Indian Journal of Animal Sciences **82** (8): 893–897, August 2012

Nutritive value, methane production and energy efficiency for animal functions of dual purpose sorghum hybrids

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Received: 21 November 2011; Accepted: 16 January 2012

ABSTRACT

Dual purpose sorghum hybrids (20) were developed using 8 male sterile lines and 18 advanced breeding selected lines. Hybrids were grown under similar agronomic and soil conditions and evaluated for their nutritional composition, palatability attributes and energetic efficiency for animal production. Mean CP contents of hybrids were 9.50%, ranging from 12.0% (673A × EC 507815) to 7.2% (673A × CSV 15). Cell wall polysaccharides (NDF, ADF and cellulose) varied from 55.71–70.53, 31.84–42.88 and 25.43–33.32%, respectively, across the hybrids. Mean EE and lignin contents were 1.40 and 4.73% in the evaluated hybrids. Hybrids had mean values of 60.91 and 57.47% for digestible dry matter (DDM) and *in sacco* dry matter digestibility (ISDMD), respectively. Relative feed value (RFV) and dry matter intake (DMI% body weight) of hybrids 682A × 62404 and 699A × ICSR 93039 were highest among the tested genotypes. Non-fibrous carbohydrates (NFC) were highest in 682A × 62404 and 699A × ICSR 93039 hybrids. Energy value in terms of total digestible nutrients (TDN) and digestible energy (DE) was higher for 673A × GD 65 and 699A × ICSR 93039 hybrids. Net energy efficiency for maintenance (NE_M), milk production and body weight gain (NE_G), (NE_L) was higher for 682A × 62404 and 699A × ICSR 93039 hybrids, respectively. Methane production (g/k DDM) of hybrids varied from 45.61 (679A × IS697) to 73.45 (673A × PC-6). Hybrids 673A × GD 65, 674A × JHV 12 and 699A × ICSR 93039 had higher CP, less fiber contents, more dry matter digestibility, higher palatability and net energy efficiency for different animal functions.

Key words: Carbohydrate profile, Energy efficiency, Methane, Palatability, Sorghum hybrid

Sorghum (*Sorghum bicolor*) is the third important cereal crop after wheat and rice in our country. Besides grain, sorghum stover is an important animal feed in India particularly in the dry seasons when other feed resources are in short supply. Dual purpose types that produce both grain and stover are the preferred types (Kelley and Parthasarathy Rao 1994, Hall 2000).

In view of changing preference of farmers for dual purpose sorghum, breeding proramme at IGFRI have focused to develop dual purpose sorghum both for grain and fodder with equal importance to higher grain yield and better fodder nutritive value for livestock.

MATERIALS AND METHODS

Twenty hybrids (Table 1) of dual purpose sorghum were developed using 8 male sterile lines and 18 advanced breeding selected lines under sorghum improvement programme of IGFRI. These hybrids were grown in 3 replicates during Kharif 2007 in research farm of Crop Improvement Division. The hybrids were grown following identical agronomic practices and soil conditions. Five plants of each hybrid harvested at 50% flowering stage were separated in to leaf and stem fractions for leaf to stem ratio estimation. Another whole 5 plants for each hybrid were chopped and used for DM, chemical and biochemical estimations. For DM estimation samples were dried at 80°C and for chemical/biochemical estimations samples were dried at 60–65°C. After drying, samples were grind, using mill through 1 mm sieve.

Ash, crude protein (CP) and ether extract (EE) contents were determined using AOAC (1992) method. NDF, ADF, cellulose and lignin were estimated following the procedure of Van Soest *et al.* (1991). *In sacco* dry matter degradability (ISDMD) of hybrids were estimated as per Orskov *et al.* (1980) incubating nylon bags for 48 h in 2 fistulated male Murrah buffaloes fed wheat straw-concentrate diet. Dry matter intake (DMI), digestible dry matter (DDM), relative feed value (RFV) and net energy for different animal functions i.e. lactation (NE_L), gain (NE_G) and maintenance (NE_M), were calculated as per Undersander *et al.* (1993).

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Digestible energy (DE, kcal/g) and NE values were calculated using equations of Fonnesbeck *et al.* (1984) and Khalil *et al*. (1986), respectively. To calculate the methane production (g/kg DDM) equation given by Singh *et al.* (2011) for dry roughages were used. Data were analyzed statistically for mean and standard error with 6 observations for each trait/ hybrid (Snedecor and Cochran 1968).

RESULTS AND DISCUSSION

Chemical composition: Crude protein content of the evaluated hybrids were as low as 7.2% and as high as 12%, while the mean OM content of the hybrids were 92.45% (Table 1). NDF, ADF and cellulose contents of hybrids differ significantly (P<0.05) and a difference of 14.82, 11.04 and 7.87% units, respectively was recorded for these fiber fractions. Lignin and ether extract contents of hybrids differed significantly (P<0.05) and varied between 3.46–6.14% and 1.02–1.93%, respectively. Differences in CP and fiber contents of sorghum hybrids has been observed by Colombo *et al.* (2007) and also by Torrecillas *et al*. (2011) for stover, head and whole plants of sorghum hybrids. As observed in the present study, variability in fiber contents of sorghum hybrids was also recorded by Neumann *et al.* (2002). NDF, ADF and cellulose contents of 4 sorghum hybrids reported by these workers were 8–10 units lower than present study while the lignin contents were similar. NDF, ADF, lignin and ash contents for leaf and stem fractions of different sorghum genotypes observed by Rattunde *et al.* (2001) are similar to our recorded values. Minimum neutral detergent insoluble protein (NDIP) contents were 1.78% and maximum 2.66%, amongst the evaluated hybrids and these values are within the range of earlier reported values (NRC 2001, Singh and Shukla 2010).

Palatability parameters: Palatability of a feed/fodder is governed mainly by chemical/physical properties constituted by intake, digestibility and proportions of plant parts. Palatability parameters estimated herein differed significantly (P<0.05) for evaluated sorghum hybrids (Table 2). Dry matter intake (% body weight) and relative feed value (RFV%) estimated for hybrids ranged from 1.70–2.15% and 75.39–106.53%, respectively.

The differences in DMI values of hybrid sorghums may be ascertained to variation in their NDF contents. Mahanta and Pachauri (2005) reported DMI between 1.84–2.55% of sheep on *ad lib.* feeding of silage from 3 sorghum cultivars. *In sacco* dry matter digestibility (ISDMD) and DDM values of sorghum hybrids ranged between 51.06–66.55 and 55.50–64.10%, respectively, and this variability in dry matter digestibility may be attributed to differences in their cell wall contents. Bani *et al.* (2007) recorded an inverse relationship between forage fiber fractions and DM digestibility. Nitrogen content and cell wall polysaccharides determine the digestibility of a crop (Barriere *et al.* 2003, Seven and Cerci 2006). Genetic variability for digestibility and fiber content for sorghum hybrids have been reported at flowering (Caravetta *et al*. 1990, Singh and Shukla 2010). The mean

Table 1. Chemical composition (% DM basis) of sorghum hybrids

Hybrids	CP	OM	NDF	ADF	Cellulose	HCL	Lignin	EE	NDIP
422A × IS 18845	10.6^{de}	92.97^{bcde}	67.62^{hijk}	36.15^{cde}	28.88^{abc}	31.47^{gh}	5.78^{cd}	1.53^{abc}	2.35^{abc}
422A × 62404	8.2^{abc}	93.26^{bcde}	70.53^{k}	38.24^{fh}	33.32^{e}	32.29^{h}	6.14^{d}	1.12^{a}	1.82^{ab}
422A × E-77	8.7^{abcd}	93.38^{cde}	65.84^{efghij}	35.91^{bcde}	29.43^{bc}	29.93^{efh}	5.32^{cabcd}	1.05^{a}	1.93^{abc}
671A × GP 65006	9.1^{abcd}	93.92^{de}	64.45^{efghi}	$35.13^{abcdefg}$	27.86^{abc}	29.32^{bcdefh}	5.28^{abcd}	1.21^{ab}	2.02^{abc}
671A × S 512	10.5^{cde}	91.68^{abcde}	68.16^{ijk}	37.19^{defgh}	30.21^{cde}	30.97^{fgh}	4.08^{abc}	1.78^{bc}	2.33^{abc}
673A × EC 507815	12.0^{e}	92.48^{abcde}	62.07^{cdefg}	$35.04^{abcdefg}$	28.15^{abc}	27.03^{bcdef}	4.80^{abcd}	1.90^{bc}	2.66^{c}
673A × G84	9.1^{abcd}	93.01^{bcde}	66.07^{fghij}	37.70^{efgh}	30.25^{de}	28.37^{bcdefg}	5.20^{abcd}	1.21^{ab}	2.02^{abc}
673A × PC-6	10.1^{bcde}	$93.4b^{cde}$	62.18^{cdefg}	33.41^{abc}	27.15^{abc}	28.77^{bcdefg}	4.48^{abcd}	1.93^{c}	2.24^{abc}
673A × CSV 15	7.2^{a}	92.79^{bcde}	70.34^{jk}	40.92^{hi}	33.28^{de}	$29.42^{bcdefgh}$	5.64^{bcd}	1.32^{abc}	1.60^{a}
673A × GD 65	11.7^{de}	92.56^{abcde}	60.31^{bcde}	33.67^{abcd}	27.92^{abc}	26.64^{bcd}	3.91^{ab}	1.82^{bc}	2.60^{bc}
673A × 62401	8.7^{abcd}	93.82^{de}	60.21^{bcd}	$34.14^{abcdefg}$	27.81^{abc}	26.07^{abcd}	4.75^{abcd}	1.70^{abc}	1.93^{abc}
674A × SSV-84	10.1^{bcde}	92.35^{abcde}	60.92^{cdef}	$34.66^{abcdefg}$	27.41^{abc}	26.26^{abcd}	4.50^{abcd}	1.82^{bc}	2.24^{abc}
674A × JHV 12	11.0^{bc}	90.67^{abc}	59.72^{abcd}	34.08^{abcde}	26.63^{abc}	25.64^{abcd}	4.14^{abc}	1.30^{abc}	2.44^{bc}
675A × JJ 1041	8.7^{abcd}	90.01^{ab}	67.75^{hijk}	39.76^{ghi}	29.90^{cde}	27.99^{bcdefg}	5.04^{abcd}	1.31^{abc}	1.93^{abc}
675A × G 84	8.7^{abcd}	92.52^{abcde}	62.95^{defgh}	$35.25^{abcdefg}$	28.61^{abc}	27.70^{bcdef}	4.49^{abcd}	1.29^{abc}	1.93^{abc}
675A × S 490	8.2^{abc}	89.9^{a}	67.40^{ghijk}	42.88^{i}	27.63^{abc}	24.52^{ab}	4.85^{abcd}	1.16^{a}	1.82^{ab}
679A × IS 697	9.7^{bcde}	93.77^{de}	61.83^{cdefg}	$34.88^{abcdefg}$	28.89^{abc}	26.95^{bcde}	3.83^{ab}	1.02^{a}	2.15^{abc}
699A × ICSR 93039	9.7^{bcde}	92.42^{abcde}	56.54^{ab}	31.84^{a}	25.45^{a}	24.70^{abc}	3.46^{a}	1.06^{a}	2.15^{abc}
679A × ICSV 700	10.1^{bcde}	90.86^{abcd}	58.45^{abc}	$35.53a^{bcdefg}$	28.13^{abc}	22.92^{a}	4.47^{abcd}	1.21^{ab}	2.24^{abc}
682A × 62404	8.0^{ab}	93.37^{bcde}	55.71^{a}	32.2^{ab}	25.80^{ab}	23.51^{ab}	4.57^{abcd}	1.34^{abc}	1.78^{ab}
Mean	9.51	92.45	63.45	35.92	28.63	27.52	4.73	1.40	2.11
SEM	0.27	0.27	0.98	0.63	0.459	0.58	0.154	0.06	0.06

Means with different superscripts ^{abcdefghijk} within a column differ significantly (P<0.05); HCL, hemicellulose; NDIP, neutral detergent insoluble protein.

Table 2. Palatability attributes of sorghum hybrids

Hybrids	DMI	DDM	RFV	ISDMD	S/L ratio
422A × IS 18845	1.77[ab]	60.74[abcd]	83.54[abcd]	58.45[bcde]	65:35
422A × 62404	1.70[a]	59.11[bcd]	77.94[ab]	57.80[abcde]	84:16
422A × E-77	1.82[ab]	60.93[cd]	86.06[bcde]	51.06[a]	76:24
671A × GP 65006	1.86[abc]	61.53[bcd]	88.79[cdef]	58.42[bcde]	72:28
671A × S 512	1.76[ab]	59.93[bcd]	81.77[abc]	61.91[bcdef]	83:17
673A × EC 507815	1.93[abc]	61.60[bcd]	92.30[def]	57.79[abcde]	76:24
673A × G84	1.82[ab]	59.53[bcd]	83.80[abcd]	59.13[bcde]	85:15
673A × PC-6	1.93[abc]	62.87[cd]	94.04[ef]	58.33[bcde]	79:21
673A × CSV 15	1.71[a]	57.02[ab]	75.39[a]	52.50[a]	77:23
673A × GD 65	1.99[abc]	62.67[cd]	96.64[fg]	66.55[f]	79:21
673A × 62401	1.99[abc]	62.30[cd]	96.24[fg]	62.31[ef]	79:21
674A × SSV-84	1.97[abc]	61.90[bcd]	94.50[ef]	61.85[def]	71:29
674A × JHV 12	2.01[bc]	62.35[cd]	97.10[fgh]	62.60[ef]	63:37
675A × JJ 1041	1.77[ab]	57.93[bc]	79.52[ab]	52.98[ab]	80:20
675A × G 84	1.91[abc]	61.44[cd]	90.77[cdef]	53.24[abc]	85:15
675A × S 490	1.78[ab]	55.50[a]	76.58[a]	55.44[bcde]	75:25
679A × IS 697	1.94[abc]	61.73[bcd]	92.85[def]	57.98[abcde]	86:14
699A × ICSR 93039	2.12[bc]	64.10[d]	105.43[gh]	60.04[cdef]	86:14
679A × ICSV 700	2.05[bc]	61.22[cd]	97.41[fgh]	56.12[a]	80:20
682A × 62404	2.15[c]	63.82[d]	106.53[h]	54.99[abcd]	89:13
Mean	1.90	60.91	89.86	57.97	78:22
SEM	0.03	0.49	2.03	1.02	-

Means with [abcdefgh] superscripts in rows within a column differ significantly at P<0.05 level; DMI, dry matter intake; RFV, relative feed value.

(89.86%) relative feed value (RFV) of different hybrids recorded here lies within the range of earlier reported values reported for sorghum (Steven 2007, Singh and Shukla 2010). Stem to leaf ratio was narrow (63:37) for 674A × JHV 12 and wider (89:13) for hybrid 682A × 62404, respectively. Earlier workers (Singh *et al*. 2003, Singh and Shukla 2010) also observed such variations in stem to leaf ratio of sorghum genotypes. A narrow stem to leaf ratio for sweet sorghum genotypes (64:36) than present values was recorded by Mohamed and Mohamed (2009).

Carbohydrate profile and total digestible nutriments: Carbohydrates composition and total digestible nutrients of evaluated sorghum genotypes differed significantly (P<0.05, Table 3). Total carbohydrate contents (TCHO% DM) were lowest (78.37) in 674A × JHV 12 and highest (84.27) in hybrid 673A × CSV 15, respectively. Structural carbohydrate (SC) and lignin bound carbohydrate fraction (C_C) ranged between 53.93–68.74% and 8.30–13.54%, respectively, among the tested sorghum hybrids. Similar variation for SC and C_C values was reported by Singh and Shukla (2010). A variability of 13.70% and 14.37% for non fiber carbohydrates (NFC) and total digestible nutrients (TDN), respectively was recorded in evaluated hybrids. Variability in TDN contents of hybrids recorded herein are similar to earlier reports (Stalling 2005, Singh and Shukla 2010).

Energy value and its efficiency for animal functions: Energy value of sorghum hybrids in terms of DE and ME differed significantly (P<0.05) and varied from 3.32–3.12 and 1.90–2.56 K cal/g, respectively, across the hybrids (Table 4). Neumann *et al*. (2002) recorded comparatively lower mean DE and ME contents in silage of sorghum hybrids (2.33 and 1.91 K cal/) than present values, while DE and ME values of evaluated sorghum hybrids are in consonance with values reported for sorghum (Stalling 2005, Singh and Shukla 2010).

Net energy efficiency for different animal functions, viz. maintenance, growth and lactation also differed significantly (P<0.05) amongst the evaluated sorghum hybrids and values for NE_M, NE_L and NE_G were highest (1.55, 1.44 and 0. 83) and (1.54, 1.42 and 0.82) for 699A × ICSR 93039 and 679A × ICSV 700 hybrids, respectively, while lowest values were recorded for 675A × S 490 and 673A × CSV 15 hybrids (1.14, 1.08 and 0.42) and (1.21, 1.15 and 0.49 K cal/g), respectively. Information on the net energy efficiency of sorghum hybrids for different animal production functions is frugal; however energetic efficiency values of sorghum hybrids, corn silage and Sudan grass silage for different functions has been reported (Colombo *et al*. 2007, Singh and Shukla 2010).

Methane production: Methane production (g/kg DDM) estimated for different hybrids differed significantly (P<0.05) being lower (45.61, 48.68 an 48.97) for hybrids 679A × IS 697, 422A × 62404 and 422A × E-77 and higher (73.45 and 70.09) for 673A × PC-6 and 673A × 62401 hybrids, respectively (Table 4). Methane production largely depends on the chemical makeup and pattern and extent of nutrients degradability. Effect of carbohydrate nature and its digestibility such as cellulose, hemicelluloses and soluble residue on methane production has been reported (Takahashi

Table 3. Carbohydrate profile and total digestible nutrients of sorghum hybrids

Hybrids	NFC	TCHO	SC	C_C	TDN
422A × IS 18845	15.57^{abc}	80.84^{abc}	65.27^{efgh}	13.87^{de}	57.90^{cdef}
422A × 62404	15.23^{abc}	83.94^{bc}	68.71^{gh}	14.74^{e}	55.18^{bcd}
422A × E-77	19.72^{cd}	83.63^{bc}	63.91^{efgh}	12.77^{bcde}	58.22^{cdef}
671A × GP 65006	21.18^{cde}	83.61^{bc}	62.43^{defg}	12.67^{bcde}	59.23^{def}
671A × S 512	13.57^{a}	79.40^{abc}	65.83^{gh}	9.79^{abc}	56.55^{bcde}
673A × EC 507815	19.17^{bcd}	78.58^{a}	59.41^{abcde}	11.52^{abcde}	59.35^{def}
673A × G84	18.65^{abcd}	82.70^{abc}	64.05^{efgh}	12.48^{bcde}	55.88^{bcde}
673A × PC-6	21.43^{cde}	81.37^{abc}	59.94^{bcdef}	10.75^{abcde}	61.47^{ef}
673A × CSV 15	15.53^{abc}	84.27^{c}	68.74^{gh}	13.54^{cde}	51.69^{ab}
673A × GD 65	21.33^{cde}	79.04^{ab}	57.71^{abcd}	9.38^{ab}	61.13^{ef}
673A × 62401	25.14^{efg}	83.42^{abc}	58.28^{abcd}	11.40^{abcde}	60.52^{def}
674A × SSV-84	21.75^{cde}	80.43^{abc}	58.68^{abcde}	10.80^{abcde}	59.84^{def}
674A × JHV 12	21.09^{cde}	78.37^{a}	57.28^{abcd}	9.94^{abcd}	60.60^{def}
675A × JJ 1041	14.18^{ab}	80.00^{abc}	65.82^{ghi}	12.10^{bbcde}	53.20^{abc}
675A × G 84	21.51^{cde}	82.53^{abc}	61.02^{cdef}	10.78^{abcde}	59.07^{def}
675A × S 490	14.96^{abc}	80.54^{abc}	65.58^{fgh}	11.64^{abcde}	49.14^{a}
679A × IS 697	23.37^{def}	83.05^{abc}	59.68^{abcde}	9.19^{ab}	59.56^{def}
699A × ICSR 93039	27.27^{fg}	81.66^{abc}	54.39^{ab}	8.30^{a}	63.51^{f}
679A × ICSV 700	23.34^{cdef}	79.55^{abc}	56.21^{abc}	10.73^{abcde}	58.71^{cdef}
682A × 62404	30.10^{g}	84.03^{bc}	53.93^{a}	10.97^{abcde}	63.05^{f}
Mean	20.21	81.55	61.34	11.37	58.19
SEM	1.00	0.44	1.00	0.37	0.82

Means with different superscripts abcdefghi within a column differ significantly ($P<0.05$); NFC, non fiber carbohydrate; TCHO, total carbohydrate; SC, structural carbohydrate; CC, lignin bound carbohydrate; TDN, total digestible nutrients.

Table 4. Energy value and net energy efficiency of sorghum hybrids for different animal functions

Hybrids	DE	ME	NE_L	NE_M	NE_G	CH_4 g/kg DDM
422A × IS 18845	2.77^{bcd}	2.28^{bcd}	1.30^{abc}	1.39^{ab}	0.67^{abc}	58.22^{cdef}
422A × 62404	2.32^{a}	1.90^{a}	1.23^{abc}	1.31^{ab}	0.59^{abc}	48.68^{ab}
422A × E-77	2.46^{ab}	2.02^{ab}	1.31^{abc}	1.40^{ab}	0.68^{abc}	48.97^{ab}
671A × GP 65006	2.77^{bcd}	2.27^{abcd}	1.33^{abc}	1.43^{ab}	0.71^{abc}	54.14^{bcd}
671A × S 512	2.92^{cd}	2.40^{cd}	1.27^{abc}	1.35^{ab}	0.63^{abc}	64.69^{efg}
673A × EC 507815	2.74^{abcd}	2.25^{abcd}	1.33^{abc}	1.43^{ab}	0.71^{abc}	65.85^{fgh}
673A × G84	2.80^{bcd}	2.30^{bcd}	1.25^{abc}	1.33^{ab}	0.61^{abc}	51.75^{abc}
673A × PC-6	2.77^{bcd}	2.27^{abcd}	1.39^{bc}	1.49^{ab}	0.77^{bc}	73.45^{h}
673A × CSV 15	2.52^{abc}	2.07^{ab}	1.15^{ab}	1.21^{a}	0.49^{ab}	57.72^{bcde}
673A × GD 65	3.12^{d}	2.56^{d}	1.38^{bc}	1.48^{ab}	0.76^{bc}	64.58^{efg}
673A × 62401	2.94^{cd}	2.41^{cd}	1.36^{abc}	1.47^{ab}	0.75^{bc}	70.09^{gh}
674A × SSV-84	2.92^{cd}	2.40^{cd}	1.35^{abc}	1.45^{ab}	0.73^{abc}	69.89^{gh}
674A × JHV 12	2.95^{cd}	2.42^{cd}	1.36^{abc}	1.47^{ab}	0.75^{bc}	52.37^{abc}
675A × JJ 1041	2.54^{abc}	2.08^{abc}	1.18^{ab}	1.25^{a}	0.53^{abc}	56.30^{bcd}
675A × G 84	2.55^{abc}	2.09^{abc}	1.33^{abc}	1.42^{ab}	0.70^{abc}	56.99^{bcde}
675A × S 490	2.64^{abc}	2.17^{abc}	1.08^{a}	1.14^{a}	0.42^{a}	55.57^{bcd}
679A × IS 697	2.75^{abcd}	2.26^{abcd}	1.34^{abc}	1.44^{ab}	0.72^{abc}	45.61^{a}
699A × ICSR 93039	2.84^{bcd}	2.33^{bcd}	1.44^{bc}	1.55^{b}	0.83^{c}	50.25^{abc}
679A × ICSV 700	2.67^{abc}	2.19^{abc}	1.32^{abc}	1.41^{ab}	0.69^{abc}	50.87^{abc}
682A × 62404	2.62^{abc}	2.15^{abg}	1.42^{bc}	1.54^{b}	0.82^{c}	63.40^{defg}
Mean	2.73	2.24	1.31	1.40	0.68	57.97
SEM	0.04	0.04	0.02	0.02	0.02	1.80

Means with different superscripts abcdefgh within a column differ significantly ($P<0.05$).

DE,Digestible energy; ME, metabolizable energy; NE_L, net energy for lactation; NE_M, net energy for maintenance; NE_G, net energy for gain.

2001, Santoso *et al.* 2003). Differences in methane production from 40.6–44.2 ml/g OMD and 41.8–46.4 ml/g OMD for brown mid rib and normal sorghum genotypes, respectively has been reported earlier (Ouda *et al.* 2005).

Findings revealed that there is a wide genetic variability in the dual purpose sorghum hybrids for protein contents, cell wall polysaccharides, carbohydrate profile, palatability attributes and energy efficiency for maintenance, milk and growth. Hybrids 673A × GD 65, 674A × JHV 12 and 699A × ICSR 93039 had higher CP, low cell wall contents, higher digestibility, more palatability and higher energetic value for animal production with moderate to low methane production should be developed for environment friendly livestock production.

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