Animal Nutrition and Feed Technology (2009) 9 : 1-10

Evaluation of Sweet Sorghum *(Sorghum bicolor L. Moench)* Used for Bio-ethanol Production in the Context of Optimizing Whole Plant Utilization

M. Blümmel*, S.S. Rao[1], S. Palaniswami[2], L. Shah[3] and Belum V.S. Reddy[4]

International Livestock Research Institute
Patancheru-502 324, India

(Received March 19, 2008)

ABSTRACT

Blümmel, M., Rao, S.S., Palaniswami, S., Shah, L. and Reddy, Belum V.S. 2009. Evaluation of sweet sorghum (Sorghum bicolor L. Moench) used for bio-ethanol production in the context of optimizing whole plant utilization. Animal Nutrition and Feed Technology, 9: 1-10.

Eighteen hybrids and 16 varieties of sweet sorghum were investigated for yields of grain, stover, juice extract for bio-ethanol distillation and bagasse and the relationships between these productive traits. There was a large degree of independency between grain and stover yields, suggesting that sweets sorghum can provide both grain and fodder yield. Juice extract yields from the stems were not significantly related to grain yields. The differences in stover fodder quality traits were significant: nitrogen content ranged from 0.44 to 0.72% in hybrids and from 0.50 to 0.89% in varieties while *in vitro* digestibility ranged from 43.8 to 54.5% in hybrids and from 48.8 to 54.8% in varieties. Differences in *in vitro* digestibility of bagasse plus stripped leaves were also substantial, ranging from 39.3 to 49.1% in hybrids and from 42.0 to 50.4% in varieties. The palatability of bagasse and stripped leaves to cattle was investigated by incorporation of the distillery residues of one sweet sorghum variety into a commercial feed block, replacing the traditionally used (non sweet) sorghum stover. There was no statistical difference in intake (DMI) and live weight gain (LWG) between bulls fed the bagasse plus stripped leaf based blocks (DMI of 3.7% of live weight and 0.73 kg/d of LWG) and bulls fed the original sorghum stover based commercial feed block (DMI of 3.5% of live weight and 0.82 kg/d of LWG). We conclude that sweet sorghum can provide food (grain), fodder (bagasse/leaf residues) and bio-ethanol at the same time.

Keywords: Sweet sorghum, Bio-ethanol, Digestibility *in vitro*.

*Reprint request: Dr. M. Blümmel, E-mail: m.blummel@cgiar.org
[1]National Research Center for Sorghum, Rajendrangar, Hyderabad-500 030, India
[2]Rusni Distilleries, Ramchandrapuram, Hyderabad-500 032, India
[3]Miracle Fodder and Feeds Pvt. Ltd., Shamshabad-501 218, India
[4]International Crops Research Institute for the Semi-Arid Tropics, Patancheru-502 324, India

INTRODUCTION

Sweet sorghum (*Sorghum bicolor* (L) Moench) is well adapted to the Semi-Arid Tropics (SAT) and is one of the most efficient dry land crops to convert atmospheric CO_2 into sugar (Schaffert and Gourley, 1982). The crop is more water-use efficient than sugar cane and is recently gaining importance as a feedstock for ethanol production (Reddy *et al.*, 2005). The increasing interest in industrial usage not withstanding, farmers still consider sweet sorghum a multipurpose crop from which they expect grain for human consumption and for the livestock fodder from the stover (Shukla *et al.*, 2006). The selling of sweet sorghum stover to distilleries after grain harvest can provide much needed income for dry land farmers, but it also diverts biomass away from livestock, thus potentially worsening problems of feed scarcity. Recycling of the bagasse residue remaining after extraction of juice from the stems for ethanol production together with the leaves, which are mechanically stripped from the stem at the distillery, could compensate for some of the fodder loss. Conversion of bagasse and stripped leaves into a marketable fodder could provide an additional source of revenue in a sweet sorghum value chain. The work presented here explored opportunities for value addition/optimization in a sweet sorghum-food-ethanol-fodder production chain in a wide range of varieties and hybrids. Specifically addressed are: 1) biomass partitioning between grain, stover, extract and bagasse, 2) laboratory fodder quality traits in sweet sorghum stover and bagasse and stripped leaves, 3) possible trade-off effects between traits; and 4) palatability of sweet sorghum bagasse plus stripped leaves to cattle when offered as major component of a total mixed ration feed block.

MATERIALS AND METHODS

Origin of sweet sorghum varieties and hybrids and their crop management

Sixteen varieties and 18 experimental hybrids of sweet sorghum were grown at the Research Farm of the National Research Center for Sorghum, Hyderabad (latitude: 17° 27' N; longitude: 78° 28' E) in the rainy season (Kharif), 2005. The experiment was carried out in a randomized complete block design (RCBD) and each cultivar was planted in 6 rows of 5 m length in 18-m^2 plots with a spacing of 60 x 15 cm in 3 replications on July 11, 2005. Fertilizer dosage of 80 N, 40 P, and 40 K ha^{-1} were applied with 50% of N as basal and the balance 35 days after emergence as side-dressing. Hand weeding was done twice followed by hoeing and inter-cultivation. The crop was entirely grown under dry land natural rainfall condition (June to October) on a soil with a silt clay loam texture of about 1.0 m depth.

Grains, stover, extract and bagasse yields

For each cultivar and replication, 10 mature plants were randomly selected from the centre-four rows of each plot, and the stalks were cut at the ground level. Before juice extraction, leaves were stripped and panicles along with the peduncles were removed from each plant. The stripped stems were squeezed thrice in a three-roller cane press mill. Another ten stalks were sampled from the centre-four rows for estimation of grain, stover and dry matter yields. Plants were separated into leaves, stems, and panicles, and dried in a hot air-oven at 80°C for 48-h until constant weight was attained. Dry matter yields were recorded separately for leaves, stems, stem juice extracts and bagasse. The dry samples were ground in a Wiley mill to pass through a 1 mm screen. Grain yield was estimated for each cultivar by adjusting the moisture content to 14.5%.

Stover and bagasse analysis for fodder quality traits

Stover quality analyses were conducted on leaf and stem samples from each plot and a weighted average (using the stover leaf and stem percentages in the sub samples) was used for the calculation of whole stover values. All samples were analyzed by Near Infrared Spectroscopy (NIRS), calibrated for this experiment against conventional chemical and *in vitro* analyses. The NIRS instrument used was a FOSS Forage Analyzer 5000 with software package WinSI. Nitrogen was determined by Auto Analyzer and neutral detergent and acid detergent fiber and acid detergent lignin were analyzed according to Goering and Van Soest (1970). For analysis of *in vitro* digestibility and metabolizable energy content, rumen inoculum was obtained from a rumen cannulated steer (local Indian breed) maintained on a stover diet supplemented with concentrate. Portions of about 200 mg of air-dry stover sample were accurately weighted (in duplicate) into 100 ml calibrated glass syringes (Menke and Steingass, 1988) that were incubated according to the procedure of Blümmel and Ørskov (1993). No nitrogen was supplemented in the incubation medium. *In vitro* digestibility and metabolizable energy content was calculated from gas volumes produced after 24-h of incubation using the equations of Menke and Steingass (1988). All laboratory analyses were conducted in duplicate samples.

Feed block manufacture from bagasse and stripped leaves and feeding trial

The bagasse residue and the stripped leaves (BRSL) were sourced from Rusni Distillery and originated from sweet sorghum variety NTJ 2. The BRSL were chopped and dried at the International Livestock Research Institute (ILRI) research facilities at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and transferred to Miracle Fodder & Feeds Pvt Ltd in Hyderabad which produces and markets a commercial feed block (CFB) that contains about 50% of (non sweet) sorghum stover on an air-dry basis. The CFB is currently (July 2007) sold at 6 Indian Rupees per kg, while the sorghum stover is purchased by the manufacturer at 2.40 to 2.80 Indian Rupees per kg (air-dry). The experimental feed blocks were produced by replacing the sorghum stover with BRSL leaving other CFB ingredients unchanged.

The feeding trial with growing bulls was conducted at ILRI, comparing the BRSL-based feed block (BRSLB) with the CFB and a treatment consisting only of sorghum stover of the type used for CFB. Five bulls of approximately 180 kg average live weight (LW) at the beginning of the experiment were allocated to each of the three treatments. The bulls were adapted to their treatment for two weeks on an *ad libitum* feeding regime that allowed for about 15% of refused feed, followed by a 10-d period for estimating daily feed intake and live weight changes. The feeds were analyzed for nitrogen, neutral detergent fiber and *in vitro* digestibility and metabolizable energy content by the methods described previously.

Statistical analysis

The SAS (1988) computer program GLM procedure was used for analysis of variance and to calculate significant differences among cultivars and hybrids, between varieties and hybrids and between the treatments of the animal feeding trial. GraphPad Prism (1994) was used for simple linear regression analysis between traits.

RESULTS AND DISCUSSION

Yields of grain, stover, juice extract, bagasse and BRSL and their relationships

Means and ranges in yields of grain, leaf, stem, stover (including peduncles), extract, bagasse and BRSL of the 34 cultivars are reported in Table 1. Except for the extract yields in varieties, these yield measurements differed consistently and significantly among cultivars within both, hybrids and varieties. The cultivars-dependent ranges were substantial and yields differed generally by 2-fold and more. Hybrids had on average higher grain yield than varieties but all other productive variables were higher in the varieties. Average grain yields were 12.0 (hybrids) and 6.7% (varieties) of total biomass yield. This proportionally low partitioning into grain yields probably reflects a sweet sorghum breeding target of high sugar yields in stems. Still, grain yields of up to 2.6 t/ha were possible in both cultivar types (Table 1) and sweet sorghum grain can contribute significantly to rural food security.

Table 1. Yields of grain, leaf, stem, stover, extract (EX), bagasse and bagasse plus stripped leaves (B+L) in 34 cultivars of sweet sorghum

	Means and ranges in dry matter yields (t/ha)						
	Grain	Leaf	Stem	Stover[1]	EX	Bagasse	B + L
Hybrids (H)							
Mean	1.6	1.5	8.1	11.7	3.8	4.3	5.8
Range	0.8-2.6	0.6-2.5	4.7-12.4	7.1-14.9	1.3-7.1	2.6-5.5	3.8-7.9
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.009
LSD	0.6	0.5	2.0	2.9	1.8	0.1	2.2
Varieties (V)							
Mean	1.0	1.8	10.7	13.9	5.8	4.9	6.7
Range	0.1-2.6	0.9-2.6	6.9-14.7	8.5-18.8	2.8-8.6	3.2-6.1	4.5-8.1
P	<0.0001	<0.0001	0.03	0.05	0.12	0.02	0.005
LSD	0.5	0.57	4.2	5.15	-	1.9	2.1
P: H *versus* V	0.007	0.07	0.002	0.02	0.002	0.05	0.02

[1]Stover yield estimates includes panicles after grain removal.

Mean extract yield in hybrids amounted to about 47% of stem yield while this figure for varieties was 54%. Mean bagasse yield was higher than extract yields in hybrids but the reverse was true for varieties. Yields of bagasse plus stripped leaves were on average higher than the extract yields in both hybrids and varieties, potentially providing 5.8 (hybrids) and 6.7 (varieties) tons of fodder per ha (Table 1). Sweet sorghum cultivation for ethanol production is supported by advanced crop management practices, hence high biomass yields on farmers' fields are feasible and expected (Reddy *et al.*, 2005). The quantitative contribution of bagasse plus stripped leaves to feed supply through a sweet sorghum food-ethanol-fodder value chain could be substantial.

Relationships between yields of grain and stover, stem and extract, extract and grain and extract and bagasse plus stripped leaves are presented in Figures la-d. Grain and stover yield were statistically unrelated in both hybrids (P=0.58) and varieties (P=0.99). High grain yields could be associated with above average stover yields (Figure 1a). In a recent comprehensive investigation of grain-stover relationships in (non sweet) sorghum cultivars tested by the National Research Center for Sorghum during the period of 2002 to 2006, Blümmel *et al.* unpublished observed that grain yields accounted for only 14% of the variation in stover yield, that is grain and stover yields in sorghum were only weakly positively associated. These findings suggest that grain and stover yield should both be recorded in sorghum improvement since stover yields cannot be accurately predicted by grain yield measurements. Grain yields do not need to be achieved at the expense of fodder for livestock and/or feedstock for ethanol production and the *vice versa*.

Stem yields accounted for more than 80% of the variation in extract yields (Figure lb) and stem yield will obviously have a direct effect on ethanol production, unless the conversion of extract (juice) into ethanol will vary substantially among cultivars. Little research has been conducted on cultivars-dependent variations in conversion of extract into ethanol and variations could be expected if sugar concentrations in stems and sugar composition in the extract would vary substantially among cultivars; more research is

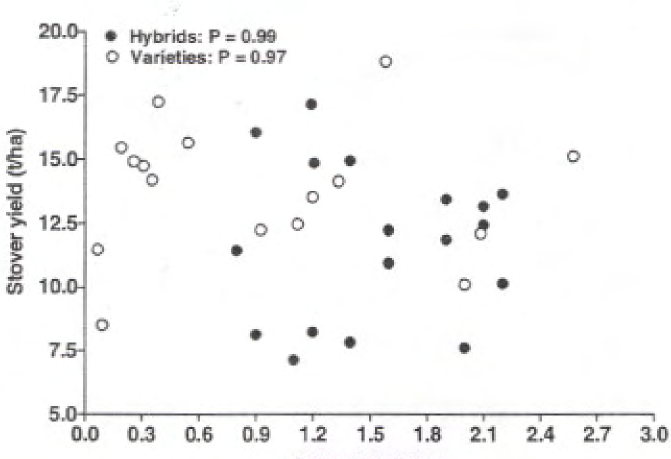

Figure 1a. Relationships between grain yields and stover yields in 16 varieties and 18 hybrids of sweet sorghum

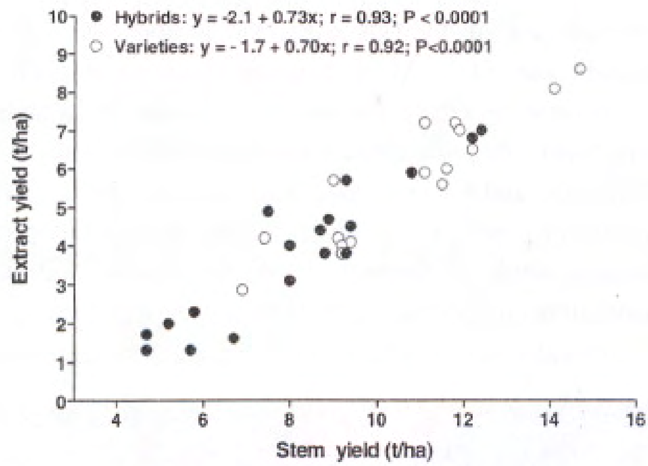

Figure 1b. Relationships between stem yields and extract yields in 18 varieties and 18 hybrids of sweet sorghum

required in this field. It is interesting to note that extract yield and grain yield were statistically not significantly associated and high extract yield and high grain yield are essentially compatible (Figure lc) in varieties where for example the variety with the highest extract yield had the 4th highest grain yield. In hybrids, however, highest extract yields were associated with below average grain yields of about 1 t/ha (Figure lc) which might be caused by the shorter growth duration of sweet sorghum hybrids compared to varieties. Extract yields were significantly correlated with yields of bagasse plus stripped leaves accounting for 48 and 28% of this variation in hybrids and varieties, respectively (Figure 1d).

The findings presented here confirm that sweet sorghum can provide grain, stover and ethanol with a considerable degree of genetic variation (Reddy *et al.*, 2005) and independence between these diverse productive traits (Figures 1 a/c). The relative value of any of these productive traits may vary with farming system, livelihoods strategies

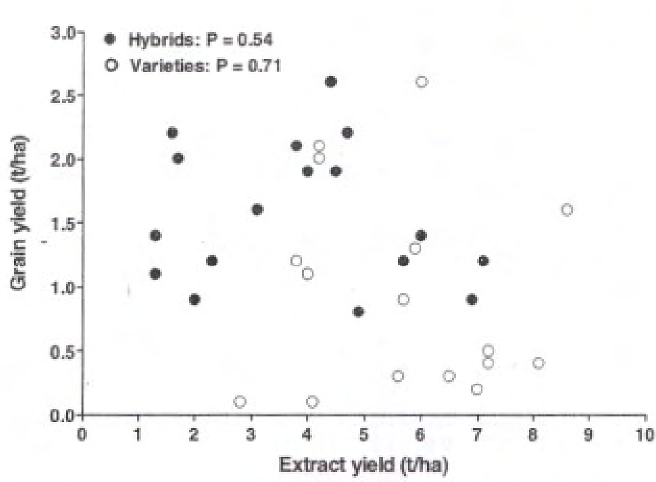

Figure 1c. Relationships between extract yields and grain yields in 16 varieties and 18 hybrids of sweet sorghum

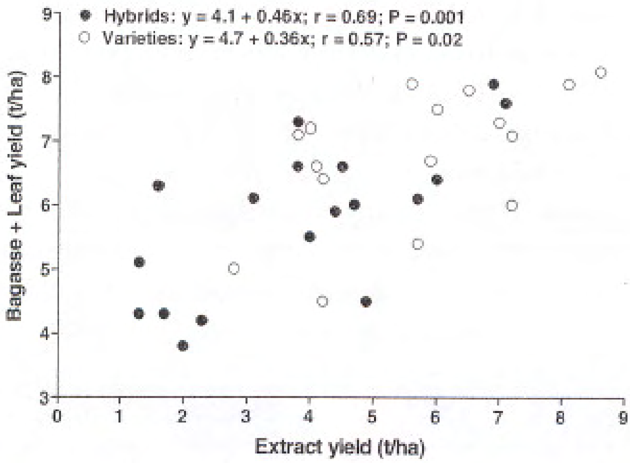

Figure 1d. Relationships between extract yields and bagasse plus leaf yields in 16 varieties and 18 hybrids of sweet sorghum

and market demand. Sweet sorghum germplasm offers the choice of a wide range of cultivars suitable for multi-purpose usages as well as for cases where one productive trait is clearly valued over the other.

Fodder quality traits in sweet sorghum and fodder options from bagasse and stripped leaves

Significant cultivars-dependent variations were observed for the measured stover fodder quality traits nitrogen content, cell wall constituents, *in vitro* digestibility and metabolizable energy content (Table 2). Stover fodder quality traits were generally superior

Table 2. Nitrogen (N), neutral detergent (NDF) and acid detergent (ADF) fiber, acid detergent lignin (ADL), *in vitro* organic matter digestibility (IVOMD) and metabolizable energy content (ME) in stover of 34 cultivars of sweet sorghum

	Nutritional composition of sweet sorghum stover					
	N%	NDF%	ADF%	ADL%	IVOMD%	ME (MJ/kg)
Hybrids (H)						
Mean	0.56	56.0	37.1	4.6	49.0	7.2
Range	0.44-0.72	49.1-64.8	32.4-43.3	4.0-5.2	43.8-54.5	6.4-8.2
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD	0.11	3.3	2.1	0.3	2.0	0.3
Varieties (V)						
Mean	0.68	52.0	33.0	3.0	51.5	7.6
Range	0.5-0.89	46.7 - 57.2	29.2-36.4	3.5-4.5	48.8-54.8	7.1-8.1
P	0.0007	0.01	0.0004	0.006	0.02	0.03
LSD	0.11	5.7	3.4	0.54	4.8	0.82
P: H *versus* V	<0.0001	0.007	0.0003	<0.0001	0.02	0.05

in varieties compared to hybrids. The importance and high monetary value of (non sweet) sorghum stover as livestock fodder was recently pointed out by Blümmel and Rao (2006) who from 2004 to 2005 surveyed monthly sorghum stover trading in Hyderabad in India. The authors noted that chopped stover was transported over distances of more than 350 km and fetched retail prices that were on a yearly average basis almost half that of sorghum grain. Higher quality stover fetched premium prices and Blümmel and Rao (2006) calculated that stover *in vitro* digestibiliy accounted for 75% of the variation in stover price. Yearly mean stover *in vitro* digestibilities of 46.9 to 51.7% were associated with prices of 3.1 to 3.9 Indian Rupees per kg dry stover (Blümmel and Rao 2006). In the present work mean sweet sorghum stover *in vitro* digestibilities were 49 and 51.5% in hybrids and varieties, respectively, reaching more than 54% in the higher quality stovers (Table 2). These findings suggest that sweet sorghum stover could fetch premium prices in stover trading. Demand for sweet sorghum as fodder in areas of feed scarcity might potentially compete with its usage as feedstock for ethanol production.

The competitive relationship between these alternative usages could be mitigated by converting residual biomass - that is the bagasse residue and the stripped leaves (BRSL) - remaining after juice extraction for ethanol. Potential fodder consisting of BRSL are described in Table 3. Nitrogen content was increased in BRSL compared to stover because of the higher leaf content in the former but all other laboratory fodder quality traits were higher in stover than in BRSL. For example, mean *in vitro* digestibility in BRSL were around 5% units lower than in stover (compare Table 2 and Table 3). This reduction in fodder quality seems minor considering that highly digestible carbohydrates must have been removed in the extract which amounted to about 47 and 54% of stem yield in hybrids and varieties, respectively. The loss of highly digestible carbohydrates was perhaps compensated by physical changes in the bagasse facilitating faster and higher microbial colonization and ultimately digestion of residual fiber particles.

Livestock performance on experimental feed blocks based on BRSL in comparisons to a sorghum stover based CFB

Nitrogen content, *in vitro* digestibility and metabolizable energy (ME) content of the BRSLB were significantly lower than in the CFB and the BRSLB was significantly superior to normal sorghum stover but there were no differences in the NDF contents (Table 4). As expected, the laboratory quality indices were lowest in the sorghum stover. An important aspect of the present work was to investigate the palatability of feed blocks when sorghum stover was entirely replaced by BRSL. It is promising to observe that there was no (statistical) difference in feed intake between the CFB and the BRSLB (Table 4). For both blocks the voluntary dry matter feed intake was high at 3.5 (CFB) and 3.7% (BRSLB) of the animals' live weight. Intakes of crop residues by non-lactating livestock are commonly around 2.0% or less of live weight (McDonald *et al.*, 1988). In fact, the intake of sorghum stover when fed as sole feed was only 1.3% of LW (Table 4). This level of intake intake is very low, probably as a result of the low nitrogen content (Table 4) of the stover. When fed as part of the well-balanced CFB, stover intake

Table 3. Nitrogen (N), neutral detergent (NDF) and acid detergent (ADF) fiber, acid detergent lignin (ADL), *in vitro organic* matter digestibility (IVOMD) and metabolizable energy content (ME) in hypothetical diets composed of bagasse and leaves of 34 cultivars of sweet sorghum

	Morphological and nutritional composition of BRSL							
	Bagasse (%)	Leaf (%)	N (%)	NDF (%)	ADF (%)	ADL (%)	IVOMD (%)	ME (MJ/kg)
Hybrids (H)								
Mean	73.7	26.3	0.73	64.5	41.4	4.9	44.6	6.5
Range	56.1-83.9	16.1-43.9	0.58-1.04	59.2-71.0	36.9-47.5	4.1-6.0	39.3-49.1	5.7-7.3
P	<0.0001	<0.0001	0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD	8.6	8.6	0.22	3.4	2.4	0.44	2.6	0.43
Varieties (V)								
Mean	72.0	28.0	0.83	64.6	39.8	4.9	46.6	6.8
Range	60.5-81.9	18.1-39.5	0.73-0.92	60.6-70.9	36.7-45.0	4.3-6.0	42.0-50.4	6.1-7.5
P	0.0005	0.0005	0.75	0.0001	0.0006	<0.0001	0.0002	0.0003
LSD	8.6	8.6		3.8	0.63	0.55	4.04	3.37
P: H *versus* V	0.55	0.55	0.0004	0.82	0.11	0.82	0.03	0.02

Table 4. Nitrogen, NDF, *in vitro* digestbility (all in%DMB) and ME content (MJ) and voluntary feed intake and changes in LW in bulls fed a marketed commercial sorghum stover-based feed block (CFB), an experimental sweet sorghum bagasse/stripped leaves-based feed block (BRLLB) and sorghum stover of the type used in the CFB

Diets	Nitrogen (%)	NDF (%)	IVDMD (%)	ME (MJ/kg)	Intake (kg/d)	Intake (g/d/kg LW)	LW changes (kg/d)
CFB	1.81^{a}	56.1^{a}	57.5^{a}	8.21^{a}	7.31^{a}	35^{a}	0.82^{a}
BRSLB	1.65^{b}	56.2^{a}	54.6^{b}	7.77^{b}	7.52^{a}	37^{a}	0.73^{a}
Sorghum stover	0.45^{c}	70.2^{b}	50.5^{b}	7.30^{b}	2.31^{b}	13^{b}	-0.38^{b}

^{a,b,c}Different superscripts in columns denote significant differences ($P<0.05$).

was increased. Since sorghum stover was more than 50% of the CFB, the intake of sorghum stover was more than 1.75% of the LW in CFB fed bulls. These findings underline the importance of balanced supplementation in improving the utilization of a basal diet and in optimizing the utilization of crop residues for livestock production. There was no significant difference between the daily liveweight gain of the bulls fed CFB (0.82 g) and the bulls fed BRSLB (0.73 g) which confirms the value of BRSL as a feed block ingredient.

CONCLUSION

Sweet sorghum can provide food, fodder and bio-ethanol production at the same time. It is particularly promising that sweet sorghum bagasse and stripped leaves – the residues after juice extraction for bio-ethanol production – have fodder qualities that allow incorporation into feed blocks without prior chemical or physical upgrading.

REFERENCES

Blümmel, M. and Ørskov, E.R. 1993. Comparison of in *vitro* gas production and nylon bag degradability of roughages in predicting feed intake in cattle. *Animal Feed Science and Technology, 40: 109-119.*

Blümmel, M. and Rao, P.P. 2006. Economic value of sorghum stover traded as fodder for urban and peri-urban dairy production in Hyderabad, India. *International Sorghum and Millets News letter.* 47: 97-100.

Goering, H.K. and Van Soest, P.J. 1970. *Forage fiber analyses (Apparatus, Reagents, Procedures and Some Applications).* Agric. Handbook No 379, USDA-ARS, Washington, DC.

GraphPad Prism. 1994 GraphPad Software, San Diego, CA 9212 USA.

Menke, K.H. and Steingass, H. 1988. Estimation of the energy feed value obtained from chemical analysis and *in vitro* gas production using rumen fluid. *Animal Research and Development.* 28:7-55.

Reddy, B. V. S., Ramesh, S., Reddy, P.S., Ramaiah, B., Salimath, P.M. and Kachapur, R. 2005. Sweet sorghum -a potential alternative raw material for bio-ethanol and bio-energy. *International Sorghum and Millets Newsletter,* 46: 79-86.

SAS. 1988. Statistical Analysis System. Release 6.03 Edition. SAS Institute, Cary New York, USA.

Schaffert, R.E. and Gourley, L.M. 1982. *Sorghum as energy source.* Pages 605-623. In: Proceedings of the International symposium on sorghum, Nov 2-7, 1981, Patancheru, India.

Shukla, G.K., Gupta, S.K. and Singh, L., Rao, S.S., Rathavathi C.V, and Dayakar Rao. B. 2006. Successful pilot production of bio-ethanol from sweet sorghum in sub-tropical India. *Jowar Samachar,* 2: 1.