Moisture Effect on Fermentation Characteristics of Cup-Plant Silage

K. J. Han*, K. A. Albrecht[1], R. E. Muck[1] and D. A. Kim[2]
Department of Agronomy, Universtiy of Wisconsin-Madison, WI 53706, USA

ABSTRACT : Cup-plant (*Silphium perfoliatum* L.) has potential to produce high biomass and highly digestible forage in the wetlands where other productive forages do not grow or produce well. However, high moisture content at harvest is a considerable disadvantage of cup-plant for the production of high quality silage. This study was conducted to determine the effect of moisture content on the characteristics of cup-plant silage. Harvested cup-plant was ensiled in farm scale plastic bag silos and laboratory silos. In the plastic bag silos, first growth (FG) and regrowth (RG) cup-plant was harvested, wilted and ensiled. Dry matter content of FG and RG was 280 g/kg and 320 g/kg after 48 hr of wilting. The silage made with FG had pH 5.3 and 5.63 g/kg DM of acetate as a major volatile fatty acid. The composition of lactate, butyrate and acetate production was 1.0: 0.9: 2.3. The pH of silage made with RG was 4.5 and lactate was a major fermentation end product (16.8 g/kg DM). In the laboratory silos, wilted and unwilted first growth cup-plant material was ensiled to compare the early fermentation end products at days 2, 4, 11, and 40. Wilting increased dry matter content by 42% in the harvested material. Wilted silage showed about one unit lower pH until day 11. The contents of ammonia nitrogen and acetate were higher in unwilted silage, while that of lactate was higher in wilted silage ($p<0.05$). Butyrate and propionate were not detected in the wilted silage until day 40. We conclude from the results that moisture control is essential for the production of high quality cup-plant silage and high pH of cup-plant silage is due to low concentrations of fermentation end products. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 5 : 636-640)*

Key Words : *Silphium perfoliatum* L., Lactate, Acetate, Forage, Wilted Silage

INTRODUCTION

Native to mid-west America, cup-plant (*Silphium perfoliatum* L.) has been studied as a new forage source in Wisconsin for ten years. With the high yielding property, cup-plant maintained high digestibility at mature stage. Albrecht and Bures (1999) summarized the advantages of cup-plant as high productivity (14.1 ton of dry matter per ha at mid-August harvest under single cut system), tolerance to wet soil conditions, extremely winterhardy persistence, and good to excellent forage quality.

Because cup-plant has thick stems and produces large amounts of fresh material in a harvest, ensiling is a practical way to preserve it. However, researchers (Klechkovskaya and Mukhin, 1990; Maslinkov and Donev, 1987; Daniel and Romf, 1994; Albrecht and Goldstein, 1997) reported low dry matter content at harvest as a big disadvantage for the preservation of cup-plant. Wet forage productivity was about two times more than that of corn or grass/legume mixture, but DM yield was equal or in slightly more than that of traditional forages (Klechkovskaya and Mukhin, 1990). According to Duranti et al. (1988), the dry matter content even at full bloom stage still remained at 206 g/kg. Therefore, wilting is required for the preservation of this high moisture containing plant.

Bacteria multiply vigorously in wet plant material containing high water soluble carbohydrate content (Greenhill, 1964). Clostridia and enterobacteria are known to be mostly responsible for the spoilage in ensiled high moisture forage material, and they produce butyrate or ammonia-nitrogen compounds from carbohydrate and protein (McDonald et al., 1991). Clostridia are more sensitive to moisture content in plant material than other aerobic bacteria. Therefore, Jonsson (1990) reported that dry matter content should be higher than 350 g/kg to prevent spoilage in big bale silage.

High moisture and water-soluble carbohydrate (WSC) concentration are associated with intensive fermentation, which result in low pH silage with high amounts of fermentation end products. Although low pH is effective in controlling clostridia and enterobacteria, high lactic acid content in silage cause a negative effect on silage intakes (Rooke, 1995). Restricted fermentation by moisture control can be a benefit for the production of high quality and palatable silage not only by minimizing spoilage but also maintaining quality, which is more close to the original forage. The purpose of this study was to determine the effect of moisture content in raw cup-plant on the fermentation characteristics.

* Address reprint request to K. J. Han. Tel: +1-608-262-3365, Fax: +1-608-262-5217, E-mail: kjhan1@students.wisc.edu.
[1] USDA-ARS, US. Dairy Forage Res. Center, Madison, WI 53706, USA.
[2] School of Agric. Biotechnol., Seoul Natl. Univ., Suweon 441-744, Korea.
Received December 30, 1999; Accepted January 29, 2000

MATERIALS AND METHODS

Farm scale bag silo

The seeding rate of the cup-plant was 7.9 kg/ha and nitrogen was applied 150 kg/ha in the spring. The early to mid-bloom cup-plant was clipped in mid-July for the first growth harvest and mid-October for the regrowth material harvest. The harvested material was wilted in the field for 48 hours and ensiled in farm scale bag silos (diameter 1.7 m). In January, four cores of samples were taken from the silo bags for analyses.

Laboratory silo

Wilted and unwilted cup-plant material was also ensiled in the laboratory silos, Glass jars, which had 946 ml of volume, were used as silos. Chemical compositions in cup-plant material were determined from the four replicated silos opened at day 2, 4, 11, and 40 after ensiling.

Sample preparation and chemical analysis

Dry matter levels were determined on sub-samples according to AOAC (1984). The remainder of each sample was dried at 60℃ for 72 hours and saved for chemical analysis. Dried samples were ground through a 1-mm screen with a Wiley mill. Siegfried et al.'s method (1984) was employed for the analysis of organic acids. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were determined by the sequential analysis method described by Hintz et al. (1996), which was a modification of Robertson and Van Soest (1977). The sample size was 0.5 g, and 0.1 ml α-amylase (Sigma Chemical Co., St. Louis, Mo. number A 5426) was added during refluxing in the neutral detergent solution and again during sample filtration. Total nitrogen analysis was done by the semimicro-Kjeldhal procedure (Bremner and Breitenbeck, 1983).

Statistical analysis

Analysis of variance (ANOVA) procedures (SAS Institute, 1988) was used to test significance of moisture effects between treatments. Mean and Least square difference (LSD) values were calculated to compare differences in fermentation characteristics between the treatments.

RESULTS AND DISCUSSION

Farm scale bag silo

Nutrient contents in original cup-plant material are presented in table 1. Dry matter content was 14% higher in RG than in FG. This difference probably was due to the relatively lower fodder yield per unit area and stem ratio in the regrowth cup-plant. The DM loss after fermentation was 5.3% and 4.7% in FG and RG, respectively (table 2).

Table 1. Nutrient content of first growth (FG) and regrowth (RG) cup-plant after wilting

Item	FG	RG
DM, g/kg	280	320
pH	6.5	6.8
Total N, g/kg DM	16.5	18.4
ADF, g/kg DM	316	184
NDF, g/kg DM	449	263

Table 2. Nutrient content and pH of first growth (FG) and regrowth (RG) cup-plant silage after preservation in the plastic bag silo

Item	FG	RG	$LSD_{0.05}$
DM, g/kg	265	305	11
pH	5.3	4.5	NS[1]
Total N, g/kg DM	16.8	17.9	NS
ADF, g/kg DM	373	217	79
NDF, g/kg DM	503	290	115

[1] NS=not significant at 0.05 level.

The pH of silage made with FG was too high for it to be regarded as lactate silage (table 2). Henderson et al. (1982) reported pH of the well preserved unwilted ryegrass silage as 3.7 to 4.2. Compared with Henderson et al. (1982), silage made with RG was corresponded to the well-fermented lactate silage. The concentrations of ADF and NDF in cup-plant silage are presented in table 2. The increased cell wall portions in silage indicated the loss of soluble cell content during the fermentation. However, the increased rates of NDF and ADF from the original material were similar in FG and RG; thus, the intensity of the degradation in soluble cell component was regarded to be similar. Total nitrogen concentration between the RG and FG silage showed little changes from the original material. The organic acid composition in cup-plant silage is presented in table 3. The composition of lactate and other organic acids in silage are more variable than that of CP or ADF (Chase, 1997). Therefore, VFA composition is a more useful index for the silage quality. The silage made with FG had acetate as a major fermentation end product, and equal amounts of lactate and butyrate, which resulted in high pH. The concentrations of acetate and propionate in FG silage were significantly higher than in RG silage ($p<0.05$). The composition of organic acid strongly indicated the RG silage had lactate fermentation because lactate was a major organic acid and butyrate was not found (table 3). However, the amount of total organic acid was small and lactate content was only about one-fourth of that in ryegrass or corn silage in other research; thus, it seemed that immediate fermentable carbohydrate sources were probably limited, and the fermentation in RG was restricted by moisture control. Fermentation intensity in silage is strongly affected by moisture content and water soluble carbohydrate. Cushnahan and Gordon (1995) observed that restricted fermentation condition reduced lactate production by 21.8% of that in enough moisture and water soluble carbohydrate (WSC) condition. Morgan et al. (1980) also observed decreased lactate production when DM content increased from 34 to 165 g/kg by wilting.

Moisture control improved the composition of fermentation end products in cup-plant to the more desirable direction. However, the amount of lactate was low even in the silage made with RG when it is compared with that in other traditional forage in other studies.

Table 3. Fermentation end products of first growth (FG) and regrowth (RG) cup-plant silage after ensiled in plastic bag silos

Item	FG	RG	$LSD_{0.05}$
	g/kg DM		
Formate	0.08	0	-
Acetate	5.63	2.42	2.99
Propionate	1.16	0.22	-
Butyrate	2.14	0	-
Lactate	2.50	16.87	4.87
Ethanol	0	1.16	-

-, value not determined.

Laboratory silo

The chemical components of the wilted and unwilted cup-plant are presented in table 4. Dry matter content of original cup-plant material was low, which is consistent with other researchers' observations (Klechkovskaya and Mukhin, 1990; Duranti et al., 1988). The DM content increased by 42% after wilting. However, the DM content was still low to control undesirable fermentation. Forage crops having thick stems have difficulties in moisture control because most of the moisture is concentrated in the stems (Nash, 1985). Generally, wilting reduces bacteria numbers. However, the bacteria numbers were higher in wilted material than unwilted. Total nitrogen, ammonia-N and organic acid contents were similar in wilted and unwilted material.

The dry matter and chemical composition of cup-plant silage from the sequentially opened laboratory silos are presented in table 5 and 6. The pH of both wilted and unwilted was high compared to the pH of the farm scale bag silos. This was probably due to the low level of lactic fermentation and non-lactic fermentation by heterofermentative microbes or enterobacteria. The high pH and low DM content of cup-plant silage supported the possibility of undesirable fermentation in laboratory silos. The pH between the wilted and unwilted silage showed differences by day 11, but after that, the pH of the wilted silage approached to the level of the unwilted by day 40.

Table 4. Chemical components in unwilted and wilted cup-plant material before ensiling in laboratory silos

Item	Unwilted	Wilted
DM, g/kg	140.5	199.5
Total microorganism[1], g/DM	3.4	4.3
pH	6.1	6.2
Total N, g/kg DM	30.3	30.6
NH_3, g/kg DM	1.6	1.4
FAA[2], g/kg DM	0.072	0.065

[1] Colony-forming units, $\log_{10}$ cfu.
[2] FAA, free amino acid.

Total nitrogen content of cup-plant silage was the same as that of the grass silage of Cushnahan and Gordon (1995). The ammonia-N portion in total nitrogen at day 2 increased about four times by day 40 in unwilted silage (table 5). The composition of ammonia-N to total nitrogen in the silage reflected the more intensive proteolysis in unwilted silage during the early fermentation period. However, ammonia-N in wilted and unwilted silage reached more than 100 g/kg TN at day 40, which indicated increased proteolysis by enterobacteria. Unwilted cup-plant silage showed similar ammonia-N concentration to Henderson et al.'s (1982) unwilted ryegrass silage.

Table 5. Dry matter, pH, and nitrogen compounds in unwilted and wilted cup-plant silage from the sequentially opened laboratory silos

Date	Unwilted				Wilted			
	D2	D4	D11	D40	D2	D4	D11	D40
DM, g/kg	152	147	139	192	233	214	228	242
pH	6.6	6.3	7.1	6.7	5.4	5.3	6.7	7.0
TN, g/kg DM	33.3	31.0	32.1	35.0	34.8	33.5	33.4	34.1
NH_3-N, g/kg TN	30.7	44.1	127	130	57.3	37.1	87.3	151

Table 6. Volatile fatty acid distribution in unwilted and wilted cup-plant silage from the sequentially opened laboratory silos

Date	Unwilted				Wilted			
	D2	D4	D11	D40	D2	D4	D11	D40
	g/kg DM							
Formate	0	0	0	1.10	0	0	0	1.11
Acetate	27.56	33.18	65.19	66.77	14.78	11.08	45.75	63.02
Propionate	0	0	0	1.85	0	0	0	0
Butyrate	0	0	0	5.26	0	0	0	0
Lactate	31.08	27.38	0	0	58.54	77.24	43.22	19.42

Acetate concentration in the wilted silage was also lower than that in unwilted, and butyrate was not detected in the wilted silage (table 6). Although there are several routes for the production of acetate and butyrate, the amounts of butyrate and acetate were enough to indicate the activity of clostridia and enterobacteria in plant material (McDonald et al., 1991). Low level or undetected butyrate showed relative difficulty in clostridia growth in the wilted cup-plant material. Moreover, lactate composition in early fermentation means the rapid lactate fermentation in raw cup-plant material. Low pH induced by lactate production probably suppressed clostridia growth in early growth stage, which is supported by undetected butyrate in unwilted cup-plant material. The low levels of fermentation end products and high levels of ammonium-N in the cup-plant silage were unique characteristics in this study. Fermentation end products are affected by the amount of WSC and the proportion of carbohydrate types like glucose-fructose ratio in crops; thus, further studies relating WSC in cup-plant and silage quality are required.

CONCLUSION

Cup-plant has low dry matter content at harvest, and dry matter content at ensiling affects chemical composition in cup-plant silage. Therefore, wilting is required to produce lactate fermented silage because moisture control improves the early fermentation characteristics in ensiled cup-plant. Low levels of the fermentation end products from the farm scale bag silos and the laboratory silos need further studies related to water soluble carbohydrates in cup-plant.

REFERENCE

Albrecht, K. A. and E. J. Bures. 1999. Long-term performance of cup-plant as a forage crop. Agronomy Abstracts. ASA, Madison, WI.

Albrecht, K. A. and W. Goldstein. 1997. Silphium perfoliatum: A North American prairie plant with potential as a forage crop. IDNO. 1113.

Association of Official Analytical Chemistry. 1984. Official methods of analysis. 14th ed. AOAC, Washington, DC, USA.

Bremner, J. M. and G. A. Breitenbeck. 1983. A simple method for determination of ammonium in semimicro-Kjeldahl analysis of soils and plant materials using a block digester. Commun. Soil Sci. Plant Anal. 14:905-913.

Chase, L. E. 1997. What should we analyze silage for? In Silage: Field to feedbunk. Proc. Northeast Regional Agricultural Engineering Service Cooperative Extension. Ithaca, NY. 11-13 Feb. 1997. Hershey, PA. pp. 257-261.

Cushnahan, A. and F. J. Gordon. 1995. The effects of grass preservation on intake, apparent digestibility and rumen degradation characteristics. Anim. Sci. 60:429-438.

Daniel, P. and R. Rompf. 1994. Possibilities and limits in the utilization of *Silphium perfoliatum* as a fodder plant, renewable raw material and a landscape conservation-plant. Agrobiol. Res. 47:354-353.

Duranti, E., R. Santilocchi and C. Casoli. 1988. Chemical composition and nutritive value of ensiled *Silphium perfoliatum* L. Zootecnicae Nutrizione-Animale. 14:349-356.

Greenhill, W. L. 1964. Plant juices in relation to silage fermentation. I. The role of the juice. J. Br. Grassl. Soc. 19:30-37.

Henderson, A. R., P. McDonald and D. H. Anderson. 1982. The effect of cellulase preparation derived from *Trichoderma viride* on the chemical changes during the ensilage of grass. J. Sci. Food Agric. 7:303-304.

Hintz, R. W., D. R. Mertens and K. A. Albrecht. 1996. Effects of sodium sulfite on recovery and composition of detergent fiber and lignin. J. AOAC Int. 79:16-22.

Jonsson, A. 1990. Enumeration and confirmation of *Clostridium tyrobutyricum* in silage using neutral red, D-cycloserine, and lactate dehydrogenase activity. J. Dairy Sci. 73:719-725.

Klechkovskaya, M. S. and N. G. Mukhin. 1990. Introduction of *Silphium perfoliatum* in the Voronezh region. Bulleten' Glavnogo Botanicheskogo-Sada. 155:12-16.

Maslinkov, M. and N. Donev. 1987. A comparative study of new perennial fodder crops in the Plovdiv region. Rasteniev dni-Nauki. 24:53-58.

McDonald, P., A. R. Henderson and S. J. E. Heron. 1991. The biochemistry of silage. 2nd ed. Chalcombe Publ., Aberystwyth, UK.

Morgan, D. A., R. A. Edwards and P. McDonald. 1980. Intake and metabolism studies with fresh and wilted silages. J. Agric. Sci. (Cambridge). 94:287-298.

Nash, M. J. 1985. Crop conservation and storage in cool temperature climates. Pergamon Press, Oxford. Quoted in P. McDonald et al. (ed.) 1991. The biochemistry of silage. Chalcombe Publ., Aberystwyth, UK.

Robertson, J. B. and P. J. Van Soest. 1977. Dietary fiber estimation in concentrate feedstuffs. J. Anim. Sci. 45(Suppl.1):254.

Rooke, J. A. 1995. The effect of increasing the acidity of osmolality of grass silage by the addition of free or partially neutralized lactic acid on silage intake by sheep and upon osmolality and acid-base balance. Anim. Sci. 61:285-292.

SAS Institute. 1988. SAS user's guide: Statistics. Version 6.12. SAS Inst., Cary, NC, USA.

Siegfried, V. R., H. Ruckemann and G. Stumpf. 1984. Method for the determination of organic acids in silage by high performance liquid chromatography. Landwirtsh. Forsch. 37.