	NS
Processing × inoculation	NS	0.02	0.04	NS	NS

[1]Day = Day corresponds to the day silos were opened (2, 3, 6, 10, or 57 d after ensiling).

[2]Proc = Corn silage was harvested with kernel processing rolls set 1 mm apart.

[3]Unproc = Corn silage was harvested with kernel processing rolls set 15.9 mm apart.

[4]NS = Not significant ($P > 0.05$).

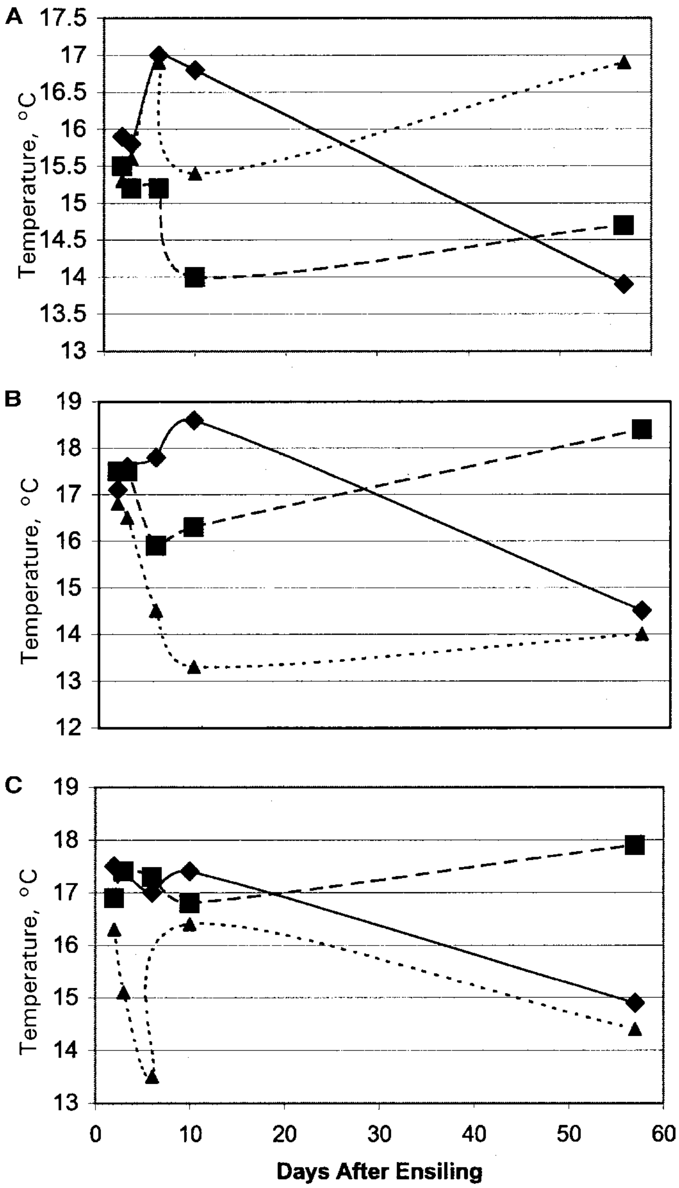

Figure 1. Temperature plotted across days after ensiling for corn silage harvested at different maturities in experiment 1 [Figure 1a—hard dough (♦), one-third milkline (■), and two-thirds milkline (▲) stages of maturity in experiment 1], for hybrid 3845 in experiment 2 [Figure 1b—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)], and for hybrid Quanta in experiment 2 [Figure 1c—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)].

fore the greater amount of moisture for corn silage harvested at the early maturities provided an environment for increased temperature.

The effect of maturity of corn silage on temperature in experiment 1 differed from experiment 2 (Table 8). In experiment 1, temperature of corn silage tended to be similar between maturities at 2 and 3 d after ensiling. By 6 ($P < 0.0001$) and 10 ($P < 0.0001$) d after ensiling, corn silage harvested at the middle maturity (one-third ML) had lower temperatures than at the early (hard dough) and advanced (two-thirds ML) maturities. At 57 d after ensiling corn silage harvested at hard dough and one-third ML had lower temperatures ($P < 0.0002$) than at an advanced maturity (two-thirds ML). These results do not follow the theory that higher concentrations of WSC and lower DM concentration in the corn silage will promote increased temperature. The reason for the difference between experiments is unknown.

In experiment 2, there was an interaction of time (days after ensiling) with hybrid and maturity for temperature of corn silage (d 2 to d 3, $P < 0.005$; d 3 to d 6, $P < 0.007$; d 6 to d 10, $P < 0.0001$; d 10 to d 57, $P < 0.0001$). Temperature decreased at a faster rate (between 2 and 6 d after ensiling) for corn harvested at physiological maturity (BL) than at earlier maturities (one-third and two-thirds ML) with both hybrids in experiment 2 (Figures 1b and 1c). Also, the temperature of hybrid Quanta corn silage harvested at BL dropped at a faster rate than hybrid 3845 corn silage harvested at BL between 2 and 6 d after ensiling (Figures 1b and 1c). The drier silage tended to have temperatures that declined at a faster rate than wetter silage in experiment 2. This may be an indication that there was less microbial activity in the drier silage.

Water-soluble carbohydrate concentrations in the corn differed among maturities in experiments 1 and 2 (Table 9). Corn harvested at the earliest maturity in both experiments had significantly greater concentrations ($P < 0.0001$ at d 2, 3, 6, and 10 for both experiments) of WSC 2, 3, 6, and 10 d after ensiling than corn harvested at advanced maturities (Figures 2a through 2c). However, the difference in WSC concentration between the earliest maturity and the two advanced maturities in both experiments became less as days after ensiling advanced (Figures 2a through 2c). The greater levels of WSC in postensiled corn silage (Table 9) harvested at early maturities was related to the greater level of WSC in pre-ensiled whole corn at early maturities (Tables 1 through 3). The whole corn plant has greater levels of sugars when it is immature. As the corn plant matures, the corncob and kernels develop, starch levels increase, and the amount of sugars present in the whole corn plant decrease. Increased levels of sugar in the corn silage help to promote a rapid fermentation, because the sugar compounds are an excellent source of energy for lactic acid producing bacteria. Therefore, it is common for less mature corn silage to go through a rapid fermentation process because there is a greater level of rapidly fermentable substrate available.

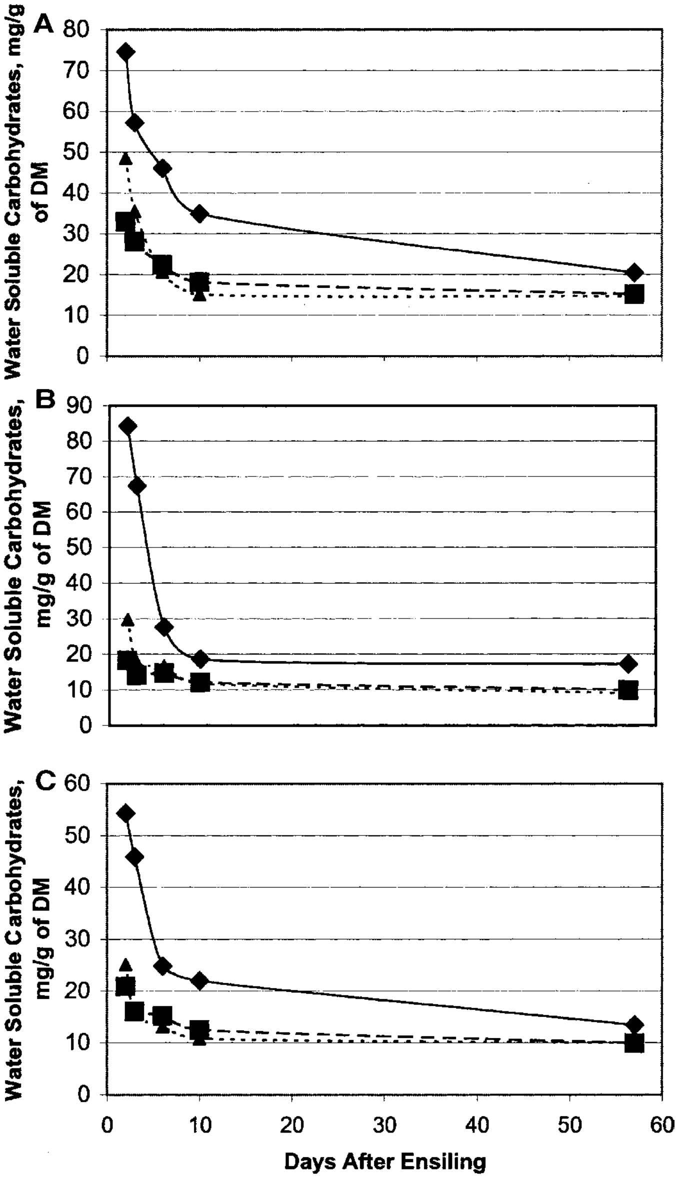

Figure 2. Water-soluble carbohydrate concentration plotted across days after ensiling for corn silage harvested at different maturities in experiment 1 [Figure 2a—hard dough (♦), one-third milkline (■), and two-thirds milkline (▲) stages of maturity in experiment 1], for hybrid 3845 in experiment 2 [Figure 2b—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)], and for hybrid Quanta in experiment 2 [Figure 2c—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)].

There was a hybrid × maturity interaction in experiment 2, and hybrid 3845 corn silage harvested at the earliest maturity (one-third ML) had a greater concentration ($P < 0.0001$) of WSC at 2 (84.2 vs 54.3 mg/g of DM) and 3 (67.4 vs 45.9 mg/g of DM) d after ensiling than hybrid Quanta corn silage (Figures 2b and 2c). There was also a time × hybrid × maturity interaction in experiment 2, and the concentration of WSC in the corn dropped more for hybrid 3845 than hybrid Quanta as d after ensiling increased from 2 to 3 ($P < 0.07$) and from 3 to 6 ($P < 0.0001$; Figures 2b and 2c). The difference in WSC concentration between hybrids can be partially explained by the tendency of hybrid Quanta to have a greater starch concentration than hybrid 3845 at similar maturities (Tables 5 and 6). The increased starch concentration replaced some of the WSC, and therefore there was lower WSC in hybrid Quanta corn silage.

In experiment 1, lactate concentrations were greater for corn silage harvested at one-third ML compared with hard dough at 2 ($P < 0.0009$), 3 ($P < 0.0001$), 6 ($P < 0.002$), and 10 ($P < 0.0004$) d after ensiling (Table 10; Figure 3a). However, the absolute differences among maturities in experiment 1 were small (0.18 to 0.53; Figure 3a). By 57 d after ensiling, corn silage harvested at hard dough stage of maturity (less mature) had the greatest concentration ($P < 0.0001$) of lactate followed by corn silage harvested at one-third ML and two-thirds ML (Table 10; Figure 3a). The reason for the rapid increase in lactate concentration of corn silage harvested at hard dough is unknown; however, it may be related to the greater concentration of WSC available to the lactate producing bacteria 10 d after ensiling compared with corn silage harvested at one-third ML and two-thirds ML (Table 9). The greater levels of WSC provided a greater energy source for lactic acid producing bacteria to use, therefore causing a rapid increase in lactic acid production.

In experiment 2, the lactate concentration was greater for corn harvested at the earliest maturity (one-third ML) compared with physiological maturity (BL) at 2 ($P < 0.003$) and 3 ($P < 0.0003$) d after ensiling (Table 10; Figures 3b and 3c). However, there was a hybrid × maturity interaction at 6, 10, and 57 d after ensiling in experiment 2 (Table 10). For both hybrids, the lactate concentration was significantly greater for corn silage harvested at one-third ML than two-thirds ML and BL at 6 (3845, $P < 0.0001$ and Quanta, $P < 0.02$), 10 (3845, $P < 0.0001$ and Quanta, $P < 0.007$), and 57 (3845, $P < 0.0001$ and Quanta, $P < 0.0001$) d after ensiling (Table 10; Figures 3b and 3c). The difference in lactate concentration between maturities tended to be greater for hybrid 3845 corn at 6 ($P < 0.002$) and 10 ($P < 0.0001$) d after ensiling than hybrid Quanta (Figures 3b and 3c).

There was a time × maturity interaction for lactate concentration as d advanced from 2 to 3 ($P < 0.05$) and a time by hybrid × maturity interaction as d advanced from 6 to 10 ($P < 0.003$) in experiment 2. The lactate concentration in the corn increased more at the early maturity (one-third ML) as d advanced from 2 to 3 than the advanced maturities (two-thirds ML and BL; 0.91 vs. 0.39 and 0.32 percentage units for one-third ML,

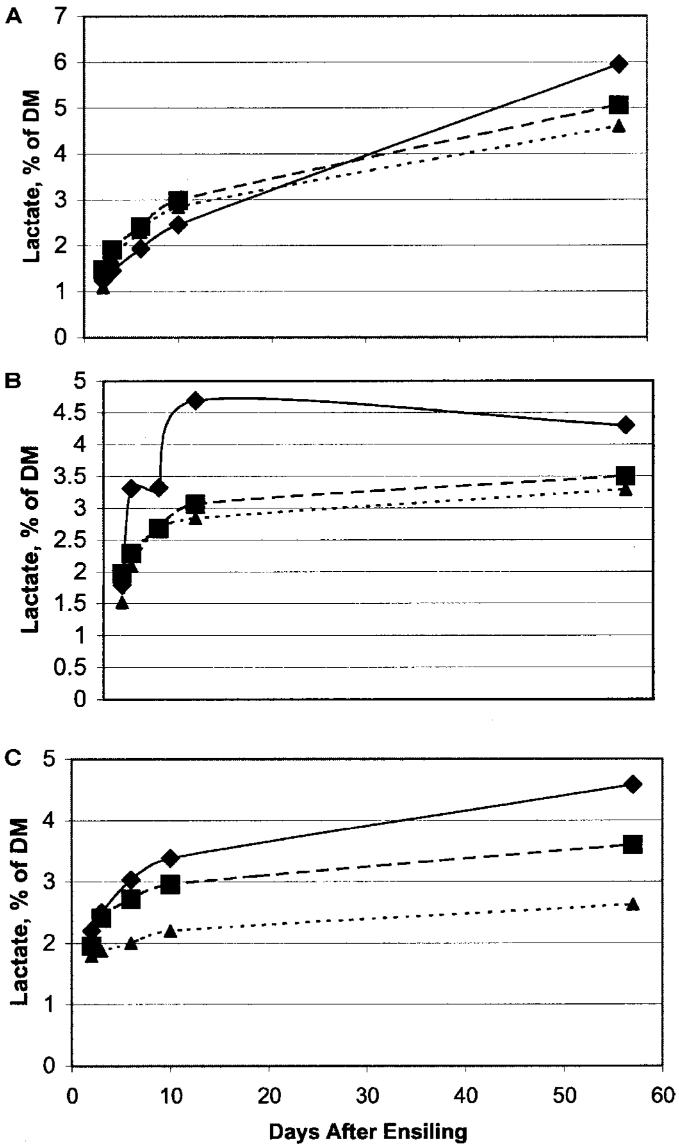

Figure 3. Lactate concentration plotted across days after ensiling for corn silage harvested at different maturities in experiment 1 [Figure 3a—hard dough (♦), one-third milkline (■), and two-thirds milkline (▲) stages of maturity in experiment 1], for hybrid 3845 in experiment 2 [Figure 3b—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)], and for hybrid Quanta in experiment 2 [Figure 3c—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)].

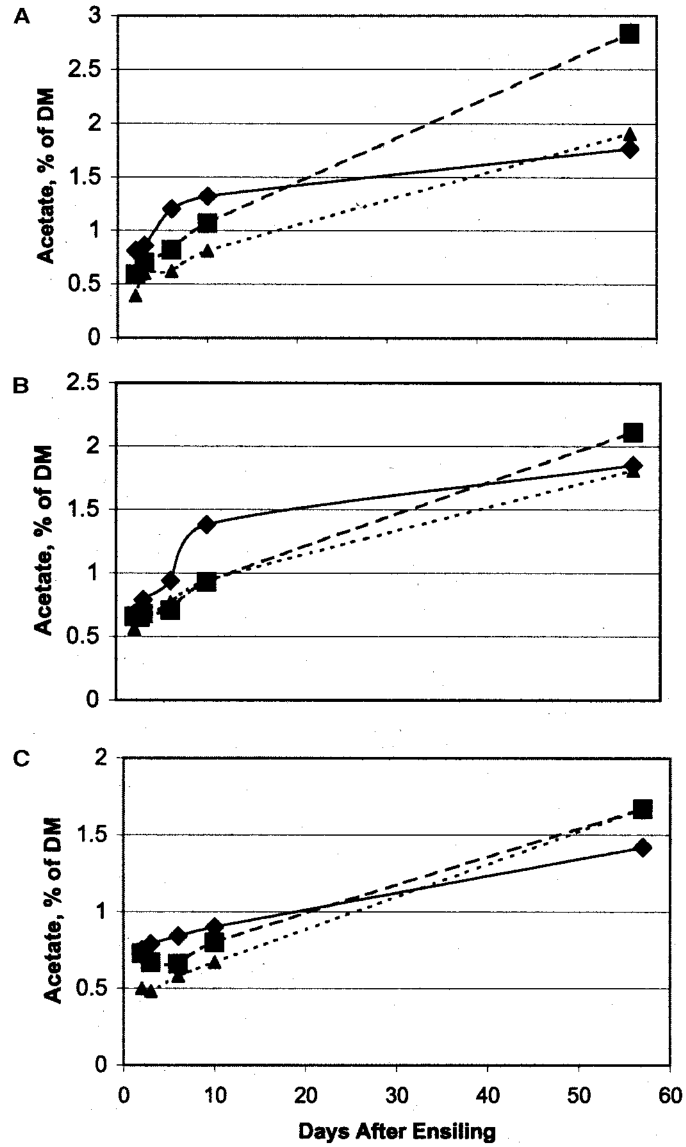

Figure 4. Acetate concentration plotted across days after ensiling for corn silage harvested at different maturities in experiment 1 [Figure 4a—hard dough (♦), one-third milkline (■), and two-thirds milkline (▲) stages of maturity in experiment 1], for hybrid 3845 in experiment 2 [Figure 4b—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)], and for hybrid Quanta in experiment 2 [Figure 4c—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)].

two-thirds ML and BL, respectively; Figures 3b and 3c). Both hybrids had lactate concentrations that increased more at one-third ML than advanced maturities (two-thirds ML and BL) as d advanced from 6 to 10. However, there was a greater increase in the lactate concentration at one-third ML as d advanced from 6 to 10 for hybrid 3845 than hybrid Quanta (1.37 vs 0.35 percentage units; Figures 3b and 3c). The increased production of lactate soon after ensiling for corn harvested at one-third ML may be partially related to more WSC being available for consumption by lactate producing bacteria present in the corn (Table 9).

Acetate concentration was significantly affected by corn silage maturity in experiments 1 and 2 (Table 11). However, many times the absolute difference between maturities was small at a given time point (Figure 4a through 4c). In experiment 1, the acetate concentration decreased as maturity advanced (Table 11). The acetate concentration was greater for corn silage harvested at hard dough than one-third ML, and corn silage harvested at one-third ML had greater acetate concentrations than at two-thirds ML at 2 ($P < 0.0001$ and $P < 0.0001$), 3 ($P < 0.005$ and $P < 0.07$), 6 ($P < 0.0001$ and $P < 0.003$) and 10 ($P < 0.008$ and $P < 0.007$) d after ensiling (Table 11; Figure 4a). In experiment 2, acetate concentration was greater for corn silage harvested at the earliest maturity (one-third ML) compared with physiological maturity (BL) at 2 ($P < 0.0007$), 3 ($P < 0.0001$), 6 ($P < 0.0002$), and 10 ($P < 0.0001$) d after ensiling. There was a hybrid × maturity interaction ($P < 0.02$) at 10 d after ensiling for acetate concentration in corn. Hybrid 3845 had a rapid increase in acetate concentration on d 10 after ensiling compared with hybrid Quanta (Figures 4b and 4c). As d advanced to 57 the acetate concentration was greater in the medium maturing corn silage than the early and advanced maturing corn silage in experiment 1 ($P < 0.0001$; Figure 4a), and there was no difference in acetate concentration across corn silage maturities in experiment 2. The greater increase in acetate concentration for the medium maturing silage compared with the early maturing silage, in experiment 1, is unknown. However, it is an indication that there is still microbial activity occurring in the silage that is causing production of acetate between d 10 and 57.

There was a time × maturity interaction as d advanced from 10 to 57 for acetate concentration in both experiments (experiment 1, $P < 0.0001$; experiment 2, $P < 0.0002$; Figures 4a through 4c). Acetate concentration in corn silage harvested at the medium maturity increased more than at the early and advanced maturities in both experiments as d advanced from 10 to 57. In experiment 1, the acetate concentration increased by 1.76 percentage units for corn silage harvested at one-third ML, whereas at hard dough and two-thirds ML the acetate concentration increased by 0.45 and 1.10 percentage units, respectively. In experiment 2, there was a greater increase in acetate concentration as d advanced from 10 to 57 for corn silage harvested at two-thirds ML (1.03 percentage units) than at one-third ML (0.49 percentage units) and BL (0.94 percentage units) maturities.

These results suggest that the rate of fermentation was greater for the less mature corn silage, therefore there was a greater concentration of acetate early after ensiling (2, 3, 6, 10 d). Acetate was being formed at a slower rate by microbes in corn harvested at advanced stages of maturity. Therefore, by the time fermentation was complete (approximately 60 d after ensiling) the acetate concentration tended to be similar across corn silage maturities.

The ethanol concentration was affected by maturity of corn silage in both experiments (Table 12). Corn silage harvested at the earliest maturity had lower concentrations of ethanol than the medium maturing silage at 2 ($P < 0.02$), 3 ($P < 0.0003$), 6 ($P < 0.0001$), and 10 ($P < 0.0001$) d after ensiling in experiment 1, and at 2 ($P < 0.0001$) and 3 ($P < 0.009$) d after ensiling in experiment 2 (Table 12). Ethanol concentrations of corn silage harvested at the earliest maturity (hard dough) were lower than at the advanced maturity (two-thirds ML) in experiment 1, also. By 57 d after ensiling there was a hybrid × maturity interaction, and the ethanol concentration was greatest ($P < 0.0001$) for the corn silage harvested at the earliest maturity (one-third ML) compared with advanced maturities (two-thirds ML and BL) for hybrid 3845 in experiment 2.

The pH was affected by maturity of corn silage in experiments 1 and 2 (Table 13). In experiment 1, corn silage harvested at one-third ML had a lower pH than corn silage harvested at earlier (hard dough) and later (two-thirds ML) maturities at 2 ($P < 0.0001$), 3 ($P < 0.0001$), 6 ($P < 0.0001$), 10 ($P < 0.0001$), and 57 ($P < 0.0001$) d after ensiling (Figure 5a). The trend for pH to be lower in corn silage harvested at one-third ML compared with corn silage harvested at hard dough and two-thirds ML follows similar trends to corn silage lactate concentration in experiment 1 (Tables 10 and 13). The lactate concentration was greater for corn silage harvested at one-third ML compared with corn silage harvested at hard dough and two-thirds ML at 2 and 3 d after ensiling, and the lactate concentration was greater for corn silage harvested at one-third ML than at hard dough at 6 and 10 d after ensiling (Table 10). These results suggest that as the lactate concentration in the medium (one-third ML) maturing corn silage increased, there was a coincidental greater decline in the pH for the medium maturing corn silage compared with the early (hard dough) and late (two-thirds ML) maturing corn silage.

There was a hybrid × maturity interaction for pH of corn silage in experiment 2. Hybrid 3845 corn silage harvested at the earliest maturity (one-third ML) had a lower pH at 6 ($P < 0.0001$) and 57 ($P < 0.0001$) d after ensiling compared with the advanced maturities (Table 13; Figure 5b). At 2, 3, and 10 d after ensiling the numerical differences in pH between maturities were minimal for hybrid 3845 in experiment 2 (Figure 5b). Hybrid Quanta corn silage harvested at the earliest maturity (one-third ML) had a lower pH at 2 ($P < 0.0001$), 3 ($P < 0.0001$), 6 ($P < 0.0001$), 10 ($P < 0.0001$), and 57 ($P < 0.0001$) d after ensiling than the advanced maturities (Figure 5c). There was also a time × hybrid × maturity interaction for pH of corn silage between d 3 and 6 ($P < 0.0001$), 6 and 10 ($P < 0.0001$), and 10 and

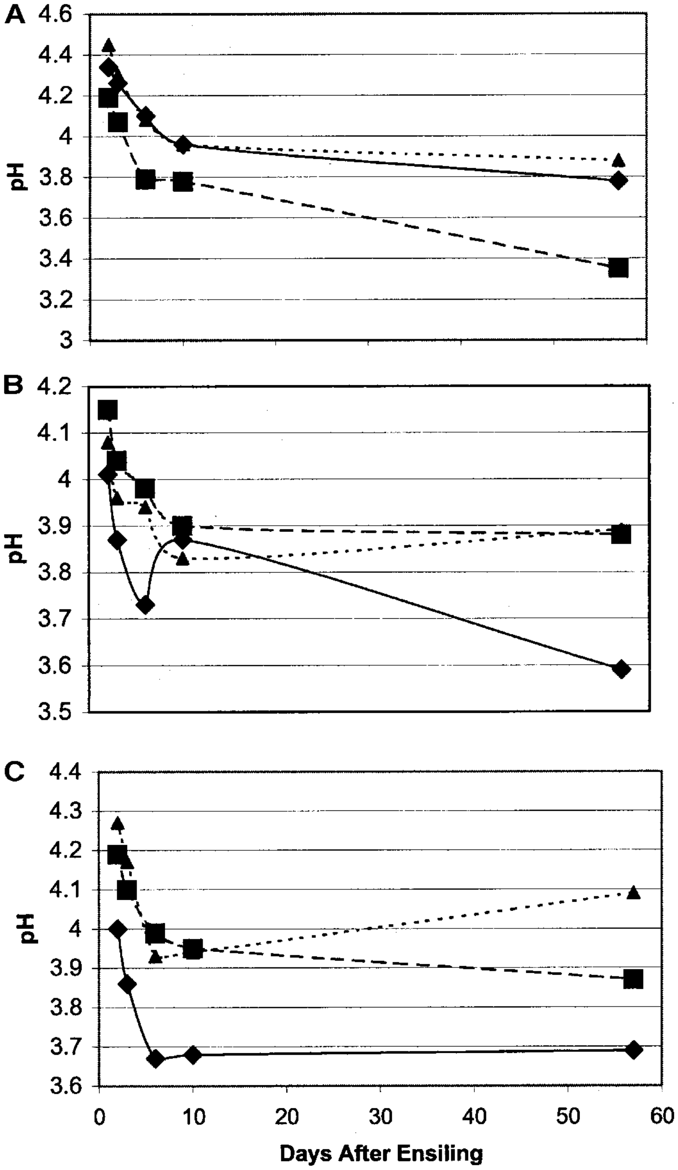

Figure 5. pH plotted across days after ensiling for corn silage harvested at different maturities in experiment 1 [Figure 5a—hard dough (♦), one-third milkline (■), and two-thirds milkline (▲) stages of maturity in experiment 1], for hybrid 3845 in experiment 2 [Figure 5b—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)], and for hybrid Quanta in experiment 2 [Figure 5c—one-third milkline (♦), two-thirds milkline (■), and blackline (▲)].

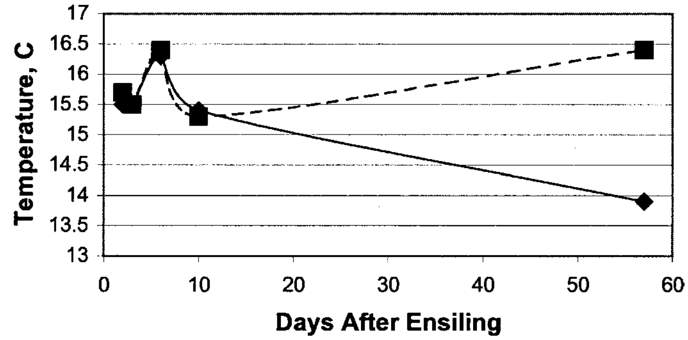

Figure 6. Temperature plotted across days after ensiling for corn silage that was processed (♦) or unprocessed (■) in experiment 1.

57 ($P < 0.0001$) in experiment 2. The pH decline was greater for hybrid Quanta compared with hybrid 3845 corn silage at all maturities as d advanced from 3 to 6 (Figures 5b and 5c). Whereas, the pH decline was greater for hybrid 3845 compared with hybrid Quanta corn silage at two-thirds ML and BL as d advanced from 6 to 10. As d advanced from 10 to 57, the hybrids behaved differently at each maturity. The main difference was that the pH of corn silage at one-third ML was similar between d 10 and 57 for hybrid Quanta, but declined for hybrid 3845 (Figures 5b and 5c).

The changes in pH of corn over time after ensiling can be explained by WSC and acetic and lactic acid production in experiment 2. Both hybrids of corn silage harvested at the early maturity (one-third ML) had a greater concentration of WSC early after ensiling (2, 3, 6, and 10 d) compared with advanced maturities (two-thirds ML and BL; experiment 2; Figures 2b and 2c). The greater concentration of WSC provides increased nutrients for homofermentative and heterofermentative bacteria to consume and produce primarily lactic acid and some acetic acid. Lactic acid concentrations were greater at one-third ML compared with two-thirds ML and BL at 6, 10, and 57 d after ensiling (experiment 2; Figure 3b and 3c). Acetate concentration was greater for corn silage harvested at one-third ML compared with BL at 2, 3, 6, and 10 d after ensiling (experiment 2; Figures 4b and 4c). Others have reported a decline in lactate (Bal et al., 1997; Huber et al., 1968; Johnson et al., 1997), acetate (Bal et al., 1997; Huber et al., 1968), and ethanol (Bal et al., 1997) as maturity advanced. McDonald et al. (1991) suggested that pH tends to increase and organic acids tend to decline as maturity advances because there are less fermentable substrates available.

Mechanical Processing

Mechanical processing had a minimal effect on silage fermentation characteristics in experiments 1 and 2 (Tables 7 through 13). In experiment 2, the DM concentration was significantly greater ($P < 0.0001$) for unprocessed corn silage at all time points of ensiling than processed corn silage. In experiments 1 and 2, there were no statistical differences in temperature between processed and unprocessed corn silage until 57 d after ensiling (Table 8). The unprocessed corn silage (16.4°C) stayed warmer than the processed corn silage (13.9°C) at 57 d after ensiling in experiment 1 (Figure 6). The

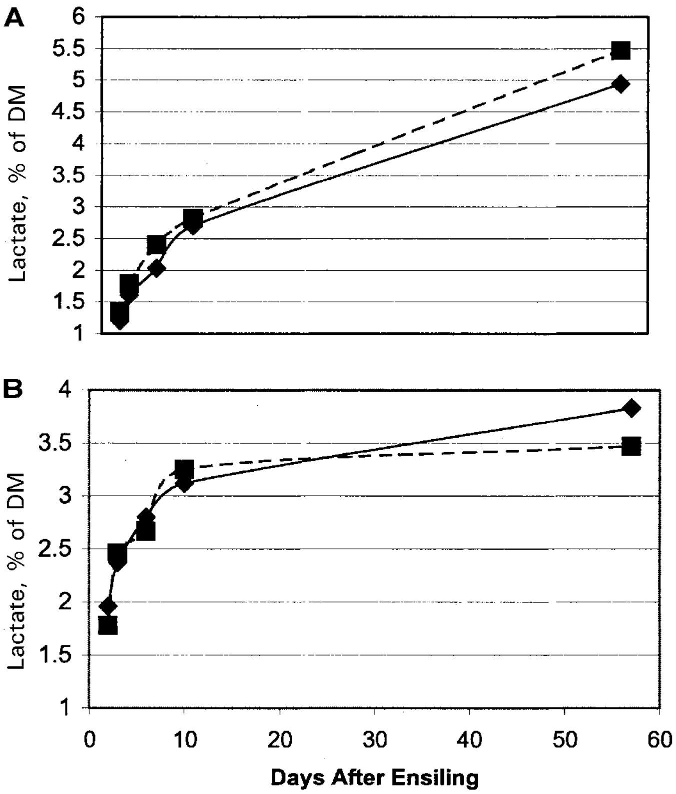

Figure 7. Lactate concentration plotted across days after ensiling for corn silage that was processed (♦) and unprocessed (■) in experiment 1 (Figure 7a), and processed (♦) and unprocessed (■) in experiment 2 (Figure 7b).

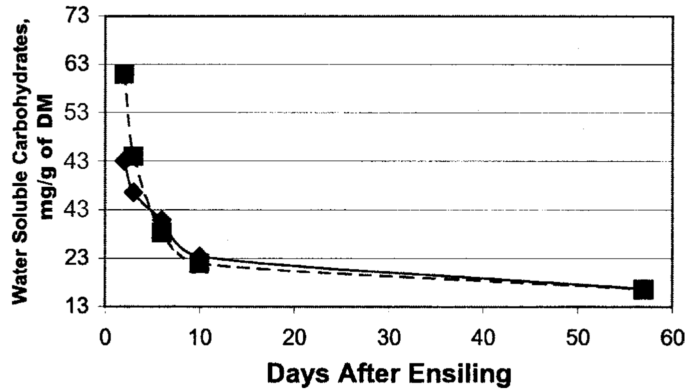

Figure 8. Water-soluble carbohydrate concentration plotted across days after ensiling for corn silage that was processed (♦) and unprocessed (■) in experiment 1.

opposite trend was reported in experiment 2. However, the difference in temperature was small (0.5°C), and it is difficult to interpret the biological impact of a small difference in temperature on silage fermentation characteristics. Water-soluble carbohydrate concentrations were similar between processed and unprocessed corn silage 6, 10, and 57 d after ensiling in experiment 1, and were similar at all days after ensiling in experiment 2 (Table 9).

There was a minor effect of mechanical processing corn silage on VFA and lactate production (Tables 10 and 11). The lactate concentration tended to be greater for unprocessed corn silage at 2 ($P < 0.02$), 3 ($P < 0.02$), 6 ($P < 0.004$), and 57 ($P < 0.0008$) d after ensiling in experiment 1 (Figure 7a). The increased WSC concentrations at 2 and 3 d after ensiling in experiment 1 may have contributed to the increased lactate concentrations observed for unprocessed corn silage (Figures 7a and 8). However, in experiment 2, the lactate concentration was greater for processed corn silage at 2 ($P < 0.04$), 6 ($P < 0.08$), and 57 ($P < 0.001$) d after ensiling (Figure 7b). In the early d after ensiling (2, 3, 6, and 10 d), the absolute difference in lactate concentration between processed and unprocessed silage (0.13 to 0.37 percentage units) was small in both experiments. Therefore, even though the differences were statistically different, it is difficult to determine the biological impact of the differences. The amount of lactate present in each silage increased over time, and by 57 d after ensiling the difference between processed and unprocessed silage was greater (0.61 to 1.53 percentage units) than at the earlier time points (Figures 7a and 7b). In experiment 2, the difference in lactate concentration was mainly attributed to hybrid Quanta processed corn silage having greater lactate concentration than hybrid Quanta unprocessed corn silage (Table 10). The reason for the different statistical trends in lactate concentrations between processed and unprocessed corn silage in experiments 1 and 2 is unknown. However, others have reported lactate levels for processed corn silage were greater (Rojas-Bourrillon et al., 1987; Weiss and Wyatt, 2000—high oil hybrid), lower (Johnson et al., 1997—one-third ML and two-thirds ML; Weiss and Wyatt, 2000—conventional hybrid), or similar (Johnson, 1996; Johnson et al., 1997—hard dough) to unprocessed corn silage.

Ethanol concentration in corn silage followed similar trends as lactate concentration for processed and unprocessed corn silage in experiments 1 and 2 (Tables 10 and 12). In experiment 1, unprocessed corn silage had significantly greater ethanol concentration at 6 ($P < 0.0001$; 0.61 percentage units) and 10 ($P < 0.0001$; 0.68 percentage units) d after ensiling than processed corn silage. However, in experiment 2, processed corn silage had significantly greater ethanol concentrations at 10 ($P < 0.001$; 0.25 percentage units) and 57 ($P < 0.0004$; 0.26 percentage units) d after ensiling.

Acetate concentration in corn silage did not follow similar trends to lactate and ethanol concentrations in experiments 1 and 2 (Tables 10 through 12). Processed corn silage had significantly greater acetate concentrations at 6 ($P < 0.0004$) and 10 ($P < 0.0001$) d after ensiling in experiment 1, at 2 ($P < 0.02$) d after ensiling in experiment 2, and at 3 ($P < 0.0008$) and 6 ($P < 0.0003$) d after ensiling for hybrid Quanta in experiment 2 (Table 11). Also, hybrid 3845 processed corn silage had a significantly lower acetate concentration at 10 ($P < 0.001$) d after ensiling than unprocessed corn silage in experiment 2 (Table 11). By 57 d after ensiling, acetate concentrations for processed and unprocessed corn silage were similar. The absolute differences were small (0.02 to 0.38 percentage units) for all the comparisons where acetate concentrations in processed corn silage were greater than unprocessed corn silage, and it is difficult to determine the biological impact of the differences. Others have reported acetate concentrations for processed corn silage that were greater [Johnson et al., 1997: one-third ($P < 0.04$) and two-thirds ML ($P < 0.04$); Weiss and Wyatt, 2000: conventional hybrid], lower (Weiss and Wyatt, 2000: high oil hybrid), or similar (Rojas-Bourrillon et al., 1987; Johnson, 1996; Johnson et al., 1997: hard dough) to unprocessed corn silage. However, once again, these differences were minimal and probably biologically insignificant.

In experiment 1, lactate concentration in the processed corn silage tended to be lower, whereas acetate concentration tended to be greater than unprocessed corn silage (Tables 10 and 11). These results suggest that with wetter corn silage, processing may promote greater acetate concentrations. However, in experiment 2 (hybrids 3845 and Quanta), lactate and acetate concentrations in the corn silage followed similar patterns within a hybrid. If lactate levels were greater for processed corn silage than acetate levels would also be greater (Tables 10 and 11). The growing and harvest conditions were drier in experiment 2, therefore the plants matured more rapidly and were drier at harvest. These factors may have contributed to the trends observed in experiment 2.

The pH decline over time was similar between processed and unprocessed corn silage in experiments 1 and 2 (Table 13). There were two situations in each experiment where pH differences reached statistical significance. However, the absolute differences were small (–0.01 to 0.06 pH units), and it is difficult to determine the biological impact. Overall, the differences between VFA and lactate concentrations in processed and unprocessed corn silage did not lead to differences in pH of the corn silage.

There were time × processing interactions for silage fermentation characteristics in this study. However, the change in silage fermentation characteristics (lactate, acetate, WSC, and pH) between days for processed

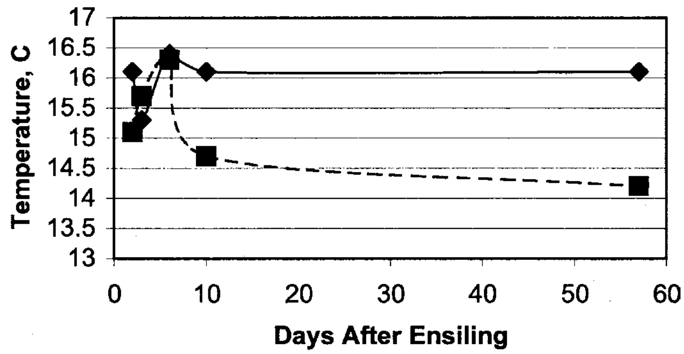

Figure 9. Temperature plotted across days after ensiling for corn silage that was inoculated (♦) and uninoculated (■) in experiment 1.

and unprocessed corn silage didn't follow consistent patterns, and many times the absolute values, although statistically different, did not have wide numerical differences between processed and unprocessed silage. There was a significant ($P < 0.0001$) time × processing interaction for temperature of corn silage between d 10 and d 57 in experiment 1. The temperature of unprocessed corn silage increased from d 10 to 57 by 1.1°C, and the temperature of processed corn silage decreased from d 10 to 57 by 1.5°C. The difference in temperature over time is an indication that there may have been more microbial activity between d 10 and 57 in the unprocessed corn silage in experiment 1.

Inoculation

Inoculation had a minor effect on corn silage fermentation characteristics in experiments 1 and 2 (Tables 7 through 13). Uninoculated corn silage tended to have a greater DM concentration than inoculated corn silage at 2 ($P < 0.0003$), 3 ($P < 0.08$), 6 ($P < 0.0001$), and 10 ($P < 0.0001$) d after ensiling in experiment 1, and at 10 ($P < 0.05$) and 57 ($P < 0.02$; Table 7) d after ensiling in experiment 2. The temperature of corn silage treated with Pioneer inoculant 1132 was greater at 2 ($P < 0.0004$), 10 ($P < 0.0001$), and 57 ($P < 0.0002$) d after ensiling compared with uninoculated corn silage by 1°C, 1.4°C, and 1.9°C, respectively, in experiment 1 (Figure 9). However, there were no significant differences in temperature between inoculated and uninoculated corn silage at all time points in experiment 2 (Table 8). Water-soluble carbohydrate concentrations were greater for uninoculated corn silage at 2 ($P < 0.05$), 3 ($P < 0.001$), and 10 ($P < 0.003$) d after ensiling in experiment 1 (Table 9). However, in experiment 2, WSC concentration tended to be similar between inoculated and uninoculated corn silage at all time points except for hybrid 3845 at d 10 (Table 9). Hybrid 3845 uninoculated corn

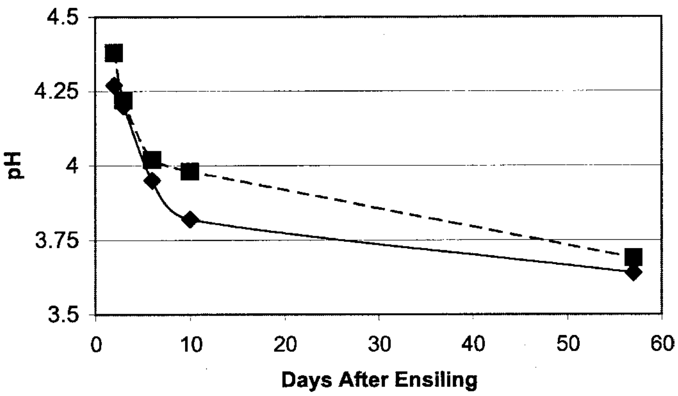

Figure 10. pH plotted across days after ensiling for corn silage that was inoculated (♦) and uninoculated (■) in experiment 1.

silage had a greater ($P < 0.08$) concentration of WSC than inoculated corn silage 10 d after ensiling in experiment 2 (Table 9).

VFA and lactate concentrations tended to be similar between inoculated and uninoculated corn silage at the majority of time-points in experiments 1 and 2 (Tables 10 through 12). However, there were occasions in both experiments where lactate, acetate, or ethanol concentrations were significantly greater in inoculated corn silage compared with uninoculated corn silage. The pH of corn silage was affected by inoculation in experiment 1, but not in experiment 2 (Table 13). Inoculated corn silage had a significantly lower pH at all time points (2, 6, 10, and 57 d, $P < 0.0001$ and 3 d, $P < 0.06$) than uninoculated corn silage in experiment 1 (Figure 10).

The increased temperature (10 and 57 d after ensiling; Figure 9), increased lactate (10 and 57 d after ensiling) and acetate (10 d after ensiling) concentrations, lower WSC (2, 3, and 10 d after ensiling), and lower pH (2, 3, 6, 10, and 57 d after ensiling; Figure 10) indicate that there was some increased microbial activity for corn silage inoculated with Pioneer 1132 inoculant compared with uninoculated corn silage in experiment 1. However, in experiment 2, there was little data to substantiate an increase in microbial activity due to inoculation. There was no significant difference in temperature, acetate concentration, or pH at any time points in experiment 2, and lactate concentration was only significantly greater for inoculated hybrid Quanta corn silage at 10 d after ensiling.

There was a significant time × inoculation interaction for temperature and pH in experiment 1 (Figures 9 and 10). However, in experiment 2, the only significant interaction of time with inoculation was for WSC concentration in corn silage, and the absolute differences were small. In experiment 1, inoculated corn silage cooled (0.7°C) from d 2 to d 3, whereas uninoculated corn silage heated (0.6°C) from d 2 to d 3 (Figure 9). Also, there was a large drop in temperature between d 6 and d 10 for uninoculated corn silage (1.7°C) compared with inoculated corn silage (0.2°C) in experiment 1 (Figure 9). The change in pH differed among inoculated and uninoculated corn silage between d 2 and d 3 ($P < 0.0001$), d 3 and d 6 ($P < 0.001$), d 6 and d 10 ($P < 0.0001$), and d 10 and d 57 ($P < 0.0001$; Figure 10). However, there was no consistent trend among treatments for the drop in pH. At some time points the inoculated corn silage would have a greater drop in pH than uninoculated corn silage, and between other time points uninoculated corn silage would have a greater drop. The consistent trend was that the pH was lower at each time point for inoculated corn silage versus uninoculated corn silage (Figure 10).

Regression Analyses

In experiments 1 and 2, the regression relationships among DM content, WSC concentration, temperature, VFA and lactate concentrations, and pH of corn silage were analyzed at 57 d after ensiling. In experiment 2, a combination of DM, lactate, and WSC concentration explained 84% of the variation ($P < 0.0001$) in pH of corn silage at 57 d after ensiling. However, in experiment 1, DM (16%; $P < 0.01$), lactate (0%; $P = 0.73$), and WSC (4%; $P = 0.51$) concentrations, did not individually explain a large amount of variation in the pH of corn silage at 57 d after ensiling. Acetate concentration explained 65% of the variation ($P < 0.0001$) in pH of corn silage at 57 d after ensiling, and when lactate, WSC, temperature, and DM content were added to acetate concentration, 86% of the variation ($P < 0.01$) in pH of corn silage at 57 d after ensiling was explained in experiment 1.

Dry matter content of the corn silage explained 64% of the variation ($P < 0.0001$) in lactate concentration in corn silage at 57 d after ensiling in experiment 2. Adding both WSC concentration and temperature to DM content to predict lactate concentration did not strengthen the R^2 to a large extent (67.5%; $P < 0.0001$). However, in experiment 1, a combination of DM content, temperature, and WSC concentration explained 64% of the variation ($P < 0.04$) in lactate concentration of corn silage at 57 d after ensiling. These results demonstrate that DM content of the whole corn plant along with the concentrations of WSC, VFA, and lactate affect each other and affect the pH of corn silage.

Dry Matter Recovery

Dry matter recovery 57 d after ensiling ranged between 88 and 100 percent (Table 7). Maturity and processing of corn silage had an effect on DM recovery in experiments 1 and 2 (Table 7). In experiment 1, DM recovery was significantly lower ($P < 0.003$) for corn silage harvested at a medium maturity (one-third ML; 92.2%) compared with hard dough (94.5%) and two-thirds ML [95.2%; Table 7]. In experiment 2, there was a hybrid × maturity interaction for DM recovery. Hybrid 3845 corn silage harvested at one-third ML (89%) had significantly lower ($P < 0.005$) DM recovery than corn silage harvested at advanced maturities [two-thirds ML—93.2% and BL—94.7%; experiment 2; Table 7]. Hybrid Quanta corn silage harvested at two-thirds ML (92.4%) had lower ($P < 0.09$) DM recovery than corn silage harvested at one-third ML (94.8%) and BL (95.4%) maturities (Table 7). The lower DM recovery for hybrid 3845 corn silage harvested at the earliest maturity (one-third ML) in experiment 2 can be partially explained by increased microbial activity (increased lactate and ethanol concentrations and lower pH 57 d after ensiling) compared with advanced maturities (two-thirds ML and BL). However, the response of DM recovery due to corn silage maturity is difficult to explain in experiment 1 and for hybrid Quanta in experiment 2.

The effect of mechanical processing of corn silage on DM recovery differed between experiments (Table 7). In experiment 1, processed corn silage had significantly greater ($P < 0.0001$) DM recovery 57 d after ensiling than unprocessed corn silage (Table 7). In experiment 2, unprocessed corn silage had significantly greater ($P < 0.0009$) DM recovery at 57 d after ensiling than processed corn silage (Table 7). The reason for the opposite trend between experiments is unknown. However, it seems that when fermentation was greater (increased temperature and lactate concentration 57 d after ensiling) the DM recovery was lower. The data in this study indicate that all silage went through a rapid and complete fermentation. Therefore, these results suggest that the slight increase in microbial activity (experiment 1 – unprocessed > processed and experiment 2 – processed > unprocessed) tended to decrease DM recovery between processed and unprocessed corn silage in experiments 1 and 2.

CONCLUSIONS

Many factors of corn silage management affected silage fermentation characteristics and DM recovery in this study. Overall, there tends to be a strong relationship between DM, WSC, lactic and acetic acid concentrations, and the pH level in corn silage by 57 d after ensiling. In experiment 1, a combination of DM content, temperature, WSC, lactate, and acetate explained 86% of the variation in pH of corn silage by 57 d after ensiling. In experiment 2, a combination of DM content, lactate, and WSC concentration explained 84% of the variation in pH of corn silage by 57 d after ensiling.

Maturity at harvest tended to have a greater impact on silage fermentation characteristics of corn silage than mechanical processing and inoculation. In experiments 1 and 2, corn silage harvested at the earliest maturity tended to have decreased DM content and increased WSC concentration during the ensiling process than corn silage harvested at advanced maturities. In experiment 2, pH levels were lower for corn silage harvested at the early maturity (one-third milkline) compared with advanced maturities (two-thirds milkline and blackline) by 57 d after ensiling. The difference in pH among maturities can be explained by the greater concentration of WSC at the early maturity (one-third ML) soon after ensiling (2, 3, 6, and 10 d after ensiling) compared with advanced maturities (two-thirds ML and BL). The increased WSC concentrations in the less mature corn silage provided nutrients for bacteria to grow and produce primarily lactic acid (6, 10, and 57 d after ensiling) and some acetic acid (2, 3, 6, and 10 d after ensiling), which reduced the pH of corn silage more than at the advanced maturities. In experiment 1, the pH of corn silage harvested at the medium maturity tended to be lower than at the other maturities by 57 d after ensiling. This can be partially explained by the greater lactate concentration of corn silage harvested at the medium maturity in the first few d following ensiling (2, 3, 6, and 10 d). The reason for the difference between experiments is unknown, and the corn silage in experiment 2 followed a more classic trend for lactic acid production and pH decline than the corn silage in experiment 1.

Mechanical processing had minimal and inconsistent effects on silage fermentation characteristics in experiments 1 and 2. There was a slight change in silage fermentation when corn silage was inoculated with Pioneer 1132 inoculant in experiment 1. In experiment 2, however, the inoculated and uninoculated corn silage tended to have a similar fermentation profile. In experiment 1, the inoculated corn silage had increased temperature, lactate and acetate concentrations, and lower WSC and pH levels compared with uninoculated corn silage.

Dry matter recovery tended to be greater for processed corn silage in experiment 1, and greater for unprocessed corn silage in experiment 2. However, the reason for the difference between experiments is unknown. It seems that when fermentation was greater (increased temperature and lactate concentration 57 d after ensiling) the dry matter recovery was lower. All of the silage treatments in this study went through a rapid and complete fermentation. Therefore, it appears that when there is a slight increase in microbial activity for a certain silage treatment (such as processed and unprocessed), there is a decrease in silage DM recovered from the silo.

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