Agro-biodiversity in Subsistence Farming Systems of South Somalia – Collection and Agronomic Assessment of Somali Sorghum (*Sorghum bicolor* (L.) Moench) Germplasm

M. Manzelli*, S. Benedettelli & V. Vecchio

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Summary

*After the collapse of Siyad Barre' regime, Somalia lost any form of agricultural research with negative consequences on food availability and seed sector stability. A first step to restore food security can be represented by enhancing local genetic resources. Sorghum (*Sorghum bicolor *(L.) Moench) is a very important crop in rainfed areas of Somalia serving as primary source of food and forage. Eight morphological and productive characteristics were chosen to assess the phenotypic variability of 7 accessions from South Somalia. Univariate (ANOVA) and multivariate (discriminant and cluster analysis) methods were used to assess the productive variation within the accession and to group the 7 accessions into clusters based on quantitative characters. The results showed that there is a wide morpho-agronomical diversity among accessions, especially regarding specific features suitable for different purpose, such as grain and/or forage production. Moreover the landraces were able to grow and produce under harsh environmental conditions. The gathered information can be used to promote the conservation and future improvement of local sorghum landraces, thus aiding in the stabilisation of a secure and sustainable food resource for farmers of southern Somalia.*

Résumé

Agro-biodiversité dans les systèmes agricoles de subsistance de la Somalie du sud – collection et évaluation agronomique du germoplasme de sorgo (*Sorghum bicolor* (L.) Moench) somalien

*Après l'effondrement du régime de Siyad Barre, la Somalie a perdu toutes ses institutions de recherche agricole. Cela s'est traduit par des conséquences négatives sur la disponibilité d'aliments et la stabilité du secteur semencier. L'amélioration des ressources génétiques autochtones peut constituer un premier pas pour rétablir la sécurité alimentaire. Le sorgho (*Sorghum bicolor *(L.) Moench) est une importante céréale dans les zones pluviales de la Somalie où elle représente une des principales sources d'aliments et de fourrage. Huit caractéristiques morphologiques et productives ont été choisies pour évaluer la variabilité phénotypique de sept accessions collectées dans la Somalie du sud. On a utilisé des méthodes d'analyse univariées (ANOVA) et multivariées (analyse discriminante et de regroupements) pour évaluer la variation productive dans les accessions et pour grouper les accessions sur la base des données quantitatives. Les résultats ont indiqué qu'il y a une ample diversité morpho-agronomique parmi les accessions, spécialement pour ce qui concerne certaines caractéristiques exploitables pour différentes utilisations, comme la production de grains et/ou de fourrage. En outre, les variétés locales ont été capables de se développer et de produire en conditions environnementales très difficiles. Les informations obtenues peuvent être utilisées pour promouvoir la conservation et l'amélioration futures des variétés locales du sorgho, en aidant à stabiliser les possibilités d'approvisionnement d'une source d'aliments de subsistance pour les agriculteurs de la Somalie du sud.*

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth worldwide most important food crop serving over 400 million people in the semi-arid regions of the world (1, 13).

According to what is reported in the literature, the species *Sorghum bicolor* was domesticated in the region of the horn of Africa in an area including Ethiopia, Sudan and Chad (10, 11). In particular, Ethiopia is considered a centre of probable origin of sorghum (12). India and China are considered as other

Department of Agronomy and Land Management, Faculty of Agriculture, University of Florence, Italy.

*P. le delle Cascine 18, 50144 Florence, Italy. Tel. +39 055 3288245, Fax +39 055 332472, e-mail marco.manzelli@unifi.it

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centres of domestication (11).

Agricultural biodiversity represents the main outcome of thousands of years of farmers activities in selection, breeding and farming and its wideness is highly correlated with duration of domestication and type of farming systems adopted. Referring to sorghum, high level of diversity was detected in Ethiopia, Eritrea, Sudan, Somalia, Burkina Faso, Tanzania, Rwanda, Zimbabwe, India, China, etc (2, 3, 4, 5, 6, 7, 8, 14, 15, 16, 19, 22, 24, 26, 28). These efforts registered a high degree of diversity in terms of morphological, productive and regional variation, climatic adaptation and crop utilisation. In particular close links were detected between landraces and environmental conditions, highlighting the central role that those landraces plays in local subsistence agriculture.

After the collapse of Siyad Barre's regime, Somalia lost all the existing institutions. The impact on agriculture and rural livelihoods is complex and many causes, as recurrent droughts, floods, farmers' displacement, etc., have determined the progressive agricultural production decrease registered in the last decade. Farmers have lost many important inputs, including local selected seed that often represents one of the few resources for local farmers to maintain or increase production. Risk of genetic erosion is particularly high and farmers' inability to preserve quality seed for the next season is increasing with unpredictable consequences on rural livelihood.

Sorghum represents the dominant crop cultivated in the rainfed areas of South Somalia between the two main rivers Juba and Shabelle, followed by cowpea (*Vigna unguiculata*) and sesame (*Sesamum indicum*), while Maize (*Zea mays*) ranks second and its cultivation is mainly concentrated in flood irrigated areas (20). Somali sorghums are important as food and fodder crop, especially in rainfed areas where livestock represents a crucial point to the success of local agro-pastoralist communities. Then sorghum biomass is an important supplementary fodder to natural grazing, especially during the dry season (*Jilaal* in Somali language), as recently documented in studies conducted in northwest (22) and southern (20) regions of Somalia. Grains are mainly used for making *injera*, an unleavened bread from fermented dough, or traditional porridges.

The objective of the present study was to *in situ* assess the extent of morphological and productive variation in 7 landraces collected in some district of south Somalia by univariate and multivariate statistical procedures. From this preliminary work, the identification of useful landraces can be useful in developing cultivars compatible with farmers' needs and assuring sustainable production levels over the years.

This research was a preliminary investigation of Somali sorghum diversity in rainfed areas of south Somalia in order to provide useful information for the implementation of some research activities foreseen in a project, funded by European Commission and assigned to the Italian NGO CINS (Cooperazione Italiana Nord Sud), entitled "Farming system improved through the strengthening of local seed systems in the Galbeed and Bay regions of Somalia".

Material and methods

Plant material

Sorghum samples were collected during the month of March 2002 in the districts of Baidoa, Burhakaba, Jowhar, Qansaxdhere and Qoryooley in south Somalia, that represent the main Somali area dedicated to rainfed sorghum cultivation. This collection consists of 20 accessions of local sorghums, maintained in the germplasm laboratory of the Department of Agronomy and Land Management of Faculty of Agriculture of Florence. Passport data and descriptors were recorded following guidelines reported in "Descriptors for Sorghum" (18). The main morphological characters used by local farmers in classifying and naming sorghum landraces include midrib and seed colour, panicle shape and compactness. Stalk juiciness is associated with midrib colour (3), with a low level associated with a white midrib, and a high sugar content with a green or yellowish midrib. Information was also gathered on growth habits, especially days to harvest.

Seed availability and collection site were the main criteria used to select 7 accessions for morphological and agronomical evaluation (Table 1).

Table 1
Collected and evaluated sorghum accessions

Accession	Local Name	Collecting area		Collecting data
		District	Village	
101	Shamurey	Burhakaba	Dugdumale	20-03-02
102	Adey	Baydoa	Gofgaduud	28-03-02
103	Galgaley	Burhakaba	Dooygadahey	22-03-02
104	Jiray	Jowhar	Morojido	17-03-02
105	Moordi	Burhakaba	Sabid	24-03-02
106	Abur Cas	Qansaxdhere	Ufurow	28-03-02
107	Gabey Godbuy	Qoryoley	Gaywarow	24-03-02

These accessions were sown in an experimental field close to the village of Kaytoy in the district of Merka on alluvial soil during the rainy season, adopting a randomised block design with four replications. Each plot was 10 m x 5 m. A skim ploughing followed by a harrowing were used as preliminary field works. The subsequent furrowing was carried out with a traditional furrow (*kababe* in Somali language) maintaining a distance of 70 cm between rows. Three seeds per hole were sowed at a distance of 15 cm along the row. A thinning activity was carried out in order to maintain a plant density of 10 p/m^2. For each accession and each plot at least 15 plants were sampled for quantitative evaluation.

Days for 50% flowering were recorded on a plot basis. Observation on midrib colour and measurements of Green Leaf Number (GLN) and Plant Height (PH) were recorded each 10-15 days on 15 plants per plot.

At harvest time the following quantitative parameters were measured: Plant Height (PH), Knot Number (KN), Plant Dry Weight (PDW), Tillering Number (TN), Panicle Weight (PW), 1000-Seed Weight (1000-SW), Inflorescence Length (IL), Harvest Index (HI).

Statistical analysis

Homogeneity of the error of variance among the 7 accessions was assessed by Bartlett's test for each of the quantitative characters, using a p value of 0.05.

The analysis of variance for repeated measures was performed for variables PH and GLF regularly monitored. Polynomial tests were performed within subjects to test changes across the repeated measures.

For the quantitative variables (PH, KN, PDW, TN, PW, 1000-SW, IL, HI) the analysis of variance was carried out using a mix model, considering the *within population* as a fixed source of variation and the *within block* as a random factor. Bonferroni multiple pairwise comparison test was performed for each source of variation.

Discriminant analysis was used to assess the differences between morphological variation of the 7 accessions for 8 quantitative characters (PH, KN, PDW, TN, PW, 1000-SW, IL, HI). Sorghum landrace ordination by canonical discriminant analysis was visualized by a 2D-graph. The measure of dissimilarity of canonical scores of group means was Euclidean distance. The resulted distance matrix was utilised for the cluster analysis by the Unweighted Pair-Group Method Using Arithmetic Average (UPGMA) algorithm (25). The relationship between accessions was visualised by a dendrogram.

Results

Six of collected landraces belong to *Durra* race, while the accessions Gabey Godbuy (107) can be classified as *Caudatum* type.

The grain colour was white (Adey, Gabey Godbuy), yellow (Galgaley, Jiray) or red (Shamurey, Moordi, Abur Cas) with a little variation within landraces.

Juiciness of the stalks, typically chewed like sugarcane, varied among accessions but little difference was recorded within accession confirming the distinction made by local farmers. The accessions Shamurey (101), Jiray (104) and Abur Cas (106) showed a high percentage of plants with a dull green midrib, while white midrib was highly frequent in accessions Adey (102), Galgaley (103), Moordi (105) and Gabey Godbuy (107). Moreover the midrib colour did not vary during the crop cycle, as confirmed by previous studies (22).

No significant differences were detected in days to 50% flowering with values ranging from 40 to 45 days. Harvesting was done after 85 days from sowing with a difference of ± 3 days between accessions.

Univariate analysis

The Bartlett's test showed homogeneity of the error of variance for each quantitative variable confirming that replication variances gave an unbiased estimation of population variance.

ANOVA for repeated measures and within subject polynomial tests detected significant differences in both plant height and green leaf number. Concerning plant height no variation was observed in growing trends, while differences in growth rate were particularly evident between the 20° and 55° day from sowing. The higher growth rate was observed in accession Moordi (105), followed by the group including the accessions Shamurey (101), Galgaley (103) and Jiray (104), the group including the accessions Adey (102) and Abur Cas (106), and the accession Gabey Godbuy (107).

Aphid attack and wind damage determined differences in green leaf number, highlighted a different susceptibility degree between accessions and, as consequence, a discontinuous trend in leaf number increase. Accessions Adey (102) and Abur Cas (106) were the most susceptible to aphid attack, while accessions Galgaley (103) and Moordi (105) were particularly damaged by wind.

Table 2 summarises the means of the quantitative variables used in this study. No block effects were observed. Significant differences in plant height were found and it is possible to distinguish between two main groups: a first group including the accessions Shamurey (101), Galgaley (103), Jiray (104) and Moordi (105) with values ranging from 176 to 197 cm, a second group constituted by the accessions Adey (102), Abur Cas (106) and Gabey Godbuy (107) ranging from 120 to 138 cm.

Even if significant, the differences detected in knot number were not so wide. The accessions arose an average number of 12 knots, except the accession Gabey Godbuy with 11 knots.

A great variation was observed in plant dry weight

Table 2
ANOVA results and means of quantitative variables by accessions

Accession		PH, cm		KN, n°		PDW, g		TN, n°	
101	Shamurey	180.7	a	11.7	ab	253.7	ab	1.5	a
102	Adey	138.7	b	11.8	ab	193.4	cd	0.9	b
103	Galgaley	176.4	a	11.7	ab	262.2	a	1.5	a
104	Jiray	176.7	a	11.7	ab	208.5	bd	1.5	a
105	Moordi	197.5	a	12.3	a	171.3	d	1.6	a
106	Abur Cas	130.4	b	11.7	ab	95.9	e	0.0	c
107	Gabey Godbuy	120.5	b	11.2	b	239.7	ac	0.0	c
F-test significativity		**		*		**		**	
		PW, g		1000-SW, g		IL, cm		HI, %	
101	Shamurey	40.9	b	25.2	b	15.7	b	16.9	c
102	Adey	30.0	b	24.2	bc	7.9	de	16.2	c
103	Galgaley	34.5	b	24.0	bc	15.1	b	13.5	cd
104	Jiray	28.8	b	23.6	bc	10.2	cd	14.8	cd
105	Moordi	45.0	b	25.1	b	10.8	c	26.4	b
106	Abur Cas	9.0	c	20.5	c	7.1	e	9.6	d
107	Gabey Godbuy	148.3	a	32.8	a	23.0	a	63.5	a
F-test significativity		**		**		**		**	

For each column means followed by a common letter are not significantly different at 0.05 level.
**= *F* test significant at 0.01 level, *= *F* test significant at 0.05 level, ns= *F* test not significant.

with values ranging from 96 to 262 g. Two of the tallest accessions, Shamurey (101) and Galgaley (103), respectively reached 254 and 262 g in weight. The accession Gabey Godbuy (107), in spite of a reduced height, reached a weight of 240 g. An other group includes the accessions Adey (102), Jiray (104) and Moordi (105) showing a range between 171 and 208 g. In particular the accession Moordi (105) reached a relatively low plant weight (171 g) despite its development in height. The accession Abur Cas (106) showed the lowest value (96 g).

The variation in tillering number followed the grouping trend observed in plant height. In particular the accessions Abur Cas (106) and Gabey Godbuy (107) did not tiller at all.

The variation observed in panicle weight permits to point out the good performance of accession Gabey Godbuy (107) raising a value of 148 g that indicates an interesting productivity level as reported by local farmers. On the opposite the accession Abur Cas (106) showed small panicles, not exceeding the average value of 9 g and confirming its aptitude for forage production instead of grain production. The other accessions grouped together with values comprised between 28 and 45 g.

The 1000-seed weight was similar for all accessions except for Gabey Godbuy (107) which had the highest value (32.8 g). With particular reference to local sorghum landraces, this parameter is positively associated with drought resistance (23), higher germination percentage, better stand established and higher grain yield (6).

Concerning the variable inflorescence length, the trend followed what was observed in panicle weight. The accession Gabey Godbuy (107) showed the highest value (23 cm), confirming its belonging to the race *Caudatum*, whilst the other accessions reached lower values. Nevertheless, the *Durra* accessions showed a high degree of variation. Accessions Shamurey (101) and Galgaley (103) grouped together with values of 15.7 and 15.1 g. A second group was represented by accessions Jiray (104) and Moordi (105) with an inflorescence length of 10.2 and 10.8 cm, while accessions Adey (102) and Abur Cas (106) did not exceed the threshold of 8 cm. Inflorescence length is an important yield component (3). It is a stable character that features a particular race (11, 17, 21). The accessions of the area, in general, belong to the race *Durra* characterised by a compact and oval panicle inserted on a recurved peduncle. Erected and semi-compact elliptic forms, e.g. *Caudatum* types, are less frequent.

Head compactness seems to be associated with humidity at flowering and ripening time. In particular very dense panicles are frequently found in areas of extremely dry conditions (3).

The harvest index was higher than 60% only for the accession Gabey Godbuy (107) indicating a specific feature for grain production. Low harvest index characterised all the other accessions showing values lower than 30%. In particular the accession Abur Cas (106) did not overcome the threshold of 10% confirming its low general productivity.

However, this suitable forage landrace aptitude has a strategic importance in such agro-pastoral environment as the whole plant represents a good forage resource, especially during the dry season (*Jilaal* in Somali language).

Table 3
Summary of discriminant analysis for 7 sorghum accessions by accession

	No	True accession						
		101	102	103	104	105	106	107
101	42	**27**		15				
102	39		**36**		3			
103	39	15		**21**	3			
104	57	3	9	9	**33**	3		
105	48				6	**42**		
106	45						**45**	
107	45							**45**
% correct		60.0	80.0	46.7	73.3	93.3	100.0	100.0

Table 4
Eigenvalues, total variance and cumulative variance

	DF1	DF2	DF3	DF4	DF5	DF6
Eigenvalues	16.817	4.652	1.197	0.453	0.036	0.004
% of total variance	72.6	20.1	5.2	2.0	0.2	0.0
% cumulative variance	72.6	92.7	97.9	99.8	100.0	100.0

Multivariate analysis

Discriminant analysis, using the accessions as grouping variable, highlighted that most of the accessions reached a high percentage of classification, except for the accessions Shamurey (101) and Galgaley (103) (Table 3). In particular all the plants belonging to the accessions Abur Cas (106) and Gabey Godbuy (107) have been classified into their accession of provenance, clearly showing a distinct and higher phenotypic homogeneity.

The first three discriminant functions explain almost the total variation between the 7 sorghum accessions for the 8 quantitative variables studied (Table 4). The variables plant dry weight, 1000-seed weight, inflorescence length and harvest index were the most important characters contributing to the first three discriminant functions.

By observing the landrace spatial distribution (Figure 1), it is possible to highlight a relatively wide area including the great part of landraces, that constitutes the basic germplasm, and two distinct areas grouping the plants of accessions Abur Cas (106) and Gabey Godbuy (107).

Cluster analysis, based on Euclidean distance matrix, was used to obtain a dendrogram of the accessions (Figure 2). The dendrogram clearly indicates that

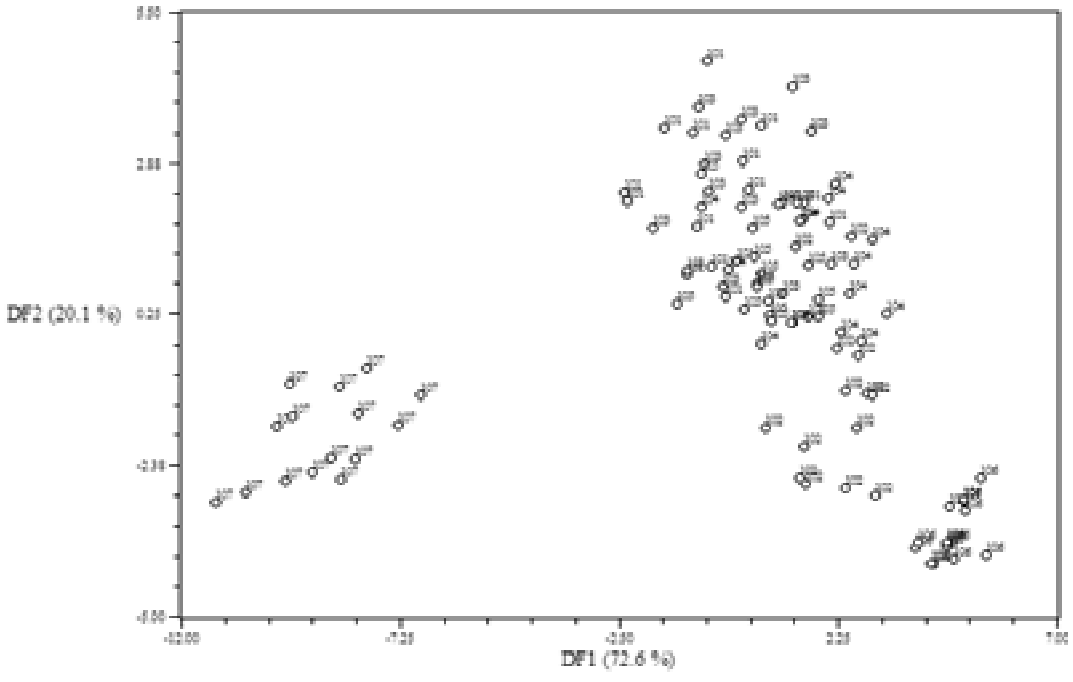

Figure 1: Sorghum landrace ordination by canonical discriminant analysis.

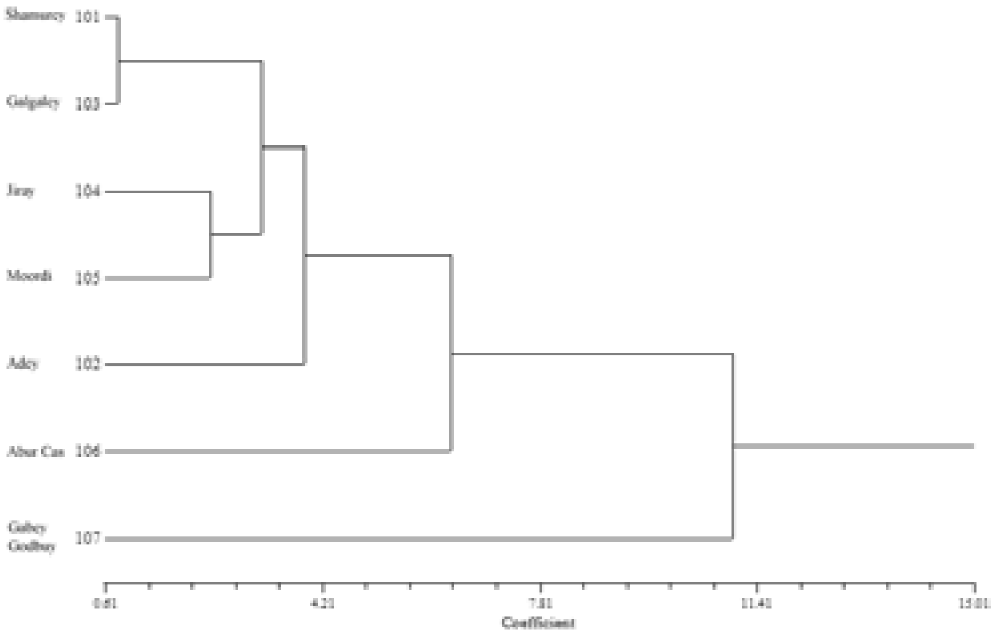

Figure 2: Dendrogram showing the clustering pattern between the 7 Somali sorghum accessions.

accessions Abur Cas (106) and Gabey Godbuy (107) are isolated from the other accessions. The other landraces form a distinct cluster, in which it is possible to underline the closeness between the accessions Shamurey (101) and Galgaley (103).

Discussion and conclusion

According to the literature, some studies on sorghum germplasm have been conducted in South Somalia (8, 24). These efforts were mainly directed to germplasm collection and *in situ* trial evaluations were carried out at Baidoa, Somalia, in order to identify desirable lines for use in the sorghum improvement programme of Somalia. However due to the beginning of civil strife, the country lost any form of agricultural research and those studies ceased completely. In general, the few available information referred to landraces with interesting features in terms of earliness, grain and fodder quality, resistance to storage pests, stem borers and drought stress (24). These authors also highlighted a close genealogical relation between Somali and Ethiopian Highlands sorghums, even if with consistent differences in panicle size and earliness. In particular they suggested a transformation of Ethiopian sorghums over a period of several years and their progressive adaptation to the short growing season and limited rainfall conditions of southern Somalia (24).

This study represents a preliminary investigation on sorghum germplasm collected in the Districts of Baidoa, Burhakaba, Jowhar, Qansaxdhere and Qoryooley. The experimental trial has been carried out *in loco* using traditional farming techniques in order to assess the productive response of accessions under local environmental conditions. As known, the landraces constitution follows an evolutionary process in which human beings and environment are the main actors in shaping the genetic dynamics of crop populations. Then, the possibility to *in situ* preserve and assess local germplasm can be particularly useful in defining those parameters necessary to the development of cultivars able to grow in marginal and heterogeneous environmental conditions. The results showed an interesting range of variation within and among accessions for the characteristics studied, confirming the existence of variable landraces with specific features. In addition names given by farmers to the accessions are consistent and indicate substantial differences, underscoring the importance to consider farmers' knowledge of diversity and use of local germplasm.

The accessions Gabey Godbuy (107), belonging to *Caudatum* race, showed characteristics different from all the other accessions: reduced height, high 1000-seed weight and harvest index, and a consistent morphological and productive stability. The good grain production and high harvest index denote a specific aptitude for grain production. Anyway it is important to note that the accession, even if of reduced height, is characterised by large stalks and, as consequence, high plant weights. Then its utilisation for forage production has not to be excluded. Also the accession Abur Cas (106) was classified far from other accessions, in particular showing the lowest grain production, plant weight and harvest index. The remaining accessions formed a quite homogenous group denoting a similar productive adaptation and, considering their good biomass production performance, a dual-purpose application. Moreover the existence of this basic germplasm permits to form the hypothesis that the accessions Abur Cas (106) and Gabey Godbuy (107) had a probable different origin and were separately maintained over the years. No significant differences were detected in days to 50% flowering and earliness confirming the landrace adaptation to Somali short growing season mentioned in previous studies. Moreover these accessions are able to grow and produce under very harsh environmental conditions (heat, drought, poor soils, etc.) making this germplasm a vital source of genes for breeding efforts. Local environment conditions influenced the genotypic constitution of landraces suggesting a close relationship between agro-ecological conditions and morpho-phenological variation of germplasm (22).

Comparing to modern varieties, these landraces have interesting earliness features and high yield potential in terms of biomass and grain production. The sugar content in the stalks have been only evaluated by empirical methods but further analysis are desirable to evaluate this character in new possible exploitation pattern of the crop.

The presence of such diversity in a narrow germplasm collection indicates that farmers deliberately maintain a wide diversity of sorghum landraces to meet their needs. In fact *in situ* conservation allows adaptation and evolution to continue. Traditional farming systems often show a wide genetic diversity well exhibited in landraces that are maintained by farmers in a dynamic process of selection and breeding (9). In particular those landraces exhibit their high potential in local marginal areas, where they appears equal or sometimes superior to modern varieties in term of yields (27). Then genetic variability present in landraces serves to avoid crop failure by reducing vulnerability to diseases, pests and environmental stresses (9).

Even if in the past the farmers' breeding activities have been considered as "primitive" by professional breeders, several researchers have recently changed their point of view concentrating their attention on those traditional activities that, even now, constitutes one of the main strong forces in local farming system development (9). It is now well known that landraces and farmers are interdependent and both are in need of each other for their survival (2).

Today this traditional interdependence is continuously threatened by unpredictable environmental and social changes with negative consequences on rural livelihoods and maintenance of agricultural genetic diversity. In particular the ecosystems in the drylands, as rainfed areas of Somalia, are fragile. The degradation of habitats and the loss of their agrobiodiversity are already leading to irreversible situations responsible for local communities' displacement, desertification and increasing food insecurity and mass poverty.

The case of Somalia follows the same trend observed in other PVS where the local agriculture is being relegated to marginal and risk-prone areas. Somali farmers report the loss of some old traditional landraces and a strong weakening in local seed networks (20, 22) with a serious negative impact on sorghum cultivation, as reported in the last decade.

Undoubtedly, the conservation and improvement of sorghum accessions are of practical value in this area. The definition of farmer-oriented conservation and improvement programs will lead to a greater production stability of this traditional food crop before loosing its high potential. This manuscript reports the first attempt to characterise some of the sorghum genetic diversity found in southern Somalia. As reported in previous studies, the analytical methods outlined in this research represents an useful tool in detecting crop genetic variability and can aid in the definition of future conservation strategies and improvement programs of Somali sorghums.

As recognized by the Convention on Biological diversity, the world-wide future food supply depends on the conservation and exploitation of genetic diversity and this research attempts to add to that body of knowledge.

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M. Manzelli, Italian, Degree in Tropical and Subtropical Agronomic Sciences, PhD in Agro-biotechnologies for tropical production, Researcher, Department of Agronomy and Land Management, Faculty of Agriculture, University of Florence, Italy.

S. Benedettelli, Italian, Degree in Agronomic Sciences, Associate Professor of Plant Breeding and Statistics, Department of Agronomy and Land Management, Faculty of Agriculture, University of Florence, Italy.

V. Vecchio, Italian, Degree in Agronomic Sciences, Full Professor of Tropical and Subtropical Crop Species, Department of Agronomy and Land Management, Faculty of Agriculture, University of Florence, Italy.