Studies on the chemical composition and digestible energy content of South African grain sorghum

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The experiment was conducted (i) to compare the chemical and physical composition of grain sorghum produced at different locations, (ii) to compare the digestible energy (DE) content of different grain sorghum cultivars produced at different locations, and (iii) to evaluate the influence of chemical composition and physical characteristics of the grain on the DE contents thereof. Highly significant ($P \leq 0.01$) differences in crude protein (CP), crude fibre (CF), tannin and starch content as well as in hectolitre and thousand seed mass, DM digestibility and DE content were observed between sorghum produced at different locations. Significant ($P \leq 0.01$) differences were also found between the DE content of different grain sorghum cultivars, while significant ($P \leq 0.01$) interactions were found between location and cultivar. The mean DE content for low tannin (GL) sorghum cultivars was determined to be 16.1 ± 0.6 MJ/kg DM, while the corresponding value for high tannin (GH) sorghum cultivars was 14.1 ± 0.6 MJ/kg DM. The mean DE contents for GL cultivars were 16.7 ± 1.2 and 16.1 ± 1.2 MJ/kg DM in the Bethlehem and Ermelo locations respectively, while the DE contents for GH cultivars were 15.0 ± 0.9 and 13.5 ± 1.9 MJ/kg DM respectively. Concerning the influence of physical parameters on DE, it was found that the percentage small seeds (< 2 mm) and percentage unthreshed grain had a negative influence on DE content. Tannin content affected DE negatively (significant at $P \leq 0.01$), while starch and protein content influenced DE positively (significant at $P \leq 0.01$). It was concluded from the study that the South African grain sorghum grading system accounts for the differences in DE content through the amounts of unthreshed grain and small seeds allowed in each grade.

Die eksperiment is uitgevoer om 'n vergelyking te tref tussen (i) die chemiese en fisiese samestelling van graansorghum uit verskillende lokaliteite, (ii) die verteerbare energie (VE)-inhoud van verskillende graansorghumkultivars vanaf verskillende lokaliteite, en om (iii) die invloed van chemiese samestelling en fisiese eienskappe van die graan op die VE-inhoud daarvan te kwantifiseer. Hoogs betekenisvolle ($P \leq 0.01$) verskille in die ruproteïen(RP)-, ruvesel(RV)-, tannien- en styselinhoud asook in hektoliter- en duisendkorrelmassa, DM-verteerbaarheid en VE-inhoud is waargeneem by sorghum vanaf veskillende lokaliteite. Betekenisvolle ($P \leq 0.01$) verskille in VE-inhoud is ook tussen verskillende sorghumkultivars gevind, alhoewel betekenisvolle ($P \leq 0.01$) lokaliteit- en kultivarinteraksies gevind is. Die gemiddelde VE-inhoud van lae-tannien(GL)-sorghumkultivars was 16.1 ± 0.6 MJ/kg DM, terwyl die ooreenstemmende VE-inhoud van hoë-tannien(GH)-sorghurmkultivars 14.1 ± 0.6 MJ/kg DM was. Die gemiddelde VE-inhoud van GL-kultivars was onderskeidelik 16.7 ± 1.2 en 16.1 ± 1.2 MJ/kg DM vir die Bethlehem- en Ermelo-lokaliteite, terwyl die ooreenstemmende GH-kultivars waardes van 15.0 ± 0.9 en 13.5 ± 1.9 MJ/kg DM vir die onderskeie lokalitelte gehad het. Betreffende die invloed van fisiese eienskappe op VE, het die persentasie klein sade (< 2 mm) en die persentasie ongedorste graan 'n negtiewe invloed uitgeoefen. Tannieninhoud het 'n negatiewe verwantskap met VE-inhoud gehad (betekenisvol by $P \leq 0.01$), terwyl stysel- en proteïeninhoud 'n positiewe verwantskap met VE-inhoud getoon het (betekenisvol by ≤ 0.01). Dit blyk uit die studie dat die Suid-Afrikaanse graansorghum-graderingsisteem verskille in VE deur die toelaatbare persentasies ongedorste graan en persentasie klein pitte in elke graad verklaar.

Keywords: Chemical composition, cultivar, digestible energy, hectolitre mass, location, mobile nylon bag technique, sorghum.

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Introduction

Grain sorghum has become increasingly important as feed grain in South Africa. In South Africa, plagued by periodic droughts, grain sorghum has the advantage that it can be produced on marginal soils. Sorghum is relatively drought resistant and has a long planting season (Hale, 1986). However, highly variable nutritional qualities have resulted in pig producers discriminating against grain sorghum as feed source.

Grain sorghum cultivars vary in their chemical composition and physical characteristics (Hibberd *et al.*, 1982; Neucere & Sumrell, 1979; Peo, 1987). Grain produced at different locations also vary in chemical composition (Hibberd *et al.*, 1980). This variation may be related to a variable digestible energy (DE) content (Morgan *et al.*, 1975a), which in turn may result in the variable results obtained in practice by pig producers (personal communication, E.H. Kemm, ADSRI, 1989). As a result, there is a need for more information on the variation in chemical composition and DE within grain sorghum cultivars and in grain produced at different locations.

The direct estimation of the DE content of feedstuffs with conventional techniques using pigs is laborious. This is especially true when large numbers of samples must be tested. For this reason, attempts have been made to devise rapid, yet accurate, methods of estimating energy values. Sauer *et al.*

(1983) have developed a mobile nylon bag technique to expedite the measurement of digestible crude protein content in small samples of feedstuffs. This technique may be used to determine the DE content of at least two feed samples per day with four pigs and 16 replicates per feed sample (Sauer *et al.*, 1983). This technique was adapted by Brand *et al.* (1989) to estimate the DE content of grain sorghum.

The DE content of a feedstuff may also be estimated accurately by indirect methods (Morgan *et al.*, 1975b) such as prediction equations based on chemical and/or physical composition (Drennan & Maquire, 1970; King & Taverner, 1975; Henry, 1976; Morgan, *et al.*, 1975b). For grain sorghum, however, it appears to be difficult to obtain any useful relationship which can predict DE content from chemical composition (Batterham *et al.*, 1980).

Owing to limited data on the effect of environmental, physical and chemical factors on the nutritive value of South African grain sorghum, this study was initiated (i) to compare the chemical and physical composition of grain sorghum produced at different locations, (ii) to compare the DE content of different grain sorghum cultivars produced at different locations, and (iii) to evaluate the effect of hectolitre mass, thousand seed mass, seed size, unthreshed grain, impurities and chemical composition of grain sorghum on the DE content thereof.

Experimental Procedures

To determine the variation in chemical and physical composition of grain sorghum growing at different locations in South Africa, samples from 20 cultivars were taken from Potchefstroom (478 mm rainfall plus 180 mm irrigation; Hutton soil type with a Makatini series; 50 kg N, 40 kg P and 20 kg K per ha), Ermelo (1 002 mm rainfall; Hutton soil type with a Msinga series; 103 kg N and 25 kg P per ha) and Bethlehem (607 mm rainfall; Avalon soil type with a Soetmelk series; 100 kg N, 29 kg P and 15 kg K per ha) during the 1985/86 harvesting season.

For the determination of the variation in DM digestibility and DE contents of different grain sorghum cultivars and grain sorghum growing at different locations, samples from 13 different cultivars were taken from test plots at Ermelo and Bethlehem. To evaluate the effect of physical and chemical compositions of grain sorghum on DE content, 21 cultivars produced at Bethlehem and Ermelo were taken. The samples were threshed and screened to remove all impurities. As a result, only the grain kernels were analysed. Two cultivars (G1560 and G1420) from the Bethlehem location were selected and unthreshed grain (grain kernels from which the husks or glumes of the seed were not removed by threshing) was added to produce samples containing 0, 4, 8, 12 and 16% unthreshed grain. The same cultivars were used to compile samples with seed sizes <2 mm, 2—2.5 mm and 2.5—3 mm. One cultivar from the Vrede district (PNR 8469) was used to make up sample combinations with different amounts of small seed (<2 mm) (0, 10 and 20%), impurities consisting mainly of chaff and a small amount of stems plus leaves (0, 1.5 and 3%) and unthreshed grain (0, 10 and 20%). The different fractions were added by weight to compile the required combinations. These combinations were selected so as to simulate grain samples defined in the current South African grain sorghum grading system.

Samples were analysed for dry matter (DM), nitrogen (N), crude fibre (CF) and starch by standard AOAC methods (AOAC, 1984). Gross energy (GE) determinations were carried out on a CP 400 adiabatic bomb calorimeter. The polyphenol content of the different cultivars was determined by the modified Jerumanis procedure (Daiber, 1975). Thousand seed mass was determined by multiplying the mass of 100 sound seeds larger than 2-mm diameter (triplicate samples) by 10. Hectolitre mass of the different samples was obtained by using the upper level of a Two-level Funnel as described by the South African Wheat Board (1986).

The DE content of the different cultivars as well as the compiled combinations were determined by the mobile nylon bag technique (MNBT) as described by Brand *et al.* (1989). Five pigs, fitted with duodenal cannulas, were used. One-gram samples (milled through a mill with a sieve size of 1 mm) were placed into small polyester bags (25 × 40 mm) with a 53-μm mesh. Twenty bags per sample were inserted through the duodenal cannulas of five pigs. After passage, the bags were collected in the faeces, washed in cold water and immediately frozen, freeze-dried and the DM and GE contents were determined. During the experiment, the pigs received a 15% protein sorghum diet (Table 1) at a rate of double the maintenance requirement. The pigs received half the amount twice daily at 08h00 and 13h00.

Table 1 Sorghum diet fed to pigs during the mobile nylon bag technique (MNBT) study

Ingredient	Amount
Sorghum	64.3%
Wheat bran	22.0%
Fish-meal	9.3%
Lucerne-meal	2.3%
Fine salt	1.0%
Feed lime	0.8%
Minerals & vitamins	0.2%
Synthetic lysine	0.1%
Composition (calculated)[a]	**Amount**
Protein	15%
Lysine	0.8%
DE	13 MJ/kg
Crude fibre	4.5%
Fat	2.7%
Ca	0.8%
P	0.7%

[a] As-fed basis.

Differences in chemical and physical composition of the grain produced at different locations and differences in DE values between cultivars, locations, percentage unthreshed grain and seed size were tested for significance by analysis of variance, while relationships between DE content and physical and chemical parameters were detected by regression analysis.

Results and Discussion

Data from the three different locations are summarized in Table 2. It is clear from the data that the region of production had a significant influence on the chemical and physical characteristics of the grain. The CP content of sorghum

Table 2 Chemical and physical characteristics of grain sorghum (n = 20) respectively produced at Bethlehem (dry land⁺), Ermelo (dry land⁺⁺) and Potchefstroom (irrigation⁺⁺⁺)

	Density* (Mean ± SD)		Chemical composition** (Mean ± SD)				
						Tannin (%)	
Location	Hectolitre mass (kg/hectolitre)	1 000 seed mass (g)	Crude protein (%)	Crude fibre (%)	Starch (%)	Low-tannin cultivars	High-tannin cultivars
Bethlehem	$73.8^{a1} \pm 2.3$	$25.1^{a1} \pm 2.4$	$12.9^{2} \pm 0.9$	$2.93^{b2} \pm 0.32$	$70.8^{1} \pm 3.5$	$0.28^{b} \pm 0.04$	$1.45^{b} \pm 0.03$
Ermelo	$75.4^{b} \pm 2.0$	$27.1^{b1} \pm 2.0$	$11.0^{1} \pm 0.9$	$2.63^{a2} \pm 0.45$	$70.9^{1} \pm 2.4$	$0.25^{a} \pm 0.03$	$1.72^{2} \pm 0.20$
Potchefstroom	$76.7^{2} \pm 2.0$	$32.1^{2} \pm 3.4$	$10.5^{1} \pm 1.1$	$2.16^{1} \pm 0.36$	$72.8^{2} \pm 2.9$	$0.24^{a} \pm 0.07$	$0.94^{a1} \pm 0.09$

⁺ 607 mm rain for the 1985/1986 season.

⁺⁺ 1 002 mm rain for the 1985/1986 season.

⁺⁺⁺ 478 mm rain plus 180 mm irrigation (total of 658 mm for the 1985/1986 season).

* On an air-dry basis.

** On a dry-matter basis.

a, b Denote significant differences ($P \leq 0.05$) in columns.

1, 2 Denote highly significant ($P \leq 0.01$) differences in columns.

produced at Bethlehem (12.85%) was significantly ($P \leq 0.01$) higher than the CP contents of sorghum produced at both Ermelo (10.96%) and Potchefstroom (10.45%), while the starch content of sorghum produced at Potchefstroom was significantly ($P \leq 0.01$) higher than that of sorghum produced at Bethlehem and Ermelo. The CF content of sorghum produced at Bethlehem (2.93%) was significantly ($P \leq 0.05$) higher than that of sorghum produced at Ermelo (2.63%), while the CF content of sorghum produced at Potchefstroom (2.16%) was significantly ($P \leq 0.01$) lower than that of sorghum produced at the other two locations. The tannin content for low-tannin cultivars (GL) was the highest for sorghum from Bethlehem (0.28%), followed by sorghum from Ermelo (0.25%) and Potchefstroom (0.24%) ($P \leq 0.05$). For the high-tannin cultivars (GH), tannin content was the highest for the Ermelo crop (1.72%), followed by Bethlehem (1.45%) and Potchefstroom (0.94%).

When physical characteristics are taken into account, sorghum produced at Potchefstroom had a significantly ($P \leq 0.01$) higher hectolitre and thousand seed mass than grain produced at Bethlehem. Hectolitre masses were 73.80 (Bethlehem), 75.44 (Ermelo) and 76.65 kg/hectolitre (Potchefstroom), while the corresponding thousand seed masses were 25.11, 27.08 and 32.07 g, respectively. The differences between the Bethlehem and Ermelo productions were significant ($P \leq 0.05$). It seems that the results presented on the chemical composition and physical characteristics of sorghum produced at different locations are in contrast with results of Batterham *et al.* (1980), who found no relationship between the physical and chemical composition of sorghum and area of production. The differences found in this study are possibly due to the large differences in rainfall and environmental conditions between locations. The results were, however, in agreement with those of Miller *et al.* (1964) (average CP content of sorghum produced at different locations vary from 8.3 to 10.6%) and Hibberd *et al.* (1980) (also found that CP content was location dependent). Hibberd *et al.* (1980) found no significant difference in starch content of sorghum produced at different locations, which is contrary to the findings of this study.

The DM digestibilities and DE contents of 13 different South African grain sorghum cultivars produced at two different locations (Bethlehem and Ermelo) are summarized in Table 3. Significant ($P \leq 0.01$) interactions between cultivar and location were found, and the results for the two locations were therefore presented separately. Significant ($P \leq 0.01$) differences in the DM digestibility and DE content between individual cultivars were found, which confirmed the results of Davis & Harbers (1974) and Hibberd *et al.* (1982). The significant interaction found between cultivar and location, however, implies that a specific nutritive value cannot be allocated to a cultivar, and indicated that important practical implications are implied. For example, Barnard Red had the highest DE content when it was grown at Bethlehem (17.5 ± 0.4 MJ/kg DM), but the lowest DE content of the low-tannin cultivars when grown at Ermelo (15.0 ± 1.7 MJ/kg DM). This result therefore indicated that the specific conditions under which the sorghum was grown may have influenced the nutritive value of the individual cultivars. The DE content of sorghum from Ermelo generally tended to be lower than the DE content of sorghum from Bethlehem. The mean DE content of GL cultivars was 16.7 ± 1.2 (Bethlehem) and 16.1 ± 1.2 MJ/kg DM (Ermelo), while DE contents for GH cultivars were 15.0 ± 0.9 (Bethlehem) and 13.5 ± 1.9 MJ/kg DM (Ermelo). The results obtained in this study suggested that climatic and seasonal effects, not investigated in this study, might have influenced values obtained. Although these effects may well be responsible for the contradictory results achieved in practice, it does not solve the problem, since it is not possible to attach a nutritive value to a specific sample or cultivar unless physically determined.

The chemical composition, density, DM digestibility and DE contents of the individual grain sorghum cultivars are presented in Table 4. The DE contents of the different low-tannin (GL) cultivars varied between 17.1 ± 0.9 (Ruby) and 15.3 ± 1.7 MJ/kg DM (RA 787), with a mean value of 16.1 ± 0.6 MJ/kg DM. The DM digestibility varied between 93.4 ± 5.2 (SNK 3241) and 87.3 ± 10% (Barnard Red) with a mean DM digestibility of GL sorghum of 90.9 ± 2.4%. The DE contents of the high-tannin (GH) grain sorghum cultivars

Table 3 Dry matter digestibility and digestible energy content of different South African grain sorghum cultivars produced at two different locations, viz. Bethlehem and Ermelo

		Measurement			
		Dry matter digestibility (%)		Digestible energy (MJ/kg)*	
Cultivar	Type	Bethlehem	Ermelo	Bethlehem	Ermelo
Barnard Red	GL	95.9 ± 1.9	73.9^{b} ± 15.9	17.5 ± 0.4	15.0^{b} ± 1.7
SNK 3345	GL	95.2 ± 2.4	89.9 ± 3.8	17.4 ± 0.4	16.2^{a} ± 0.8
NK 286	GL	94.9 ± 2.2	89.5^{a} ± 0.4	17.4 ± 0.4	16.2^{a} ± 0.9
Breytenbach Red	GL	92.8 ± 2.1	90.3 ± 3.5	17.2 ± 0.4	16.1^{a} ± 0.7
Ruby	GL	92.7 ± 2.2	92.8 ± 2.2	17.3 ± 0.4	16.9^{a} ± 0.5
PNR 8311	GL	81.4^{b} ± 7.2	93.0 ± 2.2	14.7^{b} ± 1.0	16.9 ± 0.5
RA 787	GL	83.4 ± 2.0	85.3 ± 5.5	15.4 ± 1.1	15.2 ± 2.1
NK 283	GL	92.1 ± 7.2	87.6 ± 4.3	16.9 ± 0.4	15.9 ± 1.1
PNR 8537	GL	88.8 ± 7.2	90.5 ± 4.5	15.9 ± 1.3	16.2 ± 1.1
NK 300	GL	91.0 ± 4.2	89.5 ± 5.1	16.4 ± 0.7	15.9 ± 1.2
Mean ± *SD*	GL	91.5 ± 6.2	88.5^{b} ± 10.5	16.7 ± 1.2	16.1^{b} ± 1.2
SSK 30	GH	86.1 ± 5.6	81.0 ± 10.4	15.1 ± 0.9	14.3 ± 1.5
DC 75	GH	83.7 ± 2.9	71.6^{b} ± 10.0	15.5 ± 0.7	12.3^{b} ± 2.0
Nyoni Red	GH	81.8 ± 8.3	77.4^{a} ± 7.6	14.6 ± 1.9	13.9 ± 1.4
Mean ± *SD*	GH	83.9 ± 6.1	76.6^{b} ± 9.1	15.0 ± 0.9	13.5^{b} ± 1.9
LSD ($P \leq 0.05$) between cultivars		5.9		0.7	
LSD ($P \leq 0.01$) between cultivars		7.8		0.9	

^{a} Denote significant ($P \leq 0.05$) differences between locations; ^{b} Denote significant ($P \leq 0.01$) differences between locations; * On a dry-matter basis.

Table 4 Chemical composition, density, dry matter digestibility and digestible energy content of 21 different South African grain sorghum cultivars produced under dry land conditions

		Chemical composition* (%)					Density**			
Cultivar	Type†	Dry matter	Crude protein	Crude fibre	Starch	Tannin	Hectolitre mass (kg/hl)	1 000 seed mass (%)	DM digestibility (%)	DE content (MJ/kg DM)
NK 304	GL	89.1 ± 0.4	11.7 ± 1.9	2.7 ± 0.3	72.4 ± 0.1	0.3 ± 0.04	73.2 ± 2.3	26.1 ± 3.8	92.9 ± 2.7	16.9 ± 0.2
SNK 3377	GL	88.8 ± 0.2	10.6 ± 0.5	2.9 ± 0.5	74.2 ± 1.2	0.3 ± 0.02	72.7 ± 0.4	25.8 ± 2.1	91.8 ± 4.3	15.4 ± 1.1
G 766 W	GL	89.0 ± 0.4	11.2 ± 1.4	2.9 ± 0.1	73.1 ± 0.9	0.2 ± 0.01	73.5 ± 1.8	23.4 ± 0.8	90.8 ± 4.6	15.5 ± 1.2
DC 34	GL	89.0 ± 0.3	11.6 ± 1.0	2.8 ± 0.1	70.2 ± 3.6	0.2 ± 0.01	75.2 ± 0.01	29.7 ± 0.3	91.0 ± 6.8	15.4 ± 1.7
SNK 3241	GL	89.0 ± 0.6	11.3 ± 1.0	2.8 ± 0.2	73.7 ± 1.2	0.3 ± 0.04	76.6 ± 0.4	27.2 ± 1.1	93.4 ± 5.2	15.6 ± 1.2
OPAL	GL	89.0 ± 0.2	11.7 ± 0.1	3.4 ± 0.6	72.3 ± 2.2	0.2 ± 0.01	72.3 ± 1.2	28.7 ± 1.2	92.6 ± 4.5	15.4 ± 1.0
SNK 3349	GL	89.3 ± 1.0	12.6 ± 1.3	2.9 ± 0.1	72.2 ± 0.3	0.2 ± 0.01	73.4 ± 0.5	26.0 ± 2.1	93.0 ± 3.2	16.2 ± 0.6
CAR 7611	GL	89.2 ± 0.3	12.2 ± 1.7	2.7 ± 0.1	73.1 ± 0.2	0.3 ± 0.01	76.3 ± 1.6	27.8 ± 1.6	92.4 ± 3.9	16.0 ± 0.8
Barnard Red	GL	89.3 ± 0.1	12.8 ± 0.1	2.5 ± 0.1	72.6 ± 0.3	0.3 ± 0.06	77.4 ± 1.4	28.3 ± 2.7	87.3 ± 10.0	16.6 ± 1.6
SNK 3345	GL	89.2 ± 0.1	12.1 ± 1.3	2.5 ± 0.1	70.5 ± 1.3	0.3 ± 0.01	76.6 ± 2.1	29.5 ± 1.5	92.9 ± 4.1	16.8 ± 0.8
NK 286	GL	89.1 ± 0.1	11.8 ± 0.7	3.3 ± 0.6	71.7 ± 1.3	0.3 ± 0.03	74.8 ± 0.2	23.8 ± 0.8	92.7 ± 0.8	16.8 ± 0.9
Breytenbach Red	GL	89.1 ± 0.1	11.2 ± 1.1	2.4 ± 0.3	71.3 ± 1.6	0.3 ± 0.02	77.8 ± 1.1	26.3 ± 1.7	91.5 ± 3.2	16.7 ± 0.8
Ruby	GL	89.3 ± 0.1	11.6 ± 1.3	2.6 ± 0.4	70.7 ± 1.0	0.3 ± 0.03	73.4 ± 1.0	28.2 ± 0.2	92.7 ± 2.2	17.1 ± 0.9
PNR 8311	GL	89.3 ± 0.1	12.3 ± 1.6	2.8 ± 0.4	68.2 ± 1.1	0.3 ± 0.04	75.3 ± 0.2	23.9 ± 0.5	88.6 ± 7.1	16.1 ± 1.3
RA 787	GL	89.4 ± 0.1	12.6 ± 1.2	2.6 ± 0.4	69.8 ± 2.8	0.3 ± 0.01	75.0 ± 0.4	27.7 ± 1.3	84.4 ± 8.4	15.3 ± 1.7
NK 283	GL	89.4 ± 0.1	11.8 ± 0.8	2.8 ± 0.2	69.0 ± 0.6	0.2 ± 0.03	74.9 ± 1.1	26.2 ± 0.3	88.9 ± 5.4	16.2 ± 1.1
PNR 8537	GL	89.2 ± 0.4	12.6 ± 0.6	2.4 ± 0.3	70.0 ± 1.0	0.2 ± 0.01	74.4 ± 2.3	23.2 ± 0.4	89.6 ± 5.6	16.1 ± 1.3
NK 300	GL	88.9 ± 0.8	11.2 ± 0.1	2.4 ± 0.1	73.3 ± 0.1	0.3 ± 0.03	73.4 ± 1.6	25.9 ± 1.7	90.1 ± 4.5	16.1 ± 1.0
Mean ± *SD*	GL	89.1 ± 0.2	11.8 ± 0.6	2.7 ± 0.3	71.6 ± 1.7	0.3 ± 0.03	74.7 ± 1.6	26.5 ± 2.0	90.9 ± 2.4	16.1 ± 0.6
SSK 30	GH	89.1 ± 0.1	12.1 ± 0.5	2.5 ± 0.2	67.4 ± 0.9	1.5 ± 0.09	74.6 ± 0.2	27.3 ± 0.1	83.6 ± 6.5	14.8 ± 1.3
DC 75	GH	88.4 ± 0.7	12.2 ± 1.2	3.1 ± 0.2	64.6 ± 1.4	1.7 ± 0.20	74.0 ± 1.4	22.9 ± 1.6	75.6 ± 10.1	13.4 ± 2.0
Nyoni Red	GH	88.1 ± 0.9	13.2 ± 0.3	3.1 ± 0.3	66.2 ± 0.2	1.5 ± 0.10	71.7 ± 4.3	25.0 ± 1.5	79.5 ± 8.0	14.2 ± 1.6
Mean ± *SD*	GH	88.5 ± 0.4	12.5 ± 0.5	2.9 ± 0.3	66.1 ± 1.2	1.6 ± 0.10	73.4 ± 1.3	25.1 ± 1.8	79.6 ± 4.0	14.1 ± 0.6

* On a dry-matter basis; ** On an air-dry basis; † GL: normal endosperm low-tannin sorghum; GH: normal endosperm high-tannin sorghum.

were 13.4 ± 2.0 (DC 75), 14.2 ± 1.6 (Nyoni Red) and 14.8 ± 1.3 MJ/kg DM (SSK 30), with a mean value of 14.1 ± 0.6 MJ/kg DM. The corresponding DM digestibilities for the GH cultivars were 75.6, 79.5 and 83.6% respectively, with a mean DM digestibility of 79.6% ± 4.0%.

The DE content of grain in our study was within the range of values reported by Ewan (1983) (variation between 17.3 and 14.6 with a mean value of 16.05 MJ/kg DM), Evans (1985) (variation between 16.2 and 16.6 with a general value of 16.6 MJ/kg DM) and INRA (1984) (DE content of 15.6 MJ/kg DM for GL cultivars and 14.9 MJ/kg DM for GH cultivars). The mean DE content of GH sorghum cultivars (14.1 MJ/kg DM) was in agreement with the DE content determined by Kemm & Ras (1985) for sorghum with 1.33% tannic acid (13.85 ± 0.2 MJ/kg DM). The lower DE content of GH sorghum seemed to be negatively related to a higher tannin content ($r = -0.76$). The negative influence of tannin on digestibility was also reported by other researchers (Kemm *et al.*, 1984; Halley *et al.*, 1986). A regression equation based on the data presented in Table 4, in which DE content was regressed against the different physical parameters measured, showed no effect of hectolitre mass and thousand seed mass on DE content. The DE content was, however, significantly ($P \leq 0.01$) affected by tannin, starch and protein content.

The chemical and physical composition as well as the DM digestibilities and DE contents of samples compiled to contain 0, 4, 8, 12 and 16% unthreshed grain and sorghum with seed sizes <2 mm, 2—2.5 mm and 2.5—3 mm, are presented in Tables 5 & 6. No significant differences in the chemical composition of sorghum samples with different amounts of unthreshed grain or sorghum with different seed sizes were detected. Crude fibre content, however, tended to increase with an increase in the amount of unthreshed grain ($P \leq 0.01$). The amount of unthreshed grain had significant ($P \leq 0.05$) and highly significant ($P \leq 0.01$) effects on the hectolitre mass. A negative correlation (–0.83) was found between these parameters ($P \leq 0.01$). Corah & Kuhl (1985) also found a decline in hectolitre mass when CF increased. Thousand seed and hectolitre mass differed significantly ($P \leq 0.01$ and $P \leq 0.05$ respectively) between the different seed sizes. Although the correlation coefficient between seed size and hectolitre mass (0.55) was significant ($P \leq 0.05$), that between seed size and thousand seed mass (0.98) was highly significant ($P \leq 0.01$). No significant differences in DM digestibility of DE content were found between samples with different amounts of unthreshed grain or between samples of different seed sizes. A tendency, however, existed for DE content to decrease with an increase in percentage of unthreshed grain and the percentage

Table 5 Hectolitre mass, chemical composition, dry matter (DM) digestibility and digestible energy (DE) contens of sorghum with different amounts of unthreshed grain added

	Density [b]	Chemical composition [c] (%)					
Composition [a]	Hectolitre mass (%)	Crude protein	Crude fibre	Starch	Tannin	DM [c] digestibility (%)	DE [c] content (MJ/kg DM)
0%	76.9 ± 1.2	10.7 ± 1.4	2.2 ± 0.4	72.2 ± 0.8	0.22 ± 0.04	95.1 ± 1.3	17.6 ± 0.3
4%	75.6 ± 2.1	10.7 ± 1.4	2.3 ± 0.6	72.4 ± 1.8	0.22 ± 0.04	91.5 ± 3.0	17.2 ± 0.7
8%	74.2 ± 1.6	11.2 ± 1.2	2.5 ± 0.4	72.1 ± 2.4	0.23 ± 0.05	90.7 ± 3.5	16.9 ± 0.9
12%	72.3 ± 2.0	10.8 ± 1.3	2.6 ± 0.4	72.0 ± 0.8	0.21 ±0.04	89.4 ± 6.8	16.9 ± 1.6
16%	69.0 ± 2.2	10.7 ± 0.8	2.9 ± 0.6	70.4 ± 1.9	0.21 ± 0.04	89.8 ± 6.0	16.3 ± 2.0
LSD [d] ($P = 0.05$)	2.3	–	–	–	–	–	–
LSD [d] ($P = 0.01$)	3.1	–	–	–	–	–	–

[a] Percentage unthreshed grain added to screened samples.
[b] On an air-dry basis.
[c] On a dry-matter basis.
[d] Least significant difference.

Table 6 Density, chemical composition, dry matter (DM) digestibility and digestible energy (DE) content of sorghum of different seed sizes

	Density *		Chemical composition ** (%)					
Seed size (mm)	1 000 seed mass (g)	Hectolitre mass (kg/hectolitre)	Crude protein	Crude fibre	Starch	Tannin	DM ** digestibility (%)	DE ** content (MJ/kg DM)
< 2 mm	12.8[1] ± 0.6	–	11.2 ± 0.6	2.7 ± 0.6	72.6 ± 2.1	0.22 ± 0.06	92.7 ± 3.8	14.7 ± 0.9
2—2.5 mm	22.5[2] ± 1.3	76.0[a] ± 1.8	10.9 ± 0.6	2.6 ± 0.4	72.1 ± 2.0	0.18 ± 0.10	95.1 ± 2.2	15.2 ± 0.4
2.5—3 mm	29.1[3] ± 1.3	77.7[b] ± 0.09	11.6 ± 1.2	2.3 ± 0.5	72.7 ± 2.3	0.23 ± 0.04	93.3 ± 2.9	14.9 ± 0.8

* On an air-dry basis.
** On a dry-matter basis.
[a,b] Denote significant ($P = 0.05$) differences in columns.
[1,2,3] Denote significant ($P = 0.01$) differences in columns.

unthreshed grain significantly ($P \leq 0.05$) depressed the mean DE value (r = 0.85). The DM digestibility declined from 95.1% (0% unthreshed grain) to 89.8% (16% unthreshed grain) with corresponding DE values of 17.6 and 16.3 MJ/kg DM. The decrease in mean DE content and mean DM digestibility corresponded well with the increase in crude fibre content and decrease in starch content. The mean DE content was significantly ($P \leq 0.01$) affected by starch content and a positive correlation coefficient of 0.97 was found for samples with different percentages of unthreshed grain. Crude fibre content had a significantly ($P \leq 0.01$) negative correlation ($r = -0.95$) with mean DE value.

The hectolitre mass, DM digestibilities and DE contents of grain sorghum samples, which consisted of different amounts of small (<2 mm) seeds (0, 10 and 20%), impurities (0, 1.5 and 3%) and unthreshed grain (0, 10 and 20%), are presented in Table 7. In a multiple regression analysis, hectolitre mass was significantly ($P \leq 0.01$) decreased by the amount of small seeds ($b \pm SE$ = −0.065 ± 0.013), impurities ($b \pm SE$ = −3.16 ± 0.08) and unthreshed grain ($b \pm SE$ = −0.19 ± 0.01) present. The total model accounted for 95.4% of the variation in hectolitre mass. Hectolitre mass significantly ($P \leq 0.01$) influenced DE (r = 0.27), although the correlation coefficients were low. Digestibility of DM was significantly ($P \leq 0.01$) affected by percentage of small seeds as well as by percentage of unthreshed grain. The DM digestibility values were 86.8 ± 2.9, 86.9 ± 2.9 and 84.3 ± 6.4 for 0, 10 and 20% small seeds, 86.4 ± 5.0, 85.5 ± 5.0 and 85.9 ± 4.0 for 0, 1.5 and 3% impurities, and 88.1 ± 3.7, 86.9 ± 3.9 and 83.4 ± 5.4 for 0, 10 and 20% unthreshed grain respectively. The DE contents of samples were also significantly ($P \leq 0.01$) affected by the amounts of small seeds and unthreshed grain. The DE contents were 16.0 ± 0.9, 16.0 ± 0.8 and 15.4 ± 1.4 MJ/kg DM for 0, 10 and 20% small seeds, 15.9 ± 1.2, 15.7 ± 1.2 and 15.8 ± 1.0 for 0, 1.5 and 3% impurities, and 16.3 ± 0.8, 16.1 ± 0.9 and 15.2 ± 1.3 for 0, 10 and 20% unthreshed grain respectively. Grading had a significant ($P \leq 0.01$) effect on DM digestibility and DE content. DM digestibilities found were 88.5 ± 3.4 (Grade 1), 86.8 ± 3.2 (Grade 2), and 83.4 ± 5.4 (Grade 3), and DE contents found were

Table 7 Hectolitre mass, DM digestibility and DE content (means ± SD) of grain sorghum samples which consisted of different amounts of small seeds (< 2 mm), impurities and unthreshed grain

Composition[a] (%)						
Small grain	Impurities	Unthreshed grain	Grading	Hectolitre mass (kg/hectolitre)	DM digestibility (%)	DE content (MJ/kg DM)
0	0	0	GL1	73.1 ± 0.07	89.6 ± 3.6	16.4 ± 1.1
0	1.5	0	GL1	67.7 ± 0.54	86.5 ± 4.5	15.8 ± 1.1
0	3	0	GL2	62.9 ± 0.20	86.6 ± 5.1	15.3 ± 1.7
10	0	0	GL1	72.4 ± 0.09	89.0 ± 5.4	16.1 ± 1.4
10	1.5	0	GL1	67.2 ± 0.30	89.3 ± 4.1	16.6 ± 0.8
10	3	0	GL2	61.8 ± 0.50	87.8 ± 2.8	16.3 ± 0.6
20	0	0	GL2	71.3 ± 0.17	88.1 ± 3.0	16.3 ± 0.7
20	1.5	0	GL2	66.9 ± 0.45	86.7 ± 3.8	15.8 ± 0.8
20	3	0	GL2	61,2 ± 0.68	89.8 ± 3.2	16.9 ± 0.6
0	0	10	GL1	70.4 ± 0.21	88.0 ± 3.2	16.3 ± 0.7
0	1.5	10	GL1	65.1 ± 0.49	90.1 ± 2.3	17.0 ± 0.5
0	3	10	GL2	60.1 ± 0.36	87.3 ± 3.5	16.0 ± 0.9
10	0	10	GL1	70.0 ± 0.12	89.2 ± 2.1	16.3 ± 0.5
10	1.5	10	GL1	64.9 ± 0.29	86.5 ± 3.6	15.8 ± 1.1
10	3	10	GL2	62.2 ± 0.60	88.1 ± 2.5	16.4 ± 0.5
20	0	10	GL2	68.9 ± 0.42	84.7 ± 4.5	15.3 ± 1.2
20	1.5	10	GL2	64.0 ± 1.10	855.0 ± 4.3	15.7 ± 0.9
20	3	10	GL2	61.2 ± 1.17	84.8 ± 4.8	16.1 ± 1.2
0	0	20	GL3	69.2 ± 0.48	86.9 ± 1.8	16.1 ± 0.5
0	1.5	20	GL3	64.5 ± 0.89	84.3 ± 3.7	15.4 ± 0.9
0	3	20	GL3	59.1 ± 0.78	84.2 ± 2.2	15.7 ± 0.7
10	0	20	GL3	67.4 ± 0.44	85.9 ± 2.4	16.1 ± 0.7
10	1.5	20	GL3	65.0 ± 0.62	83.9 ± 2.9	15.7 ± 1.2
10	3	20	GL3	58.3 ± 0.52	83.7 ± 3.8	15.5 ± 0.8
20	0	20	GL3	66.8 ± 0.47	80.2 ± 10.0	14.5 ± 2.2
20	1.5	20	GL3	62.9 ± 0.50	80.2 ± 7.7	14.2 ± 1.8
20	3	20	GL3	56.7 ± 0.82	82.6 ± 4.1	14.8 ± 1.0
LSD ($P \leq 0.05$)				1.13	3.7	0.87
LSD ($P \leq 0.01$)				1.51	4.9	1.14

[a] On an air-dry basis.

[b] On a dry-matter basis.

16.4 ± 0.8 (Grade 1), 16.0 ± 0.8 (Grade 2) and 15.2 ± 1.0 (Grade 3).

A correlation coefficient of 0.98 was found between DM digestibility and DE content. The following linear regression equation may be used to predict DE content from DM digestibility:

DE content (MJ/kg DM) = $-3.50 + 0.22x$ ($SE = 0.003$)
where x = DM digestibility (%)
($r = 0.98$; $P \leq 0.01$; Sy.x = 0.07; $n = 306$).

Conclusions

It can be concluded from this study that differences in DE content occur between individual GL and GH sorghum cultivars. Grain produced at different locations also differs in chemical and physical composition and DE content which is further complicated by a significant ($P \leq 0.01$) location × cultivar interaction. Some of the variation in DE may be ascribed to the variation in chemical composition and also the physical characteristics of the grain. It furthermore seemed that the specific conditions under which the sorghum was grown influenced the nutritive value of the individual cultivars, which implies that a specific nutritive value cannot be allocated to a cultivar. The observed differences described and discussed may be responsible for the variation in the nutritive value and the contradictory results achieved in practice with sorghum grain. In agreement with other researchers, it was difficult to obtain highly correlated relationships between the chemical or physical composition and DE content of sorghum. The South African grain sorghum grading system accounts for the differences in DE content through the amounts of unthreshed grain and small seeds allowed in each grade.

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