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Morphological Variation of Sorghum Landrace Accessions On-Farm in Semi-Arid Areas of Zimbabwe

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Abstract: Sorghum landraces from two districts of Zimbabwe were studied to ascertain the genetic relationships among germplasm from different areas. The study analyzed 47 landraces from Nyanga North and Tsholotsho using 24 Sorghum agromorphological characters. Genetic similarities (Manhattan coefficient) were calculated and genetic relationships between accessions were analysed by principal component analysis and cluster analysis. The landraces were grouped into 6 clusters according to the geographical location of collection, suggesting environmental adaptation. Accessions with the same name had a tendency to group together, although some of the materials were found to be scattered in the dendrogram. Agromorphological traits were highly variable even for landraces with the same farmer-given name and source. Study results also alluded to the heterogeneity of farmer varieties, whose naming appears to be a function of a few traits. The study suggests that optimisation of on-farm conservation strategy for this germplasm should primarily focus on high diversity areas and perhaps recognise those traits envisaged to be of importance by farmers for varietal identification.

Key words: Sorghum landraces, agromorphological characters, genetic diversity

INTRODUCTION

Sorghum is an important cereal crop in the world after wheat, rice and maize, with over 80% of the crop in Africa and Asia (FAO, 2006). In Zimbabwe, local sorghum landraces are the principal food source for marginal areas where erratic rainfall, high temperatures and poor soil-nutrient availability are prevalent. Moreover, this cereal has wide range of uses such as porridge, beer brewing, livestock feed and fodder (Chakauya *et al*., 2006). Other uses include production of industrial alcohol, adhesives, waxes, construction materials and most recently bioethanol from sweet sorghum (Antonopoulou *et al*., 2008). The potential of sorghum in poverty alleviation and ensuring food security is yet to be realized.

It is imperative that characterization of landrace collections prior to storage is essential for further utilization in either breeding programs or community-based seedbanks (Attere, 1994; Crouch and Ortiz, 2004; Nkongolo *et al*., 2008). The genetic diversity in farmer's crops represents management processes and indigenous knowledge guiding farmer practices (Barrera-Bassols *et al*., 2006). Thus missing diversity or insufficiently represented diversity both *in situ* and *ex situ* constitute a gap in knowledge hence the need to study this diversity. Information concerning genetic diversity is therefore important to farmers, curators, breeders and germplasm conservationists where it can be used to plan collections, exchange strategies and to identify particular divergent subpopulation that might harbor valuable genetic variation under-represented in current holdings. Limited studies have been done so far to quantify the diversity in sorghum landraces held by farmers in the rural households of Zimbabwe. However, collection and storage of those materials in gene banks has been carried out to some extent, providing a starting point in analyzing their genetic relationships.

Molecular markers are an excellent tool for the assessment of genetic relationships in crop plants including sorghum (Ritter *et al*., 2007; Mace *et al*., 2008). A study by Rao and Mushonga (1987) found that Zimbabwean farmers grow mixtures of different morphological types of sorghum in the same field and harvest small quantities at different times from the same field. It seems this harvesting approach is justified by the fact that farmers need cultivars that mature at different times to meet their immediate food requirements. The authors also reported the existence of considerable variation with regard to plant height, panicle length, panicle appearance (loose or compact) and grain colour. Furthermore, van Oosterhout (1993) estimated that each sorghum growing area has a mixture of approximately 10

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landraces, with 2 to 4 landraces per individual farmer. In a different investigation Chivasa *et al.* (2000) characterized sorghum diversity based on standing crop and found wide diversity among the crops growing in farmer's fields, often in a mixture in order to fulfill livelihood and nutritional needs. Studies elsewhere in Africa have also come up with similar observations (Barnaud *et al.*, 2007). In order to safeguard the genetic diversity of traditional sorghum varieties, full characterization and assessment of the sorghum varietal limits is essential. Agromorphological traits are the oldest, relatively simple, less expensive and most widely used genetic markers that can be used to achieve this goal.

Microsatellites are also an approach that can be used to study diversity at molecular level. In an earlier study, we used this tool to analyze a selection of sorghum landraces from two remote districts of Zimbabwe: Tsholotsho and Nyanga (Chakauya *et al.*, 2006). A high concentration of diversity was found to be concentrated in the hands of a few individual farmers and that duplication of landraces within and between villages was rife. Moreover, there was a remarkable duplication of the material from these localities. In the current study we analyzed the same sorghum germplasm from an earlier study (Chakauya *et al.*, 2006) using agromorphological characters. The major objectives of the investigation were: (a) to describe the sorghum landraces using Key Sorghum Descriptors in order to identify important traits for use in crop improvement in the smallholder sector and (b) to assess the extent of sorghum diversity in the two districts.

MATERIALS AND METHODS

The study was carried out with 47 landraces (Table 1) collected by the National Genebank of Zimbabwe from two districts of Zimbabwe, Nyanga North and Tsholotsho in 1998 (Mafa, 1999). The two districts are in almost opposite ends of Zimbabwe and isolated from each other by climates that are not very suitable for sorghum and their climates are significantly distinct. Both sites were selected because of the rich phenotypic variation observed during a pilot study, semi-aridity (Table 2) and presence of Non-Governmental Organizations (NGO) already working with the communities in related projects (Mafa, 1999). Collections were made from the two districts, three villages per district and several farmers per village. In this case a village was defined as a group of about 50 households under one social administrative authority that has a common obligation to conserve and manage genetic resources.

Table 1: Collection identities, farmer-given local names and origin of Sorghum landraces analyzed by agromorphological descriptors

Accession No.	Collection No.	Farmer-given names	District
NPGRC1343	MMB05	Nhongoro	Nyanga
NPGRC1345	MMB07	Sweet sorghum	Nyanga
NPGRC1346	MMB08	Sweet sorghum	Nyanga
NPGRC1355	MMB17	Musoswe	Nyanga
NPGRC1378	MMB40	Nzende	Nyanga
NPGRC1384	MMB46	Nzende	Nyanga
NPGRC1385	MMB47	Musoswe	Nyanga
NPGRC1392	MMB54	Nhongoro	Nyanga
NPGRC1399	MMB61	Nzende	Nyanga
NPGRC1400	MMB62	Nhongoro	Nyanga
NPGRC1401	MMB63	Musoswe	Nyanga
NPGRC1409	MMB71	Nhongoro	Nyanga
NPGRC1412	MMB74	Sorghum	Nyanga
NPGRC1425	MMB87	Musoswe	Nyanga
NPGRC1428	MMB90	Musoswe	Nyanga
NPGRC1430	MMB92	Shodhani	Nyanga
NPGRC1441	MMB103	Musoswe	Nyanga
NPGRC1448	MMB110	Musoswe	Nyanga
NPGRC1450	MMB112	Shodhani	Nyanga
NPGRC1455	MMB117	Sorghum	Nyanga
NPGRC1460	MMB122	Musoswe	Nyanga
NPGRC1461	MMB123	Sorghum	Nyanga
NPGRC1472	MMB134	Mutanda	Nyanga
NPGRC1473	MMB135	Malawi	Nyanga
NPGRC1474	MMB136	Malawi	Nyanga
NPGRC1475	MMB137	Shodhani	Nyanga
NPGRC1477	MMB139	Chipemu	Nyanga
NPGRC1478	MMB140	Sorghum	Nyanga
NPGRC1480	MMB142	Sorghum	Nyanga
NPGRC1482	MMB144	Sorghum	Nyanga
NPGRC1483	MMB145	Nyamuwayawaya	Nyanga
NPGRC1487	MMB149	Sorghum	Nyanga
NPGRC1496	MMB158	Sorghum	Nyanga
NPGRC1499	TSH03	Khaki	Tsholotsho
NPGRC1521	TSH25	Yakayaka/imfe	Tsholotsho
NPGRC1523	TSH27	Isigobane	Tsholotsho
NPGRC1527	TSH31	Cimezile	Tsholotsho
NPGRC1535	TSH40	Tsweta red	Tsholotsho
NPGRC1537	TSH42	Tsweta khaki	Tsholotsho
NPGRC1540	TSH45	Red Swazi	Tsholotsho
NPGRC1343	MMB05	Nhongoro	Nyanga
NPGRC1345	MMB07	Sweet sorghum	Nyanga
NPGRC1346	MMB08	Sweet sorghum	Nyanga
NPGRC1355	MMB17	Musoswe	Nyanga
NPGRC1378	MMB40	Nzende	Nyanga
NPGRC1384	MMB46	Nzende	Nyanga
NPGRC1385	MMB47	Musoswe	Nyanga

Table 2: Comparison of monthly rainfall and mean temperature in Nyanga North and Tsholotsho showing the substantial differences that exist between the two sites

	Rainfall (mm)		Temperature (°C)	
Month	Tsholotsho	Nyanga North	Tsholotsho	Nyanga North
Jan	370	146	24	22
Feb	320	131	23	21
Mar	221	189	23	21
Apr	100	33	22	21
May	42	3	19	19
Jun	32	0	16	18
Jul	11	0	18	18
Aug	15	0	19	18.5
Sept	10	0	23.5	21.6
Oct	55	4	26	23.9
Nov	128	54	25	25
Dec	346	149	25.8	24.5

All the sorghum accessions collected from Nyanga and Tsholotsho were planted in 4 row plots of 5 m lengths 0.75 m apart. The crop was over-planted and then thinned to 20 cm within each row. The morphological characters used for sorghum characterization were obtained from the Standard Key Descriptor Lists for Characterizations (IBPGR/ICRISAT, 1984) (Table 3) and data were entered into EXCEL version 5.0 and analysed by the software package NTSYS-pc, version 2.1 (Rohlf, 1993). The Manhattan coefficient (Sneath and Sokal, 1973) was used to calculate genetic distances and hierarchical clustering was done using the Unweighted Pair-Group Method of Arithmetic Averages (UPGMA). Principal Component Analysis (PCA) was then used to visualize the pattern of variation of the data.

Table 3: Sorghum agromorphological descriptors and their keys as they are used in the study

Descriptor	Key
Stalk Juiciness	SJ
Juice quality	JQ
Lodging	LD
Synchrony of flowering	SN
Head exertion	EN
Head compactness and shape	PS
Shattering	ST
Threshability	TS
Glume colour	GC
Kernel covering	GV
Kernel colour	SC
Bird damage	BD
Days to 50% flowering	FL
Plant height	HT
Head length	HL
Head width	HW
No. of productive tillers	PT
Kernel weight	KW
Endosperm texture	EX
Endosperm colour	EC
Endosperm type	ET
Kernel luster	KL
Sub coat	SCt
Kernel plumpness	KP

RESULTS

Cluster analysis of the sorghum accessions based on the morphological characters (Fig. 1) retrieved groupings or clusters, according geographic origin. Clusters 1, 3 and 6c indicated accessions that were collected from Tsholotsho whereas clusters 5, 6a and b were mostly composed of accessions collected from Nyanga. Generally, varieties with same common name clustered

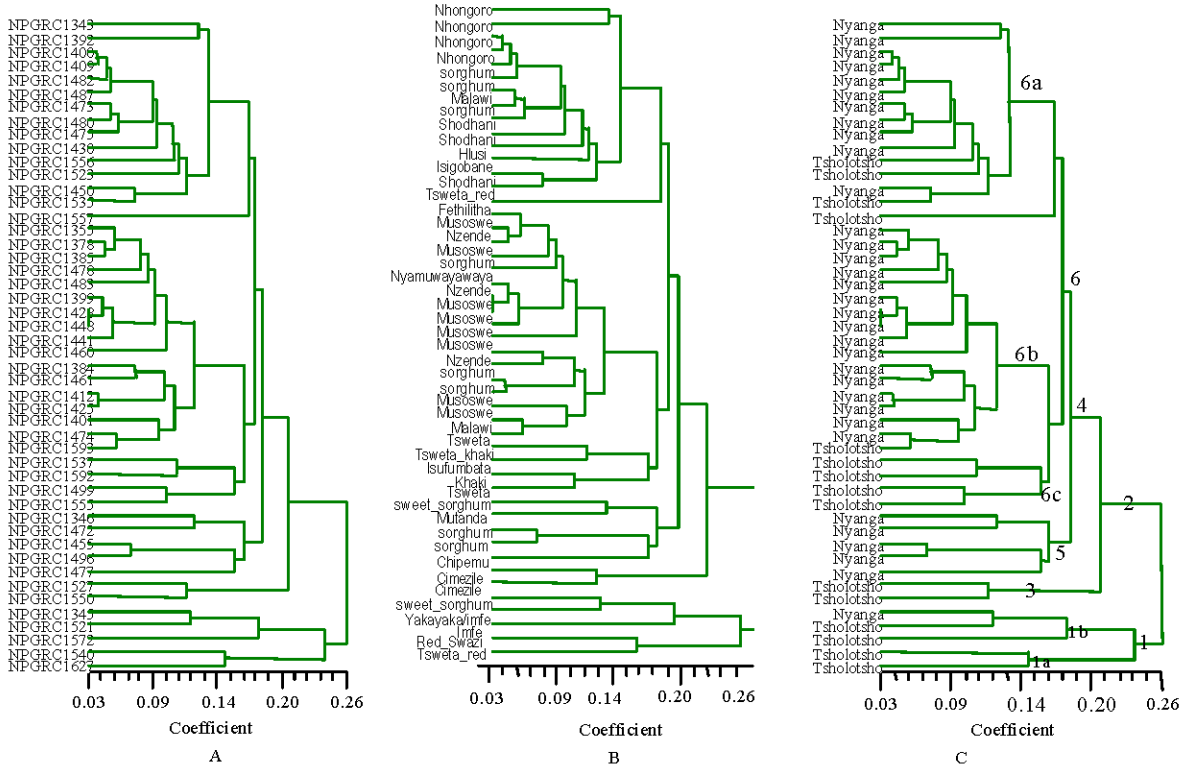

Fig. 1: Cluster analysis of Sorghum data set. A = Accession numbers being OTUs, B = Variety names being OTUs and C = Site data being OTUs

together with a few exceptions particularly, *Tsweta* varieties were found scattered in a number of groupings. However, a cophenetic correlation value of 0.785 shows that the dendrographs obtained is a reasonable representation of the dissimilarities.

Principal component analysis revealed the same discrete clusters of landraces as those above (Fig. 2). Clusters C1a, 1b, 3 and 6c are made of accessions obtained mostly from Tsholotsho while clusters C5, 6a and 6b are made of accessions most of which were

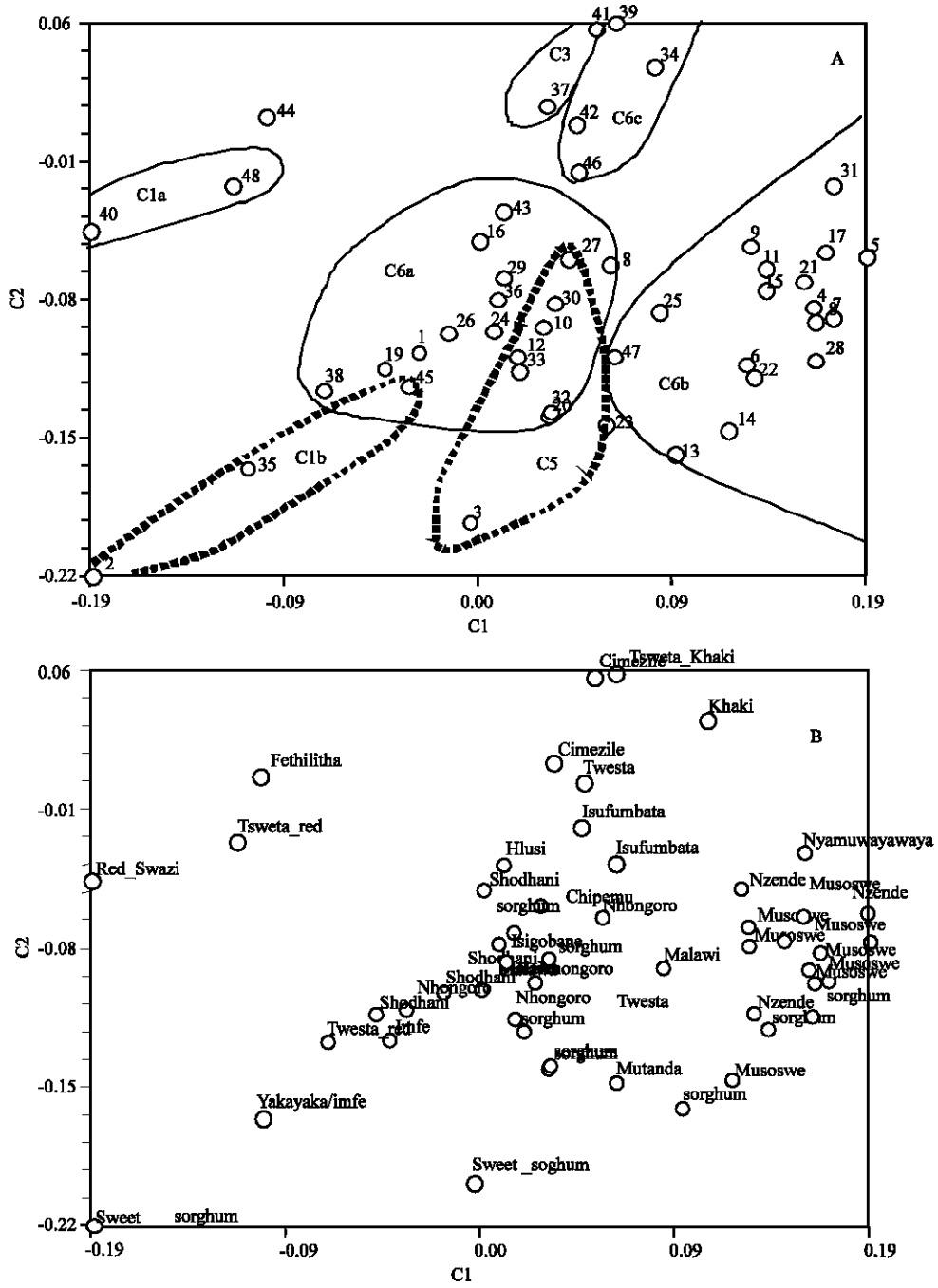

Fig. 2: Principal component analysis of the sorghum variety morphological data set in 2-dimensional model plots. Both plots represent component 2 versus 1 with a showing the groupings and numbers that represent varieties whereas b shows the varieties in a hyperspace

Table 4: Eigenvector matrix for PCA using all characters. Bolded figures under each component signify 3 characters contributing the most variation for each principal component. Components included have eigenvalues greater than 0.1

Descriptor	C1	C2	C3	C4	C5	C6	C7	C8	C9
Stalk juiciness (SJ)	**0.6715**	0.2168	0.4844	0.0724	0.0740	0.3401	0.0183	0.0634	0.1435
Juice quality (JQ)	-0.1369	0.5181	-0.0424	0.3273	**-0.5160**	-0.1817	**-0.3306**	-0.1795	-0.0524
Lodging (LD)	-0.4023	-0.3245	**-0.5771**	0.3000	0.1818	0.0247	0.1932	0.1947	-0.1008
Synchrony of flowering (SN)	0.3186	0.1142	-0.2921	**-0.4657**	-0.3245	0.1470	0.1814	**-0.3478**	0.3107
Head exertion (EN)	-0.1277	**-0.5582**	0.2904	0.3732	-0.0219	0.3028	0.1023	0.0096	0.1616
Head compactness and shape (PS)	**-0.7410**	0.0506	0.3234	-0.0106	-0.1642	0.1887	0.1201	-0.0042	-0.0457
Shattering (ST)	-0.4909	0.3161	-0.0708	-0.3642	-0.1480	**-0.4532**	-0.2314	-0.0458	-0.1005
Threshability (TS)	-0.2347	0.2053	0.0509	**0.6642**	-0.3665	0.2816	-0.2662	-0.1074	-0.0957
Glume colour (GC)	-0.3856	-0.3483	**0.5699**	-0.2609	-0.1358	-0.0033	-0.1220	-0.2181	0.2396
Kernel covering (GV)	-0.1278	0.1815	-0.2749	0.2993	-0.3639	-0.1055	**0.5987**	0.1563	0.1805
Kernel colour (SC)	-0.5737	-0.3275	-0.2688	-0.2401	0.0376	0.3532	**-0.2865**	-0.1194	0.0139
Bird damage (BD)	0.0473	-0.2031	**0.7240**	0.1234	0.0011	**-0.4833**	0.2119	0.1291	-0.0413
Days to 50% flowering (FL)	0.5918	-0.3689	-0.2570	0.2249	0.1710	0.0238	-0.2754	-0.1237	0.0178
Plant height (HT)	**0.6829**	**-0.5455**	-0.0655	0.0298	-0.0688	0.1894	-0.1036	0.0881	-0.1261
Head length (HL)	0.4437	0.0442	0.0691	-0.4203	0.2141	-0.0718	-0.1902	0.3068	0.0075
Head width (HW)	0.0723	0.4468	-0.3686	-0.0529	-0.0650	0.1772	-0.1066	**0.3444**	**0.5915**
No. of productive tillers (PT)	0.0885	-0.2719	0.1439	**-0.5082**	**-0.4912**	0.2887	0.1431	-0.0739	-0.2356
Kernel weight (KW)	0.2008	**0.7295**	0.0372	-0.1699	0.2864	0.1688	-0.0056	0.1066	**-0.2926**
Endosperm texture (EX)	-0.6250	-0.0809	0.0688	-0.4077	-0.0526	0.1676	-0.0134	0.2830	0.1217
Endosperm colour (EC)	-0.6900	-0.1267	-0.4246	0.0018	0.1357	0.1423	-0.0637	0.0880	-0.1902
Endosperm type (ET)	0.5723	-0.0055	-0.3295	-0.2159	-0.4036	0.1012	0.2408	0.0501	**-0.3940**
Kernel luster (KL)	-0.0773	-0.4915	-0.4271	-0.1222	0.0442	**-0.4652**	0.0392	-0.1823	0.1319
Sub coat (SCt)	-0.0694	-0.3352	0.0975	-0.0126	**-0.4959**	-0.1233	-0.2698	**0.6214**	-0.0499
Kernel plumpness (KP)	-0.6589	0.2141	0.2050	-0.0788	0.3068	0.2135	0.2248	-0.0133	-0.1268

collected from Nyanga. The first nine components of the PCA accounted for 78.30% of total character variation, with first component contributing 19.98 followed by 11.90, 10.86, 8.81, 6.99, 6.13, 4.88, 4.47 and 4.24%, respectively. For each principal axis, there are a number of characters contributing to the total variation and those characters with loading factors of more than 0.7 are considered of significant importance. However for this analysis such characters are few and therefore the first three characters with highest loading factors for each component were considered (Table 4). For example, the characters head compactness and shape (PS), Plant height (HT) and Endosperm Colour (EC) contributed to the first principal axis, while Kernel Weight (KW), Head exertion (EN) and Plant height (HT) contributed to the second principal axis and so on. When the relationships between characters and the sorghum accessions are examined further, the most important characters contributing to the groupings obtained by PCA become clearer. Cluster C1a was made distinct by Endosperm texture (EX), Endosperm Colour (EC) and Kernel colour (SC); C1b by Lodging (LD), Glume Colour (GC), Head exertion (EN) and Sub-coat (SCt); C5 by Number of Productive Tillers (PT); C6b by Plant height (HT), Days to 50% flowering (FL), Endosperm Type (ET) and Head Length (HL); C6a by Lodging, Glume colour, Head exertion, Sub-coat, Number of productive tillers, Plant height, Days to 50% flowering and Endosperm type; C6c by Synchrony of flowering (SN) and Stalk Juiciness (SJ) and C3 by Head Width (HW) and Kernel Width (KW), respectively. Taken together, the results suggest that agromorphological characters are highly variable within the landraces even those with the same local names and farmers seem to use a few traits to delineate varieties.

DISCUSSION

The role of sorghum as a crop in semi-arid areas and the importance of conserving the genetic diversity cannot be overemphasized. Cluster analysis of the landraces of this crop based on agromorphological traits showed interesting observations. Although there was a tendency for different accessions with the same name to group together, this was not consistent for all the varieties. Particularly, *Tsweta* and *Malawi* landraces were found scattered in a number of groupings. This is an indication that while a farmer variety name generally implies the presence of one to three clearly defined traits; many other traits may vary considerably from one farmer to another even when the variety has the same name. This, however, also reflects the heterogenous nature of farmer varieties, whose naming appear to be a function of very few traits like panicle shape (*Nyamuwayawaya*, *Isifumbata*), sweet stalk juice (sweet sorghum, *Imfe*, *Ipwa*), etc. Some varietal names are based on their source of origin (*Malawi*) but if it was nurtured in rural communal settings, farmers will still have a few characters to define its identity. Thus, farmer's nomenclature seems not to have a definite standard criterion for classification of varieties of the same species as to the farmer only one or two traits are important to delineate varieties from each other. This agrees with the few high loading factors for some characters (Table 4) which undoubtedly are most

important in contributing to the groupings just as it was observed that farmers use only few characters to separate varieties. Interestingly, this is in line with our observation in an earlier study with the same material (Chakauya *et al*., 2006).

Both, cluster analysis and principal component analyses of morphological characters for the sorghum landraces showed groupings whose pattern is geographical. This is not surprising because the two sites are more than 700 km apart in opposite ends of Zimbabwe, with slightly different agroecological challenges such as rainfall frequency. Furthermore, grouping according to geographical sites might intimate to adaptation of the landraces to specific environments. This leads to the suggestion that varieties and the processes associated with variety development (varietal selection) are essentially consequences of adaptation of populations to their agro-ecological conditions, aided by utility value (best practice) to the farmer. This is an important element to guide the development of optimal conservation strategies and subsequently the best place to preserve the genotypes whether *in situ* or on-farms. According to Smale *et al*. (2004) on-farm conservation of plant genetic resources is most rational where both the public value of diversity and its private value are high, i.e., areas where there is a lot of genetic diversity and where it makes a substantial contribution to farmer livelihoods.

Present data also showed that agromorphological characters are highly variable within landraces and looked at holistically it highlights the difficulty of using them as sole markers for delineating different groups or even in diversity studies. These characters are important to the farmer especially to spread risk during critical unpredictable climate changes such as the global warming phenomenon.

CONCLUSION

In conclusion, multivariate analysis of the agromorphological characters of the sorghum landraces clearly showed the influence of adaptation to the landraces. This explains why the farmers maintain them for risk management, optimisation of production factors as matches to difference soil water regimes, or diversity of uses as varietal diversity relates to different uses e.g., white varieties of sorghum produce better porridge (*sadza*) and red sorghum varieties are good for brewing beer. Chivasa *et al*. (2000) call this diversity a legacy for the future generation that needs to be conserved lest it becomes extinct. In that respect it can be said that development of an optimal on-farm conservation strategy for this material should primarily focus on high diversity areas and perhaps recognise those traits envisaged to be of importance by farmers for varietal identification.

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