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Sorghum bicolor landraces: Selection criteria and diversity management in Ethiopia's East-Central Highlands, 1992-2012

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The dynamics of sorghum on-farm landrace diversity in five North-Eastern, Central Highlands communities in Ethiopia have been investigated through 300 farmer interviews and surveys of their fields in each of the 1992/1993, 2000/2001 and 2011/2012 cropping seasons. Over the 20-years, farmers' selection criteria increased from 10 to 28 and the landraces from 60 to 77. That 50 of the landraces were recorded in all the surveys, suggests that they were chosen for their acceptable performances over the various and variable climatic seasons and/or for their cultural values. Landraces grown in only one or two communities increased from 37 to 53, while landraces cultivated in three or more increased by 1 (23 to 24). These increases have occurred despite increased land fragmentation related to government land redistribution policies and population growth having decreased the average field area planted to sorghum landraces by 42% (1.97 to 1.14 ha). Despite the reduced land area cultivated, 56% of the farmers increased their on-farm sorghum landrace richness and 72% increased their selection criteria over the period. The implications of cultivating huge landrace diversity, using multiple selection criteria and increasing the practice of interplanting quick-maturing standby crops in a situation of shrinking and increasingly fragmented land areas for the feeding of a growing population in an area of recognizable climate uncertainty and extremes are discussed.

Key words: Agricultural landscape, agroclimatic variations, farmers' selection criteria, landrace richness, Spatio-temporal dynamics.

INTRODUCTION

Since the dawn of agriculture, landraces have served as the foundation for humanity's food and livelihood security. They emerged through intra-and inter-speciation processes in response to human and natural selection pressures. Landraces continue to be abundant, especially where unfavourable soil and/or climatic

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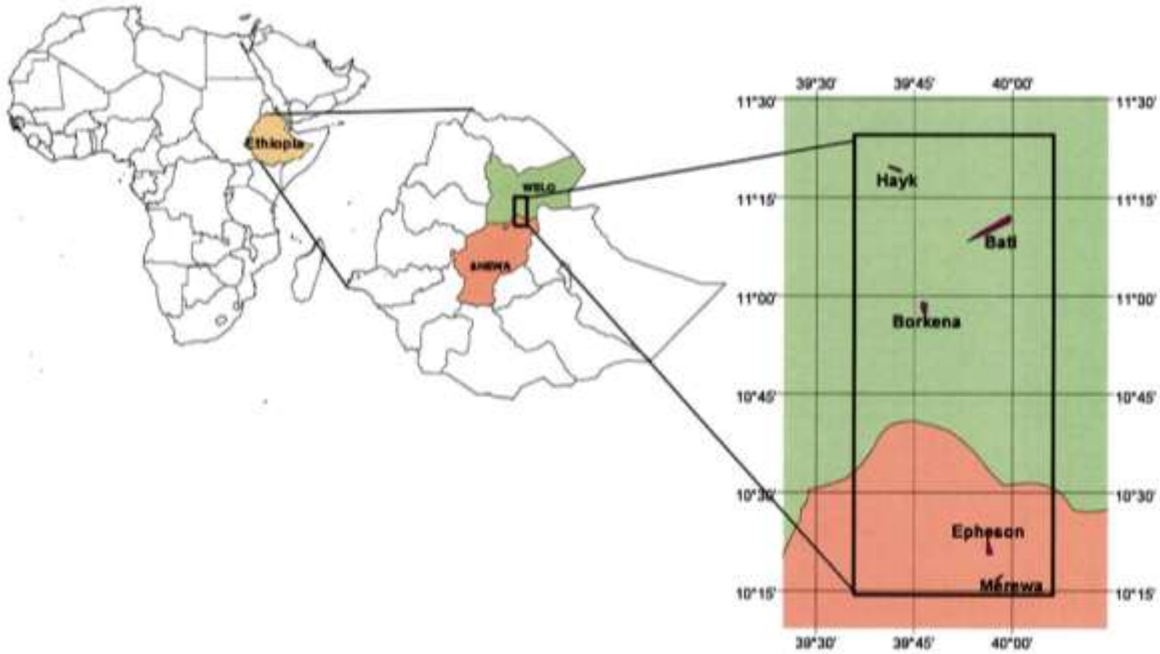

Figure 1. The research area: five agricultural landscapes in North Shewa and South Wollo, Ethiopia (Teshome et al. 2007).

conditions constrain the production systems of traditional farmers.

In Ethiopia, the centre of origin of sorghum (Vavilov, 1926), traditional farmers maintain a wealth of sorghum landraces and other locally, nationally, regionally and globally important crop species in their seed systems and agricultural fields. Sorghum [*Sorghum bicolor* (L.) Moench], which was domesticated (Vavilov, 1951; Dogget, 1988, 1991) and diversified in Ethiopia (Harlan, 1969), belongs to the elite cultivated crops that strongly dominate as sources of human energy. Indeed, sorghum is surpassed, only by rice, wheat, and maize in feeding the human race (National Academy of Sciences, 1996).

Of these crops, the untapped potential of sorghum is by far the greatest. The base of this potential resides in the genetic, morphological and physiological characteristics of the landraces selected and maintained by the traditional farmers. These characteristics have allowed sorghum to dominate in many drought-prone production systems. More than 90% of African sorghum production is from traditional-farmer-developed sorghum landraces (National Academy of Sciences, 1996). In Ethiopia, over 95% of sorghum fields are planted to sorghum landraces, and over 95% of the sorghum varieties cultivated are farmer-selected landraces (CSA, 2012). Intraspecific diversity and the farmers' knowledge and practices have worked together over climatic seasons (time) and across agricultural landscapes (space) to provide resilient and sustainable seed, food, and livelihood security and to reduce the risks of genetic erosion (Teshome et al., 2016).

Studies by Teshome (1996) to present in north Shewa and south Wollo, Ethiopia, where sorghum is the dietary staple and most important crop in production and acreage, have verified that human and natural factors interact to generate and expand the status and trends of landrace diversity in traditional farming systems at field, community and landscape levels. Surveys were conducted in five agricultural communities - Bati, Merewa Adere, Epheson, Borkena, and Hayk - by increasing altitude (Figure 1). A major south to north highway, with a link to Bati and the Rift Valley, links the communities. While the highway connects the communities, the farmers, by and large, use beasts of burden to transport agricultural produce to the nearest local market. Direct interactions with farmers of other than neighbouring communities are infrequent.

Three hundred randomly selected farmers were interviewed and their fields systematically surveyed in each of 1992/1993, 2000/2001 and 2011/2012 cropping seasons to determine if and how farmers' selection criteria and sorghum landrace diversity have changed, and to gain insight into the implications of the changes for seed, food and livelihood security. The major conclusions are that: (1) folk and numerical taxonomies for the landraces are consistent with one another (1997); (2) the landrace diversity at the field level is greater for farmers who apply more selection criteria to define their diverse needs and requirements (1999b); (3) the sorghum landraces vary in their levels of biological resistances to storage pests (1999a); (4) the farmers' knowledge of storability corresponds with laboratory tests of resistance to weevil infestations (1999a) and (5) both natural factors and farmers' selection criteria shape crop genetic diversity at the field and landscape levels (1996).

The farmers practice diversity-based agriculture in which a variety of crops and crop varieties are cultivated. Management choices are based on their knowledge of their fields in terms of size, soil variability, topography, altitudes, and microhabitats, and how these impose restrictions, or present opportunities. Recognition that climatic factors have degrees of unpredictability is always included. The farmers attempt to self-insure by choosing a sufficiently broad base of landraces to ensure at least the minimum essential degree of food and income security (Abdi et al., 2002; Dyer et al., 1992, 1993; Tunstall et al., 2001; Teshome et al., 1999b, 2007, 2016). Most of our study area experienced the severe droughts that afflicted much of East Africa in the late 1980s. As the drought abated, the farmers, in collaboration with the Seeds of Survival Program (SoS) of USC Canada, actively engaged in a major effort to rescue threatened landraces from extinction. The 1992/93 survey was undertaken to establish a benchmark, relatively early in the SoS program, against which to compare future developments.

The objective of this paper is to highlight and analyze the spatio-temporal changes of sorghum landraces, farmers' selection criteria and field sizes, as they evolved over this 20 year period. Readers are advised that, although the research for this study was conducted in five distinct agricultural communities, analysis and discussion will be conducted at the geographical scale of the whole study area. This broad landscape approach is employed to facilitate discussion of the opportunities and difficulties presented by nature's short- to medium-range changes, and the commonalities and differences in the ways that the farmers have responded to the natural and human constraints that they face as they react to agro-environmental, political and other opportunities and challenges (Manel et al., 2010; Schoville et al., 2012).

Study area

The study area (Figure 1) is dominated by steep slopes and undulating landforms with variable shapes and sizes of valley bottoms. Altitudes of the fields surveyed range from 1,200 to 2,500 m above sea level. Mountains and hills, ranging from 900 to 3000$^+$m, influence the agroclimatic patterns of the study area (Teshome, 1996). The major soil types are *Vertisols (in level valley bottoms), Alfisols (on undulating areas in valleys and on low slope and), Inceptisols (on modest slopes),* and *Entisols (on steeper slopes)* (Teshome, 1996).

Temperature and rainfall are highly heterogeneous and play deterministic roles in the crops and varieties cultivated. Mean monthly minimum and maximum temperatures range from 3-14°C and 18-30°C, respectively (EMA, 2012). The annual rainfall regime may be bimodal or unimodal. The bimodal rains come as short rains (*belg)* in February/March to April/May followed by long rains (*meher)* from May to September. The short rains (*belg)* may be adequate for quick-maturing sorghum and other fast-maturing crops, and support up to 30% of grain harvest. The long rains (*meher*) regularly support in excess of 70% of grain production. When the *belg and meher* rains overlap, a bountiful harvest may result. Even light, short rains make ploughing for the long season easier and facilitate planting. If the long rains are inadequate in the unimodal regime, severe shortfalls in grain production may result.

The agricultural system is a rain-fed, seed-farming complex, dominated by cereals, pulses and oil crops. The land is cultivated several times in preparation for planting. Seeds are broadcast over the field and then ploughed into the soil to facilitate germination. Stagger planting and crop diversification are ways of adapting to late or early onset and unpredictability of rainfalls. Nevertheless, undesirable timing and variability of rainfall can introduce serious challenges.

At harvest time, farmers fell each sorghum plant while the head is intact. The heads are removed using a sickle, collected in baskets and taken to the threshing ground. Threshing may be done as a bulk mixture or each landrace is separated by its phenotype and threshed separately. Livestock and human labour are used in threshing. The threshed grain is collected, taken home and stored.

METHODOLOGY

The sorghum landrace diversity measurements were conducted on-farm. For each survey, transect lines were set out 10 meters apart, and the owner of each field was asked to identify the landrace of the sorghum plant closest to each 5 m interval point; at least 200 plants were randomly sampled in each hectare of each field. During the field survey, individual farmers identified each sampled plant by landrace name, and identified the reasons for growing it. Farmers also were asked about the maintenance of sorghum wild relatives *in situ* and the sources of the seeds for their standing landrace populations.

Multiple samples of each landrace were selected in each field with no sample regeneration, purification or bulking being done. This sampling strategy allowed verification that the farmers' names for the sorghum landraces were consistent across the communities and consistent with scientific numerical taxonomy (Teshome et al., 1997). This strategy also facilitated the identification of new landraces. Landrace names are derived on the basis of distinctive agromorphological characteristics, use values and other criteria. The participating farmers all speak the Amharic language and are consistent in their use of sorghum landrace names; neither using the same name for different landraces nor using multiple names for a particular landrace. In Kenya, Labeyrie et al. (2014) also found that sorghum landrace names were consistent across all the farming communities within which a common language was spoken.

They were followed in the 2000/2001 resurvey conducted by Teshome with collaboration of graduate students and their supervisors from Addis Abeba University (AAU) and research personnel from the Institute of Biodiversity Conservation (IBC), and in the 2011/2012 resurvey conducted by Teshome in collaboration with USC (Unitarian Services Committee of Canada), EOSA (Ethio-Organic Seed Action. The changes between the 1992/93 to 2000/01 and 2000/01 to 2011/12 surveys have been published in Teshome et al. (2007, 2016).

RESULTS

Changes in sorghum landrace richness

The distinct sorghum landraces recorded have increased from 60 in 1992/93 to 68 in 2000/01 and 77 in 2011/2012 (Table 1). The maximum landraces grown by an individual farmer was 24 in 1992/1993, 34 in 2000/2001 and 26 in the 2011/2012 cropping seasons. The sorghum landrace diversity differences across all the seasons were significant, except between 1992/1993 and 2000/2001 (Figure 2 and Table 2).

Of the 60 landraces recorded in 1992/1993, 9 (*Adow, Aeyfere, Borie, Jiru tinkish, Marchuke/Barchuke, Senklie, Wogere tinkish, Tuba tinkish, and Zengada tinkish)* were not recorded in 2000/2001 of which 4 (*Aeyfere, Marchuke/Barchuke, Senklie, Wogere tinkish,* were again recorded in 2011/2012; a net loss of 5 over 20 years. Over the same periods, 17 new sorghum landraces were recorded in 2000/2001 (total of 68); 13 of these were again recorded in 2011/2012. Only 13 of the 17 new landraces first recorded in 2000/2001 were again recorded in 2011/2012. *Jibo tinkish, Worebabo tinkish, Wotet-begunche, and Gebsitu* were the ones not re-recorded. Nine new landraces were recorded in 2011/2012 (total of 77). Those landraces that were recorded in the first two surveys, but not recorded in 2011/2012, cannot definitively be declared as ‘lost’; they may have been at locations not captured by the survey, or they may remain in the local seed supply system but were not been chosen for planting that season by the farmers interviewed (Table 1).

The analysis to this point has been based on the accumulated data from all five communities. A few landraces were recorded in all the communities but the majority were in only one or two. This has caused us to divide the landraces into two categories: ‘specialist’ and ‘generalist’, in which ‘specialists’ are those recorded in only one or two of the agricultural landscapes, while ‘generalists’ are found in three or more. By this criterion, specialist landraces increased from 37 to 53 (by 43%) over the 20 years, accounting for 61% in 1992/93 and 69% in 2011/12. Over the same period, the generalist landraces increased from 23 to 24, accounting for 38% in 1992/1993, and 31% in 2011/2012.

A substantial proportion of the farmers have changed the number of sorghum landraces cultivated per field. By 2000/01, 39% had increased diversity, 18% had unchanged diversity and 43% had decreased diversity relative to 1992/93. By 2011/2012, 56% had increased, 30% had unchanged, and 14% had decreased the diversity relative to 1992/1993.

Changes in field sizes and farmer responses

Over the survey period, the average field size planted to sorghum landraces has changed from 1.97 ha (92/93) to 1.21 ha (00/01) to 1.14 ha in (11/12) (Figure 3 and Table 2). The average field size was 62% of the original by 2000/01 and only 58% of the original by the 2011/2012 cropping season. Despite these huge shrinkages, farmers have slightly increased the average landrace richness across the whole study area per field from 8.35 in 1992/93, to 8.63 in 2000/2001, and 9.39 in 2011/2012. The extremes of sorghum landraces planted per field were 2 and 24, 2 and 34, and 3 and 26 in 1992/1993, 2000/2001, and 2011/2012, respectively.

By 2000/01, 62% of farmers had greatly reduced field sizes planted to sorghum compared to 1992/1993, 26% maintained the same field sizes, and 11% increased the field sizes. Despite the field size changes, there was almost no change of landrace richness per field. By 2011/2012, 19% of farmers had further decreased field sizes, 53% maintained the same field sizes, and 28% had increased the field sizes; surprisingly, the number of sorghum landraces per field increased significantly. What is of most interesting is that while the field size decreased, 56% of the farmers increased landrace richness and 72% used an increased number of selection criteria (Table 3).

Changes in selection criteria

The total number of selection criteria for choosing sorghum landraces has increased greatly with time (Table 2 and Figure 4) (Teshome et al., 2016). The number of selection criteria for individual landraces ranged from 2 to 6, 2 to 8, and 4 to 8 and the number of per field ranged from 2 to 10, 2 to 16, and 2 to 16 in the successive cropping seasons. Figure 4 presents the changes in the number of selection criteria used by the individual farmers across cropping seasons.

Between 1992/1993 and 2000/2001, 79% of farmers had increased their number of selection criteria; 7.3% decreased; and 13.5% had maintained the same number. Between 2000/2001 and 2011/2012, 85.9% of farmers had hugely increased; 4.5% decreased and 9.6% maintained the same number. Over the 20-year interval, 72% of the farmers increased; 11.5%; decreased and 16.5% maintained the same number of selection criteria (Figure 4 and Table 3).

DISCUSSION

This research commenced a few years after the easing of the severe droughts that caused famine and other severe hardships for the people of the area during the 1980s. The SoS (Seeds of Survival) program had been established to assist the communities in recovering and

Table 1. Landrace distributions (1992/1993, 2000/2001 and 2011/2012).

Sorghum landraces ('92/93)		Sorghum landraces ('00/01)		Sorghum landraces ('11/12)	
Abaerie	Killo	Abaerie	Jofa tinkish	Abaerie	Key ehel
Adow	Kumie	Abdoke	Keteto	Abdoke	Keyo tinkish
Aehyo	Megalie tinkish	Aehyo	Keyo tinkish	Aehyo	Killo
Aeyfere	Malie tinkish	Aehyo-Jamuye	Killo	Aehyo-Jamuye	Kumie
Afeso	Meltae	Afeso	Kumie	Aeyfere	Malie tinkish
Amelsi	Merabete	Ajaebe	Malie tinkish	Afeso	Megalie tinkish
Bakelo	Mogayefere	Amelsi tinkish	Megalie tinkish	Ajaebe	Meltae
Barchuke/Marchuke	Mognayakish tinkish	Aso tinkish	Meltae	Amelsi tinkish	Merabete
Basohe	Mokake	Atse-bayush	Merabete	Aso	Mogayefere
Betenie	Motie tinkish	Bakelo	Mogayefere	Atse-bayush	Mognayakish tinkish
Borie	Nchero	Basohe	Mognayakish tinkish	Bakelo	Mokake
Buskie	Necho tinkish	Betenie tinkish	Mokake	Barchuke	Motie tinkish
Cherekit	Rayo	Borshe	Motie tinkish	Basohe	Muzie tinkish
Chomogo	Senkle	Buskie	Nchero	Betenie tinkish	Nchero
Dekussie	Sererge tinkish	Cherekit	Necho tinkish	Borshe	Necho tinkish
Delgome	Tenglaye	Chomogo	Rayo	Buskie	Rayo
Dobie	Tuba	Dekussie tinkish	Sedecho tinkish	Cherekit	Sedecho tinkish
Ganeseber	Tuba tinkish	Delgome	Sererge tinkish	Chomogo	Senkle
Gedalit	Wanese	Dobie	Subahan	Dekussie tinkish	Sererge tinkish
Gegretie	Watigella	Dewoye	Tenglaye	Delgome	Serina
Gorad	Wogere tinkish	Ganeseber	Tuba	Dewoye	SoS-Aehyo
Goronjo	Wofe-aeybelash	Gebsitu	Wanese	Dobie	Subahan
Gubetie	Wogere	Gedalit	Watigella	Fereji	Tenglaye
Jamuye	Wuncho	Gegretie	Wofe-aeybelash	Ganeseber	Teshale
Jemaw	Yegenfoehel	Gomzazie	Wogere	Gedalit	Tuba
Jiru	Yekermindaye	Gorad	Worebabo tinkish	Gedido	Wanese
Jiru tinkish	Yekersolate	Goronjo	Wotet-begunche	Gegretie	Watigella
Jofa tinkish	Zengada	Gubetie	Wuncho	Gomzazie	Wofe-aeybelash
Keteto	Zengada tinkish	Humera	Yegenfoehel	Gorad	Wogere
Keyo tinkish	Zeterie	Ismael	Yekermindaye	Goronjo	Wogere tinkish
		Jamuye	Yekersolate	Gubetie	Worehimenu
		Jemaw	Yifate tinkish	Humera	Wuncho
		Jibo tinkish	Zengada	Ismael	Yekermindaye
		Jiru	Zeterie	Jamuye	Yekersolate
				Jemaw	Yelem-deha
				Jiru	Yifate tinkish
				Jiru tinkish	Zengada
				Jofa tinkish	Zeterie
				Keteto	
Subtotal=30	**Subtotal=30**	**Subtotal=34**	**Subtotal=34**	**Subtotal=39**	**Subtotal=38**
Grand Total= 30 + 30= 60		Grand Total= 34 + 34= 68		Grand Total= 39 + 38= 77	

regenerating the seed stock of their major crop, sorghum, which provided the people with food, feed, fibre, fuel, building material, income and more. Most of the initial seed stock was obtained within the communities and across the study area. The 1992/93 research established a baseline against which to measure subsequent changes (recovery). The relationships among landrace richness, farmers' selection criteria and field sizes through time and space over the subsequent twenty years period are discussed below.

Diversity changes

Traditional farmers, using their knowledge of the heterogeneity and adaptive responses of the landraces to

Table 2. Diversity, field size, and farmers' selection criteria changes in1992/1993, 2000/2001 and 2011/2012

Selection criteria	Mean 1992/93	Mean 2000/01	T-stat	P-value	Mean 2000/01	Mean 2011/12	T-stat	P-value	Mean 1992/93	Mean 2011/12	T-stat	P-value
Field size (ha)	1.97	1.21	16.22	<0.0001	1.21	1.14	2.1	0.035	1.97	1.14	16.15	<0.0001
Landrace diversity (numbers)	8.35	8.63	-1.02	0.30*	8.63	9.39	-3.2	0.0015	8.35	9.39	-3.41	0.0007
Farmers selection (numbers)	5.35	8.82	-20.43	<0.0001	8.82	9.21	-2.2	0.02	5.35	9.21	-23.72	<0.0001

Changes in 1992/93, 2000/01 and 2011/12 cropping seasons were tested for significance using matched pairs *t* test.
(*) = Not significant @ P≤0.05.

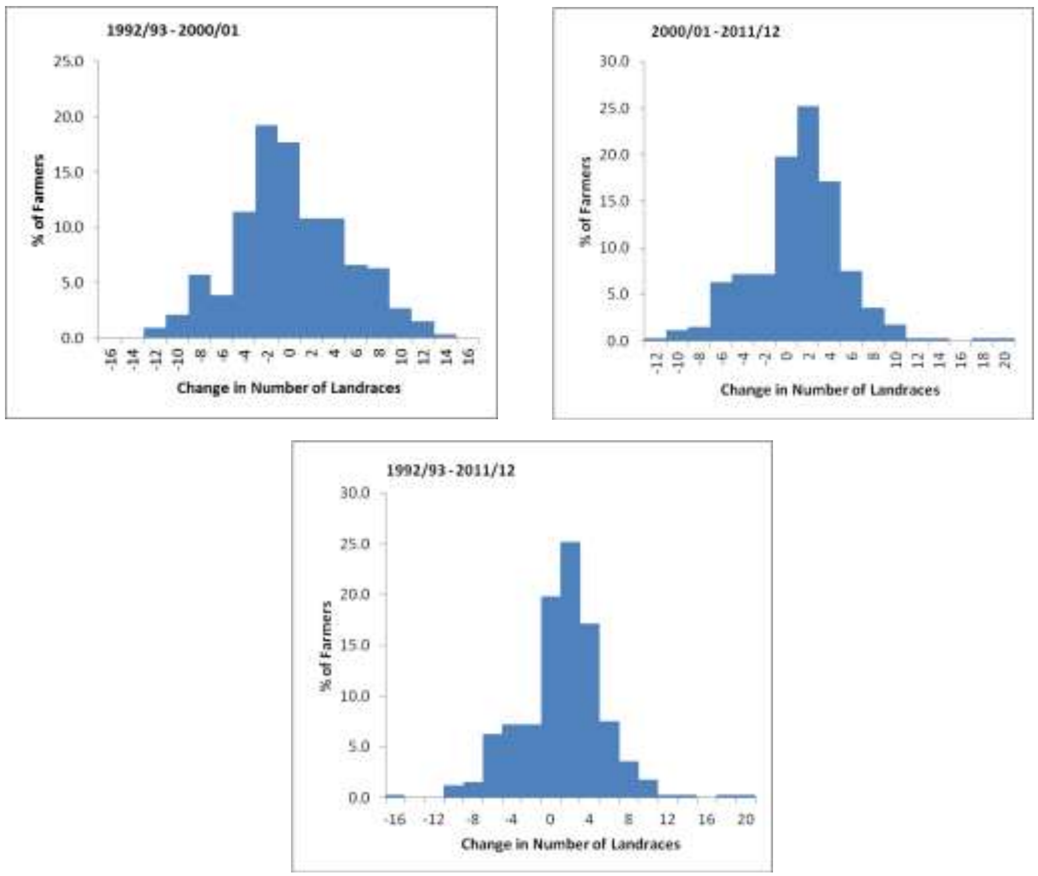

Figure 2. Landrace diversity change distributions.

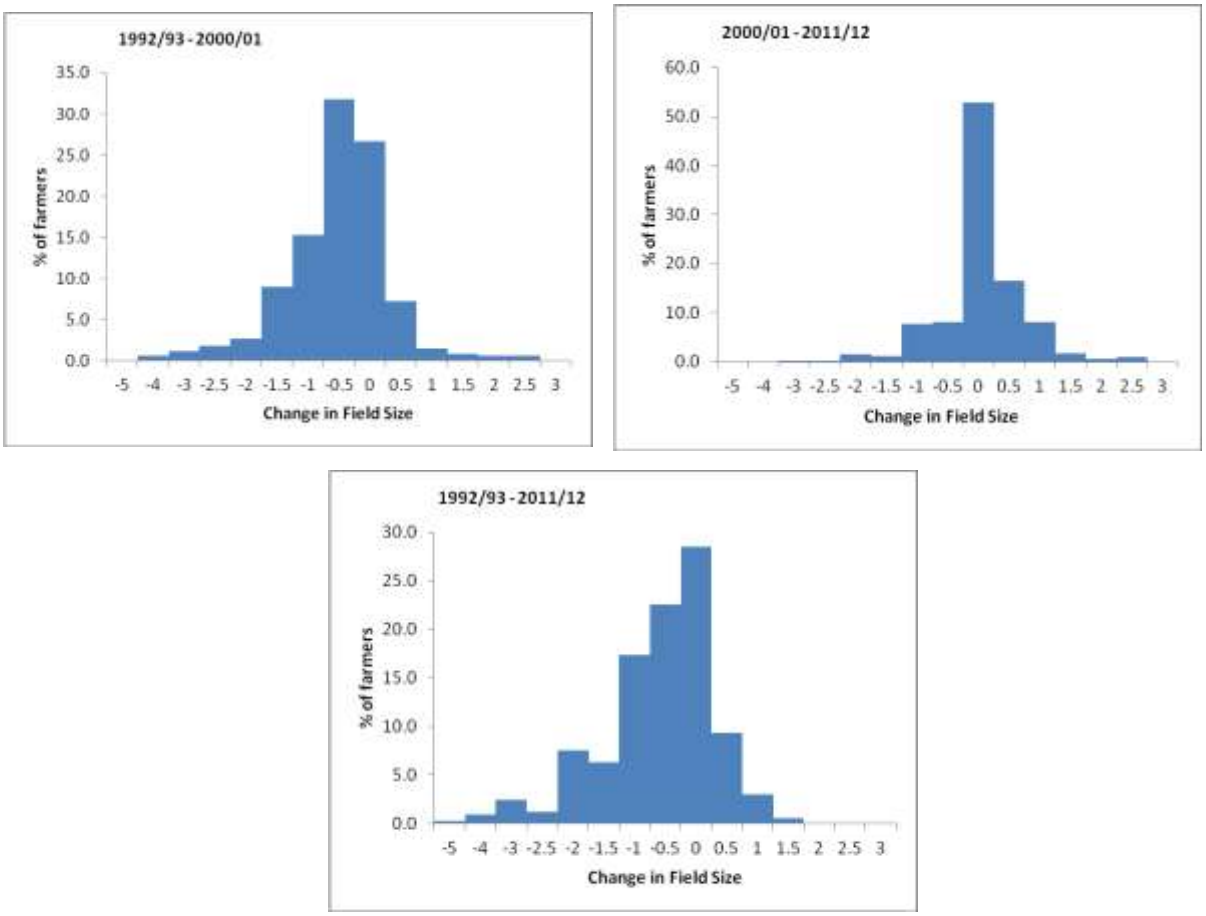

Figure 3. Field size change distributions.

Table 3. Percentages of farmers and changes in diversity, field sizes, and farmers' selection criteria (1992/1993 and 2011/2012).

Selection criteria	Increased (% farmers)	No change (% farmers)	Decreased (% farmers)
Field size changes	13.00	28.50	58.50
Diversity changes	55.90	14.10	30.00
Selection changes	72.05	16.50	11.45

variable agro-climatic conditions, cultivate a diversity of crops and crop varieties during each growing season. For the purposes of this analysis, we divide the landraces into two categories: 'generalist' and 'specialist', as defined earlier. The generalist landraces are deemed to have a broad adaptive range that allows them to perform over a substantial agro-climatic range. In contrast, the specialist landraces are deemed to be more narrowly adapted and niche-specific. Over the survey periods, the specialist landraces, grown in only one or two communities, increased from 37 to 46 to 53, while the generalists cultivated in three or more communities remained essentially constant at 23, 22 and 24, respectively in 1992/1993, 2000/2001 and 2011/2012 cropping seasons. A few landraces crossed the line from generalist to specialist, or vice-versa, during the study period (Teshome et al., 2016).

Although the absolute number of distinct sorghum landraces increased from 60 (1992/1993) to 77 (2011/2012), the number of sorghum landraces that were grown in 2 or less, 3 and 4 communities increased from 37 to 53, 6 to 9 and 9 to 10, respectively, while those in all five decreased from 8 to 3. While we anticipated an increase in 'niche-specific', specialist landraces, because the selection process starts with a single farmer with her/his family selecting adaptable landraces which might

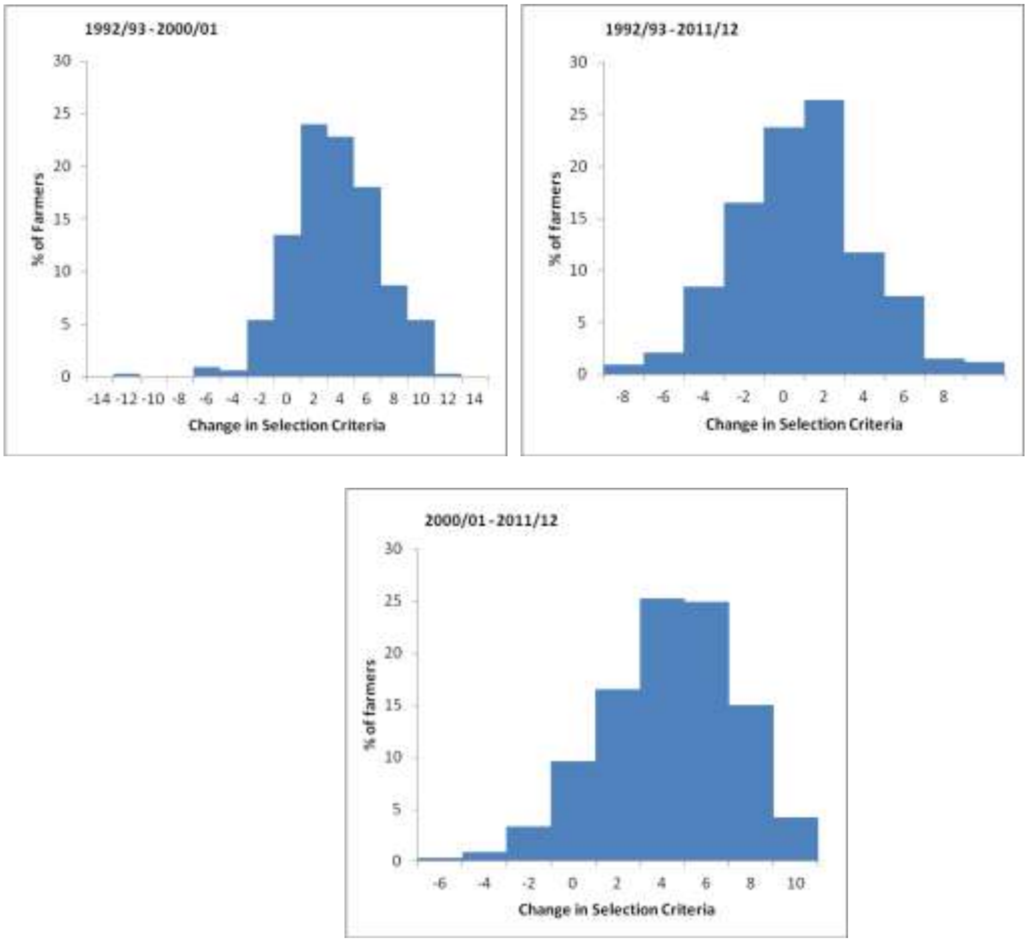

Figure 4. Selection criteria change distributions.

subsequently be adopted by neighbours, we had not expected to observe a decrease in the number of highly plastic and widely adapted landraces grown in more than three of the agricultural communities. The latter trend could, in the long term, have negative consequences for the sustainable cultivation of widely adapted landraces, especially in a context of future field-size reductions and increased fragmentation. As explained by Teshome et al., (2007, 2016), land fragmentation and field size shrinkage directly affect the viable population sizes of the landraces and the selection, amount, quality, quantity, diversity and availability of the desired seed stocks for sowing and re-sowing purposes. Should we be concerned? Should this abundance of both specialist and generalist landraces be monitored periodically? Our answer is 'Yes'.

This spatio-temporal sorghum study has demonstrated that sorghum landrace richness varies by farmer, field, and community, cropping season and agricultural landscape. These findings have commonalities with the changes of crop diversity over time as studied by Yemane et al. (2009) who reported an increment in the diversity of sorghum collections between 1997 and 2007 in northern Ethiopia and observed that sorghum landrace richness varied considerably across villages, districts and administrative regions. Their study did not directly assess whether or how the diversity changes might be related to changing farmers' selection criteria or field sizes.

Stable landraces

In our three surveys over the twenty-year period, 50 of the landraces were recorded somewhere within the study area during each survey (Table 4). We interpret this to mean that: 1) there are farmers who value these landraces; 2) the landraces satisfy a variety of their needs for seed, food, feed and livelihood security; and 3) the individual landraces, has a stable heterogeneity that is adapted to niches of soil conditions, climatic variability and socio-cultural environments found within the host communities. These landraces are, by and large, self-pollinated populations with distinctive and stable morphological characteristics that make selection, harvest, exchange, marketing and processing much

Table 4. Cultivated stable sorghum landraces (1992/1993, 2000/2001 and 2011/2012).

Landraces	Use*	Landraces	Use*	Landraces	Use*
Abaerie	DG	Goronjo	FG	Motie tinkish	SW
Aehyo	DG	Gubetie	FG	Nchero	DG
Afeso	DG	Jamuye	DG	Necho tinkish	SW
Amelsi tinkish	SW	Jemaw	DG	Rayo	DG
Bakelo	DG	Jiru	DG	Sererge tinkish	SW
Basohe	DG	Jofa tinkish	SW	Tenglaye	DG
Betenie tinkish	SW	Keteto	DG	Tuba	DG
Buskie	DG	Keyo tinkish	SW	Wanese	**FG**
Cherekit	DG	Killo	WR	Watigella	FG
Chomogo	DG	Kumie	DG	Wofe-aeybelash	DG
Dekussie tinkish	SW	Megalie tinkish	SW	Wogere	DG
Delgome	DG	Malie tinkish	SW	Wuncho	DG
Dobe	DG	Meltae	FG	Yekermindaye	SW
Ganeseber	DG	Merabete	DG	Yekersolate	SW
Gedalit	DG	Mogayefere	DG	Zengada	DG
Gegretie	FG	Mognayakish tinkish	SW	Zeterie	DG
Gorad	DG	Mokake	DG		

*Dry grain (DG), Fresh green grains (FG), Sweet stalk (SW), Wild Relative (WR).

easier for the farmers and other end users. They include broad generalists and speciality sorghum types endowed with desirable attributes, potentially including: quality protein, free threshing, storability, disease and pest resistance, popping capability, quick cooking, and short and long growing-season varieties. These 50 landraces are variously used as: dry grain [30/50 (60%)]; sweet stalk [13/50 (26%)]; fresh green immature grains [6/50 (12%)]; and a wild-relative for ecological and genetic benefits [1/50 (2%)] (Table 4). The farmers value them for their collective contributions to multiple livelihood aspects and for their survival through favourable and unfavourable conditions. Because of these desirable factors, these landraces should face very low risk of genetic erosion or displacement. They represented 83% (50/60), 73% (50/68), and 65% (50/77) of all the cultivated sorghum landraces, respectively, in 1992/93, 2000/01, and 2011/2012 cropping seasons (Table 1).

Field size and diversity

The relationship between on-farm sorghum diversity and field size is bimodal in all the surveys. Diversity tends to be high in small fields (especially those adjacent to homesteads), less in intermediate sized fields and again high in larger fields. Higher diversity in larger fields reflects both the availability of more space and the existence of a greater diversity of agroclimatic niches (Teshome et al., 1999b, 2007, 2016). In small fields near the homestead, farmers actively increase the niche diversity by using household refuse and family labour to grow preferred landraces for fresh green consumption during the growing season. Abdi and Asfaw (2005) found similar relationships between sorghum landrace richness and field sizes.

The number of landraces an individual farmer grows is influenced by many factors including: rainfall and temperature variations, seed availability, exchange mechanisms and decision making processes acting individually or collectively. Innovative individuals and groups of farmers with access to diverse and adaptable seed stocks may use a range of sowing, resowing after seedling failure and other strategies to get through dry-spells, drought and other challenging climatic conditions that may threaten to undermine their livelihood security.

Selection criteria and diversity

Farmers' selection criteria are as old as agriculture itself. Farming commenced with the selection and domestication of wild plants which had served as food sources and for other purposes. Although farmers' have used selection criteria for millennia, they have not attracted the attention from researchers and breeders that they deserve. They have rarely been described in the literature (Zeven, 2000) and little scientific data is available on the selection and maintenance of landraces by farmers (Cleveland et al., 1994). This study and others by Abdi and Asfaw (2005) and Teshome et al. (1999b, 2007, 2016) have established that dynamic relationships exist between crop diversity and traditional farmers.

Farmers' crop selection criteria reflect the range of socioeconomic, cultural, agronomic, ecological, biological, and dietary needs each farmer desires to obtain from available resources. They result from deliberate application of women's and men's selection criteria, sophisticated naming systems and environmentally friendly farming and exchange mechanisms. The selection criteria vary according to each practising farmer's desires, the crop genetic resources available and the agroclimatic environment(s). There are multiple criteria because farmers recognize that multiple crops and crop varieties are essential to meeting their livelihood requirements. The extent to which farmers have periodically increased (or decreased) their selection criteria during the twenty-year period of our surveys demonstrates their dynamic nature.

The mixtures of crops and crop varieties nurtured by current farmers, in favourable and unfavourable agroclimatic environments, provide the choices to meet the challenges of feeding present and future generations. The farmers' selection criteria are the *de facto* sources of information on the agronomic performance and adaptive responses of sorghum landraces in highly variable agroclimatic environments. The varietal names, as chosen by farmers, often provide information on how the landrace is adapted to environmental conditions and cultural preferences.

Landrace usage

Sorghum landraces are rich with nutritional, dietary and sustenance qualities. Appropriate sorghum landraces are used for dry grain products, fresh green immature grain consumption and sweet stalk consumption. The percentages of landraces used primarily for human consumption have been relatively stable over the twenty-year period.

Landraces grown for dry grain production constitute nearly 60% of the sorghum population. They are selected for their yield, marketability, and beverage and milling qualities. They are the staple for family consumption and are the most important contributor to household income generation. The dry grain sorghums are milled into flour for baking or the grain is fermented, roasted and ground for beverage production. The solid stem residue is commonly used as fuel and the leaves as livestock feed. They constituted 35/60 (58%), 38/68 (56%), and 47/77 (61%), respectively, of the sorghum landrace populations measured in 1992/1993, 2000/2001, and 2011/2012. Their dominance in all the communities confirms their vital role in meeting the livelihood needs of all farming communities.

The sweet stalk landraces are cultivated for home consumption and income generation during the bridging months between the planting and harvesting periods. Sweet stalk sorghum landraces are popular for their chewable, green, sugar-rich stems. They constitute 27% of the landraces and are sparingly planted among the other sorghum landraces and maize. Their grains can be fermented to make beer for home consumption. The stems are sold in the local market for consumption by chewing, like sugar cane. Sweet stalk sorghum landraces are adapted to a range of soil and climatic constraints. Their drought tolerance and quick maturing helps the farmers go through the food scarcity months. Sweet stalk landraces have increased from 17 (92/93) to 20 in 2011/2012.

The fresh, green, immature sorghum landraces are also cultivated for home consumption and income generation during the bridging months between the planting and harvesting periods. They constitute less than 15% of the landraces. They are quick maturing and are consumed, either roasted or boiled, during the food scarcity months between grain-filling and harvest. The peduncled head is harvested intact from the standing plant while the grain is still sufficiently soft for consumption after roasting on an open fire or pan or after boiling in a pot. They have superior nutrition quality and palatability. The soft sweet grains are free of phenolic compounds that affect the palatability of most sorghum grains. Farmers generate income by selling them in the local market. Two of these sorghum landraces, *Wotet-begunche (milk in my mouth)* and *Marchuke/Barchuke (honey oozing)*, that have been identified to contain 30% more quality protein, and twice the normal level of lysine, an amino acid critical to nutritional quality (National Academy of Sciences, 1996), are widely grown. These unique sorghum landraces would appear to have potential for enhancement and wider use within the farming communities and for sale to other end users.

Sorghum wild-relative management

As with the cultivated landraces, the wild relatives that were at a 5 m interval point on the transect lines were identified and recorded. Their abundance has remained relatively stable at <2% over the 20 years. Almost all farmers tolerate some presence of sorghum wild-relatives. Intercropping, stagger planting, non-clean cultivation, and relaxed weeding are the major farming practices by which farmers intentionally tolerate wild- and weedy-relatives of sorghum, including *S. aethiopicum* and *S. arundinacium*. They are used primarily as livestock fodder and as mulch to minimize land degradation by protecting the soil surface from wind and water erosion. Their presence encourages gene flow, enhances organic matter accumulation, soil conservation and nutrient cycling, and increases the natural enemies of crop pests.

An educational experience during one of the surveys occurred when a group of farmer experts proudly lined up, for the benefit of the research team, freshly sampled sorghum populations, in order, from wild sorghum, through the weedy- and wild-relatives (grains with total glume cover and long awns) to the highly selected, cultivated, sorghum landraces (naked grains with no

Table 5. Temporal seed sources and percentages of farmers.

Seed sources	1992/1993 % of farmers	2000/2001 % of farmers	2011/2012 % of farmers
Home Saved	50.51	53.30	60.20
Market	16.72	14.20	13.01
Exchange	03.07	05.60	01.49
Community seed bank	02.39	00.48	00.80
Home-saved + Market	00.00	03.24	12.60
Market + Home	09.89	08.09	03.23
Home-saved + Exchange	00.00	01.75	04.25
Exchange +Home	02.39	03.52	02.60
Exchange +Market	01.71	00.85	00.60
Home- saved + Community seed bank	08.19	03.57	00.76
Home + Gift	00.68	00.55	00.00
Gift +Market	01.02	00.60	00.00
Gift + Market + Home saved	00.34	O0.75	00.00
Home + Exchange + Market	01.71	01.25	00.00
Home + Exchange + Community seed bank	00.34	00.75	00.00
Home + Market + Community seed bank	01.02	01.00	00.46
Total (%)	99.98	99.50	100.00

glumes and awns) that have been developed over the ages by the farming community. The sorghum populations along this spectrum differ hugely in the agro-morphological characteristics that farmers use to distinguish their adaptive capacities and performance superiorities.

Seed source management

The availability of seeds and the nature of seed sources affect the richness and on-farm distribution of the sorghum landraces. For the most part, the seed-supply system is stocked with locally grown seeds. Both women and men participate in the decisions as to the type of landraces and the amounts of seeds to save. The dynamics of the home-saved seed system include the selection of seed stocks from the standing crop populations, the elimination of pests and their safe storage under home conditions until required for planting (Teshome et al., 2016).

Home-saved seeds that are surplus to the farmer's needs may be made available through combinations of the Market, Exchange, and Community Seed Banks (CSB) and as Gifts. Table 5, in each line, presents the primary, secondary, and tertiary sources of the seeds that individual farmers have planted. The multiple, local seed sources, centered on local knowledge and practices, reflect the socioeconomic, cultural, genetic and agroclimatic heterogeneity of the production system and are integral components of the local harvest security. Changes in rank order of the sources that have occurred through time (Table 5) show that the percentage of farmers relying exclusively on their home-saved seeds increased from 50% in 1992/1993 to 60% in 2011/2012; the proportion of farmers who primarily used the local market only decreased from 16% (1992/1993) to 13% (2011/2012).

The local markets are critical components of the secured seed system. Besides serving as sources of the desired seed stocks, they are forces of differentiation and diversification that sometimes cross topographic, ethnic, cultural and socioeconomic barriers and introduce different genotypes, possibly leading to the generation of new varieties (Teshome et al., 2016). It is not unusual for farmers who obtained seeds from local markets to report the appearance of unexpected varieties, and weedy- and wild-relatives of sorghum landraces in their fields. Augmentation of home-saved seeds with desired seeds from local Markets increased from 3% in 2000/2001 to 12% in 2011/2012.

Some farmers, who grow a large number of distinct sorghum landraces every year, have found it challenging to maintain the desired seed stocks for all their preferred landraces. A few farmers have made arrangements to co-operate with each other in the exchange and storage of home-grown seed stocks. In the highland landscape of Hayk, 20% of the farmers used such exchange arrangements as the primary source to obtain sorghum seed in 2000/01 (Teshome et al., 2007). Seed exchange mechanisms are also employed by some farmers to test the performance of new crop varieties. Across the whole study area, the farmers employing exchange increased from 3 to 6% between 1992/1993 and 2000/2001, but declined to 2% in 2011/2012.

The security of the farmer-based seed system is built on the selection and inter-mixed cultivation of many different landraces at field and landscape levels over long time periods and various weather conditions. Indeed, security requires the collective efforts of the farming communities to ensure the diversity, equity, efficiency and resiliency of the farmers' seed systems. The cooperation in the seed system is also a reflection of the social network operating in the production system (McGuire, 2008).

IMPLICATIONS AND CONCLUSION

In the process of conducting the field surveys and through other interactions, the research team has developed a great deal of respect for the farmers (male and female) throughout the research area. We have been in the position of observing their practices and accomplishments. They (and their ancestors), as the primary domesticators, users, and engines of diversifications, have established an intimate relationship with the crops and landraces they select, cultivate and conserve. Based on their time-tested, experiential knowledge and keen observation, the farmers use the environmental heterogeneity to meet their multiple social, cultural, economic and ecological needs. The human selection process, superimposed on the environmental and agro-climatic heterogeneity, has had a major role in generating and maintaining the intraspecific diversity now observed at field and landscape levels. Because substantial discussion of the results has occurred in the various subsections of this paper, we have chosen to present of terse summary of the major findings of this research project.

Lessons learnt

We have learned many things about the farmers and the landraces: 1) The farmers know the characteristics of the landraces that they grow and they know why they grow each one of them; 2) The farmers have developed sound management practices relating to seed selection, seed storage, and marketing; 3) The farmers have used the inherent heterogeneity of the landraces and the agro-climatic environments to develop a mixture of high yielding, pest and disease resistant, cold and heat tolerant, quick and long maturing landraces; 4) The farmers use the whole plant - there is no such thing as waste. If it cannot be used otherwise, the plant or, more likely, the plant part goes back into the soil; 5) The most wide-spread generalist landraces across the communities are high-yield, dry-grain landraces, or wild relatives of sorghum; 6) The traditional farmers and landraces have maintained a faithful relationship since the beginning of crop domestication and agriculture – the farmers recognize that the intraspecific diversity of crops is the foundation for resilient seed, food and livelihood systems - they need each other for mutual survival.

Reflection

This study has gone beyond the identification of variations and the assessment of diversity by examining and establishing the critical role of farmers' selection criteria in the generation, diversification, maintenance and use of sorghum landraces. Farmers' skilful management strategies applied to genetic diversity, agro-climatic diversity, agricultural seasons, and agricultural fields and landscapes have strengthened the resilience and adaptive capacities of the farmers by spreading the risks and opportunities across socio-cultural networks, agricultural landscapes and climatic seasons. Such strategic management of genetic diversity needs to be constantly adjusted to increase food production while reducing societal vulnerability. Farmers, through farmer-scientist collaborations, can play a major role in leading the scientific community to recognize the importance of the generation, selection and maintenance of on-farm diversity and the enhancement of seed, food, livelihood and environmental security. Respect for the traditional farmers and increased recognition of their roles and self-interest in the generation and maintenance of genetic diversity will, hopefully, inspire them to continue with further diversification in order to maximize and stabilize diversity-based production, especially in highly vulnerable production systems.

The farmers of the study area have enthusiastically cooperated with our team of 'outsiders' each time we came asking many (repetitive) questions. We cannot measure the degree to which our curiosity has influenced them, but we know we have. The question as to 'Why do you grow this landrace?' (asked in Amharic) had not been systematically asked before. We are confident that the simple asking of that question during our first survey set their minds in action such that when asked again in the each subsequent survey, the list was longer. We doubt that our other queries had such dramatic effects, but we acknowledge that they most probably had some influence.

Conflict of Interests

The authors have not declared any conflict of interests.

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