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Effects of Inoculation and Wilting on the Preservation and Utilization of Wheat Forage

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ABSTRACT

Wheat forage was harvested at an early head stage of maturity and ensiled in 12 900-kg experimental silos at three percentages of DM (20.8% for direct-cut forage and 27.9 or 39.3% for wilted forage) either with or without application of a lactic acid bacterial inoculant. The objective was to test the efficacy of the inoculant to alter silage fermentation, preservation, and nutritive value of wheat forage ensiled at different moisture percentages because of wilting. Wilting enhanced DM preservation and decreased fermentation end products. Inoculation made the fermentation more homolactic but did not enhance DM preservation. Silage rations (80% DM as silage) were fed at 1.8% of BW/d to six ruminally and abomasally fistulated steers (350 kg) in an experiment with a Latin-square design and a 3 × 2 factorial arrangement of treatments. Digestive responses to silage diets were not influenced by inoculation. Intake was depressed with direct-cut silage rations. Wilting improved fiber digestibility and was associated with changes in ruminal contents and fermentation end products. Wilting appears to be more effective than inoculation as a postharvest management tool to improve small grain silage.

(**Key words**: silage, digestibility, wheat forage, wilting)

Abbreviation key: **DCWS** = direct-cut wheat silage, **LAB** = lactic acid bacteria, **WSC** = water-soluble carbohydrates, **WWS1** = wheat silage wilted to 27.9% DM, **WWS2** = wheat silage wilted to 39.3% DM.

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INTRODUCTION

Wheat silage is widely utilized as the cool season component of double-cropping systems in southern dairy operations (7). Based on fiber composition and digestibility, harvesting wheat forage at an early head stage of maturity optimizes both its agronomic yield and nutritional value for lactating dairy cows (3, 4, 8). At this stage of maturity, wheat forage is difficult to preserve as direct-cut wheat silage (**DCWS**) because its high moisture content can cause excessive fermentation during ensiling (4). At present, wilting or various additives have been used to control fermentation and to enhance preservation of high moisture cereal grasses (12, 17).

The efficacy of an inoculant to preserve silage of direct-cut small grains depends upon moisture and soluble carbohydrate content at harvest. Inoculation improved preservation and digestibility of DCWS harvested at early head stage (23.0% DM) but was not effective on silage at a higher, 41.6%, DM percentage (12). Concentrations of fermentation acids were substantially higher in high moisture DCWS, which demonstrates its greater capacity to ferment (12). When water-soluble carbohydrates (**WSC**) are adequate, high moisture content at ensiling may accentuate the usefulness of an inoculant to improve forage preservation.

Wilting of high moisture forages prior to ensiling usually enhances preservation (2, 18) and intake responses of cattle fed silage (20, 27). Wilting creates an ensiling environment that is conducive to a restricted fermentation, and the resulting silage is typically higher in WSC and lower in fermentation acids (18). Inoculation, however, provides microflora that hasten pH decline by competitively excluding epiphytic bacteria, which presumably are less efficient at converting WSC to lactic acid. At present, little information exists that compares the effects of these postharvest management procedures. Therefore, this study was designed

to identify the effects of wilting and inoculation with lactic acid bacteria (LAB) on the preservation of early maturity wheat forage and its utilization by Holstein steers.

MATERIALS AND METHODS

Silage Preservation

Wheat forage ('Stacy' variety), harvested at early head stage of maturity, was ensiled as DCWS (20.8% DM), wilted to 27.9% (WWS1), or wilted to 39.3% DM (WWS2). Wilted forage was harvested with a mower conditioner and allowed to lie in a swath for either 6 or 20 h prior to cutting with a forage chopper. During wilting, forage was raked once or twice, depending on the extent of wilting, to facilitate drying. The forage was ensiled in 12 900-kg concrete stave silos (2.0 m high × 1.8 m wide); two replicate silos were assigned to each of six treatments, consisting of three levels of wilting and two levels of LAB inoculation. Large plastic bags for round bales were used to line and seal the silos. The inoculant (Pioneer brand 1174 water-soluble silage inoculant; Pioneer Hi-Bred Microbial Genetics Div., Johnston, IA) contained specific strains of *Lactobacillus plantarum* and *Streptococcus faecium* (minimum total LAB, 3×10^{10} cfu/g). As recommended by the manufacturer, this product was applied as a liquid at the rate of 2 ml/kg of wet forage containing 1.5 g of inoculant/L of nonchlorinated water as silos were filled and packed. This application rate provided 1×10^4 to 1×10^5 cfu/g of fresh ensiled forage.

The wheat forage was harvested, wilted, and placed in silos over a 2-d period. At each percentage of wilting, four silos, two replicate inoculated and two replicate control silos, were filled approximately 3 h after the forage had attained the determined DM in the windrow and had been chopped. Silos were filled, and the inoculant treatment was applied to 22.7-kg increments of forage entering the silo. One inoculated and one control silo of each replicate were filled simultaneously. Weights of material placed into silos were obtained during filling, and representative samples were collected and stored (–20°C) to provide estimates of nutrient inputs for measurements of DM recovery. Silage was stored for 322 d prior to the digestibility trial.

Digestibility Trial

Six Holstein steers, with a mean BW of 350 kg (SE = 28), were surgically fitted with ruminal and abomasal cannulas; the steers were used in the experiment with a 6 × 6 Latin-square design and a 2 × 3 factorial arrangement of treatments. The steers were fed 1.8% BW/d of a diet (DM basis), consisting of 70% wheat silage and 30% concentrate (85.0% corn, 14.1% soybean meal, .90% trace-mineralized salt, and .51% Cr_2O_3). Steers were fed concentrate and silage twice daily at 12-h feeding intervals. Steers were allowed to consume their concentrate before the silage was fed. Steers were confined to stanchions to facilitate collection of samples and measurements of individual orts. Except on sampling days, steers were released for 2 h/d from their stanchions to a loafing area. Steers were cannulated and managed under guidelines approved by the University of Georgia Animal Care and Use Committee.

One silo replicate, representing each silage treatment, was fed during periods 1 to 3; the second silo replicate, representing each silage treatment, was fed during periods 4 to 6. Each period consisted of 12 d and was divided into 10 d of ration adjustment and 2 d of sample collection.

Representative samples of silage (200 g/d) were collected as silos were emptied, composited by period, and stored (–20°C) for subsequent laboratory analyses. On d 11 and 12 of each experimental period, fecal (200 g) and abomasal samples (250 ml) were collected at 4-h intervals. On both days, steers were pulse-dosed, via the rumen, with 120 ml (.1667 g/ml) of Co-EDTA. Ruminal fluid, sampled at 0 h and every 2 h after dosing for 12 h, was strained through two layers of cheesecloth and analyzed immediately for pH. The ruminal fluid was frozen and stored for later analyses of NH_3 (10), VFA by GLC (26), and Co by atomic absorption spectrophotometry (28). Upon thawing, abomasal samples were freeze-dried; fecal, green-chop forage, silage, and concentrate samples were dried in a forced-air oven at 55°C to constant weight. All samples were air-equilibrated, ground through a 1-mm screen, and analyzed for NDF and ADF fractions using a sequential procedure (23) and for CP by Kjeldahl N × 6.25 (5). Concentrate, fecal, and abomasal samples were analyzed for

Cr_2O_3 (15). Abomasal samples were analyzed for AA (1). Thawed silage (25 g) was extracted with 100 ml of distilled water in a commercial food blender at high speed for 2 min, filtered through four layers of cheesecloth, and analyzed for pH and lactic acid by GLC of methylated esters (16), and for VFA and NH_3 as described earlier. Aqueous extracts of thawed samples of green-chop forage were similarly made and subsequently assayed for WSC (11).

Ruminal contents were completely emptied, weighed, thoroughly mixed, and sampled 6 h after the morning feeding on the last day of each period to measure ruminal liquid and DM contents. Samples of ruminal digesta were divided into two subsamples. One subsample was placed in a forced-air oven for DM determination as described. The second subsample was stored under refrigeration at 4°C for approximately 48 h for subsequent isolation of ruminal bacteria. Clarified ruminal fluid was collected for isolation of fluid-associated bacteria. The ratio of diaminopimelic acid to N concentration of an isolate of bacteria associated with ruminal fluid was used as a reference to estimate bacterial protein content of abomasal samples (1).

Results of the digestibility and silage preservation trials were analyzed statistically by using ANOVA for a 3 × 2 factorial with the general linear models procedure of SAS (24); main treatment effects were partitioned into 1) wilting, 2) inoculation, and 3) their interaction (wilting × inoculation). When an interaction was significant ($P < .05$), differences among least squares treatment means were determined by comparisons of single degrees of freedom. Because of repeated measurements, ruminal VFA, pH, and NH_3 were analyzed as a split plot in time (25). A nested interaction term, steer × period × (wilting × inoculation), was used as the error term to test the main effects. Wilting effects were also fit to a linear model using regression procedures of SAS (24). Silage fermentation end-product data were also analyzed as a split plot in time. However, a different nested interaction term, silo replicate × (wilting × inoculation), was used as an error term to test the main effects.

RESULTS AND DISCUSSION

Effects of inoculation and wilting on recovery of DM and non-NH_3 CP are reported in Table 1. Wilting improved recovery of DM by 6.0 to 14.2%, and this effect was linear. For each percentage unit of DM attained during wilting, an additional .73 percentage units of forage DM were conserved. Recovery results

TABLE 1. Effects of inoculation and wilting on recovery of DM, corrected DM (CDM), non-NH_3 CP, and the top layer waste (DM basis) of wheat forage ensiled in 900-kg silos.[1,2,3]

Component	Uninoculated			Inoculated			SE
	DCWS	WWS1	WWS2	DCWS	WWS1	WWS2	
	(%)						
DM[a]	83.2[b]	82.7[b]	90.5[b]	73.8[c]	84.6[b]	88.7[b]	2.7
CDM[a]	88.9[b]	86.4[b]	93.1[b]	78.2[c]	88.8[b]	91.0[b]	2.8
Non-NH_3 CP[d]	89.6[g]	91.5[f]	91.8[f]	91.7[f]	91.6[f]	92.8[e]	.3
Top layer waste[a]	3.73	3.48	4.13	8.83	5.06	3.67	1.6

[a]Linear effect of wilting ($P < .05$).

[b,c]Interaction effect between wilting and inoculation means in a row with unique superscripts are different ($P < .1$).

[d]Main effect of inoculation ($P < .05$).

[e,f,g]Interaction effect between wilting and inoculation means in a row with unique superscripts are different ($P < .05$).

[1]Tabular values are least squares means, each estimated from two observations.

[2]Pioneer 1174 inoculant (Johnston, IA) was applied according to manufacturer recommendations. Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

[3]CDM = Recovery of DM_3 corrected for losses of volatile components that occur when oven-drying at 55°C is used for DM determination.

for wilting were consistent with those of previous research (18). However, the DM recovery of DCWS silage decreased 11.3% with inoculation. Contrary to these results, previous research has shown improvements in the preservation of inoculated DCWS ensiled at this range of DM (12). The DCWS in this study was ensiled at 20.8% DM, that in the previous study was ensiled at 23.6% DM. Changes in DM recovery were related to the amount of material lost in the top portion of the experimental silos, and DM recovery was correlated with the extent of top layer waste ($r = -.70$; $P < .05$). Silage DM content was determined by oven-drying samples at 55°C until weight was constant; this procedure underestimates DM because of volatilization losses. Recovery of DM, corrected (13) for volatile composition of silage samples, is reported in Table 1. Correction for volatile losses increased DM recovery overall by 4.5% but did not change the treatment response with wilting or the interaction between wilting and inoculation. Although DCWS silage contained more volatiles than did WWS2 (Table 2), corrected DM recovery of DCWS was increased only 2.6 percentage units over that of WWS2. An interaction occurred between inoculation and wilting on non-NH_3 CP recovery. Recovery of non-NH_3 CP was improved by inoculation for DCWS and WWS2 by 2.3 and 1.1%, respectively. Wilting improved recovery of non-NH_3 CP from 1.2 to 2.5%.

Concentrations of silage fermentation end products per gram of silage DM were affected by inoculation and wilting (Table 2). The contents of lactic acid, acetic acid, isobutyric acid, total VFA, and NH_3 were lower in WWS1 and WWS2. Decreased NH_3 accounted for increased non-NH_3 CP recovery and preservation of 3.0 to 4.3 percentage units of protein in WWS1 and WWS2, respectively. Higher concentrations of fermentation acids and NH_3 in DCWS indicate that fermentation was more extensive. Marsh (18) reviewed the effects of wilting on silage fermentation and nutritive value and reported that pH was higher, and fermentation acids and NH_3 were lower, for wilted silages. These changes indicated that fermentation of wilted forages was restricted

TABLE 2. Effects of inoculation and wilting on concentration of silage fermentation end products.[1]

	Inoculation[2]			Wilting[3]			
Item	–	+	SE	DCWS	WWS1	WWS2	SE
pH	4.06[d]	3.92[c]	.026	3.78[c]	3.92[b]	4.27[a]	.032
	(mg/g of DM)						
NH_3	2.63[a]	2.33[b]	.08	2.95[c]	2.37[d]	2.11[d]	.10
Lactate (L)	54.53	58.58	3.63	81.50[c]	54.37[d]	33.80[e]	4.44
Acetate (A)	20.75[f]	16.35[g]	1.68	26.99[c]	18.09[d]	10.58[e]	2.06
Propionate	.76	.61	.11	.85	.47	.74	.14
Isobutyrate	.47[a]	.29[b]	.05	.72[c]	.18[d]	.24[d]	.06
Butyrate	1.64	.85	.37	1.31	1.47	.97	.46
Isovalerate	.23	.16	.03	.26	.14	.18	.04
Valerate	.19	.10	.04	.16	.13	.13	.05
Total VFA	24.04[f]	18.37[g]	2.03	30.29[c]	20.48[d]	12.84[e]	2.48
L:A	2.90	3.78	.37	3.27	3.08	3.66	.45
L:VFA	2.50[g]	3.39[f]	.32	2.92	2.77	3.15	.40

[a,b]Main effect of inoculation ($P < .05$).

[c,d,e]Main effect of wilting ($P < .05$).

[f,g]Main effect of inoculation ($P < .1$).

[1]Tabular values are least squares means, each estimated from six observations for inoculation effects and four observations for wilting effects.

[2]Inoculation treatment consisted of a control (–) or an inoculant (+). Pioneer 1174 inoculant (Johnston, IA) was applied according to manufacturer recommendations.

[3]Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

(18, 19). Similar results were reported by Froetschel et al. (12), who observed that fermentation was restricted when direct-cut wheat forage was ensiled at a higher DM content (41.6 vs. 23.6%). The concentrations of fermentation acids and NH_3 were similar for DCWS, WWS1, and WWS2 when these measurements were expressed per gram of water (data not shown), indicating that acid accumulation per unit of water present was not altered by wilting. Forages ensiled at higher percentages of moisture typically required a greater accumulation of fermentation acids per gram of DM to become stable (19). Stability was reached when the concentration of fermentation end product per unit of silage water became sufficient to inhibit further microbial activity.

Inoculated silage was .14 percentage units lower in pH than was uninoculated silage (Table 2). Acetic acid, isobutyric acid, and total VFA were decreased with inoculation by 21.2, 38.3, and 23.6%, respectively. Inoculation increased the lactic acid:VFA ratio by 35.6%. Although lactate concentrations were not significantly different, inoculation with LAB appeared to promote a homolactic fermentation. However, this effect was minimal compared with that observed in past research (12). Lactic acid concentrations were increased by as much as 25 mg/g of DM in DCWS harvested at 23.6% DM at an early head stage of maturity (12).

Inoculation increased preservation of forage protein. Inoculated silage contained 11% less NH_3 than did the control (Table 2), which equated to preservation of 2.5 more percentage units of CP in the inoculated forage. The lower NH_3 content of inoculated silage also explains the greater recovery of non-NH_3 CP that is shown in Table 1.

Compositional analyses of wheat forage before and after ensiling are shown in Table 3. Only the effects of wilting are presented in Tables 3 and 4 because inoculation did not influence compositional analysis. The DM content of the forage ensiled was 7.0 and 18.4 percentage units higher for WWS1 and WWS2 than for DCWS. The DM content of the resulting silage was 5.5 and 17.0 percentage units

TABLE 3. Partial compositional analysis of wheat forage before and after ensiling as influenced by wilting.[1]

Item	Wilting[2]			
	DCWS	WWS1	WWS2	SE
	(% of DM)			
Wheat forage[3]				
DM	20.8[c]	27.9[b]	39.3[a]	.9
NDF	59.8[d]	58.6[d,e]	57.9[c]	.5
ADF	31.6	30.3	30.3	.7
CP	14.8[a]	13.5[b]	13.5[b]	.3
Ash	5.2	8.0	11.4	1.0
WSC[4]	24.2[a]	16.4[b]	19.6[c]	1.0
Wheat silage[3]				
DM	19.2[c]	24.8[b]	36.3[a]	.2
NDF	58.5	58.0	56.8	.6
ADF	33.8	33.7	32.0	.4
CP	16.0[a]	15.0[b]	14.7[b]	.3
Ash	6.3[c]	9.9[b]	14.6[a]	.8

[a,b,c]Main effect of wilting ($P < .05$).

[d,e]Main effect of wilting ($P < .1$).

[1]Tabular values are least squares means, each estimated from four observations for wilting effects.

[2]Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

[3]Except for DM, all values are percentage of DM.

[4]WSC = Water-soluble carbohydrates.

higher for WWS1 and WWS2 than for the DCWS. The moisture content of the silages was 1.6 to 3.1 percentage units lower in DM than the moisture content of the initial ensiled forage, which reflects losses of DM during respiration and fermentation and production of water during the respiration phase of the ensiling process. The WWS1 and WWS2 forages were 2.1 to 3.2% lower in NDF, respectively, but this difference was not apparent in ensiled material. The CP content was 8.8% lower in wilted forages at harvest and 6.1 to 8.0% lower in the WWS1 and WWS2 ensiled materials.

Ash content of WWS1 and WWS2 was 54.3 to 133.5% higher, respectively, than that of DCWS. Ash content was increased during wilting, because of raking, which incorporates soil into the forage windrows. The Nutrient Requirements of Dairy Cattle (21) lists the ash content of early vegetative wheat silage as 7.5%. Bolsen and Berger (9) field-wilted wheat forage at boot and milk stages prior to ensiling and reported that ash content ranged from 11.0 to 17.1%. Some of the reported (18) effects of wilting on silage composition are likely related to ash incorporation during the wilting process, as was the case in this experiment. Expressed on an OM basis, no differences occurred in CP content because of wilting (Table 4). The NDF increased 3.1 to 6.8% with wilting when silage NDF was expressed on an OM basis. The ADF content of WWS1 expressed on an OM basis was 3.7% higher than that of DCWS.

The WSC of WWS1 and WWS2 forages decreased 18.8 to 32.2%, and WWS1 had the lowest WSC (Table 3). Differences in WSC content of WWS1 and WWS2 prior to ensiling may be due to the exposure of these forages to different solar conditions at harvest and during wilting. The changes in WSC from wilting of wheat forage were still apparent when these measurements were expressed on an OM basis (Table 4).

The composition of the ensiled forages and the silage fermentation end products did not provide a clear explanation for the negative effects of the inoculant on DCWS or the absence of effects on wilted silages. The mean WSC content of the forages ensiled was 5.0, 4.6, and 7.7% (as-fed basis) for the DCWS, WWS1, and WWS2, respectively. The WSC content (per gram of forage, as-fed basis) was reported by others (14, 22) to be minimal in supporting an acceptable fermentation. The DCWS silage was more extensively fermented, as indicated by its acidity. This result indicates that the rate, rather than the extent of fermentation, was limited by the high moisture and low percentages of WSC in DCWS and precluded the effects of the inoculant as reported (12).

TABLE 4. Partial compositional analysis of wheat forage and silage as influenced by wilting.[1]

Item	Wilting[2]			
	DCWS	WWS1	WWS2	SE
	(% of OM)			
Wheat forage[3]				
NDF	63.1[b]	63.7[b]	65.4[a]	.4
ADF	33.3	33.0	34.2	.9
CP	15.6	14.7	15.3	.4
WSC[4]	25.5[a]	17.8[c]	22.1[c]	1.0
Wheat silage[3]				
NDF	62.4[c]	64.3[b]	66.6[a]	.6
ADF	36.8[b]	37.3[a]	37.5[a]	.4
CP	17.1	16.7	17.2	.3

[a,b,c]Main effect of wilting ($P < .05$).

[1]Tabular values are least squares means, each estimated from four observations for wilting effects.

[2]Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

[3]All values expressed as percentage of OM.

[4]Water-soluble carbohydrates.

These conditions may have been responsible for the poor results of the inoculant with DCWS. Concentrations of fermentation end products were reduced for WWS1 and WWS2, indicating that the fermentation and subsequent effectiveness of the inoculant were restricted with wilting. In addition, soil contamination, as indicated by the ash concentration, may have also contributed to the ineffectiveness of the inoculant with wilting. More epiphytic bacteria were likely added to WWS1 and WWS2 as a result of soil contamination.

Some of the DCWS was not consumed, resulting in a decrease of 8.6% in silage intake and a decrease of 5.8% in total intake of rations based on DCWS (Table 5). This effect is consistent with other research that compares ad libitum intakes of direct-cut and wilted silages (20, 27). In their review on intake regulation of ruminants, Baile and Forbes (6) implicated substances associated with the protein fraction of excessively fermented high moisture silages. The fermentation end products (VFA and NH_3) were substantially higher in DCWS. Silage protein fermentation was reduced by inoculation as indicated by NH_3 concentrations; however, the changes in silage NH_3 with inoculation were apparently not of sufficient magnitude to counteract the depression in intake associated with the DC silage.

Differences in silage composition and intake were responsible for the differences in nutrient intake that were reported in Table 5. Only the effects of wilting are presented in Table 5 because inoculation did not influence feed or nutrient intake. The CP content of the DCWS diet was 4.0 to 5.3% higher than that of diets containing wilted silages. Intakes of NDF and ADF with WWS1 were 7.3 and 8.8% higher, respectively, than with DCWS. Ash intake increased by 55.9 and 117.6% in WWS1 and WWS2, respectively.

Effects of inoculation and wilting on apparent ruminal and total tract digestion are reported in Table 6. Ruminal digestion of DM and NDF increased linearly. There was an increase of .62 percentage units of ruminal DM digested for silage rations for each percentage

TABLE 5. Mean DMI of silage and concentrate and partial compositional analysis of total ration fed to steers.[1]

Item	Wilting[2]			
	DCWS	WWS1	WWS2	SE
	(kg/d)			
Ingredient				
Silage	4.14[b]	4.53[a]	4.54[a]	1.00
Concentrate	2.15	2.15	2.15	.01
Total	6.29[b]	6.68[a]	6.69[a]	.10
Component				
NDF	2.60[e]	2.79[d]	2.75[de]	.07
ADF	1.47[e]	1.60[d]	1.53[de]	.04
CP	1.03	1.06	1.04	.02
Ash	.34[c]	.53[b]	.74[a]	.04
	(%)			
Component				
DM	27.20[c]	32.40[b]	45.40[a]	.36
NDF	41.15	41.81	41.04	.52
ADF	23.40	23.99	22.83	.33
CP	16.46[a]	15.80[b]	15.59[b]	.17
Ash	5.48[c]	7.96[b]	11.13[a]	.53

[a,b,c]Main effect of wilting ($P < .05$).

[d,e]Main effect of wilting ($P < .1$).

[1]Tabular values are least squares means, each estimated from 18 observations for inoculation effects and 12 observations for wilting effects.

[2]Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

unit increase in silage DM because of wilting. Ruminal digestion of NDF increased similarly. Ruminal digestion of CP was increased by 8.6 percentage units in steers fed WWS2. Total tract digestion of DM increased linearly by .44 percentage units for each percentage unit of increase in silage DM because of wilting. Total tract digestion of OM increased linearly by .85 percentage units for each percentage unit increase in silage DM because of wilting. Total tract fiber digestion increased linearly by 1.44 percentage units for NDF and 1.29 percentage units for ADF for each percentage unit increase in silage DM because of wilting. Improved digestion is consistent with greater nutrient preservation during ensiling (12). Differences in silage particle size associated with wilting may also be responsible for improved digestion. Even though the same silage chopper was used to process the forages prior to ensiling, the mean (± SE) particle size was larger with WWS1 and WWS2 than DCWS (DCWS, 1.35 ± .3 cm; WWS1, 2.78 ± .29 cm; and WWS2, 4.73 ± .59 cm). As a result, fiber digestion may have been improved because of longer fiber retention times. Inoculation decreased apparent total tract digestion of OM, NDF, and ADF by 3.2, 5.8, and 5.5%, respectively.

Differences in ruminal VFA among steers fed treated silage indicate that inoculation and wilting influenced ruminal fermentation (Table 7). Acetic acid was 1.8 to 3.1% higher, and propionic acid was 11.8 to 13.3% lower, for WWS1 and WWS2, respectively. As a result, the acetate:propionate ratio increased by 14.8 and 18.7%, respectively. These changes indicate that wilting may have enhanced the roughage value of the silage. Changes in roughage value with wilting may be related to particle size differences as discussed and NDF content as expressed on an OM basis. Inoculated silage resulted in a decrease of 1.7% in the ruminal concentration of acetate and an increase of 5.8% in propionate. As a result, the acetate:propionate ratio was slightly lower for inoculated silage. These observations correspond to the differences in ruminal digestion

TABLE 6. Effects of inoculation and wilting on apparent ruminal and total tract digestion coefficients for selected dietary ingredients.[1]

	Inoculation[2]			Wilting[3]			
	–	+	SE	DCWS	WWS1	WWS2	SE
	(%)						
Ruminal							
DM[a]	51.0	49.8	1.5	48.3	50.2	52.7	1.9
OM	58.6	56.9	1.4	56.0	56.4	60.0	1.7
NDF[a]	65.8	64.1	1.2	62.3	65.8	66.9	1.5
ADF	69.2	67.6	1.1	66.4	68.9	69.9	1.4
CP[a]	17.2	14.3	2.6	12.9	12.8	21.5	3.2
Total tract							
DM[a]	72.0	69.4	1.1	69.2	70.5	72.3	1.4
OM[b]	74.9[c]	72.6[d]	.9	71.3	72.7	77.3	1.1
NDF[b]	65.3[c]	61.5[d]	1.4	58.9	62.2	69.1	1.8
ADF[b]	69.3[c]	65.4[d]	1.3	63.1	66.6	72.3	1.6
CP	69.1	68.2	1.2	67.7	67.7	71.0	1.5

[a]Linear effect of wilting ($P < .1$).

[b]Linear effect of wilting ($P < .05$).

[c,d]Main effect of inoculation ($P < .05$).

[1]Tabular values are least squares means, each estimated from 18 observations for inoculation effects and 12 observations for wilting effects.

[2]Inoculation treatment consisted of a control (–) or an inoculant (+). Pioneer 1174 inoculant (Johnston, IA) was applied according to manufacturer recommendations.

[3]Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

coefficients (Table 6). The acetate:propionate ratio changed positively relative to ruminal fiber digestion. The concentration of valerate was 8.6% higher for inoculated silage; however, the biological significance of this result is unknown. Concentration of ruminal NH_3 decreased 17.4% with WWS1 and WWS2. The temperature increase during ensiling is greater for wheat forage ensiled at higher DM concentrations (12) and may be responsible for the decreased protein degradability in wilted forages. In addition, lowered ruminal NH_3 with wilted silages may reflect a tendency for greater ruminal digestion of OM and microbial utilization of NH_3.

Ruminal contents differed for steers fed WWS1 and WWS2 (Table 8). Only effects of wilting are presented in Table 8 because inoculation did not influence ruminal contents. At 6 h after feeding, when steers were fed WWS1 and WWS2, ruminal liquid contents were 6.8 to 8.5% higher. Ruminal DM contents of steers fed wilted silages increased 19.4 to 23.9%, and total ruminal contents increased linearly for steers fed WWS1 and WWS2 by 8.7 to 9.8%, respectively. The percentage of DM contents in the rumen was higher for steers fed WWS1 and WWS2 by 7.5 to 13.5%.

The inverse relationship between ruminal contents and digestibility in this study was unexpected but might have been a function of controlled intake (1.8% BW). Other research (20, 27) has demonstrated an intake-related decrease in digestibility when wilted forage diets were fed for ad libitum consumption. These studies have shown that ad libitum intake of wilted silage was higher than ad libitum intake of direct-cut forage (20, 27). In the present study, increased retention of digesta, as indicated by greater ruminal liquid and DM contents, might have been responsible for increased digestibility. Apparently, WWS1 and WWS2 remained in the rumen longer, thus allowing the microorganisms more time to utilize the material as substrate. As mentioned previously, the WWS1 and WWS2 were not chopped as finely as was DCWS, which was likely responsible for greater ruminal retention of WWS1 and WWS2.

Effects of inoculation and wilting on the efficiency of microbial protein synthesis and postruminal flow of OM, CP, and AA (29) are not presented in tabular form. Efficiency of production of ruminal microbial protein was not influenced by dietary treatments. Based on other research (20, 27), changes in efficiency of

TABLE 7. Effects of inoculation and wilting on concentration of ruminal fermentation end products.[1]

	Inoculation[2]			Wilting[3]			
Item	–	+	SE	DCWS	WWS1	WWS2	SE
VFA, mol/100 mol							
Acetate (A)	66.12[d]	65.02[e]	.16	64.52[c]	65.67[b]	66.54[a]	.20
Propionate (P)	18.87[e]	19.97[d]	.10	21.20[a]	18.69[b]	18.37[b]	.12
Isobutyrate	1.08	1.10	.01	1.08	1.09	1.11	.01
Butyrate	10.96	10.81	.05	10.22	11.34	11.11	.06
Isovalerate	1.85	1.82	.02	1.84	1.93	1.73	.02
Valerate	1.16[c]	1.26[d]	.01	1.14	1.28	1.21	.02
A:P	3.57[d]	3.53[e]	.02	3.10[c]	3.56[b]	3.68[a]	.03
Total VFA, m*M*	92.39	91.25	.73	90.40	94.28	90.78	.90
pH	6.58	6.61	.03	6.57	6.58	6.64	.04
NH_3, mg/dl	15.41	15.45	.42	17.46[a]	14.40[b]	14.43[b]	.51

[a,b,c]Main effect of wilting ($P < .05$).

[d,e]Main effect of inoculation ($P < .05$).

[1]Tabular values are least squares means, each estimated from 18 observations for inoculation effects and 12 observations for wilting effects.

[2]Inoculation treatment consisted of a control (–) or an inoculant (+). Pioneer 1174 inoculant (Johnston, IA) was applied according to manufacturer recommendations.

[3]Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

TABLE 8. Effects of wilting on ruminal contents, liquid volume, and dilution.

Item	Wilting[1]			
	DCWS	WWS1	WWS2	SE
Ruminal contents[2,3]				
Liquid,[a] kg	40.11[d]	43.53[b]	42.82[c]	1.00
DM,[e] kg	5.15[h]	6.15[g]	6.38[f]	.23
Total,[c] kg	45.25	49.67	49.20	1.09
DM,[e] %	11.54[g]	12.41[g]	13.10[f]	.40
Ruminal liquid[2,4]				
Dilution, %/h	11.39	11.06	10.51	.79
Volume, L	35.60	37.33	38.47	1.93

[a]Linear effect of wilting ($P < .1$).

[b,c,d]Main effect of wilting ($P < .1$).

[e]Linear effect of wilting ($P < .05$).

[f,g,h]Main effect of wilting ($P < .05$).

[1]Wilting treatment consisted of direct-cut ensiled at 20.8% DM (DCWS), 6-h wilt ensiled at 27.9% DM (WWS1), and 20-h wilt ensiled at 39.3% DM (WWS2).

[2]Tabular values are least squares means, each estimated from 12 observations for wilting effects.

[3]Obtained by ruminal evacuation 6 h after feeding.

[4]Obtained by dilution of a ruminal pulse dose of Co-EDTA.

microbial protein synthesis were anticipated because of differences in digestibility of the treated silages. However, with controlled intakes, variations in forage composition in the present experiment were insufficient to alter ruminal synthesis of microbial protein. The increased production of microbial protein associated with wilting, as reported (20), was dependent on an intake response. A trend was observed for increased postruminal outflow of certain AA, including lysine, with the WWS1 diet. The significance of this finding is uncertain because of the restrictions in intake that were imposed.

CONCLUSIONS

Potential interactions between inoculation and wilting to optimize preservation and digestibility of early maturity wheat forage were not very evident in this experiment. Inoculation apparently altered the fermentation end products in silage; however, the low WSC content, the extensive fermentation of the DCWS forage, and the restricted fermentation of the wilted forages may have precluded effects of inoculation on preservation. The positive effects of wilting on the preservation of wheat forage during ensiling and the utilization of rations based on wheat silage were substantial. Wilting was effective in improving DM preservation and was responsible for improved digestibility. Wilting, independent of inoculation, was a most effective management tool in the preservation of early maturity, small grain silage.

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REFERENCES

1 Amos, H. E., W. R. Windham, and J. J. Evans. 1984. Nitrogen metabolism of steers fed sun-cured hay and drum dehydrated alfalfa and coastal bermuda grass. J. Anim. Sci. 58:987.

2 Anderson, B. K., and N. Jackson. 1970. Conservation of wilted and unwilted grass ensiled in air-tight metal containers with and without the addition of molasses. J. Sci. Food Agric. 21:235.

3 Arieli, A., and G. Adin. 1994. Effect of wheat silage maturity on digestion and milk yield in dairy cows. J. Dairy Sci. 77:237.

4 Ashbell, G., H. H. Theune, and D. Sklan. 1985.

Ensiling whole wheat at various maturation stages: changes in ingredients during maturation and ensiling and upon aerobic exposure. J. Agric. Food Chem. 33:1.

5 Association of Official Analytical Chemists International. 1984. Official Methods of Analysis. 13th ed. AOAC, Washington, DC.

6 Baile, C. A., and M. J. Forbes. 1974. Control of feed intake and regulation of energy balance in ruminants. Physiol. Rev. 54:160.

7 Baxter, H. D., M. J. Montgomery, and J. R. Owen. 1980. Digestibility and feeding value of corn silage with boot stage wheat silage and alfalfa silage. J. Dairy Sci. 63:255.

8 Belyea, R. L., F. A. Martz, R. E. Ricketts, R. R. Ruehlow, and R. C. Bennett. 1978. In vitro dry matter digestibility, detergent fiber, protein and mineral content of wheat forage as a dairy cattle feed. J. Anim. Sci. 46:873.

9 Bolsen, K. K., and L. L. Berger. 1976. Effects of type and variety and stage of maturity on feeding values of cereal silages for lambs. J. Anim. Sci. 42:168.

10 Broderick, G. A., and S. H. Kang. 1980. Automated simultaneous determination of ammonia and total amino acids in total ruminal fluid and in vitro media. J. Dairy Sci. 63:64.

11 Dubois, M., K. A. Giles, J. K. Hamilton, P. A. Debers, and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350.

12 Froetschel, M. A., L. O. Ely, and H. E. Amos. 1991. Effects of additives and growth environment on preservation and digestibility of wheat silage fed to Holstein heifers. J. Dairy Sci. 74:546.

13 Galletti, G. C., and R. Piccaglia. 1988. Water determination in silage by Karl Fischer titration. J. Sci. Food Agric. 43:1.

14 Haigh, P. M. 1990. Effect of herbage water-soluble carbohydrate content and weather conditions at ensilage on the fermentation of grass silage made on commercial farms. Grass Forage Sci. 45:263.

15 Hill, F. W., and D. L. Anderson. 1958. Comparison of metabolism and productive energy determinations with growing chicks. J. Nutr. 64:587.

16 Holdeman, L. V., and W.E.C. Moore. 1973. Anaerobe Laboratory Manual. 2nd ed. Virginia Polytechnic Inst. State Univ., Anaerobe Laboratory, Southern Printing Co., Blacksburg.

17 Kung, L., Jr., B. R. Carmean, and R. S. Tung. 1990. Microbial inoculation on cellulase enzyme treatment of barley and vetch silage harvested at three maturities. J. Dairy Sci. 73:1304.

18 Marsh, R. 1979. The effects of wilting on fermentation in the silo and on the nutritive value of silage. Grass Forage Sci. 34:1.

19 McDonald, P. 1981. The Biochemistry of Silage. John Wiley & Sons, New York, NY.

20 Narasimhalu, P., E. Teller, M. Vanbelle, M. Foulon, and F. Dasnoy. 1989. Apparent digestibility of nitrogen in rumen and whole tract of Friesian cattle fed direct-cut and wilted grass silages. J. Dairy Sci. 73: 1800.

21 National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.

22 Pettersson, K. L., and S. Lindgren. 1990. The influence of the carbohydrate fraction and additives on silage quality. Grass Forage Sci. 45:223.

23 Robertson, J. B., and P. J. Van Soest. 1980. The detergent system of analysis and its application to human foods. Page 123 *in* The Analysis of Dietary Fiber. W.P.T. James and O. Theander, ed. Marcel Dekker, New York, NY.

24 SAS® Users Guide: Statistics, Version 3 Edition. 1982. SAS Inst., Inc., Cary, NC.

25 Snedecor, G. W., and W. G. Cochran. 1980. Statistical Methods. 7th ed. Iowa State Univ. Press, Ames.

26 Supelco, Inc. 1975. GC Separation of VFA. C2-C5, Bull. 7498. Supelco, Inc., Bellefonte, PA.

27 Teller, E., M. Vanbelle, P. Kamatali, and J. Wavreille. 1989. Intake of direct cut or wilted grass silage as related to chewing behavior, ruminal characteristics, and site and extent of digestion by heifers. J. Anim. Sci. 67:2802.

28 Udén, P., P. E. Colucci, and P. J. Van Soest. 1980. Investigation of chromium, cerium, and cobalt as markers in digesta. Rate of passage studies. J. Sci. Food Agric. 31:625.

29 Williams, C. C. 1991. Effects of inoculation and wilting on the preservation and utilization of wheat forage. M.S. Thesis, Univ. Georgia, Athens.