Factors Affecting Corn Silage Quality in Hot and Humid Climates

Adegbola T. Adesogan[1]
Department of Animal Sciences
University of Florida, Gainesville

General Introduction

This paper presents the results of a series of experiments that were performed to address producer concerns about links between the quality of corn silage produced in the southeast and poor productivity or disease problems in dairy cattle. The experiments focus on how certain climatic, plant and management factors affect the quality of silage made in hot, humid environments.

Experiment 1. Effect of simulated rainfall, ensiling temperature and Delayed sealing on the quality and aerobic stability of corn silage (Adesogan and Kim., 2005).

Introduction

Dairy farmers in many parts of the world rely on corn silage as a source of digestible fiber and readily fermentable energy for their cattle. In Florida, Georgia and many tropical countries, such farmers face several climatic challenges that can complicate corn silage production including temperatures that reduce the rate of photosynthesis (Crafts-Brandner and Salvucci, 2002) and reduction in potential yields due to faster crop life-cycles. In addition, the hot, humid conditions that occur during the corn growing season in these states is partly responsible for the production of four generations per year of European corn borer (*Ostrinia nubilalis*) compared to one generation per year in Northern states. These climatic conditions are also conducive for proliferation of many bacterial and fungal pathogens which cause stalk rot, smut, leaf blight and southern rust, and predispose to growth of mycotoxin-producing Penicillium, Aspergillus and Fusarium molds (Ono et al., 1999; Raid and Kucharek, 2005; Samapundo et al., 2005). In addition to affecting crop growth and disease incidence, previous studies showed that these climatic factors have adverse effects on silage fermentation and aerobic stability (Dewar et al., 1963; Garcia et al., 1989; McDonald et al., 1966; Muck, 1987). Rainfall at harvest can increase proteolysis in the silo ((McDonald et al., 1991) and effluent production (Fransen and Strubi, 1998) thereby reducing DM recovery. Ensiling at high temperatures reduces lactic acid concentration and aerobic stability, and increases pH and DM losses (Ashbell et al., 2002; Weinberg et al., 2001). Most of these findings were based on grass and alfalfa silages and the experiments examined the effect of temperature or moisture on silage fermentation

[1]Contact at: P.O. Box 110910, Department of Animal Sciences, University of Florida, Gainesville, FL 32611; 352-392-7527-Pho.; 352-392-7652-Fax; adesogan@animal.ufl.edu

separately. The few studies found on corn silage only examined temperature effects. Therefore, the objective of the first experiment was to determine how high temperatures and high moisture concentrations during ensiling affect silage quality. Since corn is often transported for up to 3 hours from custom growers fields to bunkers at dairies, a further objective was to determine how delayed sealing affects silage quality. This aspect of the study also examines the benefit of allowing wet corn forage to dry before ensiling.

Methods

Pioneer corn hybrid 31R87RR was grown on four replicated 6 x 1.5 m plots at the Plant Science and Education Research Unit of the University of Florida. The plots were harvested at 35 %DM with (Wet) or without (Dry) application of 4 mm of simulated rainfall from a tanker. Forage samples from each moisture treatment were ensiled immediately in plastic bags (Prompt) or after a 3 h delay (Delay). The delay forages were left uncovered in a pile for the 3-hour period. Half of the bags from each moisture x sealing time treatment combination were stored in a 40^{o}C incubator (Hot) for 82 d and the other half in a 20^{o}C, air-conditioned room (Cool). This experiment had a 2 x 2 x 2 factorial design.

Simulated rainfall effects

The moisture effects in this study should not be compared to those in studies where differences in treatment moisture contents were maturity–related because this study demonstrates effects of surface moisture, while the others demonstrate effects of cell-bound moisture. Wetting had no effect on chemical composition except for decreasing DM concentration (32.8 vs. 35.9%) and increasing ash concentration (4.2 vs. 3.9%) (Table 1). However, wet forages had higher concentrations of acetic acid (2.27 vs. 1.83%), ammonia-N (17.4 vs. 15.0 % total N) and ethanol (1.27 vs. 1.06%) than dry forages (Table 2). Therefore wetting increased proteolysis and produced a more heterolactic fermentation. Wetting increases proteolysis because it can restore enzyme activity in dry forages and enhance the growth of proteolytic bacteria (Muck et al., 2004).

Temperature effects

Storage at high temperatures slightly reduced concentrations of NDF (42.0 vs. 44.2%) and ADF (21.3 vs. 22.9%), and increased concentrations of DM (35.3 vs. 33.5 %), starch (42.7 vs. 36.2%), acid detergent insoluble protein (ADICP; 4.30 vs. 2.52%) and in vitro DM digestibility (IVDMD; 65.8 vs. 62.2%) values (Table 1). In addition the elevated temperatures reduced lactic to acetic acid ratios (2.08 vs. 2.84) and concentrations of lactic acid (3.92 vs. 6.76 %), acetic acid (1.71 vs. 2.38%), propionic acid (0.0 vs. 0.68%) and total VFA (11.1 vs. 14.6%), while increasing pH (4.23 vs. 3.76) and concentrations of ammonia-N (18.0 vs. 14.3% total N), ethanol (1.25 vs. 1.08%) and isovaleric acid (1.53 vs. 1.20%) Table 2). The higher pH and NH_3N concentration, and lower lactic to acetic acid ratio of silages ensiled at the higher temperature reflect increased proteolysis, curtailed, more heterolactic fermentation and reduced silage quality, respectively. Others have also shown that high ensiling temperatures reduce numbers of certain lactic acid bacteria (Weinberg et al., 2001; Weinberg et al., 1998), enhance proteolysis (Muck and Dickerson, 1988; Weinberg et al., 2001) and make the fermentation less homolactic (McDonald et al., 1966; Weinberg et al., 2001).

The reduced fiber concentration and increased digestibility associated with the higher ensiling temperature agrees with observations that ensiling ryegrass at 37^{o}C instead of 22^{o}C increased hemicellulose hydrolysis (Dewar et al., 1963). This is largely because the optimal temperature range for hemicellulase enzymes is 30 to 40^{o}C. Cellulose hydrolysis by cellulase has also been found to be greater at 30^{o}C than at 25^{o}C (Pitt, 1990). The increased fibrolysis results in seepage-related nutrient losses and decreased digestibility in grass silages (McDonald et al., 1991). The contrasting effect on the digestibility in this study probably reflects the higher DM concentrations of the corn silages and the absence of seepage losses from the mini-silos used. Seepage losses from low DM corn silage stored in bunkers may therefore prevent silages stored at elevated temperatures from being more digestible in practice.

As in the study of Garcia et al. (1989), the higher ensiling temperature increased ADICP or heat-damaged proteins formed in the Maillard reaction. The higher ensiling temperature falls within the range (>35 - 40^{o}C) at which the Maillard reaction occurs in silages (Muck et al., 2003), and the rate of the reaction increases exponentially with temperature (Goering et al., 1973). Heat-damaged proteins formed in the Maillard reaction are usually not digestible in vivo, therefore elevated temperatures can limit the availability of protein from corn silage.

Delayed sealing effects:

Delayed sealing increased DM concentration (36.3 vs. 32.5%), tended to reduce pH (3.96 vs. 4.03), DM losses (1.7 vs. 11.0%) and mold counts (3.10 vs. 4.00 log cfu/g) and reduced concentrations of ammonia-N (14.9 vs. 17.5 % total N), isobutyric acid (3.31 vs. 4.27%), isovaleric acid (1.19 vs. 1.54%) and total VFA (11.7 vs. 14.0%). These effects are similar to the reduced fermentation and curtailed in-silo proteolysis in wilted forages (Morgan et al., 1980). These respective effects are caused by water-soluble carbohydrate (WSC) depletion arising from continued plant and microbial respiration, and reduced amino acid deamination due to decreased clostridial and enterobacteria activity (McDonald et al., 1991). The beneficial effects of delayed sealing in this study should not be confused with effects of prolonged (>10 h) delays which tend to render inoculant or additive treatment less effective, reduce fermentation quality and enhance spoilage (Mills and Kung, 2002; Uriarte, 2001).

Interaction effects

Delayed sealing accentuated the effect of temperature on DM, starch and NDF concentration (temperature x sealing time interaction, P=0.037). Delayed sealing also increased the effect of moisture on ethanol concentration at the lower ensiling temperature, but not at the higher ensiling temperature (temperature x sealing time x moisture interaction, $P < 0.001$). In wet silages, delayed sealing reduced yeast counts and increased aerobic stability at both ensiling temperatures, but in dry silages, delayed sealing only reduced yeast counts and increased stability at the lower ensiling temperature (temperature x time x moisture, interaction, $P < 0.05$). This suggests allowing wet corn forage to dry for about 3 hours before filling bunkers can improve aerobic stability under hot or cool temperatures. However, if the forage is dry, high temperatures can prevent delayed sealing from being beneficial at enhancing stability.

Silages that were wetted, sealed after 3 h and stored at high temperatures were more aerobically stable (45.66 vs. 13.35 h), and had fewer yeasts (4.42 vs. 6.26 log cfu/g) than the other silages (temperature x sealing time x moisture interaction, $P<0.01$). However, such silages had less lactic acid and total VFA, lower lactic to acetic acid ratios, greater pH and DM losses and more heat-damaged protein than most of the other silages. They also had a distinctive dark color and tobacco odor. Therefore they were less desirable for feeding.

Conclusion

This study shows that high ensiling temperatures and simulated-rainfall had detrimental effects on the fermentation process and silage quality, but delayed silo sealing for 3 h did not. The beneficial effects of delayed sealing in this study should not be confused with effects of longer delay periods which tend to render inoculant treatment ineffective, reduce fermentation quality and enhance spoilage. Corn silage producers in hot, humid regions need to need to adhere strictly to excellent silage making practices to overcome the adverse effects of moisture and temperature on corn silage production in such areas.

Experiment 2: Effect of applying molasses or two dual-purpose inoculants at recommended and higher rates on the fermentation and aerobic stability of corn silage (Adesogan et al., 2005).

Introduction

The review of Muck and Kung (1997) showed that traditional homolactic inoculants don't usually improve the fermentation of corn silage, but *L. buchneri* inoculants do improve their aerobic stability. While confirming the stability-enhancing properties of *L. buchneri* inoculants, some studies have shown that the heterofermentative pathway of *L. buchneri* can cause greater silage pH and ammonia-N concentration (Neylon and Kung, 2003) and increased losses of WSC and DM (Adesogan and Salawu, 2004; Muck, 2002) during the fermentation. Consequently, dual-purpose or combo inoculants that contain homofermentative bacteria for improving the fermentation as well as *L. buchneri* bacteria for improving aerobic stability were recently developed. Such inoculants have improved the fermentation and aerobic stability of ryegrass (Ashbell et al., 2002; Driehuis et al., 2001; Filya, 2004) and prevented clostridial growth on wet bermudagrass silages (Adesogan et al., 2004), but they have not been evaluated on corn silages produced in hot and humid environments.

The appropriateness of using recommended inoculant application rates for corn silage produced under the hot and humid conditions in the southeast has been question by Florida dairy producers. Some individuals have advocated doubling inoculant application rates to guarantee efficacy though this strategy has not been validated through independent research. Therefore the objective of this experiment was to determine whether doubling the rate of applying two dual-purpose inoculants can improve silage quality. Since the concentration of soluble sugars was low in about 25% of hybrids evaluated in the Florida 2004 Corn Hybrid Evaluation (Figure 1), a second objective was to determine how addition of fermentable substrates at ensiling compares with inoculant application at improving the quality of corn silage. Molasses application has improved the fermentation of low sugar forages (Adesogan et al., 2004; Umana et al., 1991), therefore it was used as the source of supplemental fermentable substrates.

Methods

Monsanto corn hybrid Dekalb 69-70 was harvested at 400 g/kg DM and ensiled (15 kg) in quadruplicate in 20 l mini-silos after treatment with nothing (Control), molasses (35 g/kg DM; United States Sugar Corp., Clewiston, Florida), Buchneri 500 inoculant (BB, Lallemand Animal Nutrition, Milwaukee, WI) or Pioneer 11C33 inoculant (PN, Pioneer Hi-bred International, Des Moines, IA). The inoculants were applied at the recommended rates (8 and 1.1 mg/kg fresh forage for BB and PN respectively) and at double the recommended rates (DBB and DPN). According to the manufacturers, PN contains 1.1 x 10^{11} cfu/g of fresh forage of a mixture of *L. plantarum, L. buchneri,* and *Enteroccocus faecium,* while BB contains a mixture of *Pediococcus pentosaceus* 12455 (1 × 10^5 cfu/g of fresh forage), *Lactobacillus buchneri* 40788, (4 × 10^5 cfu/g fresh forage), beta-glucanase, alpha-amylase and xylanase. The additives were dissolved in 2 l of deionized water and sprayed in a fine mist on 120 kg of forage. A similar quantity of deionized water was sprayed on untreated forages. Four replicates of each of the untreated or treated forages were weighed (15 kg) into plastic bags and ensiled in 20 l macro silos for 135 d. The experiment had a completely randomized design.

Molasses application effects

Apart from a surprising increase in starch concentration molasses treatment had negligible effects on silage chemical composition (Table 3). The only effect of molasses application on the fermentation was that it tended to reduce ammonia-N concentration indicating reduced proteolysis relative to untreated forages (Tables 4). Small (1 %) increases in forage WSC concentration due to molasses addition markedly improved the fermentation of low WSC bermudagrass (Adesogan et al., 2004; Umana et al., 1991). The limited benefit of molasses application in this study may be because the WSC concentration of the untreated forages was close to that (4%) required for optimizing the fermentation in high DM corn silages (Pitt, 1990).

Compared to inoculant-treated silages, Control and Mol silages had greater residual WSC concentrations which led to greater yeast growth (Table 4) and faster (25 h) deterioration (Figure 2). Such problems are typical of silages with high initial or residual WSC concentrations (Weinberg et al., 1993). Therefore, molasses application hardly affected the fermentation or stability of the corn silage. Applying higher levels of molasses than that studied (3.5%) is risky as this would further enhance yeast growth and deterioration.

Inoculant effects

Most of the inoculant treatments did not affect silage pH and lactic acid concentration, but they led to lower lactic to acetic acid ratios (Table 4) and lower residual WSC concentrations compared to Mol and Control silages. They also tended to increase ammonia-N concentrations and decrease DM losses. Reduced WSC concentration and lactic to acetic acid ratio in inoculant-treated silages indicates that their fermentation was more heterolactic than those of Control and Mol silages. This is primarily attributable to the presence of heterofermentative *L. buchneri* in the inoculants, which typically enhances acetic acid production. Though inoculant-treated silages tended to have greater ammonia-N concentration, than untreated silages, the difference was small and practically not significant. The tendency for less DM losses in inoculant-treated silages justifies the inclusion of *L. plantarum* (and *E. faecium* for the PN inoculant) in the inoculants because inoculants that contain only *L. buchneri* have increased DM losses in certain studies (Muck, 2002). It can be surmised from these results that treatment with dual-purpose inoculants reduced DM losses and did not adversely affect the fermentation.

Inoculant-treated silages had lower yeast counts and were more stable (Table 4) than Control and Mol silages (Figure 2). The *L. buchneri* in the inoculants successfully stimulated the production of acetic acid, which is antimycotic and therefore reduced yeast counts and enhanced aerobic stability. This study therefore supports several others (Adesogan et al., 2004; Driehuis et al., 2001; Muck, 2002; Neylon and Kung, 2003) that highlight the potential of *L. buchneri* at reducing spoilage and increasing the bunk life of corn silage.

Effect of doubling the rate of inoculant application

Compared to the control treatment, doubling the rate of inoculant application increased ash and acetic acid concentrations and aerobic stability. Application of DPN also led to lower yeast counts than in the control silage. However, the chemical composition, fermentation product concentrations and aerobic stability of silages treated with normal and double inoculant application rates were similar, indicating that doubling the application rates was unwarranted. This is because though doubling inoculant application rates would have doubled bacterial counts at the outset (e.g. counts for PN would have increased from 1.1×10^{11} to 2×10^{11} cfu/g), it is typically necessary to increase bacterial counts by at least 0.5 log cfu/g to modify bacterial effects on fermentation and stability (Neylon and Kung, 2003; Ranjit and Kung, 2000; Ranjit et al., 2002). This study therefore refutes anecdotal suggestions that doubling inoculant application rates will improve their efficacy. Producers should be strongly discouraged from embracing this practice because it is expensive and ineffective.

Conclusions

This experiment shows that application of dual-purpose inoculants increased the aerobic stability of corn silage without adversely affecting the fermentation. Doubling the rate of inoculant application was not more effective than using the recommended rate. Molasses application tended to reduce proteolysis but had no other effects on the fermentation or stability of corn silage. For this reason as well as the potential for greater more yeast growth and deterioration at higher application rates, molasses application to corn silage is not recommended.

Experiment 3: Effect of maturity at harvest of corn hybrids differing in stay-green ranking on the quality of corn silage (Arriola et al., 2005).

Introduction

Florida producers have been concerned about a possible link between poor productivity, digestive upsets and Hemorrhagic bowel syndrome in cattle and intake of corn silage with high stay-green rankings. Such hybrids form the bulk of silage hybrids currently sold in the US. Selection for improved resistance to diseases and reduced leaf senescence at high plant densities have led to introduction of stay-green hybrids The stay-green ranking is assigned to corn hybrids to reflect greater retention of green leaf area, improved health and high lodging resistance late in the season, typically beyond the black layer stage. Such stay-green hybrids have asynchronous ear and stalk dry-down rates, therefore their ears turn brown and their kernels dry-down and mature faster than their stalks and leaves which remain green. The presence of this characteristic implies that the traditional relationship between whole plant silage, moisture and kernel milk line may no longer hold because it probably results in silages that have milk lines that are more advanced relative to whole-plant maturity (Bagg, 2001). High stay-green rankings are genetically correlated with high stalk and leaf moisture contents (Bekavac et al., 1998). The stay-green characteristic hinders prediction of corn harvest dates with the kernel milk line because kernels get very mature while whole-plant DM remains under 30% (Thomas, 2001). Therefore, using kernel milk line to predict harvest dates for stay-green corn destined for silage may result in greater seepage (Lauer, 1998). Silage producers in Georgia and Florida have been concerned that ensiling stay-green hybrids has contributed to increased incidences of digestive upsets and Hemorrhagic bowel syndrome in their cattle in recent years. These problems may be partly due to excessive moisture in corn harvested at previously recommended maturity stages (⅓ - ⅔ milk line) due to the asynchronous dry-down rates of the ear, stalk and leaves of stay-green hybrids. However these speculations have not been verified by independent research. Therefore, the objective of this experiment was to determine how maturity and stay-green ranking affect the quality of corn silage. Since traditional non-stay-green hybrids or low stay-green hybrids are not readily available, we compared hybrids with average and high stay-green rankings.

Methods

Four corn hybrids with high (Croplan genetics 827 and Pioneer 31Y43) stay-green (HSG) or average (Croplan genetics 799 and Pioneer 32D99) stay-green (ASG) rankings and similar relative maturity (118 days) were grown on four replicate 6 x 1 m plots, located in each of four blocks. The hybrids were harvested at 26 (Cut1), 34 (Cut2), and 39 (Cut3) % DM and ensiled (15 kg) in quadruplicate within plastic bags in 20 l mini-silos for 107 days, after which nutritive value and aerobic stability were assessed. The experiment had a split plot design with seed company x stay-green ranking as the main plot and maturity as the subplot.

Maturity effects

As the forages matured, DM yield tended to increase, concentrations of DM and residual WSC linearly increased, while concentrations of starch, neutral and acid detergent fiber, and crude protein (CP) linearly decreased (Table 5). However in vitro DM digestibility was unaffected by maturity. Others have also noted that in vitro digestibility and in situ degradability remain unchanged within the range of maturities examined in this study, and attributed this to the transition from vegetative to reproductive growth (Bal et al., 2000).

Silage pH linearly increased with maturity but ammonia-N concentration decreased quadratically, while lactic and acetic acid concentrations decreased linearly (Table 6). Yeast counts also increased linearly with maturity while mold counts linearly decreased, but aerobic stability was unaffected by maturity. The benefits of harvesting at Cut 3 including greater DM yields, more starch, less fiber and fewer molds were countered by a less desirable fermentation as shown by lower pH values and less lactic acid, and greater yeast counts. Conversely, Cut 1 silages had more desirable pH, lactic acid and crude protein contents than more mature silages, but also had more molds, lower DM yields, less starch and more fiber and proteolysis. These factors suggest the best combination of yield, nutritive value, fermentation quality and fungal counts was obtained in hybrids harvested at Cut 2 (34% DM).

Stay-green ranking effects

DM yield was greater for HSG than ASG hybrids at Cuts 1 and 2, but this trend was reversed at Cut 3 (stay-green x maturity interaction, $P < 0.01$) (Table 5). High stay-green hybrids had more CP, less starch and lower IVDMD values than ASG hybrids (Table 5). The higher CP concentration of HSG versus ASG hybrids agrees with observations of higher leaf N concentrations in stay-green sorghum hybrids (Borrell and Hammer, 2000). This is probably related to greater retention of chloroplast proteins and greater capacity for N uptake in stay-green hybrids (Borrell et al., 2001). However, the small difference in CP is of limited practical significance, particularly as corn silage is not primarily fed as dietary protein source. The reductions in starch and IVDMD are more important, since corn silage is primarily fed to supply readily fermentable and slowly digested energy. The lower IVDMD values are probably attributable to faster ear dry-down rates which result in more mature, less digestible kernels.

When the preconserved forages used in this study were examined (data not shown), stover (leaf and stalk) DM contents of HSG hybrids were lower (1 - 3%) than for ASG hybrids, whole plant DM was also numerically lower for HSG hybrids, while ear content was numerically greater. This suggests that stay-green affects the distribution and quantity of moisture in corn hybrids. While stover digestibilities were similar across both stay-green treatments, HSG hybrids had lower whole-plant digestibility values than ASG hybrids, as found in the silages. This suggests that the rapid maturation of the ears in high stay-green hybrids reduces whole plant digestibility. Lower starch and IVDMD in HSG versus ASG silages indicate that nutritive value was lower in the HSG hybrid. This contradicts findings of similar digestibility between HSG and conventional hybrids by Australian researchers (Havilah and Kaiser, 1994), possibly due to climatic differences in growing conditions. Kernel processing may be beneficial for improving energy availability from high stay-green hybrids in the southeast.

Despite the differences in chemical composition and nutritive value, stay-green ranking did not affect pH, fermentation product concentrations or aerobic stability (Table 6). Higher moisture contents often predispose to undesirable heterolactic fermentations and greater proteolysis (Kim et al., 2005, see Experiment 1)(Wilkinson and Hill, 2003). Moisture content was greater in HSG than ASG at cuts 1, 2 and 3 (26 vs. 24%, 32 vs. 31% and 38 vs. 37%), but this did not affect the fermentation. Likely greater moisture differences between high and low or non-stay-green hybrids, could conceivably result in differences in fermentation quality. Florida and Georgia producers tend to notice more problems with stay-green hybrids in wet years, when adverse effects of crop moisture on the fermentation may be exacerbated.

Conclusions

This study suggests that corn silages grown in hot, humid areas should be harvested at 34 % DM to optimize DM yield, nutritive value, fermentation quality and reduce fungal counts. Higher stay-green rankings in corn hybrids resulted in greater moisture and CP concentrations and less IVDMD and starch concentrations, but stay-green ranking did not affect the fermentation or stability of the corn silages. Fermentation quality differences could arise from potentially greater differences in chemical composition between high and low or non stay-green hybrids. Therefore more research is needed on how the interaction between crop moisture and stay-green ranking affects silage fermentation before definitive conclusions can be drawn on stay-green effects on the fermentation.

Implications

Rainfall at harvest and high temperatures during ensiling adversely affect the fermentation and quality of corn silage. Corn silage producers in hot, humid regions need to avoid harvesting corn in wet weather, and ensure that excellent silage management practices are followed to overcome these climatic challenges to quality silage production. Delayed sealing wet corn silages for about three hours can be beneficial at reducing the adverse effects of moisture on the fermentation but prolonged delays (>10 h) are known to worsen the fermentation and increase deterioration.

Corn silage produced in hot, humid regions is highly prone to aerobic deterioration (within 24 h), but dual purpose inoculants containing *Lactobacillus buchneri* can improve their aerobic stability. Doubling the rate of inoculant application was not more effective than the recommended rate at enhancing the quality or stability of corn silage. Producers should be advised to avoid this costly, ineffective strategy.

Corn hybrids with high stay-green rankings were found to have higher moisture and protein concentrations and lower starch content and IVDMD values than average stay-green hybrids, but the fermentation process was unaffected by stay-green ranking. Stay-green hybrids should be harvested at about 34% DM (66% moisture) as this maturity stage gave the best combination of yield, nutritive value and low fungal counts. Due to the higher moisture content of high stay-green hybrids, they should not be harvested at DM concentrations below 30% particularly during rainfall or in wet years because excess moisture can cause undesirable fermentations. Kernel processing is recommended for high stay-green silage hybrids in order to increase energy availability from in dairy cow diets.

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Table 1. Effect of simulated rainfall (R; Dry, 0 mm vs. Wet, 4 mm), ensiling temperature (T; Cool, 20°C vs. Hot, 40°C) and sealing time (S; Immediate, Imm vs. 3 h delay, Del) on the nutritive value (% DM) of corn silage.

	Dry				Wet				SEM	Effects[1]						
	Cool		Hot		Cool		Hot			R	T	S	RxT	RxS	TxS	RxTxS
	Del	Imm	Del	Imm	Del	Imm	Del	Imm								
DM loss	3.91	1.23	0.0	1.6	12.0	7.4	11.7	13.3	1.5	ns	ns	***	ns	ns	ns	ns
CP	7.41[a]	5.63[b]	6.80[ab]	6.43[ab]	6.77[ab]	5.96[ab]	6.14[ab]	6.99[ab]	0.35	ns	ns	x	ns	*	x	*
WSC	0.35[b]	0.51[b]	0.71[b]	0.66[b]	0.51[b]	0.48[b]	1.95[a]	0.60[b]	0.13	**	***	**	*	***	***	x
Ash	3.8[bc]	3.9[bc]	3.4[c]	3.8[bc]	4.5[ab]	4.4[ab]	4.0[abc]	4.7[a]	0.2	***	ns	*	ns	ns	*	ns
Starch	30.9[b]	37.0[ab]	43.4[a]	44.7[a]	34.7[ab]	42.3[ab]	43.4[a]	39.1[ab]	2.5	ns	**	ns	x	ns	*	ns
NDF	46.9[a]	42.5[ab]	40.6[ab]	42.8[ab]	42.4[ab]	45.2[ab]	39.9[b]	44.6[ab]	1.4	ns	*	ns	ns	*	*	ns
ADF	24.5	21.7	20.9	20.8	22.3	23.0	20.8	22.6	1.1	ns	x	ns	ns	ns	ns	ns
ADICP[2]	1.6	3.3	2.3	3.6	3.2	2.0	5.5	5.8	1.2	ns	x	ns	ns	ns	ns	ns
IVDMD[3]	61.9	63.6	66.0	66.9	63.0	60.5	68.0	62.4	2.0	ns	*	ns	ns	x	ns	ns

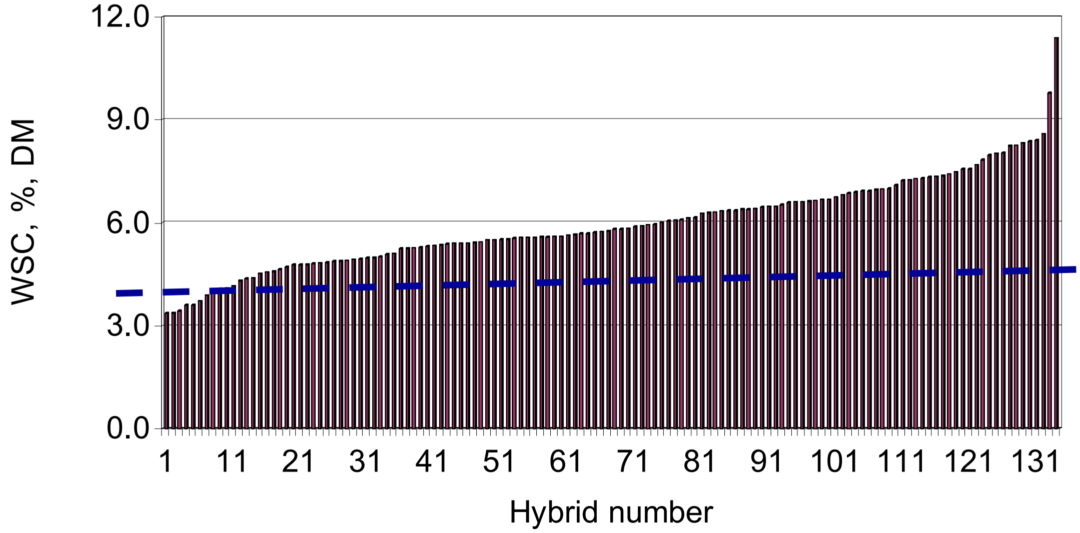
Means in rows with unlike superscripts differ ($P < 0.05$); [1] x = $P < 0.1$; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$
[2] Acid detergent insoluble crude protein, % CP; [3] In vitro apparent dry matter digestibility, %

Table 2. Effect of simulated rainfall (R; Dry, 0 mm vs. Wet, 4 mm), ensiling temperature (T; Cool, 20^{o}C vs. Hot, 40^{o}C) and sealing time (S; Immediate, Imm vs. 3 h delay, Del) on the fermentation indices (% DM) and stability of corn silage.

	Dry				Wet				SEM	Effects[1]						
	Cool		Hot		Cool		Hot			R	T	S	RxT	RxS	TxS	RxTxS
	Del	Imm	Del	Imm	Del	Imm	Del	Imm								
pH	3.76^{b}	3.82^{b}	4.11^{a}	4.30^{a}	3.72^{b}	3.73^{b}	4.25^{a}	4.27^{a}	0.05	ns	***	x	ns	ns	ns	ns
NH_3-N [2]	11.4^{b}	13.8^{ab}	15.8^{ab}	19.0^{ab}	14.8^{ab}	17.6^{ab}	17.7^{ab}	19.7^{a}	1.61	*	**	*	ns	ns	ns	ns
Total VFA[3]	11.63^{ab}	15.41^{a}	10.59^{ab}	11.29^{ab}	15.41^{a}	16.22^{a}	9.46^{b}	13.08^{ab}	1.18	ns	***	*	ns	ns	ns	x
Lactic acid	5.42	6.78	3.95	3.97	7.31	7.53	3.22	4.53	0.61	ns	***	ns	ns	ns	ns	ns
Acetic acid	1.89	2.35	1.66	1.44	2.68	2.63	1.86	1.90	0.28	*	**	ns	ns	ns	ns	ns
Propionic acid	0.60^{a}	0.83^{a}	0.00^{b}	0.00^{b}	0.51^{ab}	0.79^{a}	0.00^{b}	0.00^{b}	0.11	ns	***	ns	ns	ns	ns	ns
Iso-butyric acid	2.80^{b}	4.12^{ab}	3.58^{ab}	4.21^{ab}	3.68^{ab}	3.94^{ab}	3.16^{b}	4.81^{a}	0.32	ns	ns	***	ns	ns	ns	*
Iso-valeric acid	0.91^{b}	1.33^{ab}	1.40^{ab}	1.68^{a}	1.22^{ab}	1.34^{ab}	1.22^{ab}	1.83^{a}	0.16	ns	**	**	ns	ns	ns	ns
Ethanol	0.82^{b}	1.16^{ab}	1.22^{ab}	1.07^{ab}	1.48^{a}	0.87^{b}	1.22^{a}	1.50^{a}	0.09	**	*	ns	ns	x	ns	***
La:Ac [4]	2.90^{a}	2.90^{a}	2.40^{abc}	1.81^{bc}	2.72^{abc}	2.84^{ab}	1.73^{c}	2.41^{abc}	0.22	ns	***	ns	ns	*	ns	x
Yeast [5]	6.72^{a}	7.68^{a}	7.00^{a}	6.44^{a}	6.83^{a}	7.30^{a}	4.42^{b}	6.07^{ab}	0.37	**	***	*	*	ns	ns	*
Mold [5]	2.77	4.33	3.40	2.53	2.93	4.16	3.33	4.99	0.63	ns	ns	x	ns	ns	ns	ns
Aerobic stability	15.33^{b}	13.00^{b}	12.00^{b}	12.50^{b}	14.00^{b}	10.67^{b}	45.66^{a}	16.00^{b}	2.67	***	***	***	***	**	*	**

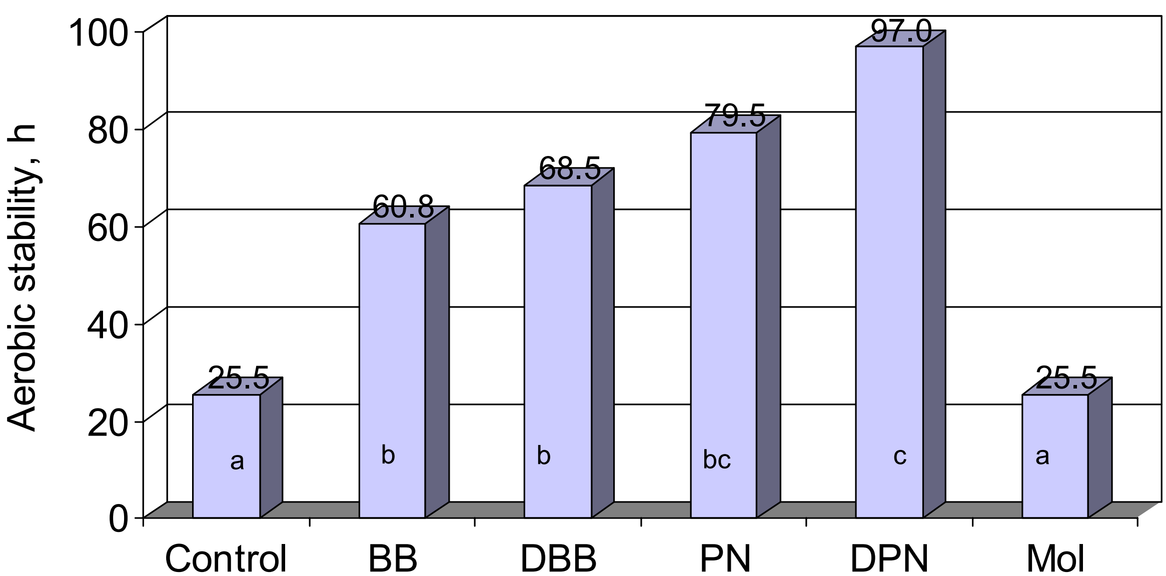
^{abc} Means in rows with unlike superscripts differ ($P < 0.05$); [1] x = $P < 0.1$; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$
[2] %Total N; [3] Volatile fatty acids; [4] Lactic to acetic acid ratio; [5] log cfu/g

Figure 1. Water-soluble carbohydrate concentrations (%, DM) of 134 corn hybrids evaluated in the 2004 Florida Corn Hybrid Evaluation Test.



Dotted line depicts minimum WSC concentration for good fermentation (McDonald et al., 1991)

Figure 2. Effect of molasses (Mol) or recommended or double rates of pioneer 11C33 (PN and DPN), and Buchneri 500 inoculants (BB and DBB) on aerobic stability of corn silage.



Bars with different letters differ ($P<0.05$)

Table 3. Effect of inoculant or molasses treatment on the chemical composition of corn silage (%, DM) or as stated)**.**

	Control	BB[1]	DBB[2]	PN[3]	DPN[4]	MOL[5]	S.E.M.	*P*
DM, %	40.5[a]	38.2[ab]	36.6[b]	38.8[ab]	37.2[b]	39.0[ab]	0.6	0.004
DM Recovery	92.1	93.4	93.9	94.7	100.0	96.3	3.0	0.051
Water-soluble carbohydrates	1.03[a]	0.39[b]	0.39[b]	0.38[b]	0.39[b]	1.13[a]	0.09	0.001
Starch	25.8[a]	33.8[bc]	29.8[ab]	36.8[c]	29.6[ab]	33.7[bc]	1.6	0.001
Crude protein	6.51	6.64	6.85	6.77	6.58	6.89	0.12	NS
Neutral detergent fiber	45.9	47.0	50.2	48.0	50.6	46.2	1.33	0.087
Acid detergent fiber	22.7	24.8	25.9	24.3	27.4	24.1	1.09	NS
Ash	3.01[a]	3.23[abc]	3.49[bc]	3.09[ab]	3.56[c]	3.53[c]	0.09	0.001
In vitro DM digestibility	62.6	59.8	60.9	56.8	62.5	57.4	3.5	NS

[a,b,c] Means with different superscripts in the same row differ (P < 0.05)
[1] BB = Lallemands Buchneri 500 inoculant applied at the normal rate.
[2] BB applied at double the normal rate;
[3] PN = Pioneer inoculant 11C33 applied at the normal rate;
[4] DPN = PN applied at double the normal rate;
[5] Mol = molasses applied at 3.5 % forage DM.

Table 4. Effect of inoculant or molasses treatment on lactic acid bacterial counts and fermentation characteristics (%, DM) of corn silage.

	Control	BB[1]	DBB[2]	PN[3]	DPN[4]	MOL	S.E.M.	*P*
Lactic acid bacteria, log cfu/g	7.58	8.05	7.37	7.22	7.98	7.17	0.42	ns
pH	3.84^{ab}	3.96^{bc}	3.93^{abc}	4.06^{c}	3.94^{abc}	3.81^{a}	0.03	0.001
Ammonia-N, % total N	11.65	12.74	13.02	12.74	14.55	10.79	0.82	0.072
Lactic	2.6^{ab}	1.99^{ab}	2.52^{ab}	1.51^{a}	2.68^{ab}	2.85^{b}	0.27	0.019
Acetic acid	1.43^{a}	2.31^{ab}	3.49^{bc}	3.08^{abc}	4.03^{c}	1.68^{a}	0.38	0.001
Propionic acid	0.88	0.76	1.01	1.01	1.22	0.82	0.11	0.063
Iso-butyric acid	2.25	2.22	2.89	2.37	3.43	2.88	0.31	0.053
Iso-valeric acid	1.11	1.04	0.82	0.95	1.05	1.04	0.15	NS
Valeric acid	0.15^{abc}	0.00^{a}	0.00^{a}	0.19^{bc}	0.23^{c}	0.08^{ab}	0.033	0.001
Total volatile fatty acids	8.42	8.32	10.86	9.12	12.65	9.33	1.06	0.071
Lactic:Acetic acid ratio	1.81^{c}	0.88^{b}	0.74^{ab}	0.50^{a}	0.69^{ab}	1.68^{c}	0.07	0.001

[a,b,c] Means with different superscripts in the same row differ ($P < 0.05$)
[1] BB = Lallemand Buchneri 500 inoculant applied at the normal rate.
[2] BB applied at double the normal rate;
[3] PN = Pioneer 11C33 inoculant applied at the normal rate;
[4] DPN = PN applied at double the normal rate;
[5] Mol = molasses applied at 3.5 % forage DM.

Table 5. The effect of maturity, company (C; Pioneer (PN) or Croplan Genetics (CPL)) and stay-green (S) ranking of corn hybrids on the yield and chemical composition of corn silage samples (% DM or as stated).

	Maturity	High stay-green		Average stay-green		SEM	Effects[1]						
	(M)	PN31Y43	CPL827	PN32D99	CPL799		C	S	M[2]	SxM	SxC	MxC	SxMxC
Yield, t DM/ha	1	17.0	18.5	15.1	13.1	2.9	ns	ns	x	**	ns	**	ns
	2	16.1	13.8	16.3	12.8								
	3	13.3	17.8	17.8	23.0								
DM, %	1	26.8	22.0	25.8	26.5	3.6	ns	ns	**, L	ns	**	**	ns
	2	30.6	32.2	29.0	35.2								
	3	38.4	34.8	38.3	37.4								
Starch	1	16.9	14.3	15.3	21.6	3.1	ns	x	**, L	ns	***	ns	ns
	2	28.3	24.4	26.4	35.5								
	3	32.1	30.8	29.7	37.3								
WSC[3]	1	0.9	1.0	1.0	1.0	0.2	ns	ns	**, L	ns	ns	ns	ns
	2	0.7	0.4	0.5	0.4								
	3	0.5	0.5	0.4	0.5								
Crude protein	1	11.1	10.4	10.0	9.8	1.1	ns	x	**, L	ns	ns	ns	ns
	2	9.6	9.0	8.8	8.9								
	3	8.8	8.4	8.1	8.2								
NDF[4]	1	50.9	53.6	54.4	47.4	3.0	ns	ns	**, L	ns	***	ns	ns
	2	42.0	44.6	44.9	38.3								
	3	42.4	45.0	45.0	37.0								
ADF[5]	1	28.1	30.3	31.8	26.8	2.4	ns	ns	**, L	ns	***	ns	ns
	2	22.7	25.5	25.5	20.2								
	3	23.6	26.8	26.4	19.5								
IVDMD[6]	1	61.0	58.7	66.0	62.7	4.6	ns	x	ns	ns	**	ns	ns
	2	64.0	61.0	61.7	67.6								
	3	63.1	59.0	60.5	65.4								

[1] x = $P < 0.1$; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$
[2] L = linear polynomial effect; [3] Water-soluble carbohydrates; [4] Neutral detergent fiber; [5] Acid detergent fiber; [6] In vitro DM digestibility

Table 6. The effect of maturity, company (C; Pioneer (PN) or Croplan Genetics (CPL)) and stay-green (S) ranking of corn hybrids on fermentation indices and aerobic stability of corn silage samples (% DM or as stated).

	Maturity	High SG		Average SG		SEM	Effects[1]						
	(M)	PN31Y43	CPL827	PN32D99	CPL799		C	SG	M[2]	SxM	SxC	MxC	SxMxC
NH_3-N, % total N	1	14.2	11.8	13.7	15.2	1.7	ns	ns	**, Q	ns	ns	ns	**
	2	13.1	10.9	10.8	11.7								
	3	12.6	12.2	14.0	11.2								
pH	1	3.75	3.66	3.73	3.73	0.06	ns	ns	**, L	ns	**	ns	ns
	2	3.75	3.79	3.72	3.81								
	3	3.80	3.74	3.79	3.82								
Lactic Acid	1	7.6	7.3	6.4	8.7	1.5	ns	ns	**, L	ns	ns	ns	ns
	2	5.8	4.6	5.7	5.1								
	3	4.3	4.7	5.7	4.6								
Acetic Acid	1	4.5	4.3	3.9	5.1	0.9	ns	ns	**, L	ns	ns	ns	ns
	2	3.1	2.4	2.8	2.6								
	3	2.3	2.5	3.1	2.9								
Propionic Acid	1	1.3	0.6	0.8	1.3	0.4	ns	ns	**, L	ns	ns	ns	**
	2	1.1	0.8	0.9	0.7								
	3	0.7	0.6	0.8	0.3								
Molds, log cfu/g	1	3.27	3.27	3.2	3.39	0.55	ns	ns	**, L	ns	ns	ns	**
	2	2.25	2.68	3.23	2.25								
	3	3.02	2.25	2.25	2.25								
Yeasts log cfu/g	1	5.39	5.51	6.35	6.47	1.37	ns	ns	**, L	ns	ns	ns	ns
	2	5.81	5.3	6.43	6.66								
	3	7.98	6.59	6.79	6.79								
Aerobic stability (hours)	1	24.5	24.9	24.9	24.3	1.0	ns	ns	ns	ns	ns	ns	ns
	2	24.4	25.6	25.1	24.0								
	3	24.1	24.1	25.1	25.0								

[1] ** = $P < 0.01$; [2] L = linear polynomial effect; Q= quadratic polynomial effect.