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# Evaluation of sorghum hybrids for biomass and biogas production

**Athar Mahmood[1,2]*, Habib Ullah[3], Muhammad Ijaz[4], Muhammad Mansoor Javaid[2], Ahmad Naeem Shahzad[3] and Bernd Honermeier[1]**

**[1]Institute of Agronomy and Plant Breeding I, Justus Liebig University, Ludwigstrasse. 23, D- 35390 Giessen, Germany**
**[2]Department of Agronomy, University College of Agriculture, University of Sargodha, 40100, Pakistan**
**[3]University College of Agriculture, Bahauddin Zakarriya University Multan, Pakistan**
**[4]University College of Agriculture, Islamia University Bhawalpur, Pakistan**

***Corresponding author: athar_1012@yahoo.com, athar8946@yahoo.com**

**Abstract**

Biogas from biomass is a promising renewable energy source and its importance is increasing increased in European countries. The biomass of 14 sorghum cultivars (Bovital, Branko, Cerberus, GK Csaba, Goliath, Inka, Lussi, KSH 6301, Maja, Silage king, Super Sile 15, Super Sile 18, Super Sile 20 and Superdolce 1) and 1 maize cultivar (Agrogas) were included in field experiments carried out at the experimental station Gross-Gerau and Giessen experimental stations during 2009. The contents of protein, sugar, starch, neutral detergent fibre, acid detergent fibre, and acid detergent lignin in each sorghum sample were determined using near infrared reflectance spectroscopy. The volume of biogas was measured by using a Gas Wet Ritter. A non-dispersive Infrared (NDIR) sensor (GS IRM-100) was used to measure the concentration of methane. Briefly indicate how the study was conducted. The Cerberus and Goliath cultivars produced significantly higher biomass yields compared to other cultivars studied at both experimental stations. The cultivars and sites differed significantly in the chemical composition of the sorghum biomass. The lowest lignin content was exhibited by cv. Branko while Maja achieved the highest lignin content followed by Goliath and Cerberus. Maize cv. Agrogas produced the highest biogas yield of 720 nL/kg volatile solid, compared to the sorghum cultivars. Among the sorghum cultivars, Branko achieved the maximum specific biogas yield followed by Super Sile 15, Super Sile 20, and Super Sile 18. The highest biogas yields per ha was produced by maize cv. Agrogas, followed by sorghum cv. Lussi, Cerberus, and Branko. Therefore, cultivars having higher biomass and specific methane yields should be selected to maximize methane yield per ha. The biogas and methane yields of some of the tested cultivars, such as Maja, Lussi, Branko, Supersile 20, KSH 6301 and Supersile, are comparable to that of maize. Hence, it can be concluded that sorghum can be used as an alternative to maize for energy production.

**Keywords:** Bio-methane; lignin content; Maize cultivar; Sorghum cultivar; Starch content.
**Abbreviations:** ADF_Acid detergent fibre, ADL_Acid detergent lignin, BMR_Brown mid-rib,CP_Protein, DM_Dry Matter Yield, GG_Gross Gerau, GI_Giessen, IR_Infrared, LSD_Least significant difference, NDF_neutral detergent fibre, NDIR_Non-dispersive Infrared, NIRS_Near infrared reflectance spectroscopy, nL_Norm liter, SG_sugar, ST_Starch, VS_Volatile solid, WSC_water soluble carbohydrates.

## Introduction

Renewable energy resources are a part of the European battle against climate changes, while at the same time contributing to economic growth, increasing the number of employed people and providing energy security (Oslaj et al. 2010). Biogas from biomass is a promising renewable energy source whose importance is increasing in European countries. Maize silage is considered as a key substrate for agricultural biogas production in Germany (Weiland, 2006; Schittenhelm, 2008). Since the last decades, mono-cropping of maize for biogas production has caused various problems such as decreasing the diversity of the crop species, and enhancing pest/disease intensity as well as nutrient losses (Schittenhelm, 2010). To tackle these problems, different crops are being studied for biogas production through anaerobic digestion. These include sunflower, miscanthus, cup plant, jerusalem artichoke, switch grass, poor oat grass meadows, small-sedge poor-fen meadow, tall herb meadow, montane hay meadow, hemp, sorghum and sudan grass (Beck et al., 2007; Rishter, 2009; Schittenhelm, 2010; Mahmood and Honermeier, 2012).

Venuto and Kindiger (2008) reported that forage sorghum and sorghum–sudan grass hybrids have potential for increased biomass yields. Differences among sorghum cultivars for biomass yields have been reported by many researchers (Habyyarimana 2004, Amaducci et al. 2004, Zhao et al. 2009). Habyarimmana et al. (2004) carried out a study with different sorghum hybrids under different climatic conditions in Italy for biomass evaluation. They found that the hybrid ABF 25 produced significantly higher biomass yield followed by H 132 and Abetone. Significant differences among cultivars have also been observed in chemical composition, including contents of water-soluble carbohydrates (WSC) and proteins, as well as their structural fibrous ingredients, including neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL). Previous studies on sorghum also reported clear differences between different varieties with respect to DM and NDF-digestibility of the silage (Hanna et al., 1981; Miron et al., 2005).

**Table 1.** Weather conditions during crop growing season at experimental station Gross-Gerau (GG 2009) and Giessen (GI 2009).

| Months. | GG-2009 | | | | GI-2009 | | | |
|---|---|---|---|---|---|---|---|---|
| | AT °C | LAT °C | PS mm | LPS mm | AT °C | LAT °C | PS mm | LPS mm |
| April | 15.1 | 9.5 | 36 | 41 | 15.1 | 12.9 | 82 | 58 |
| May | 15.7 | 14.0 | 55 | 57 | 11.8 | 16.0 | 73 | 62 |
| June | 17.1 | 17.2 | 109 | 65 | 18.5 | 17.8 | 77 | 66 |
| July | 19.7 | 19.0 | 72 | 67 | 18.5 | 17.2 | 44 | 59 |
| August | 20.2 | 18.2 | 46 | 64 | 11.4 | 13.7 | 39 | 50 |
| September | 15.6 | 14.4 | 40 | 47 | - | - | - | - |
| Sum/Mean | 16.2 | 14.5 | 405 | 391 | 15.1 | 14.3 | 315 | 295 |

AT: Air temperature (°C), LAT: Long term air temperature (°C), PS: Precipitation sum (mm), LPS: Long term precipitation average (mm)

The composition and biodegradability of biomass are key factors in methane yield. Compounds like crude protein, crude fat, crude fibre, cellulose, hemi-cellulose, starch, and sugars clearly affect methane production (Balsari et al. 1983, Amon et al. 2007). Richter et al. (2009) carried out a study on different energy crops and found methane yields of around 158 to 268 nL $kg^{-1}$ VS with poor oat grass meadows (Arrhenaterion), small-sedge poor-fen (*Caricion fuscae*) meadow, tall herb (*Filipendulion ulmariae*) meadow and with montane hay meadow (Polygono-Trisetion). A very similar methane yield was obtained by Baserga (1998), who obtained 280 nL $kg^{-1}$ VS from extensive grassland, as well as by Lemmer and Oechsner (2001), who reported 240 nL $kg^{-1}$ VS from silage originating from extensive grassland. The highest methane yield was achieved with *Sorghum halapense*, which can be used as a potential energy crop (Chynoweth et al. 1983). Jerger and Chynoweth (1987) conducted a study on different sorghum cultivars indicating that cv. Rio produced the highest methane yield, while the lowest yields were obtained from Gaza 114 and RS 610 among the tested cultivars. Great diversity can be expected among sorghum cultivars in biomass and chemical composition. Both of these parameters can ultimately affect either the specific biogas yield or methane production on a per hectare basis. Therefore, to use sorghum as an energy crop, an appropriate choice of cultivars is of prime importance. This study was therefore carried out to evaluate different sorghum cultivars for dry matter production, chemical composition, and biogas production under climatic conditions in Germany.

## Results and discussion

### *Biomass yield*

During the 2009, 14 sorghum cultivars and 1 maize cultivar were used. The Cerberus and Goliath cultivars had out-performed other cultivars tested in terms of yield in the current study at both experimental stations, at Gross-Gerau (GG) and Giessen (GI; Table 3). It can therefore be suggested that cv. Cerberus and Goliath possess greater genetic potential for biomass production. Nevertheless, reasonable DM yields were also generated by cv. Maja, Lussi, Inka KSH 6301 and maize cv. Agrogas at both sites. Silage King and Super Sile 20 produced reasonable DM yields at GG station but showed an unexpected yield decline in yield at GI. The choice of sites also had a significant impact on DM yield. Despite its sandy soil, DM yields at the GG experimental station were higher than that at Giessen (clayey soils). Greater rainfall and supplemental irrigation of 50 mm applied at this station may have increased the DM yield of sorghum. Moreover, a site × cultivar interaction was also observed for DM yield. Biomass yield is of prime importance because higher biomass yield per ha can significantly affect methane yield per ha. Therefore, cultivars with higher biomass yields may be the best choices for higher methane production.

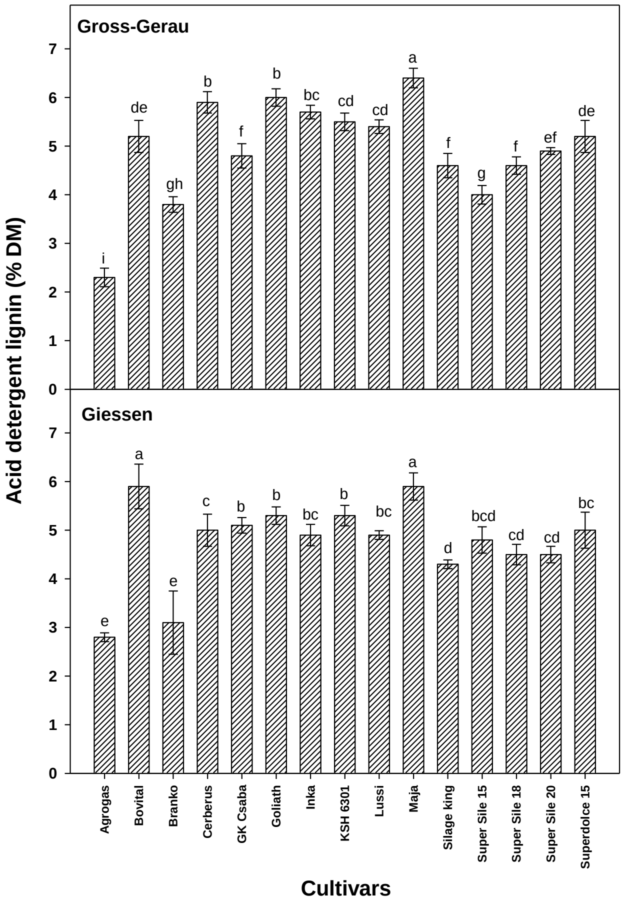


**Fig 1.** Effect of cultivars on lignin content of sorghum at Gross-Gerau and Giessen experimental station. Different letters representing significant differences among treatments means±SD.

### *Chemical composition*

Methane production potential is dependent on the chemical composition of the biomass in maize cultivars (Oslaj et al., 2010); this might be true for sorghum as well. Chemical composition was therefore determined in the present research including sugar, protein, ash, lipids and fibre contents (ADF, NDF and ADL). Regarding sugar contents, choice of the cultivars had a significant influence, ranging from 5.4% (GK Csaba; GG) to 24.3% (Branko; GI).

**Table 2.** Overview of cultivars used in both experimental years**.**

| Cultivars | Genetic background | Maturity | Supplying company and country |
|---|---|---|---|
| Agrogas | *Maiz* | S 280 | Agromais,Germany |
| Bovital | *S. b* X *S. sudanense* | Early | Saatenunion,Germany |
| Branko | *S. b* X *S. B* (BMR) | Late | KWS,Germany |
| Cerberus | *S. b* X *S. b* | Mid early | KWS,Germany |
| GK Csaba | *S. b* X *S. sudanense* | Early | Energy plant,Germany |
| Goliath | *S. b* X *S. b* | Late | Saatenunion,Germany |
| Inka | *S. b* X *S. sudanense* | Mid late | KWS,Germany |
| KSH 6301 | *S. b* X *S. b* | Early | KWS,Germany |
| Lussi | *S. b* X *S. sudanense* | Mid early | Caussade,Germany |
| Maja | *S. b* X *S. b* | Early | KWS,Germany |
| Silage king | *S. b* X *S. b* | Late | KWS,Germany |
| Super Sile 15 | *S. b* X *S. Saccharatum* | Early | Caussade,Germany |
| Super Sile 18 | *S. b* X *S. Saccharatum* | Medium | Caussade,Germany |
| Super Sile 20 | *S. b* X *S. Saccharatum* | Late | Caussade,Germany |
| Superdolce 15 | *S. b* X *S. sudanense* | Mid early | NK seeds,Germany |

S. b; *Sorghum bicolor*

**Table 3.** Effect of different cultivars on dry matter concentration (DMC), dry matter yield (DMY) and lodging of sorghum in Gross-Gerau (GG) and Giessen (GI) (2009).

| | DM % | | DMY (t/ha) | | Lodging (1-9) |
|---|---|---|---|---|---|
| Cultivars | GG 09 | GI 09 | GG 09 | GI 09 | GG 09 |
| Agrogas | 30ab±2.0 | 29ab±1.7 | 19.7abcd±2.0 | 16.67abc±1.3 | 1f±0.0 |
| Bovital | 29abc±1.4 | 29ab±1.6 | 15.17f±1.1 | 14.58bcd±2.3 | 5ab±0.0 |
| Branko | 21g±1.0 | 23ef±0.2 | 17.66cdef±1.2 | 12.94cd±1.8 | 6.25a±0.5 |
| Cerberus | 30ab±0.3 | 29ab±2.4 | 22.65a±2.2 | 18.55ab±4.1 | 1f±0.0 |
| GK Csaba | 29abc±0.7 | 27bcd±1.5 | 15.03f±2.8 | 12.28d±3.4 | 4.25bc±0.5 |
| Goliath | 29abc±2.2 | 28bc±1.0 | 21.94ab±2.5 | 19.11a±2.1 | 2.75cde±2.2 |
| Inka | 24efg±1.9 | 24de±0.8 | 19.35abcde±2.3 | 14.42bcd±2.1 | 2.25def±1.3 |
| KSH 6301 | 28bcd±1.4 | 30ab±1.2 | 18.68bcde±1.5 | 15.89abcd±1.5 | 2.75cde±0.5 |
| Lussi | 25def±0.83 | 23ef±1.3 | 19.3abcde±1.4 | 15.35abcd±1.6 | 1f±0.0 |
| Maja | 32a±3.3 | 32a±1.8 | 20.69abc±3.3 | 15.39abcd±1.0 | 4.5b±1.7 |
| Silage king | 22fg±0.6 | 20f±0.7 | 18.06cdef±1.1 | 11.98d±2.8 | 1.25ef±0.5 |
| Super Sile 15 | 26de±1.4 | 24de±0.8 | 16.22ef±0.8 | 13.47cd±1.2 | 1f±0.0 |
| Super Sile 18 | 23efg±1.9 | 25cde±1.0 | 17.02def±1.4 | 14.79bcd±2.1 | 1f±0.0 |
| Super Sile 20 | 22fg±1.2 | 22ef±0.4 | 18.03cdef±1.2 | 13.32cd±1.1 | 1f±0.0 |
| Superdolce 15 | 28bcd±2.0 | 25cde±0.9 | 16.05ef±1.0 | 15.51abcd±0.4 | 3.75bcd±0.5 |
| CV ($LSD_{0.05}$) | 3.36 | 3 | 3.47 | 4.31 1.7 | |
| Site | 0.8 | | 0.63 | .... | |
| Site x CV | ns | | 2.44 | ..... | |

Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at p <0.05 and indicated by different letters.

At both sites, cv. Branko accumulated a considerably higher sugar content than other cultivars, followed by cv. Inka. Besides the choice of cultivars, the sites also differed in terms of sugar contents with significantly higher accumulations at GI than GG. A remarkable cultivar × site interaction was also noted for sugar contents (Table 4). It can be assumed that the higher sugar contents at GI might be associated with the soil characteristics because, the clay soil of that station is characterized by a greater nutrient holding capacity as compared to the sandy soil of the GG station. Starch accumulation was greatly affected by choice of cultivars at both sites. Maize cv. Agrogas synthesized a significantly higher starch content than sorghum cultivars. The higher starch contents of maize cv. Agrogas may be associated with a higher proportion of the plant consisting of the head (cob), because the head usually contains a higher starch content than the other organs. Among sorghum cultivars, cv. GK Csaba was characterized by a higher starch contents, followed by Superdolce 15 (Table 4). The results further showed that the starch contents are significantly higher at the GG site than at GI as indicated by a significant interaction between cultivar and site. Protein contents also varied among sorghum cultivars. At the GG site, cultivars GK Csaba, Super Sile 15, and Super Sile 20 had comparable values of protein content and that were markedly higher than the other cultivars. The minimal protein content was exhibited by cv. Cerberus followed by Goliath, Inka and Lussi. Cv. Silage King and Super Sile 15 showed the highest protein contents among cultivars at the GI site. Previous work also showed clear differences in protein concentration among forage cultivars of sorghum (Miron et al., 2006). Choice of sites also had a notable impact on protein contents, and the cultivar x site interaction was also significant. The higher protein content at the GI site probably reflects the better nitrogen supply in its clay soil over sandy soil (at GG) because greater leaching of nitrogen can be expected from sandy soil than clay soil. Significant differences among cultivars were observed for ADF content. Maize cv. Agrogas had the lowest ADF content, followed by sorghum cv. Super Sile 15 and Super Sile 18, while the highest contents were accumulated by cv. Cerberus and Goliath among the sorghum cultivars (Table 4). Variations in acid detergent fibre (ADF) concentrations

**Table 4.** Effect of different cultivars on sugar, starch, protein and acid detergent fiber (ADF) of sorghum in Gross-Gerau (GG) and Giessen (GI) (2009).

| | Sugar (% DM) | | Starch (%DM) | | Protein (% DM) | | ADF (% DM) | |
|---|---|---|---|---|---|---|---|---|
| Cultivars | GG 09 | GI 09 | GG 09 | GI 09 | GG 09 | GI 09 | GG 09 | GI 09 |
| Agrogas | 5.7f±0.5 | 10.2de±0.7 | 28.7a±1.4 | 18.4a±1.1 | 7.6ab±0.5 | 9.2abcd±0.4 | 24.4i± | 25.8h±1.2 |
| Bovital | 6.7fg±2.2 | 7.2e±1.9 | 8.8c±2.7 | 9.3b±3.1 | 7.4b±0.4 | 9.7ab±0.5 | 36.9cd± | 32.9de±2.1 |
| Branko | 19.7a±1.7 | 24.3a±2.7 | 2.2d±0.8 | ---- | 7.3b±0.1 | 9.2abcd±0.1 | 33.2efg± | 26.5gh±2.3 |
| Cerberus | 11.6d±0.6 | 12cd±2.1 | 0.76d±0.4 | 0.3c±0.0 | 5.6e±0.4 | 8.5de±0.8 | 40.8a± | 38.2a±1.4 |
| GK Csaba | 5.4f±1.2 | 6.4e±1.6 | 15.6b±1.8 | 9.9b±2.1 | 8.3a±0.5 | 9.3abcd±0.4 | 32.3fgh± | 34.2cd±1.2 |
| Goliath | 12.6cd±1.0 | 15.6bc±2.9 | 1.4d±0.7 | ---- | 5.9de±0.5 | 8e±0.5 | 40.8a± | 34.8cd±1.1 |
| Inka | 16.7ab±1.8 | 18.3b±2.6 | 1.7d±0.5 | ---- | 6.4cd±0.4 | 8.7cde±0.7 | 36.5cd± | 33.4cd±1.0 |
| KSH 6301 | 10.5de±1.8 | 11.9cd±0.8 | 2.3d±1.8 | 1.1c±0.5 | 7.4b±0.4 | 9.3abcd±0.6 | 36.4cd± | 35bcd±1.1 |
| Lussi | 14.6bc±0.9 | 11.8cd±2.2 | 1.2d±0.5 | 1.2c±1.2 | 6.5cd±0.2 | 9.5abc±0.3 | 38.1bc± | 35.6ab±0.7 |
| Maja | 8.7ef±0.9 | 9.3de±0.6 | 2.5d±1.2 | 1.4c±1.0 | 7bc±0.7 | 9.2abcd±0.6 | 39.5ab± | 37.6ab±1.2 |
| Silage king | 16.4b±1.4 | 15.7bc±1.1 | 0.9d±0.9 | ----- | 6.9bc±0.3 | 10a±0.2 | 33.9ef± | 33.4cd±0.6 |
| Super Sile 15 | 8.7ef±1.0 | 14.7bc±2.2 | 10.7c±0.9 | 1c±0.5 | 8.2a±0.2 | 10a±0.7 | 31.3gh± | 27.9fgh±1.2 |
| Super Sile 18 | 12.3cd±0.8 | 17.6b±2.5 | 2.3d±0.2 | 2.1c±0.02 | 7.4b±0.6 | 8.8bcd±0.5 | 35.1de± | 29fg±1.0 |
| Super Sile 20 | 14.3bc±0.9 | 17.8b±1.3 | 0.6d±0.5 | 0.04c±0 | 6.9bc±0.3 | 9.6abc±0.4 | 35.1de± | 30.5ef±2.0 |
| Superdolce 15 | 9ef±1.2 | 12.8cd±2.4 | 10.1c±1.9 | 7.2b±1.8 | 7.6ab±0.4 | 9.3abcd±0.5 | 33.9ef± | 30.2f±0.6 |
| CV ($LSD_{0.05}$) | 2.5 | 4 | 2.6 | 3.6 | 0.8 | 1 | 2.2 | 2.7 |
| Site | 0.9 | | 0.8 | | 0.2 | | 0.6 | |
| Site x CV | 3.3 | | 5 | | 0.9 | | 2.4 | |

Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at $p < 0.05$ and indicated by different letters.

**Table 5.** Effect of different cultivars on neutral detergent fiber (NDF), lignin, ash and lipids concentration of sorghum in Gross-Gerau (GG) and Giessen (GI) (2009).

| | NDF (% DM) | | Ash (% DM) | | Lipid (% DM) | |
|---|---|---|---|---|---|---|
| Cultivars | GG 09 | GI 09 | GG 09 | GI 09 | GG 09 | GI 09 |
| Agrogas | 46.2j±0.5 | 44.1f±1.4 | 6.1d±0.4 | 7f±0.3 | 2.3a±0.11 | 2.6a±0.20 |
| Bovital | 58.1bc±0.2 | 53.4abcd±1.4 | 7.7bc±0.2 | 9bcde±0.4 | 1.4c±0.07 | 1.9bc±0.13 |
| Branko | 49.5i±1.4 | 47.9ef±4.0 | 7.3c±0.2 | 8.3e±0.6 | 1.3cd±0.03 | 1.8cd±0.13 |
| Cerberus | 60.6a±1.2 | 57a±1.8 | 7.7bc±0.1 | 8.5de±0.5 | 1fg±0.04 | 1.5fg±0.10 |
| GK Csaba | 56.4cd±1.2 | 55.6abc±3.3 | 8.3ab±0.3 | 9.8a±0.4 | 1.6b±0.12 | 1.9bc±0.05 |
| Goliath | 59.1ab±1.1 | 55.2abc±2.4 | 7.7bc±0.3 | 8.6de±0.4 | 0.9g±0.06 | 1.4g±0.07 |
| Inka | 54.8defg±1.6 | 51.2cde±2.2 | 8.4a±0.5 | 8.8cde±0.2 | 1.1ef±0.08 | 1.6ef±0.09 |
| KSH 6301 | 57.4bc±1.1 | 53.5abcd±0.6 | 8ab±0.3 | 8.4e±0.4 | 1.3cd±0.03 | 1.7de±0.10 |
| Lussi | 56.1cde±0.5 | 56.4ab±2.8 | 7.8abc±0.4 | 9.5abc±0.6 | 1.2de±0.03 | 1.7de±0.02 |
| Maja | 59.5ab±1.2 | 54.9abc±1.6 | 7.8abc±0.3 | 8.6de±0.4 | 1.2de±0.05 | 1.6ef±0.07 |
| Silage king | 53.1gh±1.1 | 52.2bcde±1.7 | 8ab±0.4 | 9.2abcd±0.5 | 1.2de±0.05 | 1.8cd±0.05 |
| Super Sile 15 | 52.5h±0.4 | 50.1de±0.5 | 8.3ab±0.4 | 9.7ab±0.2 | 1.6b±0.02 | 2b±0.03 |
| Super Sile 18 | 53.9efgh±1.1 | 51.2cde±0.6 | 8.3ab±0.4 | 8.9cde±0.1 | 1.4c±0.11 | 1.8cd±0.10 |
| Super Sile 20 | 53.8fgh±1.4 | 51.1cde±2.2 | 7.9abc±0.3 | 9.2abcd±0.1 | 1.3cd±0.10 | 1.8cd±0.10 |
| Superdolce 15 | 56cdef±2.7 | 54.2abcd±4.8 | 7.7bc±0.5 | 9.2abcd±0.2 | 1.4c±0.14 | 1.8cd±0.04 |
| CV ($LSD_{0.05}$) | 2.3 | 4.8 | 0.7 | 0.8 | 0.2 | 0.2 |
| Site | 1 | | 0.2 | | 0.05 | |
| Site x CV | ns | | ns | | 0.2 | |

Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at $p < 0.05$ and indicated by different letters.

among different cultivars have been previously reported for sorghum (Beck et al., 2007) as well as for maize (Iptas and Acar, 2006). The major factors such as effect of site as well as an interaction between site × cultivar were also presented. A significantly higher level of ADF contents was observed at the GG site. The neutral detergent fibre (NDF) content in the present experiments varied from 44 to 60% of DM which is concomitant with the findings of other investigations with forage sorghum and maize (Marsalis et al., 2010). The NDF contents were pronouncedly affected by choice of cultivars, with cv. Cerberus producing the highest content while the lowest values were observed for maize cv. Agrogas. Among sorghum cultivars, Branko accumulated the lowest NDF concentrations at either site (Table 5). The greater content of non-structural carbohydrates like sugar may explain the phenomenon of greater structural carbohydrates (NDF) in this cultivar. Other researchers have also found that cultivars of forage sorghum exhibit significant differences regarding lignin concentration (Miron et al., 2006; Beck et al., 2007). Choice of site also had a marked influence on NDF content with GG showing higher NDF contents than GI. The higher ADF and NDF contents at GG are likely the result of higher rainfall and supplemental irrigation, because water supply is considered to affect the synthesis of secondary cell walls in plants (Carmi et al., 2006) and it is obvious that ADF (cellulose + lignin) and NDF (cellulose + hemicelluloses + lignin) are major components of the cell walls. Additionally, an interaction of cultivar x site was also noticed. Lignin is a polymer formed from monolignols derived from the phenylpropanoid pathway in vascular plants. This compound is considered an anti-quality component because it interferes with the digestion of cell wall polysaccharides by acting as a physical barrier to microbial enzymes. Lignin accumulation was significantly influenced by cultivars at either site. Similar

**Table 6.** Effect of different cultivars on specific biogas yield (Sp. BGY), specific methane yield (Sp. MY), methane concentration, total biogas yield ($m^3$/ha) and total methane yield ($m^3$/ha) and of sorghum in Gross-Gerau (2009).

| | Sp. BGY | Sp. MY | MC | BGY | MY |
|---|---|---|---|---|---|
| Cultivars | nL/kg VS | | % vol | $Nm^3$/ha | $Nm^3$/ha |
| Agrogas | 720a±32 | 367a±16 | 51±0.2 | 14386a±2179 | 7120a±1097 |
| Bovital | 539abc±107 | 272abc±56 | 51±0.4 | 8181de±1359 | 4136cd±716 |
| Branko | 685ab±40 | 354ab±20.4 | 52±0.1 | 11835abc±1373 | 6129ab±699 |
| Cerberus | 566abc±45 | 286abc±23 | 51±0.6 | 12605ab±715 | 6371a±431 |
| GK Csaba | 574abc±53 | 289abc±30 | 50±0.6 | 8605cde±641 | 4339bcd±371 |
| Goliath | 503bc±88 | 258bc±40 | 52±1.1 | 10758bcde±1056 | 5530abcd±516 |
| Inka | 583abc±64 | 297abc±33 | 51±0.1 | 10844abcde±576 | 5535abcd±309 |
| KSH 6301 | 611abc±10 | 310abc±8 | 51±1.7 | 11660abcd±740 | 5917abc±530 |
| Lussi | 644abc±16 | 328abc±12 | 51±0.8 | 12886ab±263 | 6554a±174 |
| Maja | 566abc±24 | 288abc±8 | 51±0.7 | 11311abcd±1748 | 5755abcd±922 |
| Silage king | 570abc±33 | 294abc±21 | 52±0.6 | 10452bcde±628 | 5387abcd±387 |
| Super Sile 15 | 681ab±30 | 350ab±17 | 51±0.3 | 11197abcde±719 | 5696abcd±381 |
| Super Sile 18 | 668abc±43 | 337abc±23 | 50±0.4 | 11778abc±1286 | 5941abc±686 |
| Super Sile 20 | 670abc±106 | 347ab±57 | 52±0.4 | 11805abc±2049 | 6047ab±1079 |
| Superdolce15 | 487c±207 | 250c±108 | 51±0.8 | 7649e±2001 | 3924d±1225 |
| CV ($LSD_{0.05}$) | 186 | 97 | ns | 3580 | 1881 |

Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at $p < 0.05$ and indicated by different letters.

to NDF, lignin contents were minimal for cv. Agrogas and Branko among the cultivars at both sites (Figure 1). The lower lignin content in cv. Branko compared to other sorghum cultivars is associated with the BMR trait. The BMR trait in sorghum, characterized by reduced lignin concentration, considerably enhances the level of digestibility (Oliver et al., 2004). Cv. Maja achieved the highest lignin content followed by Goliath and Cerberus at the GG site. Similarly, at experimental station GI, maximum lignin values of 5.9% were observed with cv. Maja and Bovital. The lower contents of non-structural carbohydrates like sugar or starch may explain the phenomenon of higher levels of structural carbohydrates (ADF, NDF and lignin) in these cultivars. Ash content was affected both by cultivar and by site, ranging from 6.1% (Agrogas; GG) to 9.8% (GK Csaba; GI). Considerably higher levels of ash content were recorded at GI than at GG. The range of lipid contents was low varying between 0.9 and 2.6%. Both major factors, site and cultivars, showed clear differences for lipid contents (Table 5).

***Biogas and methane yield***

During 2009, different sorghum cultivars were compared for specific biogas yield, specific methane yield, methane concentration, biogas yield per ha and methane yield per ha the GG site. ANOVA revealed that the choice of cultivars had a clear impact on specific biogas yield. Maize cv. Agrogas produced the highest biogas yield, of 720 nL kg VS, compared to the sorghum cultivars. Among the sorghum cultivars, cv. Branko achieved the maximum specific biogas yield followed by Super Sile 15, Super Sile 20 and Super Sile 18 (Table 6). A similar trend was observed for specific methane yield, where the highest specific methane yield was observed with maize cv. Agrogas followed by sorghum cv. Branko. The higher methane yield in maize cv. Agrogas might be the result of the lower lignin and higher starch concentrations in that cultivar. On the other hand, the higher methane yield of the sorghum cultivar cv. Branko may be linked with the lower lignin and higher sugar contents of that cultivar. It has been reported that brown midrib mutants significantly enhanced the rate of conversion in the lignocellulosic bioenergy process (Sattler, 2010). Therefore, it can be concluded that the reduced lignin contents of maize cv. Agrogas and Branko may enhance the NDF digestibility of these cultivars in the anaerobic digestion process. The lowest levels of specific biogas as well as methane yields, were determined for cv. Superdolce 15, Goliath and Bovital (250–272 nL per kg VS). With respect to methane content, a very narrow range of 50 to 52% was found (Table 6). Methane production per ha is the product of the specific methane yield (nL per kg volatile solids) and the biomass yield of the tested crop. In our study, some cultivars produced higher specific methane yields; however, due to their reduced biomass production, the net gain of in methane yield per ha was lower and vice versa. Cultivars differed significantly for biogas and methane production per ha, ranging from a minimum of 7649 to a maximum 14386 $Nm^3$ per ha and 3924 to 7120 $Nm^3$ per ha, respectively. The highest gain in biogas yields per ha was determined for by maize cv. Agrogas followed by sorghum cv. Lussi, Cerberus and Branko (Table 6). Production of methane yield per ha was also the highest in maize cv. Agrogas, which had a produced methane yield of 7120 $Nm^3$ per ha. The worst gain was observed for Superdolce 15, followed by cv. Bovital and GK Csaba at 3924, 4136 and 4339 $Nm^3$ per ha, respectively. The higher methane yield per ha in maize cv. Agrogas is likely the result of its higher specific methane yield and biomass production on a per ha basis. Nevertheless, some of the sorghum cultivars investigated in the present study had methane yields comparable to maize cultivar Agrogas.

**Materials and Methods**

***Field experiments and plant materials***

Field experiments were carried out at the Gross-Gerau (49° N 8° E) and Giessen (50° N, 8° E) experimental stations during 2009. The soil is characterized as sandy loam and clay at Gross-Gerau and Giessen, respectively. The long and short-term weather conditions (temperature and precipitation) at both experimental stations are given in Table 1. The 14 cultivars tested in the current study are given in Table 2. The net size of each plot was 15 $m^2$. Nitrogen was applied at a rate of 120 kg $ha^{-1}$ as ammonium nitrate after sowing at both experimental stations. Immediately after harvest, the dry matter and moisture contents of all samples were determined by drying 100 g of each sample in an oven at a constant temperature of 105°C for 48 h.

### *NIRS Analyses*

Samples intended for NIRS analysis were oven-dried, finely ground and stored in paper bags. Their contents of protein (CP), sugar (SG), starch (ST), neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) of sorghum were determined using near infrared reflectance spectroscopy (NIRS) as described by Schittenhelm (2008).

### *Biogas measurement*

Biogas measurements were carried out in laboratory digesters under mesophilic conditions (38°C) based on a method used by Richter et al. (2009). Liquid manure was used as a source of microbes for the anaerobic digestion process in 20 L pot. A 300 g sorghum sample and 16 kg of liquid manure were deposited in different digesters and allowed to digest for a retention time of 21 days. The volume of biogas was measured using a Gas Wet Ritter consisting of a multi-chamber rotary measuring drum containing water. The drum works upon the principle of positive displacement. As biogas flowed from one chamber of the drum to the other, the drum rotated. This rotated the needle dials around the scales so that the positions of the needles on the scales could be read directly as the volume of gas that had flowed through the meter. Information about the full volume and fractions of volumes were provided by large and small needles, respectively. On the basis of the calculated volatile solids (VS), the specific biogas yield (nL/kg VS) of the corresponding sorghum samples was measured.

### *Methane concentration*

A non-dispersive Infrared (NDIR) sensor (GS IRM-100), consisting of an infrared source (lamp), a sample chamber, a wavelength filter, and an infrared detector was used to measure the concentration of methane. The gas was diffused into the sample chamber, and gas concentration was estimated electro-optically by its absorption at a specific in the infrared (IR) wavelength. The IR light was directed through the sample chamber towards the detector, equipped with an optical filter. The filter prevented all types of light except the wavelength that the selected gas molecules can absorb. The intensity of IR light reaching the detector is inversely related to the concentration of target gas in the sample chamber. As the concentration of the specific gas increases, the intensity of IR light striking the detector decreases.

### *Statistical analyses*

The experimental design was a RCBD (randomized complete block design) with four replications. The location effect was significant therefore data from the two different locations were presented separately. Statistical analysis of the results was carried out by an analysis of variance (ANOVA) using the statistical package PASW version 18 (predictive analytics software) for determining the normal distribution and significance of the different treatments (SPSS INC., Chicago, IL). The means of the studied parameters were compared by LSD (least significant difference) at $p < 0.05$.

## Conclusion

It can be concluded from the above results that the cultivars having lower lignin and higher non-structural carbohydrates contents had increased the digestibility during anaerobic digestion. For that reason, these cultivars produced more biogas and methane yield per kg of volatile solids. However, the methane yield is a product of specific methane yield and biomass yield $ha^{-1}$. Therefore, a higher biomass yield is also of prime importance in evaluating utility for biogas production. In the present study, the specific methane yields from some of the cultivars were remarkably high but, owing to their reduced biomass production, the net gain in methane yield per ha was lower. The biogas and methane yields of some of the tested cultivars, such as Maja, Lussi, Branko, Supersile 20, KSH 6301 and Supersile, were comparable to those of maize. Hence, it is suggested that sorghum can be used as an alternative to maize for energy production.

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