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Factors Affecting the Porridge-Making Quality of South African Sorghums

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Abstract: Research was undertaken to facilitate the breeding and selection of sorghums with both good milling and good porridge-making characteristics. Twenty seven cultivars were grown in the same locality under rainfed and supplementary irrigation conditions. The two measures of milling quality, abrasive hardness index and Brabender hardness (BH) were significantly correlated ($P \leqslant 0{\cdot}001$) in all sample sets; ie all data, rainfed samples and supplementary irrigation samples. The genetic basis of kernel hardness was confirmed as the hardest and softest cultivars were the same under both cultivation conditions. For all three sample sets there was a significant negative correlation ($P \leqslant 0{\cdot}05$) between kernel hardness according to BH and pasting peak viscosity (PPV). PPV is of importance as consumers prefer stiff porridges. The negative correlation between BH and PPV indicates that to select sorghum cultivars with good milling and good porridge-making quality, both kernel hardness and PPV need to be assessed. The sorghums produced under supplementary irrigation were softer according to BH, had higher PPV and set-back viscosity, and the starch contained a higher proportion of amylose than those produced under rainfed conditions. Thus, cultivation environment as well as genetics has a major effect on sorghum milling and porridge-making quality.

Key words: sorghum, kernel hardness, porridge, pasting, amylose, starch gelatinisation.

INTRODUCTION

Porridge made from sorghum was traditionally the staple diet of the black people of southern Africa. Although today sorghum has been displaced to a considerable extent by maize, sorghum porridges, especially fermented, sour porridges remain popular, particularly among the Tswana of Botswana and South Africa (Novellie 1982; Sooliman 1993)

The production of sorghum porridge involves first producing a meal from sorghum grain. Commercially, this is generally done by first removing the pericarp and much of the germ (commonly referred to as de-hulling), usually by a process of abrasion, then hammer milling the remaining part of the kernel (essentially endosperm) into a coarse meal. Alternatively, endosperm meal can be produced directly from grain by roller milling (Munck 1995). The meal is then cooked with boiling water into a porridge, either directly or after a lactic acid fermentation (Novellie 1982). The exact porridge-making process varies considerably depending on the type of porridge being produced.

It is well known that kernel hardness affects the yield of meal from sorghum grain (Maxson *et al* 1971). For this reason, sorghum millers demand hard cultivars. However, the interrelationship between kernel hardness and sorghum porridge-making quality is little understood. This relationship is important because one of the reasons that the consumption of sorghum has declined relative to maize is that it apparently produces much less stiff porridges. Stiff porridges are generally preferred as porridges are traditionally eaten by hand.

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The objective of the work described here was to investigate the factors involved in sorghum porridge-making quality. The work was undertaken to facilitate the breeding and selection of sorghums with good both milling and porridge-making characteristics.

MATERIALS AND METHODS

Materials

Twenty seven sorghum cultivars were grown by the Grain Crops Institute of the Agricultural Research Council at Potchefstroom (North West Province, Republic of South Africa) during the 1992–1993 season, under two conditions: rainfed (450 mm) and supplementary irrigation. In the latter condition the plants were irrigated only when necessary to prevent moisture stress.

The cultivars were as follows: SNK 3975, PAN 8560, NK 283, PAN 8564, SNK 3727, PAN 8590, SNK 3939, PAN 8591, CRN 7686, PAN 8510, CRN 7610, CRN 766W, SNK 3211, PAN 8501, DC 333, PAN 8529, PAN 8425, SNK 3355, SNK 3337, PAN 8521, SNK 3399W, PAN 8526, A 1994M, PAN 8420, Phb 8601, PAN 8522 and Phb 8505.

Grain cleaning

Prior to performing the various analyses, the grain samples were cleaned using a small-scale impeller-type dehuller operating on the principle of air classification. Broken kernels were removed by sieving the samples through a 1·28 mm screen.

Kernel hardness

Brabender hardness (BH) (energy required to grind the grain into a meal) was measured using an instrument based on the Farinograph (Brabender OHG, Duisburg, Germany) where the dough mixing equipment is replaced by a small burr mill. The grinding energy was measured as the area (cm^2) under the load curve obtained when 30 g of grain was milled in the instrument.

Abrasive hardness index (AHI) was measured by progressively decorticating the grain using a tangential abrasive dehulling device (TADD) (Oomah *et al* 1981). Abrasion was brought about by sand paper (60 grit, Norton type R284 metalite). For each sample, 5 × 50 g aliquots of grain were weighed out. An aliquot was distributed into the TADD cups. Abrasion was performed for 2 min. The abraded grain was then cleaned with a cyclone, weighed and then discarded. The procedure was repeated for 4, 6, 8 and 10 min of abrasion and the data plotted graphically. AHI was calculated from the graph as the time in seconds to abrade off 1% by weight of the grain.

Pasting properties

These were determined using a Rapid Visco Analyser, model RVA-3C (Newport Scientific, Narrabeen, Australia) which was operated as an amylograph. Whole grain samples were milled using a disc mill (Miag, Braunschweig, Germany) at a gap setting of 0·2 mm. Whole and not dehulled grain was used so as to include all the endosperm. Flour (3 g) was transferred into a RVA cup, 25 ml distilled water was added and the analysis was performed. The time–temperature settings for the RVA were as follows: 2 min, 50°C; 8 min, 91°C; 8 min, 50°C. Pasting peak viscosity (PPV) was measured as the first amylogram peak (ie the maximum paste viscosity under the conditions of analysis) and expressed in stirring number units (SNU). Set-back viscosity (SBV) was measured as the second amylogram peak (where such a peak occurred), or as the viscosity at the end of the run where no second peak was reached (ie the maximum viscosity obtained upon cooling the paste).

Starch properties

The grain was milled to a fine flour using a laboratory hammer mill (Falling Number AB, Huddinge, Sweden) fitted with a 800 μm screen. The flour (20 g) was mixed with 100 ml 1% (w/v) sodium metabisulphite solution to form a slurry, then stirred at intervals over a period of 1 h. After this, the slurry was passed through a wet mill (Retsch, Haan, Germany), fitted with 250 μm sieve. The liquid containing the starch was retained and the fibrous residue on the screen discarded. The liquid was passed through a 100 μm sieve, then centrifuged in 100 ml glass centrifuge tubes in a swing-out rotor at 800 × g for 2 min. The supernatant was decanted off and the brown coloured protein layer was scraped off. The white coloured starch-rich pellet was then resuspended in distilled water and recentrifuged. Again the supernatant was decanted and the protein layer scraped off. This process was repeated until there was an apparently pure starch pellet. The pellet was then dried at 50°C overnight in a forced draught oven.

The iodine binding capacity method of Bates *et al* (1943) was used to determine the amylose content of the starch samples. The initial and final gelatinisation temperatures of the starch samples were determined by hot stage microscopy, using polarised light. The temperature at which the first birefringence cross in a field of view disappeared was recorded as the initial gelatinisation temperature, and the temperature at which the final birefringence cross disappeared was recorded as the final gelatinisation temperature.

Statistical analysis

All analyses were performed at least in duplicate and results recorded as the mean. The data were analysed by multifactor analysis of variance and linear regression analysis.

RESULTS AND DISCUSSION

The 27 sorghum cultivars exhibited a wide range of milling quality as measured by kernel hardness (Table 1). Under both rainfed and supplementary irrigation conditions, the two softest cultivars were PAN 8501 and SNK 3355 and the two hardest Phb 8505 and PAN 8420, as determined by both AHI and BH. This confirms the genetic basis of sorghum kernel hardness (House *et al* 1995). With the BH method, the cultivars grown under supplementary irrigation conditions were significantly softer ($P \leqslant 0·05$) than those grown under rainfed conditions. However, with the AHI method there was no significant difference between the two sets of samples. The difference in results between the two methods is an indication that they are measuring somewhat different facets of kernel hardness. Despite this, there was a highly significant correlation ($P \leqslant 0·001$) between kernel hardness as measured by the two methods for all the sample sets, ie all data, rainfed samples and supplementary irrigation samples (Table 2). This finding confirms previous research by Reichert *et al* (1982) which showed that AHI was correlated with BH. However, in view of the difference in effect of supplementary irrigation, it appears to be of value to determine sorghum kernel hardness using both methods, especially as various different technologies are used to mill sorghum grain (Munck 1995).

The cultivars also exhibited a wide range of PPV (Table 1). PPV is of considerable importance with

TABLE 1

Brabender hardness (BH), abrasive hardness index (AHI), pasting peak viscosity (PPV) and set-back viscosity (SBV) for 27 sorghum cultivars grown under rainfed and supplementary irrigation conditions.[a]

	BH		*AHI*		*PPV*		*SBV*	
	Rainfed	*Supplementary irrigation*	*Rainfed*	*Supplementary irrigation*	*Rainfed*	*Supplementary irrigation*	*Rainfed*	*Supplementary irrigation*
SNK 3975	95·1	90·4	5·58	5·31	76	94	120	163
PAN 8560	106·1	106·0	6·15	8·26	67	86	110	154
NK 283	111·7	109·0	6·09	5·85	71	91	112	162
PAN 8564	106·6	107·8	5·64	5·78	62	72	120	155
SNK 3727	134·5	122·2	6·35	6·08	62	75	124	181
PAN 8590	122·9	95·8	6·06	6·07	54	69	115	184
SNK 3939	115·7	88·0	6·35	6·14	67	81	121	174
PAN 8591	92·5	95·5	6·17	6·12	67	84	124	180
CRN 7686	112·8	100·8	6·52	6·39	68	86	130	178
PAN 8510	117·4	98·2	6·31	5·97	54	70	114	182
CRN 7610	118·7	92·5	6·98	6·24	61	79	120	175
CRN 766W	99·7	95·7	5·98	6·10	77	83	134	184
SNK 3211	109·7	107·2	5·65	5·84	73	84	127	164
PAN 8501	74·6	57·5	4·63	4·57	72	89	119	158
DC 333	97·5	103·5	5·93	5·95	77	94	126	183
PAN 8529	121·7	105·5	6·31	5·72	51	63	112	160
PAN 8425	101·4	88·9	5·95	5·44	67	85	121	168
SNK 3355	79·5	77·9	5·44	5·39	84	101	131	188
SNK 3337	129·9	115·5	6·60	6·24	60	73	123	155
PAN 8521	111·9	98·4	5·75	5·80	50	62	123	205
SNK 3399W	118·4	127·1	5·99	5·98	71	84	134	170
PAN 8526	126·5	117·8	6·46	7·02	74	86	174	194
A 1994M	113·3	95·9	6·58	6·41	82	95	159	183
PAN 8420	135·4	127·1	7·71	8·59	64	74	187	198
Phb 8601	146·5	131·6	7·10	7·21	64	75	164	185
PAN 8522	111·8	100·0	6·22	6·17	75	83	155	174
Phb 8505	156·3	130·9	7·94	8·02	57	70	156	205
Mean	113·6a	103·2b	6·24a	6·27a	67a	81b	132a	176b

[a] Where the means of the rainfed and irrigated samples for a particular characteristic have different letters they are significantly different from each other ($P \leqslant 0·05$).

TABLE 2

Correlation matrix for Brabender hardness (BH), abrasive hardness index (AHI), pasting peak viscosity (PPV) and set-back viscosity (SBV) for sorghum cultivars grown under rainfed and supplementary irrigation conditions

	SBV	*PPV*	*AHI*
BH	−0·006[a]	−0·526**	0·677***
	0·458[b]*	−0·528**	0·845***
	0·264[c]	−0·395*	0·641***
AHI	0·278	−0·192	
	0·580**	−0·324	
	0·327	−0·212	
PPV	0·501**		
	0·256		
	−0·192		

[a] All data (54 samples).
[b] Rainfed samples ($n = 27$).
[c] Supplementary irrigation samples ($n = 27$).
* $P \leqslant 0{\cdot}05$.
** $P \leqslant 0{\cdot}01$.
*** $P \leqslant 0{\cdot}001$.

regard to sorghum porridge-making quality, as consumers generally prefer stiff porridges because the porridge is traditionally eaten using the hand. The lowest PPVs were obtained with cultivars PAN 8521 and PAN 8529, and the highest with cultivars SNK 3355 and A 1994M, under both rainfed and supplementary irrigation conditions, indicating a genetic basis for differences in PPV. PPVs were significantly higher ($P \leqslant 0{\cdot}05$) for the cultivars grown under supplementary irrigation conditions. This is probably related to the fact that the supplementary irrigated samples were softer as measured by BH, thus facilitating greater expansion of the starch during gelatinisation. This is supported by the suggestion that sorghum grain hardness is related to the distribution density of protein bodies in the endosperm (Shull *et al* 1990) and that a high density of protein bodies acts as a barrier to starch gelatinisation (Chandrashekar and Kirleis 1988).

With all three sample sets there was a significant negative correlation ($P \leqslant 0{\cdot}05$) between BH and PPV (Table 2). In other words, the harder the kernel the lower the PPV and *vice versa.* A limited study of two sorghum cultivars by Hallgren (1984) also showed that soft endosperm gave higher PPV. This inverse relationship is probably also due to softer endosperm permitting greater expansion of the starch during cooking, as suggested above.

Porridges are eaten cold as well as hot. Often the remains of the morning hot porridge are eaten cold during the day. Thus, SBV is also of some importance. Cultivars PAN 8560, PAN 8529 and NK 283 gave the lowest SBV under rainfed conditions and supplementary irrigation conditions. Cultivars PAN 8526 and PAN 8420 gave the highest SBV under rainfed conditions, whereas PAN 8521 and Phb 8505 gave the highest under supplementary irrigation conditions, although PAN 8420 and PAN 8526 were third and fourth highest, respectively (Table 1). Thus, as with PPV there appears to be a genetic basis for differences in SBV. Also as with PPV, the SBVs of the samples grown under supplementary irrigation were significantly higher than those of the rainfed samples, probably for the same reason. For all data, SBV was significantly correlated ($P \leqslant 0{\cdot}01$) with PPV (Table 2), but there were no significant correlations for the individual rainfed and supplementary irrigation sets. SBV was also significantly correlated with both AHI ($P \leqslant 0{\cdot}01$) and BH ($P \leqslant 0{\cdot}05$) for the rainfed sample set only. These latter correlations are difficult to account for since SBV is usually a function of starch retrogradation (Rasper 1980).

To investigate the factors affecting PPV, starch was isolated from the six cultivars giving the highest PPV and the six giving lowest PPV. The starch from the cultivars exhibited a very wide range of mean amylose content, from 14·1 for DC 333 to 37·7% for PAN 8529. The low amylose value is possibly indicative of the heterowaxy type of sorghum (Ring *et al* 1982). A wide range in starch amylose content (19·6—29·3) has also been found in a survey of West African sorghums (Fliedel 1994).

There was no significant difference ($P > 0{\cdot}05$) in the mean amylose content of the starch between the high and low PPV groups, 26·1% for the high PPV group and 29·5% for the low PPV group (Table 3). The mean amylose values are similar to those found by Ring *et al* (1982) for sorghums grown in India and Texas, 24·9–27·4% and 26·2%, respectively, In contrast, the starch from cultivars grown under supplementary irrigation had a significantly higher ($P \leqslant 0{\cdot}05$) mean amylose content (32·0%) than that from those grown under rainfed conditions (23·5%) (Table 3). These findings support the suggestion of Ring *et al* (1982) that for non-waxy (normal starch) sorghums, environmental effects may exert more influence on amylose content than genetic differences.

It has been found that waxy (nearly 100% amylopectin starch) sorghum flour gives a much lower PPV than normal sorghum flour (Akingbala *et al* 1982). This was attributed to gelatinised waxy starch being fragile and unable to withstand the external pressure imposed by the endosperm matrix. It has also been found that the firmness of sorghum Tô porridge was highly correlated ($r = 0{\cdot}81$) with the amylose content of the starch (Fliedel 1994). The fact that cultivars produced under supplementary irrigation conditions (those with a lower proportion of amylopectin) also had a higher PPV (Table 1) strongly supports the theory of Akingbala *et al* (1982) and is in agreement with the findings of Fliedel (1994).

Tables 4 and 5, respectively, show that the high PPV group had a negligible but significantly higher

TABLE 3

Amylose content of starch extracted from sorghum cultivars with high and low pasting peak viscosity (PPV) grown under rainfed and supplementary irrigation conditions[a]

Cultivar	*Rainfed*	*Supplementary irrigation*	*Mean cultivar*	*Mean group*
High PPV				
SNK 3975	25·4	27·0	26·2b	26·1a
CRN 766W	19·8	35·7	27·8ab	
DC 333	14·5	13·6	14·1e	
SNK 3355	23·1	24·6	23·9cd	
PAN 8526	23·0	31·4	27·2b	
A 1994M	38·1	36·9	37·5a	
Low PPV				
PAN 8590	23·1	24·1	23·6cd	29·5a
PAN 8510	27·8	32·2	30·0ab	
PAN 8529	28·1	47·3	37·7a	
SNK 3337	27·1	34·1	30·6ab	
PAN 8521	16·7	42·3	29·5ab	
Phb 8505	15·5	35·2	25·4b	
	Mean rainfed 23·5a	Mean irrigated 32·0b		

[a] Mean values in rows or columns with different letters differ significantly from each other ($P \leqslant 0{\cdot}05$).

($P \leqslant 0{\cdot}05$) initial and final starch gelatinisation temperature than the low PPV group. Fliedel (1994) investigating factors affecting sorghum Tô quality, also found negligible differences in starch gelatinisation temperature between varieties. These results suggest that starch gelatinisation temperature is not a major factor in sorghum porridge quality. Tables 4 and 5 also show that there was no significant difference between the initial or final starch gelatinisation temperatures of the rainfed and supplementary irrigation groups. These findings support the conclusion that sorghum starch gelatinisation temperature is under genetic control (Akingbala *et al* 1982). The mean initial (63·6°C) and final (69·5°C) starch gelatinisation temperatures found in this study are rather lower than the values generally given in the literature, eg 68·5–75°C (FAO 1995) or

TABLE 4

Initial starch gelatinisation temperature of sorghum cultivars with high and low pasting peak viscosity (PPV) grown under rainfed and supplementary irrigation conditions

Cultivar	*Rainfed (°C)*	*Supplementary irrigation (°C)*	*Mean cultivar*	*Mean group*
High PPV				
SNK 3975	63·3	63·8	63·6abc	63·7a
CRN 766W	64·0	63·3	63·7bcd	
DC 333	63·5	63·8	63·7bcd	
SNK 3355	64·3	63·8	64·1d	
PAN 8526	64·3	63·5	63·9cd	
A 1994M	63·5	63·8	63·7bcd	
Low PPV				
PAN 8590	63·0	63·3	63·2a	63·4b
PAN 8510	63·5	63·8	63·7bcd	
PAN 8529	63·0	64·0	63·5abc	
SNK 3337	63·3	63·5	63·4ab	
PAN 8521	63·3	63·0	63·2a	
Phb 8505	63·8	63·3	63·6abc	
	Mean rainfed 63·6a	Mean irrigated 63·6a		

[a] Mean values in rows or columns with different letters differ significantly from each other ($P \leqslant 0{\cdot}05$).

TABLE 5

Final starch gelatinisation temperature of sorghum cultivars with high and low pasting peak viscosity (PPV) grown under rainfed and supplementary irrigation conditions

Cultivar	*Rainfed (°C)*	*Supplementary irrigation (°C)*	*Mean cultivar*	*Mean group*
High PPV				
SNK 3975	69·3	69·3	69·3ab	69·7a
CRN 766W	69·5	69·5	69·5bc	
DC 333	69·5	70·5	70·0de	
SNK 3355	70·5	69·8	70·1e	
PAN 8526	70·0	69·5	69·8cd	
A 1994M	70·0	69·5	69·8cd	
Low PPV				
PAN 8590	69·0	69·0	69·0a	69·2b
PAN 8510	69·0	69·0	69·0a	
PAN 8529	69·0	69·5	69·3ab	
SNK 3337	69·3	69·5	69·4bc	
PAN 8521	69·5	69·0	69·3ab	
Phb 8505	69·3	69·8	69·6bc	
	Mean rainfed 69·5a	Mean irrigated 69·5a		

[a] Mean values in rows or columns with different letters differ significantly from each other ($P \leqslant 0{\cdot}05$).

71·7–79·7°C (Serna-Saldivar and Rooney 1995). Some of this difference is obviously attributable to differences in analytical methodology. However, the values found in this study are in agreement with our practical experience when mashing with South African sorghums, where there is a very large increase in extract (due primarily to starch gelatinisation and solubilisation) when the mashing temperature is raised from 60 to 70°C, with little if any further increase above this temperature (Taylor 1992). This suggests that South African sorghums may have a somewhat lower gelatinisation temperature range than that of the sorghums reported to date.

CONCLUSIONS

There appears to be an inverse relationship between sorghum kernel hardness and PPV. Hence the selection of sorghum cultivars for good milling and good porridge-making quality can only be done by assessing both properties. Cultivation environment as well as genetics has a major effect on sorghum milling and porridge-making quality, as shown by the effect of supplementary irrigation on BH, PPV, SBV and starch amylose content, and this should be taken into consideration when selecting sorghum grain for milling and porridge-making.

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