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Sweet sorghum and its bagasse ensiled with urea and molasses can be used as alternatives for maize silage in semi-arid areas from *in situ* and gas production evaluations

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Abstract

In situ degradability and gas production (GP) parameters of sweet sorghum and sweet sorghum bagasse silages compared with maize silage were determined in mini silos in order to compare the nutritional value of ensiled sweet sorghum and its bagasse with maize silage. Experimental treatments were 1) maize silages (MS) as control, 2) sweet sorghum silage (SS) and 3) sweet sorghum bagasse silage (BS) both supplemented with urea or molasses (10 and 50 g/kg dry matter (DM) basis, respectively). Triplicate silage samples were prepared for each treatment in laboratory silos for 90 days. The *in situ* degradability of DM and crude protein (CP) of fresh and 90-d ensiled forages were measured using three none lactating dairy cows fitted with rumen cannulae over 96 h. *In vitro* gas production was measured for 96 h and organic matter digestibility (OMD), metabolisable energy (ME) and net energy for lactation (NE_l) were estimated based on gas production parameters. Fresh sorghum and its bagasse had lower (P<0.01) ME, NEl and OMD than fresh maize. Fresh sorghum and bagasse had greater (P<0.05) immediately soluble fraction (*a*) of DM than fresh maize but for slowly degradable fraction (*b*) of DM opposite trend (P<0.01) was observed. The *a* fraction of CP *in situ* degradability of maize plant was greater than fresh sorghum and bagasse (P<0.01). Adding urea plus molasses increased (P<0.05) *in situ a* fraction of DM and CP and effective rumen degradability of DM and CP (P<0.01) in addition to ME and *in vitro* OMD for SS and BS which were rather comparable with MS. It seems that combination of urea and molasses as silage additives improves the nutritional quality of sweet sorghum and bagasse silages.

Keywords: Maize, sweet sorghum, sweet sorghum bagasse, silage, *in situ* degradability, gas production

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Introduction

Maize (*Zea mays* L.) silage is used extensively for lactating dairy cows. However, maize requires large quantity of water (Gowda et al., 2007) in order to be high yielding and have good nutritional quality. One way to continue forage production under declining water resources is to replace maize with alternative crops which are more efficient in using water. Sweet sorghum (*Sorghum bicolor* var. *saccharatum*) is a crop that provides grain and stem that can be used for sugar, alcohol, syrup, fodder, fuel, bedding, roofing, fencing, paper and chewing. Sorghum due to good adaptation to harsh environmental conditions, high water use-efficiency and high production, even in low water conditions, is an important forage crop in many parts of the world (Almodares et al., 2008). It is often grown in areas of low fertility and unpredictable rainfall (Van-Oosteroma et al., 2001). Sweet sorghum usually is planted for sugar (Almodares and Sepahi, 1996) and ethanol production (Sipos et al., 2009). Sorghum is cultivated in 7.84 and 0.137 million ha in the Asia and Europe, respectively (FAO, 2013).

A previous study has shown that lactating dairy cows fed normal forage sorghum had less intake and produced less milk than cows fed traditional forages such as maize and alfalfa silages (Oliver et al., 2004). Reductions in dry matter (DM) intake and milk yield ranged from 11.7 to 15% and from 8.3 to 27.1%, respectively (Amer et al., 2012). Historically, sorghum silage energy content and digestibility have been lower than that of maize (NRC, 2001). Some attempts have been made to increase nutritive value of sorghum silage. Harris and Mitchell (1941) introduced urea as the best nitrogen source that has not any toxicity effects in cattle and sheep. Urea can be used for increasing nitrogen concentration and improving the fermentation quality of sorghum forage (Filya, 2001). Also molasses can be used as a water-soluble carbohydrates (WSC) source for fast fermentation and lactic acid production by lactic acid bacteria and increasing dry matter content (McDonald et al., 1991).

The beneficial effects of adding urea and molasses to sorghum silages have been reported (Demirel et al., 2004; Guney et al., 2007). Urea-treated feeds increase the rumen fluid pH and fiber digestibility, and consequently increase the silage consumption (Tetlow, 1992). Cabral Filho et al. (2005) have reported that sorghum has high apparent DM degradation (600 g/kg). However, there are opposite findings about sorghum nutritional characteristics, which could be due to differences in hybrid or variety (Bolsen et al., 2003; Oliver et al., 2004). The DM digestibility in sorghum silage with grain is more than forage sorghum silage, which is due to the greater digestion of grain (Pesce et al., 2000; Bolsen et al., 2003).

The objective of the current study was to evaluate the nutritional quality of sweet sorghum and sweet sorghum bagasse silages ensiled with or without urea and molasses under laboratory conditions compared to maize silage as determined by *in situ* degradability and gas production techniques.

Materials and Methods

Plant materials

Sweet sorghum (*Sorghum bicolor* var. saccharatum) and maize were planted on 5 and 22 June 2014 and harvested after 120 days and 70 days (early dent), respectively in Isfahan University Research Station (32º 34'N, 51º 45' E, altitude 1550 m). The plant materials are described in details by Zafari Naeini et al. (2014). To obtain the sorghum bagasse, the grain clusters and leaves were separated from the stem. The resulted stems were extracted using an apparatus having two pairs of rollers to reduce the weight by 200 ±20 g/kg fresh weight. Extracted stems along with separated leaves were chopped into 2-3 cm pieces. Whole plant maize and sweet sorghum forages including stems, seeds and leaves were chopped similarly.

Ensiling procedure and treatments

Whole sorghum and maize plants and sorghum bagasse were ensiled in PVC containers (12×60 cm; 4.0±0.2 kg capacity) with the density of 521±62.5, 543±48.5 and 451±29.0 kg/m^3 for maize, sweet sorghum and sorghum bagasse, respectively. Urea and molasses (10 and 50 g/kg on DM basis, respectively) were added to the silage batches prior to filling whenever appropriate. The ensiling procedure is described by Zafari Naeini et al. (2014). The laboratory silos were placed in a dark room with average temperature of 18°C until their opening at 90 days later.

The experimental treatments were as following: 1) maize silage (MS), 2) sweet sorghum silage (SS), 3) sweet sorghum silage plus urea (SSU), 4) sweet sorghum silage plus urea and molasses (SSUM), 5) sweet sorghum bagasse silage (BS), 6) sweet sorghum bagasse silage plus urea (BSU), 7) sweet sorghum bagasse silage plus urea and molasses (BSUM). Each treatment had three replicates.

Sampling and chemical analysis of fresh and ensiled forages

After chopping, 500 g of fresh forage was dried at 55°C for 48 h in triplicate and ground to pass a 1 mm screen for chemical analysis and *in vitro* degradability. Fermentation characteristics were measured as described previously by Zafari Naeini et al. (2014). The silages were evaluated after 90 days of ensiling.

In situ rumen degradability of DM and CP

The *in situ* measurements of ruminal DM and CP degradations were carried out using three non-lactating Holstein cows (third parity and above; 740±11.2 kg live weight) equipped with ruminal cannulae. The cows were housed in an air-conditioned room with maximum and minimum temperature of 25.0±2.5 and 17.0±1.8°C, respectively. A maintenance ration (AFRC, 1992) was fed in equal portions two times per day (07:00 and 19:00) consisting of approximately 490 g/kg silage (1:1 MS:SS), 400 g/kg chopped alfalfa, 100 g/kg concentrate (containing 5 g/kg urea) and 10 g/kg molasses. Also an adaptation period of 10 days was allowed before incubations. Three g dry samples ground with 2 mm sieve, transferred into polyester bags (pore size, 52±10 µm; internal dimensions, 10×15 cm). Bags were placed sequentially in the ventral rumen of the three fistulated cows in duplicate, whereas the third bag served as blank. Samples were soaked in water for 3 min before ruminal incubation for 2, 4, 8, 12, 24, 48, 72, and 96 h in a mesh bag. Also, six bags (three cows×two replicates) were washed with cold tap water to estimate zero time incubation. Upon removal of the bags (including the zero time incubation), samples were hand-washed with cold water 5 times for 4 min each until the rinse water remained clear and then dried at 55°C for 48 h. After drying, bags were weighed and rate of disappearance and lag time were calculated with non-linear regression (Ørskov and McDonald, 1979) using the NLIN procedure of SAS (2003) as below:

$$P= a +b (1-e^{ct})$$

where, P is the proportion of disappeared material at time t, *a* is immediately disappeared fraction, *b* is slowly degradable fraction which disappears at a measurable rate and *c* is the fractional rate constant at which the fraction *b* will degrade per h. The effective rumen degradability of DM (ERD) and CP (ERDP) were calculated as $a+\{b\times[c/(c+k_p)]\}$ (Ørskov and McDonald, 1979), where k_p is the ruminal particulate passage rate, which was assumed to be 0.02, 0.04, 0.06 and 0.08 per h for feeding at maintenance, two, three and four times of the maintenance level, respectively.

Gas production

The *in vitro* gas accumulation was measured according to the procedures described by Weimer et al. (2005). Dried samples (200 mg) ground with 1 mm sieve, were put into vials in triplicate. Three vials were placed as blank (containing 30 ml of rumen fluid and artificial saliva mixture and no sample) in the beginning, middle and end of vial rows. Micro-mineral solution (13.2 g $CaCl_2.2H_2O$, 10 g $MnCl_2.4H_2O$, 1 g $CoCl_2.6H_2O$, 8 g $FeCl_3.6H_2O$ per 100 ml solution), rumen buffer solution (4 g NH_4HCO_3, 35 g $NaHCO_3$ per 1 liter of solution), macro mineral solution (5.7 g Na_2HPO_4, 6.2 g KH_2PO_4, 0.6 g $MgSO_4.7H_2O$ per 1 liter of solution), resazurine solution (1 g per 1 liter) and regenerative solution (4 ml NaOH 1 N, 625 mg $Na_2S.9H_2O$ and 95 ml distilled water) were prepared. The rumen fluid collected and filtered from three ruminally fistulated non-lactating Holstein cows which were used for estimating *in situ* ruminal degradability. All procedures of handling rumen fluid were conducted under continuous flow of CO_2. The vials were then filled with 10 ml of rumen fluid plus 20 ml of buffer solution, and placed in a shaking water bath at 39.0±0.5°C. Rubber stopper under CO_2 gassing were sealed with a light coating of petrolatum and vials were capped with butyl rubber stoppers and sealed with aluminum crimps. Gas pressure was measured with a digital pressure gauge (UniMano 1000, NeTech, USA). Gas production was recorded at 2, 4, 6, 8, 12, 24, 36, 48, 72 and 96 h of incubation. The disposable needles used to measure the gas production (GP) were replaced after every ten rubber stopper penetrations. The amount of GP was corrected for blanks and fitted to the following model (Ørskov and McDonald, 1979): $Y=B(1-e^{-Ct})$ where, B is the asymptotic gas production (GP) from the digestible fraction as ml, C is the GP rate constant for the digestible fraction per h, t is incubation time as h and Y is GP at time t.

Metabolisable energy (ME) of samples was estimated from GP at 24 h as described by Close and Menke (1986):

$$ME\ (MJ/kg\ DM) = 1.06 + 0.157\times GP_{24} + 0.0084\times CP + 0.022\times EE + 0.0081\times CA \quad ,t \le L \quad P = a$$

Where, GP_{24} is gas production as ml/200 mg DM at 24 h of incubation, CP is crude protein as g/kg DM, EE is ether extract as g/kg DM and CA is crude ash as g/kg DM.

Organic matter digestibility (OMD) was estimated as described by Menke et al. (1979):

$$OMD\ (g/kg\ DM) = 148.8 + 8.89\times GP_{24} + 0.45\times CP + 0.0651\times CA$$

Also net energy for lactation (NE_l) was calculated using equation of Menke and Steingass (1988) as follows:

$$NE_l\ (MJ/kg\ DM) = 0.54 + 0.0959\times GP_{24} + 0.0038\times CP + 0.001733\times EE$$

Statistical Analysis

Data were analyzed using the general linear model (GLM) procedure of the SAS software (2003) using the following model:

$$Y_{ij}=\mu + T_i + e_{ij}$$

Where μ is the overall mean for each parameter, T_i is treatment effect ($i = 1–7$) and e_{ij} is the residual. Percentage data were transformed into Arcsine before analysis. The Tukey's test was used for mean

comparisons. The effects of urea, molasses and urea plus molasses were assessed using orthogonal comparisons.

Results

Fresh forages

Chemical composition of fresh maize, sweet sorghum forages and sweet sorghum bagasse are presented in Table 1. Maize had lower DM and water soluble carbohydrates (WSC) concentrations compared with sorghum or sorghum bagasse (P<0.01). On the other hand, CP, neutral detergent fibre (NDF) and neutral detergent insoluble protein were greater in fresh maize forage than other two fresh forages (P<0.01). Fresh sorghum and its bagasse were significantly different in DM, CP, NDF, acid detergent fibre (ADF), neutral detergent insoluble protein and acid detergent insoluble protein concentrations (Table 1).

The GP_{24} for maize forage was higher (P<0.05) than sorghum but not significantly different from sorghum bagasse (Table 2). However, ME, NE_l and OMD were significantly greater (P<0.01) for fresh maize forage compared with sorghum forage and sorghum bagasse.

Maize forage had lower (P<0.01) *in situ a* fraction of DM compared with sweet sorghum and sorghum bagasse (Table 3). However, maize forage had greater (P<0.01) *a* fraction of CP than sorghum forage and sorghum bagasse. Maize forage had greater (P<0.01) *in situ b* fraction of DM compared with sorghum forage and sorghum bagasse, while maize and sorghum had greater (P<0.05) *b* fraction of CP compared with sorghum bagasse. Degradation rate (*c*) of DM or CP in maize forage were greater (P<0.05) than bagasse, while there was no difference between *c* of maize and sorghum forage (Tables 3). The ERD for maize forage, with all rumen k_p, was higher (P<0.01) compared with other forages. The ERDP at all k_p values, were highest for maize forage and lowest (P<0.01) for sorghum bagasse (Table 3).

Silages

The MS silage had the highest (P<0.05) and SSUM had the lowest *b* fraction of DM (Table 4). Maximum and minimum of *b* for DM were observed in MS and SSUM (537 and 428 g/kg DM, respectively; P<0.01), respectively. Chemical composition of experimental silages has been presented in the earlier report (Zafari Naeini et al., 2014). The *a* fraction of CP for SSU, BSU and BSUM silages was greater (P<0.01) than that for MS (Table 5). Maximum and minimum *b* of CP were observed for BS and SSU (411 and 247 g/kg CP, respectively; P<0.01). At 0.02 and 0.04 ruminal k_p, ERDP was the greatest (P<0.01) for MS, BSU and BSUM (Table 5). Silages containing urea were greater in *a* of DM (P<0.05; Table 4), *a* of CP, and ERDP (for all k_p values) (P<0.01; Table 5) compared with silages without urea. Adding either urea or molasses increased *a* fraction of both DM and CP while adding urea decreased (P<0.05) only *b* fraction of CP (Table 4, Table 5). Adding either urea or molasses had no significant effect (P>0.05) on gas production parameters such as ME, NE_l and OMD (Table 6). Silages containing urea plus molasses were greater in C of gas production, ME and OMD, especially for bagasse silage.

Table 1: Chemical composition (g/kg DM) of fresh whole plant maize, whole plant sweet sorghum and sweet sorghum bagasse

Parameter[1]	Maize	Sorghum	Bagasse	SEM[2]	P value[3]
DM (g/kg fresh material)	177^{c}	331^{b}	362^{a}	2.2	**
CP	88^{a}	56^{b}	51^{c}	2.4	**
WSC	94^{b}	136^{a}	152^{a}	8.8	**
NDF	526^{a}	447^{c}	491^{b}	6.1	**
ADF	263^{a}	213^{b}	258^{a}	4.1	**
ADL	81	82	97	4.7	ns
NDIP	27^{a}	24^{b}	22^{c}	0.8	**
ADIP	11^{b}	13^{a}	10^{c}	0.3	**

[1]DM, dry matter; CP, crude protein; WSC, water soluble carbohydrates; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin; NDIP, neutral-detergent insoluble protein, ADIP, acid-detergent insoluble protein; [2]Standard error of means, n=3; [3]** Significant at P<0.01; ns non-significant; a–c Within each row, means with the same superscript(s) are not significantly different.

Table 2: The gas production parameters of the fresh whole plant maize, whole plant sweet sorghum and sweet sorghum bagasse

Parameter[1]	Maize	Sorghum	Bagasse	SEM[2]	P value[3]
GP_{24}	41.0^{a}	36.8^{b}	38.4^{ab}	0.68	*
B	68.1	64.4	65.6	1.16	ns
C	0.041	0.037	0.039	0.002	ns
ME	9.7^{a}	8.4^{b}	8.6^{b}	0.12	**
NE_l	4.9^{a}	4.3^{b}	4.5^{b}	0.07	**
OMD	557^{a}	505^{b}	517^{b}	6.1	**

[1]GP_{24}, gas production (ml/g DM) at 24 hour incubation; B, GP from the digestible fraction (ml); C, GP rate constant for the insoluble fraction; ME, metabolisable energy (MJ/kg DM); NE_l, net energy (MJ/kg DM); OMD, organic matter digestibility (g/kg DM). [3]* Significant at P<0.05, ** Significant at P<0.01, ns non-significant. [2] Standard error of means, n=3; a –c Within each row, means with the same superscript(s) are not significantly different.

Discussion

The low DM concentration of whole plant maize (177 g/kg Fresh material; Table 1) was due to the early stage of harvesting which accordingly resulted in low DM concentration of MS (203 g/kg Fresh material) after 90 days of ensiling (Zafari Naeini et al., 2014). In the current study, silages had good visual appearance,

odour and colour, low final pH (*i.e.* 3.74-3.91), which in addition to absence of butyric acid production, indicate good fermentation quality (McDonald et al., 1991). Adding 10 g/kg DM urea to the silages had no effect on NDF and ADF concentrations but there are reports showing that addition of 45 to 65 g/kg urea to low quality grass forages or plant wastes (such as bagasse in this study) decreased NDF concentration; an effect which was more evident for lower quality forages (high NDF concentration) than for high quality forages (low NDF concentration; Ramirez et al., 2007).

However, it is possible that decrease in fibre concentrations results simply from the addition of high amounts of urea to the silages. Some researchers (Mattoni et al., 2007; Larwence, 2000) have reported that urea supplementation increased DM and NDF contents in sorghum straw compared with the untreated straw. Silages with additives were lower than those without additives in hemicellulose and cellulose contents, and also *b* fraction of *in situ* rumen degradability for both DM and CP.

The OMD and ME were not improved due to the addition of molasses, which are in agreement with results of Guney et al. (2007) in sorghum silage. Celik et al. (2009) reported that urea, molasses and urea plus molasses had no significant effect on mean pH and ME value of maize silage, but had significant effect on *in vitro* OMD. This study showed that adding urea plus molasses had significant effect on pH, ME and OMD values of sweet sorghum silage.

In this study, no significant difference of ME content between untreated and urea-treated sorghum silages was observed. In contrast, Guney et al. (2007) reported that the addition of different levels of urea decreased the OMD and ME values in sorghum silage. Adding mixture of urea and molasses to bagasse silages increased OMD, while for sorghum silage the additives were not effective. Some studies reported that molasses as additive increased the ME value of silages (Seoane et al., 1992; Petit and Veira, 1994), which is contrary to the current study. For conventional feeds, there is a positive correlation between the calculated ME *in vitro* gas production (using fat and protein concentrations) with the ME obtained *in vivo* (Menke and Steingass, 1988; Sallam et al., 2007). Adding urea or molasses alone had no effect on GP_{24}, B and NE_l, while adding mixture of urea and molasses to sorghum and bagasse silage increased C, ME and OMD.

Table 3: DM and CP *in situ* degradability of the fresh maize, sorghum and sorghum bagasse

Parameter[1]	DM *in situ* degradability					CP *in situ* degradability				
	Maize	Sorghum	Bagasse	SEM[2]	P value[3]	Maize	Sorghum	Bagasse	SEM	P value
a	220^{b}	256^{a}	254^{a}	4.2	**	281^{a}	184^{b}	165^{b}	9.5	**
b	549^{a}	465^{b}	470^{b}	6.6	**	507^{a}	504^{a}	466^{b}	11.4	*
c	0.132^{a}	0.123^{a}	0.106^{b}	0.0031	**	0.150^{a}	0.133^{ab}	0.120^{b}	0.0079	*
	ERD					ERDP				
k_p = 0.02	697^{a}	656^{b}	650^{b}	3.5	**	728^{a}	622^{b}	564^{c}	5.1	**
k_p = 0.04	642^{a}	608^{b}	595^{b}	3.3	**	681^{a}	571^{b}	514^{c}	6.3	**
k_p = 0.06	598^{a}	569^{b}	554^{c}	3.2	**	643^{a}	531^{b}	475^{c}	7.2	**
k_p = 0.08	562^{a}	539^{b}	522^{c}	3.2	**	611^{a}	499^{b}	444^{c}	7.6	**

[1] *a*, immediately soluble fraction (g/kg); *b*, slowly degradable fraction (g/kg); *c*, fractional rate constant at which the fraction *b* is degraded (/h); ERD, effective rumen degradability of DM; ERDP, effective rumen degradability of CP; k_p, constant ruminal passage rate (/h); [2] Standard error of means, n=3; [3] * Significant at P<0.05, ** Significant at P<0.01; [a–c] Within each row, means with the same superscript(s) are not significantly different.

Table 4: DM *in situ* degradability of maize, sorghum and sorghum bagasse silages with or without urea and molasses after 90 days ensiling

Parameter[1]	Silage[2]								Orthogonal comparisons[4]		
	MS	SS	SSU	SSUM	BS	BSU	BSUM	SEM[3]	U	M	U + M
a	251^{d}	271^{cd}	284^{bc}	314^{a}	251^{d}	266^{cd}	304^{ab}	5.3	*	**	**
b	537^{a}	456^{b}	455^{b}	428^{c}	462^{b}	455^{b}	453^{b}	4.4	ns	**	**
c	0.160	0.111	0.106	0.127	0.108	0.104	0.107	0.0274	ns	*	Ns
ERD											
k_p = 0.02	702^{a}	658^{bc}	667^{bc}	683^{ab}	640^{c}	647^{c}	686^{ab}	6.6	ns	**	**
k_p = 0.04	642^{a}	607^{abc}	614^{abc}	639^{ab}	587^{c}	594^{bc}	634^{ab}	9.5	ns	**	**
k_p = 0.06	597^{ab}	567^{ab}	575^{ab}	604^{a}	547^{b}	554^{ab}	595^{ab}	11.5	ns	**	**
k_p = 0.08	563	536	544	576	515	523	564	12.9	ns	**	**

[1] *a*, immediately soluble fraction (g/kg); *b,* slowly degradable fraction (g/kg); *c*, fractional rate constant at which the fraction *b* is degraded (/h); ERD, effective rumen degradability of DM; k_p, constant ruminal passage rate (/h); [2] MS, maize silage; SS, sweet sorghum silage; BS, sweet sorghum bagasse silage; suffixes of U and M refer to urea and molasses, respectively; [3] Standard error of means, n=3; [4] U, orthogonal comparison of SSU and BSU *vs.* SS and BS *i.e.* effect of urea; U, orthogonal comparison of SSUM and BSUM *vs.* SSU and BSU *i.e.* effect of molasses; U + M, orthogonal comparison of SSUM and BSUM *vs.* SS and BS *i.e.* effect of urea plus molasses; *, P<0.05; **, P<0.01; ns, non-significant (P>0.05); [a–d] Within each row, means with the same superscript(s) are not significantly different.

Table 5: I*n situ* CP degradability of maize, sorghum and sorghum bagasse silages with or without urea and molasses after 90 days ensiling

Parameter[1]	Silage[2]								Orthogonal comparisons[4]		
	MS	SS	SSU	SSUM	BS	BSU	BSUM	SEM[3]	U	M	U + M
a	424^{b}	316^{c}	488^{a}	408^{b}	225^{d}	496^{a}	490^{a}	9.7	**	**	**
b	359^{b}	360^{b}	247^{e}	338^{bc}	411^{a}	304^{cd}	296^{d}	8.8	**	**	**
c	0.161^{ab}	0.136^{bc}	0.148^{b}	0.195^{a}	0.168^{ab}	0.100^{c}	0.135^{bc}	0.0096	ns	**	Ns
ERDP											
k_p = 0.02	743^{a}	628^{c}	706^{b}	714^{b}	592^{d}	747^{a}	748^{a}	4.0	**	ns	**
k_p = 0.04	711^{a}	592^{c}	682^{b}	688^{b}	556^{d}	710^{a}	718^{a}	4.6	**	ns	**
k_p = 0.06	685^{ab}	564^{c}	664^{b}	666^{b}	527^{d}	683^{ab}	695^{a}	5.2	**	ns	**
k_p = 0.08	664^{ab}	544^{c}	648^{b}	647^{b}	503^{d}	676^{ab}	677^{a}	5.6	**	ns	**

[1]*a*, immediately soluble fraction (g/kg); *b*, slowly degradable fraction (g/kg); *c*, fractional rate constant at which the fraction *b* is degraded (/h); ERDP, effective rumen degradability of CP; k_p, constant ruminal passage rate (/h); [2] MS, maize silage; SS, sweet sorghum silage; BS, sweet sorghum bagasse silage; suffixes of U and M refer to urea and molasses, respectively; [3] Standard error of means, n=3; [4] U, orthogonal comparison of SSU and BSU *vs.* SS and BS *i.e.* effect of urea; U, orthogonal comparison of SSUM and BSUM *vs.* SSU and BSU *i.e.* effect of molasses; U + M, orthogonal comparison of SSUM and BSUM *vs.* SS and BS *i.e.* effect of urea plus molasses; *, P<0.05; **, P<0.01; ns, non-significant (P>0.05) ; [a–e] Within each row, means with the same superscript (s) are not significantly different.

Table 6: Gas production parameters of maize, sorghum and sorghum bagasse silages with or without urea and molasses after 90 days ensiling

Parameter[1]	Silages[2]								Orthogonal contrasts[4]		
	MS	SS	SSU	SSUM	BS	BSU	BSUM	SEM[3]	U	M	U + M
GP_{24}	41.6	36.2	35.9	36.8	32.0	36.6	38.7	1.63	ns	ns	Ns
B	75.4	67.1	61.2	63.8	61.5	65.2	63.9	1.89	ns	ns	Ns
C	0.030	0.032	0.037	0.044	0.031	0.033	0.041	0.0035	ns	ns	*
ME	9.6^{a}	8.2^{ab}	8.4^{ab}	8.5^{ab}	7.5^{b}	8.5^{ab}	8.9^{ab}	0.30	ns	ns	*
NE_l	4.9^{a}	4.3^{ab}	4.3^{a}	4.4^{ab}	3.8^{b}	4.4^{ab}	4.6^{a}	0.16	ns	ns	Ns
OMD	561^{a}	499^{ab}	505^{ab}	511^{ab}	456^{b}	511^{ab}	531^{a}	14.6	ns	ns	*

[1]GP_{24}, gas production (ml/g DM) at 24 h of incubation; B, GP from the digestible fraction (ml); C, GP rate constant for the insoluble fraction; ME, metabolisable energy (MJ/kg DM); NE_l, net energy (MJ/kg DM); OMD, organic matter digestibility (g/kg DM); [2] MS, maize silage; SS, sweet sorghum silage; BS, sweet sorghum bagasse silage; suffixes of U and M refer to urea and molasses, respectively; [3] Standard error of means, n=3; [4] U, orthogonal comparison of SSU and BSU *vs.* SS and BS *i.e.* effect of urea; U, orthogonal comparison of SSUM and BSUM *vs.* SSU and BSU *i.e.* effect of molasses; U + M, orthogonal comparison of SSUM and BSUM *vs.* SS and BS *i.e.* effect of urea plus molasses; *, P<0.05; **, P<0.01; ns, non-significant (P>0.05); [a–b] Within each row, means with the same superscript(s) are not significantly different.

There was no relationship between urea or molasses supplementation of the silages with GP_{24}. The C increased by the addition of urea or urea plus molasses, but this increase was only significant when mixture of urea and molasses were used. Larbi et al. (1998) and Nsahlai et al. (1994) reported positive correlation between protein concentration and rate of gas production, and negative correlation between concentrations of NDF and ADF, with the rate and extent of gas production. Mahala and Khalifa (2007) reported that adding molasses to sorghum silage decreased NDF and ADF concentrations, and increased gas production rate, OMD and ME compared with the control treatment, which may be due to lower ADF and NDF content of molasses. This finding was not in agreement with the finding of Nayigihugu et al. (1995) who observed that adding molasses lowered pH, NDF and ADF concentrations and increased *in vitro* dry matter digestibility of Bermuda grass silage.

Higher *in situ a* fraction of DM degradability for fresh sorghum forage and bagasse compared with maize can be a result of high WSC concentration. The addition of urea to SS and BS increased *a* fraction of CP, while the addition of molasses to SSU reduced this fraction. Urea and molasses both are soluble in the rumen and using them as additives is expected to change *a* fraction of *in situ* degradability. Di Marcoa et al. (2009) reported a close relationship between *in situ* DM disappearance and *in vivo* DM digestibility at 12 h of incubation for sweet sorghum silages.

Conclusions

The present experiment based on laboratory silos showed that sweet sorghum bagasse can be ensiled successfully with or without urea and molasses as silage additives. However, simultaneous addition of urea and molasses would improve the metabolisable energy content, organic matter digestibility and *in situ* rumen degradability of dry matter and crude protein of whole plant sweet sorghum and sweet sorghum bagasse silages, although molasses seems not to be beneficial for whole sweet sorghum silage compared with its

bagasse. It seems that urea as an additive is necessary for sweet sorghum bagasse silages to increase its CP content and its quality for long time preservation.

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