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THE EFFECT OF A FORMIC ACID-BASED PRESERVATIVE ON STRUCTURAL CARBOHYDRATES AND NUTRITIVE VALUE OF LOW DRY MATTER SWEET SORGHUM SILAGES

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This study was conducted to evaluate the effects of a formic acid-based preservative (FAP) on the structural carbohydrates and nutritive value of low dry matter sweet sorghum (*Sorghum bicolor* L. Moench) silages. Sorghum was harvested at the flowering stage of maturity (23.0±0.69% dry matter). The FAP (KemiSile® 2000, Kemira Oyj-Industrial Chemicals, Finland) was applied to approximately 2 cm chopped fresh material at 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 ml/kg levels, respectively and ensiled in 1.5 liter anaerobic jars (*Le Parfait*, France) equipped with a lid that enabled gas release only. The jars were stored at 24±2 ºC under laboratory conditions. All jars were opened at the end of the ensiling period (90 days) and sampled for analysis. As a result, the FAP treatment reduced structural carbohydrates such as neutral detergent fiber, acid detergent fiber and lignin, hemicellulose and cellulose contents; however, they increased residual water soluble carbohydrates of silages ($P < 0.05$). Due to the reduction in structural carbohydrates, the application of FAP increased *in situ* dry and organic matter degradability of silages ($P < 0.05$). Most effective level of FAP on sorghum silage was found as 4.0 ml/kg.

Key words: sweet sorghum; silage; chemical preservative; structural carbohydrates; *in situ* rumen degradability; nutritive value

ЕФЕКТ НА КОНЗЕРВАНС НА БАЗА НА МРАВЈА КИСЕЛИНА ВРЗ СТРУКТУРНИТЕ ЈАГЛЕХИДРАТИ И ХРАНЛИВАТА ВРЕДНОСТ НА СИЛАЖА ОД СЛАДОК СИРАК СО НИСКА СУВА МАТЕРИЈА

Истражувањето беше изведено за да се проценат ефектите на конзерванс на база на мравја киселина (КМК) врз структуралните јаглехидрати и хранливата вредност на силажа од сладок сирак (*Sorghum bicolor* L. Moench) со ниска сува материја. Бербата на сиракот беше извршена во фаза на цутење (23.0±0.69% сува материја). Конзервансот на база на мравја киселина (KemiSile® 2000, Kemira Oyj-Industrial Chemicals, Finland) беше применет кај свеж материјал исечкан на парчиња долги 2 cm, на ниво од 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, и 4.0 ml/kg, и силажирани во 1,5 l вакуумирани тегли (*Le Parfait*, France) опремени со капачиња кои овозможуваат испуштање само на гасови. Теглите беа складирани на температура од 24±2 ºC во лабораториски услови. Сите тегли беа отворени на крајот од силажниот период (90 дена) и дадени за анализа. Како резултат на третманот КМК ги редуцираше структурните јаглехидрати како што се неутрални детергентни влакна, киселински детергентни влакна и лигнин, хемицелулозни и целулозни содржини. Меѓутоа, се зголеми количината на остаточни јаглехидрати од силажата, растворливи во вода ($P < 0,05$). Поради редукцијата во структурните јаглехидрати, примената на КМК ја зголеми *in situ* растворливоста на сува и органска материја во силажата ($P < 0,05$). Најефикасно ниво на КМК кај силажа на сирак е на 4,0 ml/kg.

Клучни зборови: сладок сирак; силажа; хемиски конзерванс; структурални јаглехидрати; *in situ* желудочна растворливост; хранлива вредност

1. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is one of the major cereal in the semi-arid regions of the world where it is an important food and feed crop. The increased popularity of grain and forage sorghum silages for dairy and beef cattle production can be attributed to their desirable ensiling traits and potential for competitive whole-plant dry matter (DM) yields compared with corn (Bolsen, 1995). In addition, silage-type sorghums have been investigated as a viable alternative crop because they can be planted later than corn, use water more efficiently, adapt to a variety of soil types and fertility levels, have high biomass yields, increase soil cover, reduce soil erosion, and have a low requirement for pesticides (Sanderson et al., 1992).

An important silage management decision that affects cattle performance is the use of silage additives. In order to improve the ensiling process a lot of additives (stimulators and inhibitors of fermentation, inhibitors of aerobic deterioration, nutrients and absorbents) have been improved. Formic acid (FA), which is a chemical preservative, partially restricts fermentation and results in high quality silage. Appearing in many commercial proprietary silage additives, FA functions either as a sole ingredient or in combination with other chemicals (Kung et al., 2003).

Forage sorghums typically have a lower DM content and protein concentration at harvest and digestibility of conventional forage sorghum hybrids is lower than that of many corn hybrids. Besides, the whole plant sorghum hybrids contain much more lignin than corn commonly fed but less content of grain (Aydın et al., 1999). Adding FA to sorghum silages can increase intake by minimizing changes in the nitrogen and carbohydrate fractions during ensilage (Steen et al., 1998); for example, by the use of high levels of FA thereby restricting silage fermentation. Kennedy (1990) demonstrated a significant increase in silage DM intake and live weight gain when growing cattle were offered silage with restricted fermentation. Castle and Watson (1973) stated that FA-treatment to wilted for ages improved chemical quality of silages, recovery of DM, intake of DM, and milk production.

The objective of this study was to assess the effects of application of different concentrations of FAP on structural carbohydrates and nutritive value of low DM sorghum silage.

2. MATERIALS AND METHODS

Experimental

Sorghum (*Sorghum bicolor* L.) was harvested by hand at the flowering stage of maturity and chopped using a conventional forage harvester (Sezer, Bandırma, Turkey) to approximately 2 cm. For morphological measurements randomly 10 plants from each replication were taken just before cutting for forage production. The plant height was measured individually. The chopped fresh material was treated with the liquid formulation of FAP and ensiled in 1.5 liter anaerobic jars (Le Parfait, France) equipped with a lid that enabled gas release only. Each jar was filled with approximately 1125.9 kg (wet weight) of chopped forage. The packing density was 172.6 kg of DM/m^3. There were 24 jars and they were stored at 24±2 ºC under laboratory conditions. Fresh and ensiled materials (3 jars on d 90 after ensiling) were sampled for chemical analysis.

- Control (no additives).
- The liquid formulation of FAP (KemiSile® 2000, Kemira Oyj-Industrial Chemicals, Finland), containing 86% of active ingredients including FA (55%), ammonium formate (24%), propionic acid (5%), benzoic acid (1%) and ester of benzoic acid (1%) was added at the rate of 0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 ml/kg levels fresh forage within 1 h after chopping.

Analytical procedures

Chemical analyses were performed in triplicate and presented on a DM basis. The DM content of the fresh material was determined by oven drying for 48 h at 60°C. Ash was obtained after 3 h at 550°C (AOAC, 1990). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were analyzed by using the sodium sulfite addition method without α-amylase and expressed with residual ash (Van Soest et al., 1991). Hemicellulose was calculated as the difference between NDF and ADF and cellulose as the difference between ADF and ADL. Water-soluble carbohydrates (WSCs) were determined by the phenol sulfuric acid method (Dubois et al., 1956). Rumen degradability of the silages was measured by the *in situ* procedure of Mehrez and Ørskov (1977). Air-dried forage samples were ground through a 2.5 mm screen using a laboratory 3303 mill (Hundunge, Sweden). The milled samples were placed in 9×14 cm Dacron bags (pore size 10 to 40 μm), which were inserted into the rumen of three fistulated Merino sheep fed a concentrate and alfalfa hay diet. The Dacron bags were incubated in the rumen for 48 h.

The data were analyzed as a completely randomized design and subjected to ANOVA by the general linear model procedure of Statistical Analysis System (SAS, 1988). Differences in silage characteristics between additive treatments within forage were tested by means of Duncan's Multiple Range test and the significance was declared at $P < 0.05$.

3. RESULTS AND DISCUSSION

Some agronomic and chemical characteristics of fresh sorghum are presented in Table 1. The fresh forage yield was about 77 t with total DM of 17.7 t ha^{-1}. The harvest year had drought and rainfall during the growing period was much below than the long term average (164 vs. 115 mm). Several reports indicated that the potential of whole plant DM yields typically range from 10 to 20 t ha^{-1} which corresponds to our results; however, hybrid selection is important to succeed optimum agronomic performance (White, 1989; Sonon and Bolsen, 1996). Additionally, lower water demand and high tonnage yield of sorghum have been reported by Fazaeli et al. (2006). They established that the fresh forage yield was 80 t with the total DM of 19.3 t ha^{-1}. Through a study carried out, with 37 sorghum cultivars, Siefer and Bolsen (1997) explained that DM and DM yield ranged between 23–39% and 990–1080 kg ha^{-1}, seed yield was approximately at 24 kg ha^{-1}. When chemical characteristics of fresh sorghum taken into account the findings were in agreement with the results reported by Sonon and Bolsen (1996). They revealed DM, NDF and ADF contents of the whole plant sorghum were 25.4, 60.2 and 33.7% respectively.

When the literature and the results of this research are considered, it might be discussed that the phenotypic traits of forage sorghum cultivars (e.g., hybrids and varieties) vary greatly, and the wide ranges in season length, plant height, DM concentration, and the whole-plant DM and grain yields contribute to large differences in nutritional values among cultivars (Bolsen et al., 1991). Also, both the agronomic performance and nutritive value of grain and forage sorghums are influenced by the stage of maturity at harvest (Dickerson et al., 1986; Sonon et al., 1991).

Table 1

Some agronomic and chemical characteristics of fresh sorghum ($\bar{x} \pm S\bar{x}$)

DM, %	23.00±0.690
Plant height, cm	260.10±1.356
Forage yield, t ha^{-1}	77.08±2.567
DM yield , t ha^{-1}	17.73±0.590
OM yield , t ha^{-1}	67.81±2.258
Seed yield , t ha^{-1}	3.98±0.114
WSCs, % of DM	24.37±1.257
OM , % of DM	94.27±0.064
CA , % of DM	5.81±0.038
NDF , % of DM	60.52±0.125
ADF , % of DM	33.99±0.183
ADL , % of DM	7.38±0.085
Hemicellulose* , % of DM	26.53±0.079
Cellulose** , % of DM	26.61±0.090

DM, dry matter; OM, organic matter; WSCs, water-soluble carbohydrates; CA, crude ash; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; FAP, formic acid-based preservative.

*Hemicellulose = NDF – ADF

** Cellulose = ADF – ADL

The soluble and structural carbohydrate contents of sorghum silages are presented in Table 2. After 90 days of ensiling, structural carbohydrates reduced with the increasing application rate of FAP. The decline in the NDF content, which could be considered remarkable, started following 1 ml/kg FAP ($P < 0.05$). When ADF, ADL and cellulose levels taken into account, they revealed a significant reduce following 1.5 ml/kg FAP compared to control silages ($P < 0.05$). Although the same trend was also observed in hemicellulose, statistically effective fall began at 2.5 ml/kg FAP when evaluated according to the control silage values ($P < 0.05$). Jaakkola et al. (1991) also found lowered NDF and ADF content of FA-treated silage, supposedly as a result of acid hydrolysis (Morrison, 1979). Polan et al. (1998) showed that FA decreased NDF and ADF contents of alfalfa silages.

The WSCs levels of silages were lower than the fresh material. However, increasing levels of

FAP application overbid the residual WSCs in sorghum silages. Statistically effective increase of WSCs observed at following 2.5 ml/kg FAP (P < 0.05). Formic acid has an anti-bacterial effect on many bacterial species, including LAB. Therefore, it results in limited fermentation and reduction in organic acid but a greater amount of WSC content of silage (Kennedy, 1990; Spoelstra et al., 1990). Filya and Sucu (2007) also obtained a similar result and expressed that the usage of FAP rose residual WSC content of wheat silage.

The FAP employed in the research has increased *in situ* DM and organic matter (OM) degradabilities of sorghum silages (Table 3, Figure 1). In comparison to the control values DM, OM degradabilities and yields showed a statistical rise following 3 and 1.5 ml/kg FAP respectively (P < 0.05). The ADF (Marten et al., 1975) and lignin (percentage of cell wall; Danley and Vetter, 1973) were good predictors of digestibility in the whole plant sorghum. Besides, a greater amount of WSC might be a better source of energy for rumen microorganisms than lactic acid (Bosch et al., 1991). In the present study, FA consistently reduced ADF and lignin content of silages, on the other hand increased residual WSCs, as a result, it improved silage DM and OM digestion in the rumen. Haigh and Parker (1985) revealed that FA-treated grass silage had higher digestibility of OM than the untreated silage (66.8% *vs.* 65.4%). This is in agreement with Kennedy (1990) who reported that the *in vitro* digestibility of OM of the silage treated with FA was 73.0% compared to 71.8% in the control silage. In our previous experiments in farm conditions (Filya et al., 2004) and laboratory silos (Filya et al., 2005; Filya and Sucu 2006) also indicated that application of FAP improved ruminal DM and OM degradability of low DM maize silages. However, Keady and Murphy (1996) found out that FA-treatment significantly reduced the silage OM digestibility (69.6% and 70.9% for treated and control silage, respectively).

Table 2

Soluble and structural carbohydrate contents of sorghum silages ($\bar{x} \pm S\bar{x}$, %)

FAP treatment (ml/kg)	WSCs	NDF	ADF	ADL	Hemicellulose*	Cellulose**
Control	5.95±0.167^{d}	59.53±0.117^{a}	33.87±0.400^{a}	7.42±0.052^{a}	26.44±0.358^{a}	32.61±0.325^{a}
1.0	6.37±0.410^{cd}	57.40±0.080^{b}	33.59±0.183^{ab}	7.31±0.027^{a}	26.28±0.176^{ab}	32.07±0.249^{a}
1.5	6.63±0.718^{cd}	57.56±0.310^{c}	32.94±0.141^{b}	6.64±0.075^{b}	26.31±0.212^{ab}	30.48±0.185^{b}
2.0	7.83±0.373^{cd}	55.39±0.191^{d}	31.94±0.416^{c}	6.38±0.053^{b}	25.56±0.468^{abc}	27.82±0.340^{c}
2.5	8.37±0.677^{c}	54.73±0.108^{e}	31.11±0.280^{d}	5.73±0.086^{c}	25.38±0.365^{bc}	28.22±0.311^{c}
3.0	10.41±0.808^{b}	54.27±0.018^{f}	30.56±0.303^{e}	5.72±0.082^{c}	24.84±0.293^{cd}	27.94±0.429^{c}
3.5	12.11±1.118^{b}	53.33±0.254^{g}	29.88±0.090^{e}	5.13±0.079^{d}	24.74±0.012^{cd}	25.52±0.085^{d}
4.0	14.15±0.236^{a}	52.55±0.125^{h}	28.51±0.184^{f}	4.64±0.179^{e}	23.88±0.339^{d}	25.44±0.197^{d}

FAP, formic acid-based preservative; WSCs, water-soluble carbohydrates; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin;

* Hemicellulose = NDF – ADF;

** Cellulose = ADF – ADL

$^{a\text{-}h}$ Means within rows with unlike superscripts differ (P < 0.05).

Table 3

In situ degradability characteristics of sorghum silages ($\bar{x} \pm S\bar{x}$)

FAP treatment (ml/kg)	DM (%)	OM (%)	Digestible DM yield (t ha^{-1})	Digestible OM yield (t ha^{-1})
Control	36.67±4.920^{b}	35.59±2.300^{d}	28.27^{b}	27.43^{d}
1.0	39.08±1.320^{ab}	36.83±0.310^{d}	30.12^{ab}	28.39^{d}
1.5	39.96±4.500^{ab}	41.48±1.450^{c}	30.80^{ab}	31.97^{c}
2.0	40.45±1.170^{ab}	42.82±2.450^{c}	31.18^{ab}	33.01^{c}
2.5	42.02±1.350^{ab}	43.18±0.930^{c}	32.39^{ab}	33.28^{c}
3.0	46.30±1.820^{a}	48.61±1.250^{b}	35.69^{a}	37.47^{b}
3.5	46.45±5.160^{a}	49.81±0.920^{ab}	35.80^{a}	38.39^{ab}
4.0	46.49±1.600^{a}	52.45±0.820^{a}	35.83^{a}	40.43^{a}

FAP, formic acid-based preservative; DM, dry matter; OM, organic matter

$^{a\text{-}d}$ Means within rows with unlike superscripts differ (P < 0.05).

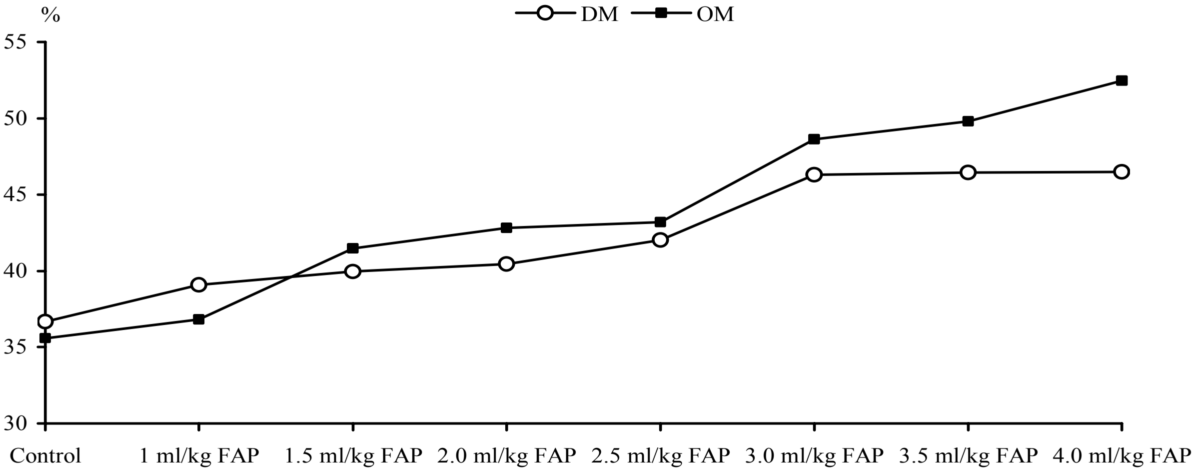

Fig. 1. *In situ* dry and organic matter degradability of sorghum silages (%)
DM, dry matter; OM, organic matter; FAP, formic acid-based preservative

4. CONCLUSION

Sorghum is agronomically suited to the High Plains region of Turkey and has considerable potential as a silage crop. In the current study, sorghum had high tonnage of forage DM, OM and seed yield, as well as an adequate level of WSCs, necessary for a successful fermentation. Application of different concentrations of FAP to sorghum silages markedly reduced structural carbohydrates, because of acid hydrolysis, and it increased levels of residual soluble carbohydrates in silage as expected. The reduction in structural carbohydrates and the increased WSCs in silage owing to application of FAP, improved *in situ* DM and OM degradability of silages. These results displayed that treatment with FAP, 4 ml/kg, was the most effective on low DM sorghum silages.

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