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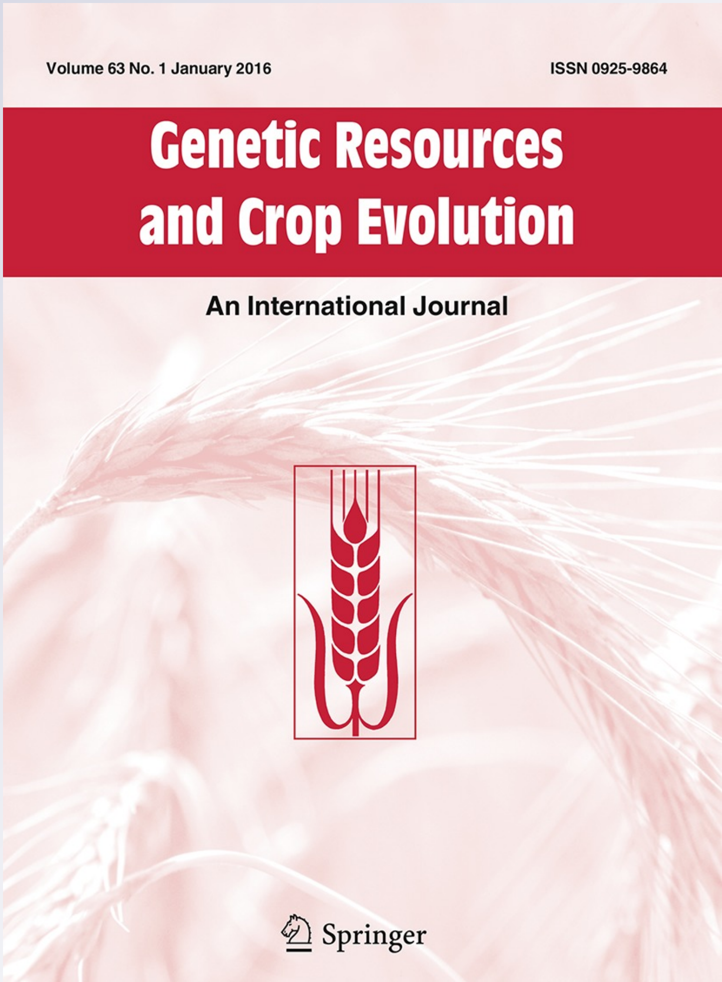

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RESEARCH ARTICLE

Changes of *Sorghum bicolor* landrace diversity and farmers' selection criteria over space and time, Ethiopia

Awegechew Teshome · Daniel Patterson · Zemede Asfaw · Sarah Dalle · J. Kenneth Torrance

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Abstract Temporal and spatial changes in sorghum landrace diversity and distribution, field sizes, and farmers' selection criteria were studied in five agricultural landscapes in North Shewa and South Wollo, Ethiopia. The study was undertaken during 2000/2001 and 2011/2012 cropping seasons in order to ascertain the stability of a range of factors that support the maintenance of sorghum landrace diversity. The same farmers were interviewed and the same sorghum fields were surveyed during both cropping seasons to determine the changes over the 11-year period. Farmers' selection criteria increased significantly in all agricultural landscapes [Bati ($P < 0.0001$); Borkena ($P < 0.0015$); Epheson ($P < 0.002$); Hayk ($P < 0.022$); and Merewa Adere ($P < 0.05$)]. In Bati ($P < 0.0081$) and Merewa Adere ($P < 0.0087$), fields planted to sorghum landraces have increased significantly. Changes in field sizes in Epheson ($P < 0.36$) and Hayk ($P < 0.237$) did not show significant differences. The field sizes in Borkena ($P < 0.0001$) have decreased significantly due to population growth, land distribution policy, and seasonal variations followed by inter-and intra-species crop diversification. Sorghum landrace richness has increased significantly in Bati ($P < 0.0001$) and Hayk ($P < 0.0001$), marginally increased in Merewa Adere ($P < 0.08$). No significant changes have been observed in sorghum landrace richness in Borkena ($P < 0.344$) and Epheson ($P < 0.24$). In 2011/2012, 24 "generalist" sorghum landraces (grown widely across three or more agricultural landscapes), and 53 "specialist" sorghum landraces (restricted to certain microhabitats in one or two agricultural landscapes) were found. Landrace dynamics in response to farmers' selection criteria and environmental variations are explained.

Keywords Agricultural landscape · Diversity · Ethiopia · Farmers' selection criteria · Landraces-landrace richness · *Sorghum bicolor* · Spatio-temporal dynamics

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] was domesticated (Vavilov 1926, 1951; Dogget 1988, 1991), and diversified (Harlan 1969) in Ethiopia where it is currently grown at altitudes from 400 to 3000 m in areas where annual rainfalls vary from 400 to 2000 mm. *Sorghum*, among the most diverse domesticated crop plants, poses challenges of classification (House 1995). Numerous taxonomists have used morphological characteristics to classify *Sorghum*. According to House (1978) and Clayton (1961), Moench, in 1794, established the genus *Sorghum* and brought all the sorghums together under the name *S. bicolor* (L.) Moench. Snowden (1936) classified sorghum into 52 species composed of 31 cultivated, 17 wild, and 4 weedy species. De Wet and Huckabay (1967), on the basis of the absence of genetic barriers among the *Sorghum* taxa, combined these 52 species into a single species. Subsequently, Harlan and de Wet (1972), using inflorescence type as a grouping criterion, divided all the cultivated taxa into five races and fifteen intermediate races, under *S. bicolor*. Four of the five major races of cultivated *Sorghum* and one intermediate race are found in Ethiopia (Stemler et al. 1977).

Sorghum, the world's fifth most cultivated cereal crop (after wheat, rice, maize and barley) is a dietary staple for millions of people in Africa, Asia and Central America (National Academy of Sciences 1996). Sorghum is the most versatile among these cereal crops, having strong drought-defying mechanisms and other characteristics that have allowed it to become highly adapted to a heterogeneous range of marginal agroclimatic and production systems. The capabilities and remarkable versatility of sorghum is underutilized in the world's agricultural systems.

Sorghum's remarkable versatility arises from its rich intra-specific diversity in the attributes of adaptability, productive capacity and grain properties and quality. This intra-specific diversity needs to be documented systematically over climatic seasons and agricultural landscapes if the potential of sorghum to improve seed, food and livelihood security and agricultural sustainability in traditional farming systems is to be realized.

Traditional farming systems keep crop evolution alive through landrace dynamics in which the combination of natural and human factors shape the expansion of its diversity status at the field, community and landscape levels. This has been demonstrated in the traditional farming systems in North Shewa and South Wollo, Ethiopia, where sorghum, the second most important crop in production and acreage in the country, features as the main cereal crop (Teshome 1996). The national, regional and global values of the Ethiopian sorghum landraces as sources of valuable genes for breeding and crop improvement or for direct cultivation have been elaborated by the Institute of Biodiversity Conservation (2007), Wu et al. (2006), Singh and Axtell (1973), Rosenow et al. (1983) and Reddy et al. (2009). As we use the term, landraces are defined as being "variable plant populations adapted to local agroclimatic conditions which are named, selected and maintained by the traditional farmers to meet their social, economic, cultural and ecological needs" (Teshome 1996; Teshome et al. 1997, 1999b).

In a study of factors maintaining sorghum landrace diversity in North Shewa and South Wollo, Ethiopia, Teshome (1996) interviewed farmers and systematically sampled the sorghum landraces grown on 300 randomly selected sorghum fields in five agricultural communities—Bati, Merewa Adere, Epheson, Borkena, and Hayk—by increasing average altitude (Fig. 1; Table 1). The major conclusions were that: (1) folk and numerical taxonomies for the landraces are consistent with one another (Teshome 1996; Teshome et al. 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 (Teshome 1996; Teshome et al. 1999b); (3) the sorghum landraces vary in their levels of biological resistances to storage pests (Teshome 1996; Teshome et al. 1999a); (4) the farmers' knowledge of storability corresponds with laboratory tests of resistance to weevil infestations (Teshome 1996; Teshome et al. 1999a) and (5) both natural factors and farmers' selection criteria shape crop genetic diversity at the field and landscape levels (Teshome 1996). The fields in North Shewa and South Wollo surveyed in 1992/1993 were resurveyed in each of the 2000/2001 and 2011/2012 cropping seasons to document the status and trends of farmers' selection criteria and sorghum landrace diversity over time and space and to assess the implications on seed, food and livelihood security.

Agricultural fields in traditional farming communities are the production units where a diversity of crops are grown over the local cropping seasons to meet the range of essential needs of the communities. These fields constitute heterogeneous landscapes which, through their varied soils, topography and climate, impose natural selection pressures that influence the generation, diversification and maintenance

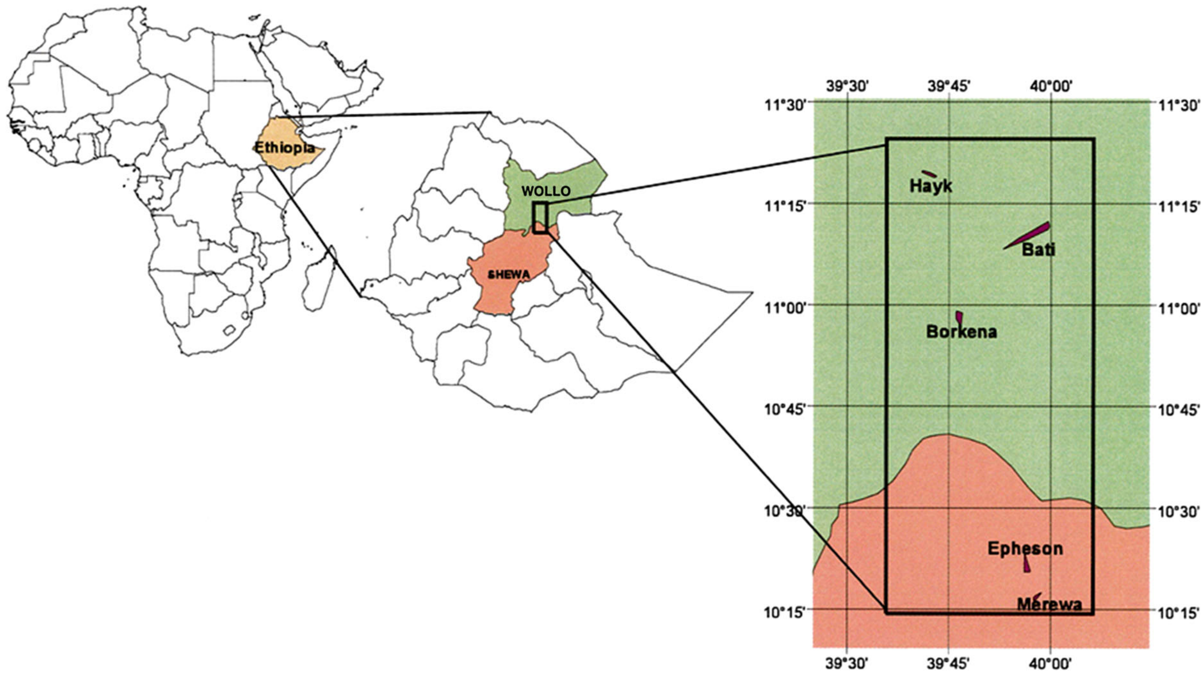

Fig. 1 The research area: five agricultural landscapes in North Shewa and South Wollo, Ethiopia (Teshome et al. 2007)

Table 1 Agricultural landscapes and agroclimatic variations

Agroclimatic factors	Bati	Borkena	Epheson	Hayk	Merewa Adere
Landforms	Broken and undulating landscape	Broken and undulating landscape with valley bottoms	Broken and undulating landscapes with valley bottoms	Wide valley bottom with a lake surrounded by mountains	Hilly landscape with narrow valley bottoms
Slope	5–20	0–30	0–30	0–15	0–15
Altitude (m a.s.l)	1100–1500	1600–2200	1500–2000	1800–2400	1200–1500
Soils (major orders)	Inceptisols	Alfisols	Vertisols	Vertisols	Inceptisols
		Vertisols	Alfisols	Alfisols	Vertisols
		Inceptisols	Inceptisols		
Temperatures (monthly minimums and maximums in °C)	5–10	8–11	5–9	4–7	9–11
	30–34	29–32	27–32	22–29	29–33.5
Rainfall (annual minimums and maximums in mm)	300	400	500	800	300
	900 (unimodal rainfall regime)	1300 (bimodal rainfall regime)	1450 (bimodal rainfall regime)	1700 (bimodal rainfall regime)	750 (unimodal)
Risk to droughts and dry spells	Highly vulnerable	Moderately vulnerable	Moderately vulnerable	Not vulnerable	Highly vulnerable

of local crop genetic resources over time. The farmers in the study area do not currently use external technical resources to reduce the heterogeneity of the landscape, or their individual fields. Instead, over generations, they have met their varied needs and reduced the risk of crop failures by using the multiple microhabitats of the natural landscape to grow a variety of crops through the practices of diversity-based agriculture. Part of their strategy is the recognized need to maintain and use, on a sustained basis, a broad genetic base that is adapted to the range of growing season conditions and particular niches of their agricultural fields. Thus, the location, altitude, size, heterogeneity, distance from homestead, aspect, fertility and other conditions of each agricultural field generate natural selection pressures that, along with farmers' decisions, determine the population sizes, levels and trends of diversity of the crops grown in particular spaces and agricultural seasons (Teshome 1990; Dyer et al. 1992; Teshome et al. 1993, 1999b, 2007; Teshome 1996; Derbie et al. 2002; Tunstall et al. 2001).

Teshome and his collaborators (Teshome 1996; Teshome et al. 1997, 1999a, b, 2007; Tunstall et al. 2001; Abdi et al. 2002; Geleta et al. 2002) in this and other related field-based research used agromorphological characteristics to estimate the levels of variability among sorghum landraces as named and cultivated by the farmers in North Shewa and South Wollo regions of Ethiopia. Farmers' naming and numerical taxonomy for the landraces are consistent across the communities and with one another (Teshome 1996; Teshome et al. 1997). Along with multiple selection criteria and use values, *stem juiciness*, *midrib color*, and *grain color, grain size, glume color* and *glume hairiness* were the lead agromorphological characteristics used by the farmers in their consistent naming of the sorghum landraces. The farmers participating in the research area all speak the Amharic language and have been consistent in maintaining the consistency of the sorghum landrace names with no risk of either using one name for different landraces or using too many names for particular landrace as stated by Mekbib (2007).

The specific objectives of this paper are to present the spatio-temporal changes of sorghum landrace diversity, farmers' selection criteria and field sizes in North Shewa and South Wollo study sites between the 2000/2001 to 2011/2012 cropping season, and to analyze the results of mapping the distribution of sorghum landraces across the agro-ecological gradients of the study area. This is done in the context of how the conservation and sustainable uses of agricultural biodiversity *in situ* may contribute to meeting the challenges of seed, food and livelihood security at the household and community levels. The 1991/1993 to 2000/2001 changes are discussed in Teshome et al. (2007).

Research site characterization

The research was conducted in five agricultural communities in North Shewa and South Wollo regions of Ethiopia (Fig. 1). Each community has its own "heterogeneous agricultural landscape" which encompasses the interrelatedness and continuity of: agroclimatic factors (soils, rainfalls, temperatures, altitude, landforms, and agricultural fields); socio-cultural factors (villages, communities, and farmers' selections, cultural practices and exchange mechanisms); and biological factors (the spatial and seasonal distributions and the plasticity of sorghum landraces). As used in this research, the term 'agricultural landscape' encompasses the totality of the agroclimatic, socio-cultural and biological characteristics of the individual community.

Each agricultural landscape investigated in this research is a unique, locally continuous area, with its specific range of attributes, selected from within a larger geographical area in which the soil resources, landforms, climate (temperatures and rainfalls), vegetation, culture and agricultural practices influencing the distributions, continuity and plasticity of sorghum landraces and other cultivated crops and their weedy and wild relatives are broadly similar but far from identical. Dessie, one of the four big cities in the country, is situated on a N–S highway between Hayk and Borkena. This highway continues southward past Epheson and Merewa Adere, with an off-shoot road at Kombolcha to the Rift Valley passing through Bati. Daily and weekly markets operate in all the agricultural landscapes. Table 1 provides the physical and agro-climatic attributes of each agricultural landscape. These are summarized below, according to increasing altitude.

Bati (1100–1500 m) The undulating landscape occupied by coarse-textured Inceptisols with little profile development and poor water-retention characteristics, is situated in a region with unfavourable drought-prone agroclimatic conditions of hot temperatures and an erratic unimodal rainfall regime, and presents a major challenge to farmers. Under such unfavourable conditions, the availability of adapted resilient sorghum landraces, as developed through the faithful and knowledge-based seed selection skills by the women and men farmers, and their soil management practices and knowledge of soil microhabitats are essential to success.

Merewa Adere (1200–1500 m) The hilly topography with narrow valley bottoms and a unimodal rainfall regime with seasonal precipitation shortfalls due to its location on the leeward sides of the Ataye-Epheson mountain ranges present the major challenges. The soil resources of low fertility Inceptisols on slopes and the fertile, clay-rich Vertisols dominating the valley bottom of the agricultural landscape present different challenges.

Epheson (1500–2000 m) This second largest agricultural landscape of the research area has relatively favourable agroclimatic resources. It is moderately vulnerable to droughts and dry spells due to its bimodal rainfall regime of short and long growing seasons. The relatively large valley bottoms are generally fertile and suitable for the specialized high-yield sorghum landraces for income.

Borkena (1600–2000 m) This largest agricultural landscape of the research areas has relatively favourable agroclimatic resources. The bimodal rainfall regime has a low frequency of dry spells and droughts. The large size of the agricultural landscape and the diversity of its agroclimatic resources contribute to the immense diversity of sorghum landraces that are cultivated for seed, food, and livelihood security. This site has many heterogeneous agricultural habitats, a long history of sorghum production, and a recognized richness in sorghum landrace diversity (Teshome 1996).

Hayk (1800–2400 m) This agricultural landscape, located at higher elevations, is endowed with relatively favourable agroclimatic resources. The strong bimodal rainfall regime is the least vulnerable to drought and dry spells. Its disadvantage is that the cooler temperatures prolong sorghum's maturity period to in excess of 6 months. The farmers tend to grow intraspecific sorghum landraces that are adapted to the cooler temperatures to broaden harvest and livelihood security.

Materials and methods

Awegechew Teshome conducted the first field survey of the sites during the 1992/1993 cropping season. In collaboration with graduate students and their supervisors from Addis Abeba University (AAU) and research personnel from the Institute of Biodiversity Conservation (IBC), the area was resurveyed during the 2000/2001 cropping season. Through the collaboration of USC (Unitarian Services committee of Canada), EOSA (Ethio-Organic Seed Action), Wollo University (WU), AAU, IBC and numerous expert women and men farmers another survey was conducted during the 2011/2012 cropping season. The methodology developed for the 1992/1993 survey was followed during all the subsequent two surveys.

In 1992/1993, 300 fields in which sorghum was growing were randomly selected across the five agricultural communities. The same 300 fields were resurveyed during the 2000/2001 and 2011/2012 cropping seasons. The surveys of all fields were conducted by setting out transect lines 10 meters apart, and asking the owner of each field to identify the landrace name of the sorghum plant that grew closest to each 5 m interval point along each transect line (Teshome 1996; Teshome et al. 2007). By this method, at least 200 plants were randomly sampled in each hectare of each field. During each survey, the farmers were asked the reasons why they grew each of the different landraces (farmer's selection criteria), and the field size was measured in hectares. Sorghum landraces as named by the farmers are a measure of sorghum intraspecific diversity *in situ* and the changes between surveys are a measure of whether the richness of sorghum landraces is increasing, decreasing or stabilizing over cropping seasons and across agricultural landscapes. During the field surveys the farmers also were asked questions regarding the sources of the seeds for the standing landrace population, and questions about the maintenance of sorghum's wild relatives. The changes between the 1992/1993 to 2001/2002 surveys have been published in Teshome et al. (2007). The changes between 2000/2001 and 2011/2012 are discussed below.

Results and discussion

Changes in field sizes planted to sorghum landraces, farmers' selection criteria and sorghum landrace diversity have occurred in all five agricultural landscapes over the 11 year period between the 2000/2001 and 2011/2012. These changes in sorghum landrace richness, distribution, and its relationship to field size and farmers' selection criteria are presented in Table 8.

Changes in sorghum landrace diversity (2000/2001–2011/2012)

Let us begin with consideration of the number of landraces that were recorded across all five communities and then proceed stepwise to those recorded in four, three, two and one of the communities for the 2000/2001 and 2011/2012 cropping seasons. These numbers follow the same general pattern of distribution in both seasons, but the total number of landraces recorded has increased from 68 in 2000/2001 to 77 in 2011/2012, an increase of nine (Table 2). These are the net figures. The full reality is that eight landraces recorded in 2000/2001 were not recorded in 2011/2012 (one previously at three sites, three previously at two sites and three previously at one site) and 15 new landraces were identified (one at four sites, two at two sites and 12 at only one site). There was a net gain of nine landraces.

The specific landraces that were recorded across all five sites through to those recorded at only one site are presented in Tables 3, 4, 5, 6 and 7. It is interesting that only one of the five landraces found at all the sites in 2000/2001 has that rank in 2011/2012; the new landraces recorded at all sites were found at four sites in 2000/2001. Of those no longer at all sites, two were still at four sites in 2011/2012 and two were still at three sites.

At a local scale, it is of interest to investigate the in-field diversity as selected by the individual farmers. This in-field diversity is wide ranging within the individual agricultural landscapes (Borkena; 2–26; Bati: 3–24; Epheson: 2–16; Merewa-Adere: 2–15; and Hayk: 3–13), and across the agricultural landscapes the maximum difference is a factor of 2. It is interesting to note that, in 2011/2012, the relatively smaller agricultural landscape of Bati scored almost identical maximum in-field diversity as the much larger agricultural landscape of Borkena.

The average sorghum landrace diversity per field in 2011/2012 (Table 8) across the agricultural landscapes were: Hayk—6.23; Epheson—8.56; Merewa Adere—8.76; Bati—9.04; and Borkena—11.29. Between 39 and 90 % of the farmers in all agricultural landscapes (Bati—67 %; Borkena—43 %; Epheson—39 %; Hayk—90 % and Merewa-Adere—58 %) have increased their in-field sorghum landrace diversity in 2011/2012 as compared to 2000/2001 cropping season (Fig. 2 and Tables 8, 9). Of particular note is that over 90 % of the farmers in the Hayk agricultural landscape increased their in-field sorghum landrace diversity in the 2011/2012 cropping season (Table 9). Also of interest is that, in the Borkena agricultural landscape, 48 % of the farmers have decreased the sorghum landrace diversity per field cultivated in since 2000/2001, while 43 % increased the number. The greatest increases of in-field diversity occurred in Bati and Hayk, the two agricultural landscapes where sorghum faces the greatest stresses, from heat and drought in Bati, to cool temperatures in Hayk (Table 8).

The distribution of these sorghum landraces across the agricultural landscapes has changed somewhat. Table 7 shows the landraces that are restricted to being grown in only one of the five agricultural landscapes in 2011/2012. Borkena ($n = 11$) registered the highest number and Hayk ($n = 2$) and Merewa Adere ($n = 2$) registered the lowest numbers. At this stage, we have no definitive information as to why these agro-morphologically distinct sorghum landraces are distributed as they are. Tentatively, we assume that a number of distinct and interrelated factors, including

Table 2 Occurrences of sorghum landraces at landscape and regional levels from 1992/1993 to 2011/2012 cropping seasons

Distribution across landscapes	Landrace occurrence (number of landraces)		
	1992/1993	2000/2001	2011/2012
Five agricultural landscapes	7	5	5
Four agricultural landscapes	8	11	10
Three agricultural landscapes	11	6	9
Two agricultural landscapes	13	17	19
One agricultural landscape	21	29	34
Total sorghum landraces at regional level	60	68	77

Table 3 Distribution of sorghum landraces across the five agricultural landscapes—2011/2012 cropping season

Sorghum landrace	Use category[a]	Bati	Borkena	Epheson	Hayk	Merewa Adere
Aehyo	DG	XXXX	XXXX	XXXX	XXXX	XXXX
Ganeseber	DG	XXXX	XXXX	XXXX	XXXX	XXXX
Killo	WR	XXXX	XXXX	XXXX	XXXX	XXXX
Wofe-aeybelash	DG	XXXX	XXXX	XXXX	XXXX	XXXX
Zengada	DG	XXXX	XXXX	XXXX	XXXX	XXXX

Table 4 Distribution of sorghum landraces across four agricultural landscapes—2011/2012 cropping season

Sorghum landrace	Use category[a]	Bati	Borkena	Epheson	Hayk	Merewa Adere
Gorad	DG	XXXX	XXXX	XXXX		XXXX
Barchuke	FG	XXXX	XXXX	XXXX		XXXX
Cherekit	DG	XXXX	XXXX	XXXX		XXXX
Merabete	DG	XXXX	XXXX	XXXX		XXXX
Mokake	DG	XXXX	XXXX	XXXX		XXXX
Tenglaye	DG	XXXX	XXXX	XXXX		XXXX
Watigella	FG	XXXX	XXXX	XXXX		XXXX
Wogere	DG	XXXX	XXXX	XXXX		XXXX
Keyo tinkish	SW	XXXX	XXXX		XXXX	XXXX
Yekersolate	SW	XXXX	XXXX		XXXX	XXXX

[a] Use categories are as follows: dry grain (DG), fresh green consumption (FG), sweet stalk (SW), wild relative (WR)

Table 5 Distribution of sorghum landraces across three agricultural landscapes—2011/2012 cropping season

Sorghum landrace	Use category[a]	Bati	Borkena	Epheson	Hayk	Merewa Adere
Wuncho	DG		XXXX	XXXX		XXXX
Mogayefere	DG		XXXX	XXXX		XXXX
Necho tinkish	SW	XXXX	XXXX			XXXX
Jamuye	DG	XXXX	XXXX		XXXX	
Gedalit	DG	XXXX		XXXX	XXXX	
Wanese	FG	XXXX	XXXX	XXXX		
Jiru	DG	XXXX	XXXX	XXXX		
Goronjo	FG	XXXX	XXXX	XXXX		
Bakelo	DG	XXXX	XXXX		XXXX	

[a] Use categories are as follows: dry grain (DG), fresh green consumption (FG), sweet stalk (SW), wild relative (WR)

location, community size, field heterogeneity, seed sources, exchange mechanisms, and other agricultural landscape factors acting individually or collectively are responsible. We expect that a more diverse agricultural landscape with more unique niches would lead to new landraces being selected from the results of local in-field cross pollination. It might also stimulate a willingness to try landraces from more distant locations. We expect that diversity of the local agricultural landscape is more important than its total area. Most importantly we cannot rule out the importance of a single innovative individual. This all leads to a premise that the sorghum landrace richness is likely to be greatest in community with a large agricultural landscape with heterogeneous agricultural fields and access to diverse seed sources (such as Borkena). Nevertheless, smaller agricultural landscapes with high agroclimatic heterogeneity, climatic challenges and innovative farmers (such as Bati) could attain a high intraspecific diversity of crops and crop varieties. We posit that a substantial portion of the landraces that are grown in only one of the agricultural landscapes have originated by farmer selection in that community,

The ranges of distinct numbers of sorghum landraces planted per field in 2000/2001 and 2011/2012 cropping seasons were 2–34 and 3–26, respectively. The relationship between sorghum

Table 6 Distribution of sorghum landraces across two agricultural landscapes—2011/2012 cropping season

Sorghum landrace	Use category[a]	Bati	Borkena	Epheson	Hayk	Merewa Adere
Yifate tinkish	DG			XXXX		XXXX
Serina	DG		XXXX			XXXX
Rayo	DG	XXXX				XXXX
Mognayakish tinkish	DG		XXXX			XXXX
Keteto	DG			XXXX		XXXX
Chomogo	DG		XXXX			XXXX
Betenie tinkish	SW		XXXX			XXXX
Aehyo-Jamuye	DG	XXXX			XXXX	
Buskie	DG	XXXX			XXXX	
Yekermindaye	SW		XXXX	XXXX		
Motie tinkish	SW		XXXX	XXXX		
Malie tinkish	SW		XXXX	XXXX		
Jemaw	DG	XXXX		XXXX		
Abdoke	DG	XXXX	XXXX			
Amelsi tinkish	SW	XXXX	XXXX			
Borshe	DG	XXXX	XXXX			
Gubetie	FG	XXXX	XXXX			
Ismael	DG	XXXX	XXXX			
Tuba	DG	XXXX	XXXX			

[a] Use categories are as follows: dry grain (DG), fresh green consumption (FG), sweet stalk (SW), wild relative (WR). Within each category there are many more specific culinary and livelihood uses, with all landraces having a minimum of two uses or selection criteria (Teshome et al. 1999a)

landrace diversity and field size remains bimodal (Teshome 1996; Teshome et al. 1999a, b) in that both small (often near the home) and large heterogeneous agricultural fields support a high diversity of sorghum landraces. Some farmers were observed to grow a composition of over twenty-six different sorghum landraces per field in the 2011/2012 cropping season, as opposed to thirty four landrace in the 2000/2001 cropping season. Through faithful practices of selections, breeding and exchange activities farmers in all the five agricultural landscapes combined have increased the total number of distinct sorghum landrace richness from 68 (2000/2001) to 77 in the 2011/2012 cropping season (Table 2).

Sorghum landraces grown in three or more agricultural landscapes maintain their dominance in both cropping seasons as sources of seed, food, and livelihood security. The number of 'generalist' sorghum landraces grown in three or more agricultural landscapes has increased from 22 in 2000/2001 to 24 in 2011/2012 cropping season (Tables 3, 4, 5). These generalist landraces represent over 32 % of the cultivated sorghum landraces in the 2011/2012 cropping season. The generalists are heterogeneous sorghum landrace populations with broad adaptive capacity to the variable agroclimatic conditions and the diverse farmers' selection criteria. The number of 'specialist' (niche-specific) sorghum landraces cultivated in only one or two agricultural landscapes has also increased from 46 in 2000/2001 to 53 in 2011/2012 cropping season (Tables 6, 7). The specialists are adapted to local agroclimatic conditions and the specific needs of individual farmers and families in the respective agricultural landscapes. Specialist sorghum landraces represent 68 % of the sorghum landrace population cultivated across the agricultural landscapes in 2011/2012 cropping season. The percentages of both generalists (32 % in 2000/2001 vs. 31.16 % in 2011/2012) and specialists (67.8 % in 2000/2001 vs. 68.8 % in 2011/2012) did not show significant changes over the two cropping seasons thereby demonstrating the relative stability of sorghum landrace population in the research region.

Changes of crop diversity over time have been studied on sorghum by Yemane et al. (2009) and on manioc by Marchetti et al. (2013). Yemane et al. (2009) reported an increment in the diversity of sorghum collections obtained in 2007 cropping season compared to in 1997 in northern Ethiopia. According to their diversity assessment, sorghum landrace richness varied considerably by village, district and administrative region. Marchetti et al. (2013)

Table 7 Distribution of sorghum landraces across one agricultural landscape—2011/2012 cropping season

Sorghum landrace	Use category[a]	Bati	Borkena	Epheson	Hayk	Merewa Adere
Abaerie	DG	XXXX				
Dewoye	DG	XXXX				
Fereji	FG	XXXX				
Gedido	DG	XXXX				
Humera	DG	XXXX				
Jegretie	FG	XXXX				
Jiru tinkish	SW	XXXX				
Key ehel	DG	XXXX				
Yelem-deha	DG	XXXX				
Senklie	DG	XXXX				
Aeyjaebe	FG		XXXX			
Aeyfere	DG		XXXX			
Aso	SW		XXXX			
Dekussie tinkish	SW		XXXX			
Jofa tinkish	SW		XXXX			
Megalie tinkish	SW		XXXX			
Meltae	GF		XXXX			
Nechero	DG		XXXX			
Sererge tinkish	SW		XXXX			
Teshale	DG		XXXX			
Subahan	DG		XXXX			
Wogere tinkish	SW			XXXX		
Zeterie	DG			XXXX		
Sedecho tinkish	SW			XXXX		
Afeso	DG			XXXX		
Basohe	DG			XXXX		
Delgome	DG			XXXX		
Dobe	DG			XXXX		
Gomzazie	DG			XXXX		
Muzie tinkish	SW			XXXX		
Worehimenu	DG				XXXX	
SoS-Aehyo	DG				XXXX	
Atse-bayush	FG					XXXX
Kumie	DG					XXXX

[a] Use categories are as follows: dry grain (DG), fresh green consumption (FG), sweet stalk (SW), wild relative (WR). Within each category there are many more specific culinary and livelihood uses, with all landraces having a minimum of two uses or selection criteria (Teshome et al. 1999a)

evaluated Manioc (*Manihot esculenta*) diversity as cultivated by traditional farmers in 1992 and 2011 in the state of Mato Grosso, Brazil and observed: similar manioc diversity for both years but with considerable varietal frequency and abundance variations; changes in field sizes planted to manioc; reduced mean number of varieties per farmer; and new varieties in 2011 that were not recorded in 1992. Unlike the sorghum landrace diversity study by Awegechew Teshome and his collaborators in Ethiopia, both Yemane et al. (2009) and Marchetti et al. (2013) did not investigate directly the relationship between field sizes and landscape diversity and the farmers' selection criteria and on-farm diversity.

Landrace distribution across agricultural landscapes

The heterogeneity and adaptive capacity of the landraces allow the farmers to cultivate them in

Table 8 Changes in field size, landrace richness and farmers' selection criteria in Bati, Borkena, Epheson, Hayk and Merewa Adere agricultural landscapes

	Agricultural landscape	Mean 2000/2001	Mean 2011/2012	*t* stat	*P* value
Field size (ha)	Bati	1.05	1.22	2.77	0.0081
	Borkena	1.67	1.29	6.44	<0.0001
	Epheson	0.99	1.07	−0.91	0.362
	Hayk	0.74	0.68	1.20	0.237
	Merewa Adere	0.95	1.18	−2.76	0.0087
Sorghum diversity (number)	Bati	5.71	9.04	5.30	<0.0001
	Borkena	11.73	11.29	0.95	0.34
	Epheson	8.11	8.56	−1.17	0.24
	Hayk	4.23	6.23	−6.75	<0.0001
	Merewa Adere	7.73	8.76	1.75	0.08
Farmers' selection criteria (number)	Bati	7.64	9.36	4.42	<0.0001
	Borkena	10.40	9.58	2.81	0.005
	Epheson	8.48	9.20	−2.34	0.02
	Hayk	6.31	7.46	−2.38	0.02
	Merewa Adere	8.51	9.66	1.99	0.05

Changes between the 2000/2001 and 2011/2012 cropping seasons were tested for significance using matched pairs *t* test

variable agricultural landscapes and climatic seasons. This is demonstrated by the number of generalist and specialist landraces grown in a specific and combination of agricultural landscapes (Tables 3, 4, 5, 6, 7).

The distribution of sorghum landraces across the agricultural landscapes has been relatively stable over the 11-year period. In both 2000/2001 and 2011/2012 cropping seasons five sorghum landraces were found to be grown in all the five agricultural landscapes. Four of the five sorghum landraces were, however, different in both cropping seasons. *Aehyo* is the only sorghum landrace common to all agricultural landscapes cultivated in both cropping seasons.

Killo, a sorghum wild-relative (*Sorghum aethiopicus*) has been sampled across the five agricultural landscapes in 2011/2012 cropping season (Table 3). The sampling of wild-relatives in all the five agricultural landscapes is an indication of farmers' deliberate tolerance of the occurrences of wild-relatives in the fields to confer cultivated sorghum with desirable traits through various gene exchange mechanisms. It also is important to notice the presence of *Zengada*, a sorghum landrace adapted to cooler climatic conditions, in all agricultural landscapes in 2011/2012 cropping season, including in the drier and drought prone Bati agricultural landscape (Table 3).

In 2011/2012, ten sorghum landraces were grown in four agricultural landscapes, down from 11 in 2000/2001 cropping season. Five of the landraces (*Cherekit*, *Merabete*, *Mokake*, *Tenglaye*, and *Yekersolate)* were cultivated in four agricultural landscapes in both cropping seasons. Five sorghum landraces (*Gorad*, *Barchuke*, *Watigella*, *Wogere* and *Keyo tinkish*) were cultivated in four agricultural landscapes in 2011/2012 but not in 2000/2001 cropping season (Table 4).

Nine sorghum landraces were cultivated in three agricultural landscapes in 2011/2012, up from six in 2000/2001. All the nine sorghum landraces cultivated in the three agricultural landscapes were not grown in 2000/2001 cropping season [three moved down from higher levels (*Necho*, *Jiru* and *Goronjo)*; seven moved up from lower levels (*Wanesie*, *Jamuye*, *Wuncho*, *Mogayefere*, *Gedalit*, *Rayo* and *Bakelo*; *Wotetbegunche* was not represented at all in the 2011/202012 samples]. The two cropping seasons did not have common sorghum landraces cultivated in three agricultural landscapes. *Bakelo* was cultivated in the drier agricultural landscape of Bati in 2000/2001 cropping season. In 2011/2012 cropping season besides the drier Bati agricultural landscape, *Bakelo* was also cultivated in the relatively favorable agricultural landscapes of Borkena and Epheson. The

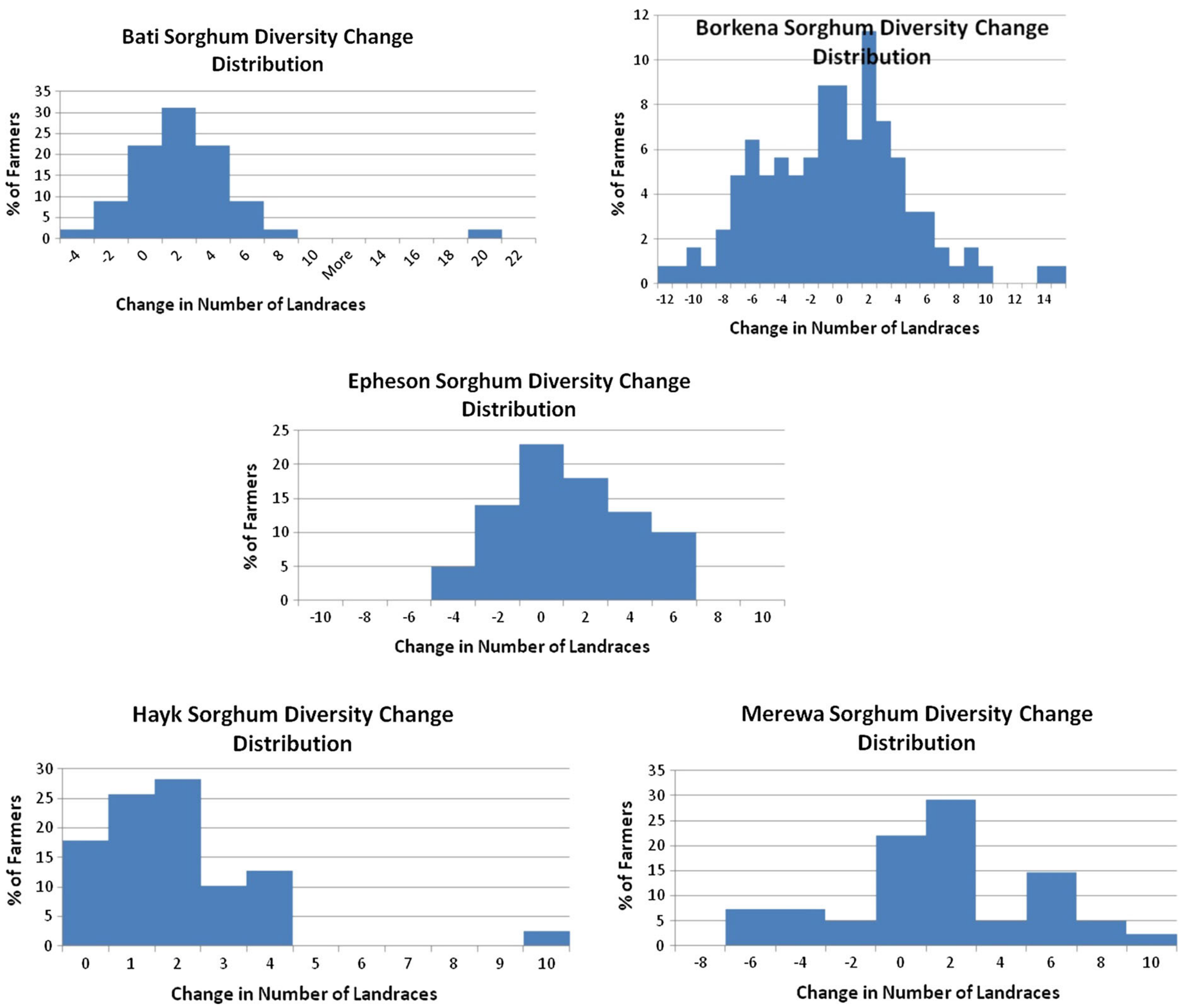

Fig. 2 Distribution of the changes in sorghum landrace richness in the five agricultural landscapes between the 2000/2001 and 2011/2012 cropping seasons

cultivation of *Bakelo* in three agricultural landscapes demonstrates the manifestation of the niche-specific characteristics of a specialist transitioning to more widely adapted generalist cultivated in three agricultural landscapes (Table 5).

In 2011/2012, nineteen sorghum landraces were grown in two agricultural landscapes, up from 17 in 2000/2001 cropping season (Table 6). Some of the landraces grown in two agricultural landscapes are common to geographically adjacent agricultural landscapes (*Keteto* in Epheson and Merewa Adere; *Ismael in* Borkena and Bati; and *Buskie* and *Aheyo-Jamuye* in Bati and Hayk). The presence of many landraces in both of the two most agro-ecologically different agricultural landscapes (i.e. Bati and Hayk), even though they appear to be geographically close to one another, demonstrate the adaptive capacity of the landraces to these climatically contrasting agricultural landscapes. There are, however, some landraces grown in non-adjacent agricultural landscapes in 2011/2012 cropping season. A sweet stalk landrace, *Mognayakish*, was grown in four agricultural landscapes in 2000/2001 cropping season. The same sweet stalk landrace in 2011/2012 cropping season was only grown in two non-geographically adjacent agricultural landscapes of Merewa Adere and Borkena, demonstrating the adaptive capacity of the variety to larger and smaller numbers of agricultural landscapes

Table 9 Percentages of farmers and changes in diversity, field sizes and farmers' selection criteria observed between 2000/2001 and 2011/2012 cropping seasons

	Agricultural landscape	Increased (% farmers)	No. change (% farmers)	Decreased (% farmers)
Field size changes	Bati	42	51	07
	Borkena	38	10	52
	Epheson	36	44	20
	Hayk	20	68	12
	Merewa Adere	37	60	03
Diversity changes	Bati	67	22	11
	Borkena	43	09	48
	Epheson	39	23	38
	Hayk	90	18	02
	Merewa Adere	58	22	20
Selection changes	Bati	64	22	14
	Borkena	13	48	39
	Epheson	23	28	49
	Hayk	50	34	16
	Merewa Adere	55	25	20

(Table 6). In many cases, the landraces grown in only two agricultural landscapes are common to geographically adjacent communities. These distributions indicate that both agro-ecological conditions and the geographic distance influence the distributions of the sorghum landraces.

Thirty four sorghum landraces (44 %) were grown in 2011/2012 in one agricultural landscape up from 29 (42 %) in 2000/2001 cropping season (Table 7). By and large, these sorghum landraces cultivated in each of the agricultural landscapes represent a mixture of quick maturing varieties of dry-grain, sweet stalks and fresh green sorghum landraces serving as "bridging crops" for income generation and home consumption between planting and harvest periods. The number of unique landraces per agricultural landscape ranged from 2 to 11, as result of the adaptive responses of the landraces to farmers' selection criteria and niche diversity within the respective agricultural landscapes. Table 7 shows sorghum landraces restricted to each of the agricultural landscapes in 2011/2012 cropping season (i.e. 10, 11, 9, 2 and 2 in Bati, Borkena, Epheson, Hayk and Merewa Adere agricultural landscapes, respectively). The larger numbers of landraces (11 in Borkena and 9 in Epheson) reflect the agroecological and topographical diversity of these two larger agricultural landscapes. The two in Hayk and the ten in Bati are adapted to the cooler (Hayk) and the warmer, drier (Bati) agroecological conditions of those agricultural landscapes. What is surprising is the ten sorghum landraces grown exclusively in Bati agricultural landscape in 2011/2012, which was up from the 6 in 2000/2001. This demonstrates the adaptable performance of the landraces to the newly converted land from pasture and rangelands to agricultural fields in Bati agricultural landscape.

Field size changes: 2000/2001–2011/2012

Changes in the field sizes planted to sorghum landraces in 2011/2012 compared to 2000/2001 have been observed in all the five agricultural landscapes (Fig. 3; Tables 8, 9). In the Borkena agricultural landscape 52 % of farmers have greatly reduced the field sizes planted to sorghum in 2011/2012 as compared to 2000/2001; 10 % of the farmers have maintained the same field sizes for sorghum cultivation; and 38 % of farmers have increased the field sizes planted to sorghum landraces. In Bati (42 %), Merewa Adere (37 %), Epheson (36 %) and Hayk (20 %) farmers have increased field sizes planted to sorghum landraces between 2001/2002 and 2011/2012. In Bati, Epheson, Hayk and Merewa Adere, respectively, 51, 44, 68 and 60 % of farmers have maintained the same sizes of sorghum fields in 2011/2012 as in 2000/2001 (Table 9).

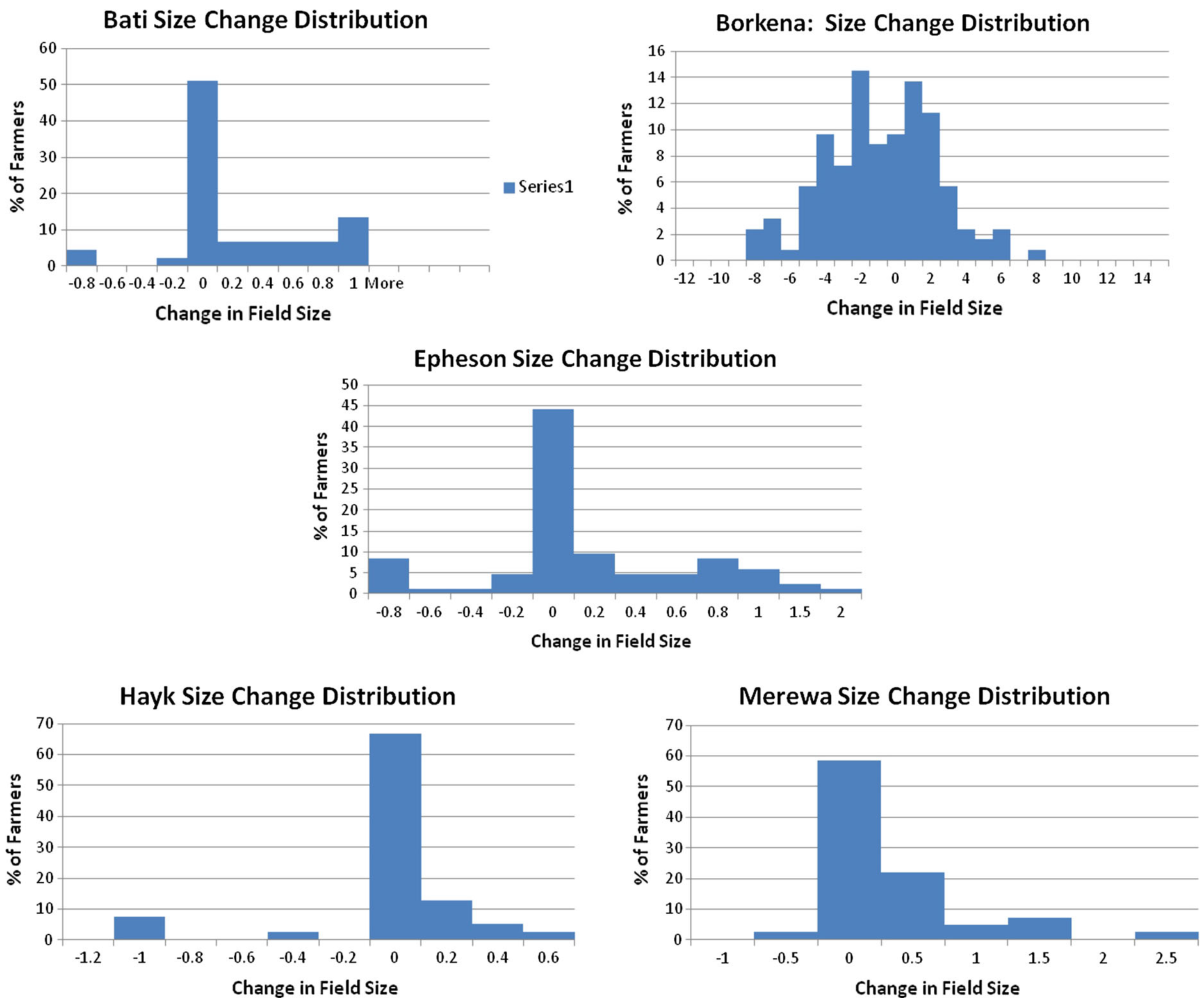

Fig. 3 Distribution of the changes in field size (hectares) in the five agricultural landscapes between the 2000/2001 and 2011/2012 cropping seasons

The relationship between in-field sorghum landrace diversity and field size remains bimodal, with landrace diversity within fields tending to be high in small fields (particularly those located close to homesteads), less in intermediate-sized fields and again high in larger fields (Teshome 1996; Teshome et al. 1999b). Over 26 different sorghum landraces were grown in at least one field in 2011/2012 season, as opposed to a maximum of 34 in 2000/2001 (Teshome et al. 2007; Teshome 2001). The high landrace diversity in the larger fields is interpreted to derive from farmers' decisions and the availability of more and diverse environmental niches in these larger fields (Teshome 1996; Teshome et al. 1999b). In the small fields, conscious decisions by the farmers, including creation of desirable niches by using household refuses and family labor, are the reason (Teshome 1996; Teshome et al. 1999b). Farmers, when asked, identify other reasons, including availability of seed, land fragmentation, seasonal changes, and changing cropping patterns at both intra-species and inter-species levels for the changes of sorghum landrace diversity that they plant (Teshome 2001). Abdi and Asfaw (2005) found similar correlations between sorghum landrace richness and field sizes in this same research area.

Farmers attribute the changes in field size to political, economic, social and climatic events that have occurred over the intervening 11-year period. Among these are: population increase; partition and reapportioning of land according to government policy; seasonal dry spells which have led to stagger cropping in some years; and seasonal displacement of sorghum by other crops. Population increase and government land repartition policies have contributed to both the fragmentation and shrinkage of the land areas used by individual farmers. Farmer responses during the 2011/2012 survey and interviews with research collaborators confirm that the rural land-partitioning and reapportioning process has decreased the total land available to individual farmers and affected their decisions on how much area to cultivate with sorghum landraces. Land fragmentation associated with reapportioning has also created situations where areas planted to sorghum by individual farmers in 2000/2001 are still planted to sorghum landraces in 2011/2012, but with the ownership distributed among a greater number of farmers. A change in ownership is accompanied by a change in decision-making processes that, in turn, influence the dynamics of the landraces planted and the interactions among landraces planted on the affected areas. Such changes could lead to changes to the metapopulation of sorghum landraces and initiate changes in the specific landraces that are planted in the various niches of the fragmented agricultural landscape (Teshome 2001, 2013; Teshome et al. 2007). In other situations, the physical fragmentation of farmers' fields may facilitate the biological fragmentation of sorghum landraces and allow the evolution of new landraces through the changes in patch occupancy, and temporal and spatial isolation; or it could lead to the vulnerability of certain landraces (Tunstall et al. 2001). Such changes accompanying ownership changes should not necessarily be considered as undesirable in biological terms because the interactions among adjacent populations of closely related taxa may encourage gene flow, thereby boosting the adaptability and pest resistance of cultivated crops, even though the resulting genetic combinations may pose inconveniences to individual farmers with regard to seed selection and harvest for the next planting season.

Changes in farmers' selection criteria (2000/2001–2011/2012)

Farmers' selection criteria derive from a range of complementary and competing socio-economic, cultural, agronomic, ecological, biological, dietary and nutritional needs each farmer must satisfy in the long term from the range of crop genetic resources planted in her/his agricultural fields (Teshome 2001; Teshome et al. 2007). Farmers in the North Shewa and South Wollo agricultural landscapes grow a largely stable, but changing, range of both intra- and inter-specific crops and crop varieties to meet their multiple livelihood needs. This is necessary because no single crop or crop variety possesses all the necessary attributes to meet the multiple needs of the individual farmers. Hence, all farmers grow several landraces along with companion crops and use a range of selection criteria, appropriate to their household requirements, when deciding which landraces and companion crops to grow.

The long-term study on "Factors maintaining sorghum landrace diversity in North Shewa and South Wollo regions of Ethiopia" (Teshome 1996, Teshome et al. 1999a, b, 2007) has demonstrated that as farmers increase their selection criteria, diversity at the field level increases. This finding remains valid for most farmers for both the 2000/2001 and 2011/2012 cropping seasons. The ten selection criteria that the farmers identified in 1992/1993, the 12 selection criteria measured across the five agricultural landscapes in 2000/2001 and the further six in 2011/2012 are shown in Table 10. Some farmers reporting the medicinal uses of sorghum varieties as a selection criterion in the production system in 2011/2012 is new to this research in Ethiopia, but has been reported as being common in Nigeria, West Africa (Akande et al. 2010). The additions of adaptability (to climate variations) and harvest security to farmers' selection criteria emphasize the dynamic nature of farmers' evolving strategies to ensure food security in a time of recognizable environmental changes. Abdi and Asfaw (2005), in their study of *Sorghum* landraces in South Wollo and North Shewa, also have demonstrated the positive relationship between landrace diversity and farmers' selection criteria, and the increase of the latter, from 15 to 25 over only four cropping seasons from 1999/2000 to 2003/04.

The number of selection criteria has changed in all the five agricultural landscapes during the 11 years between the 2000/2001 and 2011/2012 cropping seasons (Fig. 4; Tables 9, 10). Over 50 % of the farmers in each of the agricultural landscape in Bati (64 %), Hayk (50 %) and Merewa-Adere (55 %) have increased the number of selection criteria between 2000/2001 and 2011/2012. In Borkena and Epheson

Table 10 Observed farmers' selection criteria for sorghum landraces

Selection criteria in 1992/1993 cropping season	Selection criteria in 2000/2001 cropping season	Additional selection criteria in 2011/2012 cropping season
Grain yield	Fresh green consumption	Disease resistance
Biological yield	Sweet stalk	Medicinal value
Insect/pest resistance	Nutritional value	*Striga* resistance
Market value	Popping quality	Storability
Beverages	Livestock feed	Adaptability to climate variations
Milling quality	Biomass for fuel	Harvest security
Maturity level	Biomass for construction	
Drought resistance	Buffer crop against bird attack/ invading pests	
Threshability	Maternity meal	
Bird resistance	Adaptation to marginal soils	
	Seed experimentation	

agricultural landscapes 39 % and 49 % of the farmers, respectively, have reduced substantially the number of selection criteria in 2011/202012 cropping season, while more than 20 % of the farmers in all the agricultural landscapes [Bati (22 %); Borkena (48 %); Epheson (28 %); Hayk (34 %) and Merewa Adere (25 %)] have maintained the same number of selection criteria. The dynamics of farmers' selection is influenced by several factors including seed sources, cropping seasonality, markets, seed and information exchange mechanisms and the heterogeneity of the agricultural fields on which sorghum landraces are grown each season.

In 2011/2012 the number of selection criteria applied to individual sorghum landraces ranged from four to eight, while the number of selection criteria used per field ranged from two to over sixteen. In risk-prone situations, the farmers are aware that growing a range of sorghum landraces increases the security of obtaining a satisfactory harvest. Farmers currently use the term "harvest security" to lump together the use of multiple selection criteria in choosing the diversity of crops and crop varieties to plant for seed, food and livelihood security. This is because farmers realise that they are never selecting for just one agronomic value, but for a broad package of attributes.

An intimate knowledge of individual landrace characteristics also allows for the farmer to compensate for its vulnerabilities. For example, a landrace selected for its taste, milling or beverage quality may be particularly susceptible to decimation by insects or birds and may only be able to survive or produce adequate yield if its vulnerabilities are managed through transplanting and the use of reserve seeds when germination or early survival is insufficient. Thus, the survival of a desirable, highly vulnerable landrace in heterogeneous agricultural environments is heavily dependent on farmers' decisions and strategic management practices.

Moreover, in highly vulnerable agroclimatic conditions, the farmers also know that growing a range of sorghum landraces in a field based on multiple selection criteria increases the probability of some harvest. This being the case, the selection criteria associated with each landrace can be used to identify what is considered to be useful by the farmers and to identify valuable characters within the sorghum landrace germplasm for the development of appropriately adaptable new varieties (Teshome 1996; Teshome et al. 1999b). Although farmers in North Shewa and South Wollo are egalitarian in their approaches to the conservation and uses of sorghum landraces, they are more strategic in selecting and giving more values to those landraces critical to food and income security. Selection criteria of milling quality, grain yield, maturity level, biomass production and drought resistance have all been employed by all farmers in all the five agricultural landscapes to ensure food and income security at the household level. Over 75 % of the farmers [Hayk (78 %); Bati (90 %); Borkena (94 %); Epheson (94 %); and Merewa Adere (97 %)] have used the market as a selection

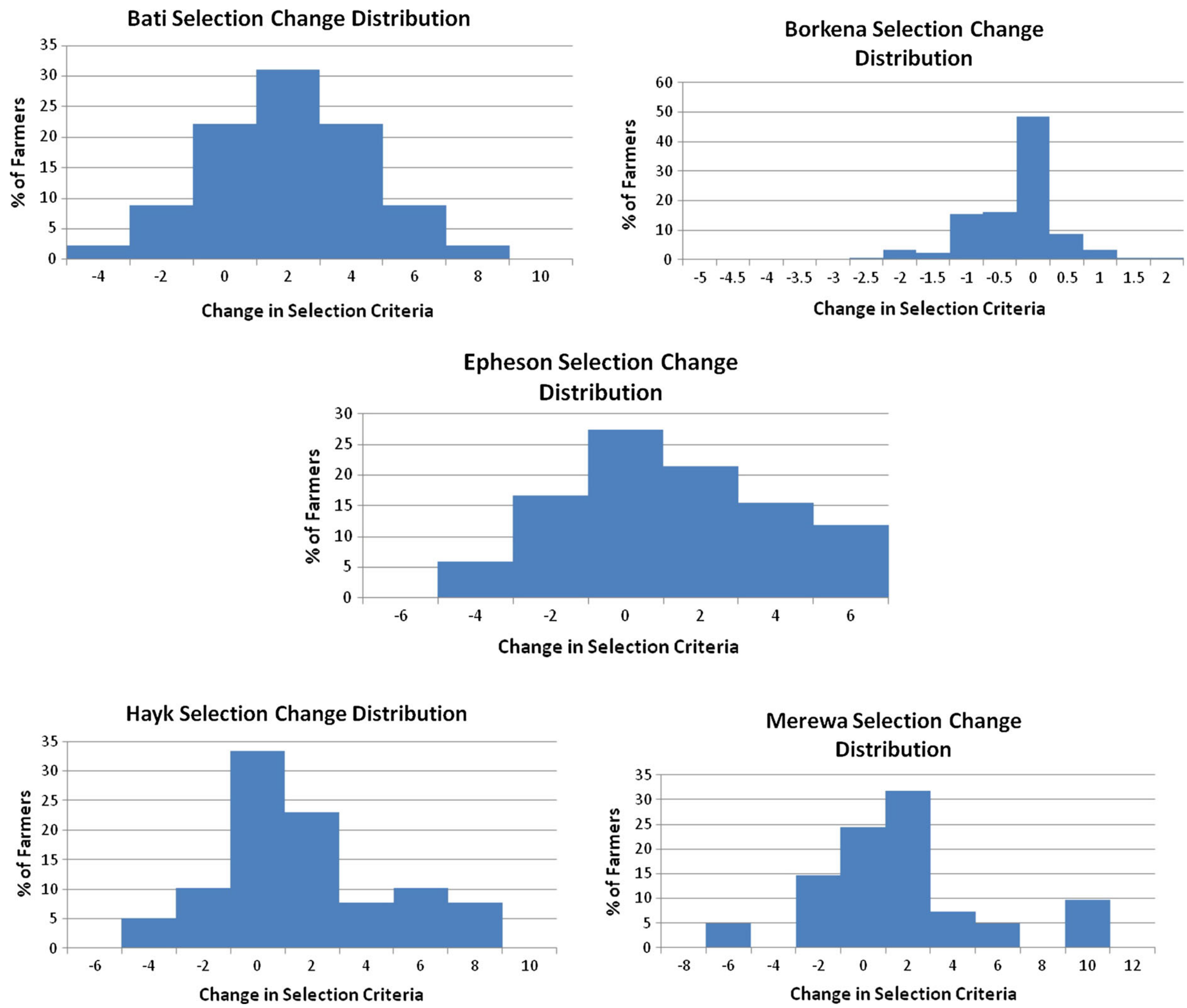

Fig. 4 Distribution of the changes in the number of farmers' selection criteria in the five agricultural landscapes between the 2000/2001 and 2011/2012 cropping seasons

criterion for choosing marketable sorghum landraces for income security. Huge percentages of farmers [Hayk (69 %); Bati (76 %); Borkena (82 %); Epheson (89 %); and Merewa Adere (89 %)] used beverage quality as a selection criterion for choosing sorghum landraces for home brewing and income security by selling the grain in the local market (Table 11).

Milling quality, grain yield, and maturity level were the three selection criteria employed by all farmers, across the five agricultural landscapes in both 2000/2001 and 2011/2012 cropping seasons. The predominance of milling quality, grain yield, maturity level, drought resistance, market demand, and beverage quality as selection criteria clearly establishes the deterministic role of farmers in choosing the landraces most likely to feed their family and to generate income to purchase other essentials.

Landrace attributes and uses

Sorghum landraces can be broadly categorized as dry grain (DG), sweet stalk (SW), and fresh green immature (FG), based on how they are used. Landraces that are grown for dry grain production tend to dominate the agricultural landscape. The farmers have selected them for their yield, marketability, beverage quality and milling quality. The dry grain landraces are the most important overall for their contributions to both direct home consumption and for income generation. The sweet stalk and fresh green immature sorghum landraces are selected for the uses of home consumption and income security during the bridging months between planting and the dry-grain harvesting period. The sweet stalk landraces rank second in importance, represented by over 25 % of the landraces planted in both cropping seasons. The landraces selected for fresh green immature consumption (during the growing season) represent nearly 15 % of the landraces grown (Table 12).

Dry grain landraces are cultivated primarily to serve as staple food of the household and to be sold for cash in the local market. Ultimately they meet the food and beverage needs of nearby populations, urban and otherwise. The grain may be milled into flour for baking or the grain is fermented, roasted and ground for beverages. The abundance of dry grain landraces has increased from 38 in 2000/2001 to 47 in 2011/2012, and constitute 55.88 % (in 2000/2001) and 61.04 % (in 2011/2012) of the total sorghum landraces cultivated in the five agricultural landscapes combined (Table 12). They play the key role in meeting the seasonal food needs and income security of all the farming communities. Over 40 % of the sorghum landraces cultivated in each agricultural landscape were for dry grain production, and the number of dry grain landraces has increased in three communities, held steady in one and declined slightly in one. In all agricultural landscapes dry grain landraces dominate in meeting both the seasonal food needs and the income security requirements of the farming families.

Sweet stalk sorghum landraces are high in sugar content and are grown primarily for sweet juice consumption between the planting and harvesting months. The grains may also be threshed and fermented into beverages. Some farmers sell sweet stalk in the local market to earn income. Sweet stalk sorghum abundance has shown relative stability, with no significant changes between 2000/2001 and 2011/2012 cropping seasons, except in Hayk where it decreased sharply in the 2011/2012. In Borkena, sweet stalk landraces constituted over 30 % of the landraces cultivated in both cropping seasons (Tables 13, 14).

A few quick-maturing sorghum landraces are cultivated for the consumption of fresh green immature grains, either roasted or boiled to bridge food scarcity between planting and harvest months. The proportion of sorghum landraces cultivated for fresh green immature consumption increased in Bati but decreased in all the other agricultural landscapes between the 2000/202001 and 2011/202012 cropping seasons, with none being recorded in Hayk in 2011/202012 (Tables 13, 14).

Almost all farmers selectively maintain wild-relative of sorghum landraces (*S. aethiopicum*) in their fields for ecological and genetic benefits, to use as livestock fodder, and to protect the soil resources

Table 11 Percentages of farmers and selection criteria for sorghum landraces

	Bati farmers (%)	Borkena farmers (%)	Epheson farmers (%)	Hayk farmers (%)	Merewa farmers (%)
Grain yield	100	100	100	100	100
Biomass production	80	85	78	80	86
Maturity level	100	100	100	100	100
Threshability	59	44	57	69	67
Bird resistance	35	66	45	75	69
Insect resistance	38	64	25	58	25
Disease resistance	41	36	39	42	22
Drought resistance	70	100	52	67	69
Milling quality	100	100	100	100	100
Beverages	76	82	89	69	89
Fresh green consumption	72	78	83	27	69
Sweet stalk	77	78	38	17	69
Market value	90	94	94	78	97

Table 12 Sorghum landrace uses and compositions in 2000/2001 and 2011/2012 cropping seasons, all five agricultural landscapes combined

Sorghum landrace uses category	Landrace representations in 2000/2001 cropping season	Landrace representations in 2011/2012 cropping season
Dry grain	38 (55.88 %)	47 (61.04 %)
Fresh green immature	10 (14.93 %)	09 (11.69 %)
Sweet stalk	19 (28.36 %)	20 (25.97 %)
Wild relative	1 (1.49 %)	1 (1.30 %)
Total	68 (100 %)	77 (100 %)

from wind and water erosion. Non-clean cultivation and relaxed weeding are the major farming practices by which farmers intentionally tolerate wild and weedy relatives of sorghum. They recognize that the wild relatives encourage gene flow, enhance organic matter accumulation and soil nutrient cycling, and increase the abundance of natural enemies of cultivated crop pests. *S. aethiopicum* is the only sorghum wild relative that was recorded in the 2000/2001 and 2011/2012 surveys. It was recorded at all sites, except Hayk, in 2000/2001, and constituted less than 2 % of the total landraces. In 2011/2012, it was recorded at all sites and constituted greater than 7 % of the total landraces at Hayk (Tables 13, 14).

Seed sources dynamics

Seed supply systems in traditional agricultural systems are multi-faceted, and change through time. They are an essential component of these systems and serve as one of the vehicles that allow changes in landrace numbers and distribution, particularly in heterogeneous agroclimatic, physical and social environments such as North Shewa and South Wollo. During the field surveys, each farmer was asked to identify the sources of the seed of the various landraces that she/he grew in each of the 2000/2001 and 2011/2012 cropping seasons. The multiple seed sources that the farmers reported in each of the agricultural landscapes are listed in rank order in Table 15. The reported seed sources and their rank order vary by household and agricultural landscape. Combinations of seed sources are reported by different farmers to augment the seed materials available first in type, then quantity, quality and diversity. The sequences of the seed sources indicate the primary, secondary, and tertiary sources of availability for seeding during the planting season. For example, the combination of seed sources of Home, Market and Gift indicates that the farmers had their own seed materials harvested from their own fields, but, to diversify the seed in type, quality and quantity, they got additional seeds from the market as a secondary source and as gift from a tertiary source, respectively.

Sourcing home-saved seeds involves the actual selection of seed stock from the standing crops of last harvest and its maintenance under household conditions until the planting season by the farmer himself/herself. Such practice is well practised by most farmers in all agricultural landscape who use home-saved seeds the primary source to grow a diversity of sorghum landraces for food and livelihood security. Over 65 % of the farmers in Bati (70.27 % in 2000/2001 and 70 % in 2011/2012), and Borkena (61.24 % in 2000/2001 and 66 % in 2011/2012) used home-saved seeds in both growing seasons. The percentages of farmers in Hayk (53–73 %) and in Epheson (40–60 %) who used home-saved seeds have increased from 2000/2001 to 2011/2012 cropping season. On the other hand, the percentages of farmers who relied on home-saved seeds in Merewa Adere have decreased from 49 % in 2000/2001 to 32 % in 2011/2012 cropping season (Table 15).

Table 13 Sorghum landrace compositions and uses at agricultural landscape level in 2000/2001 cropping season

Sorghum landrace use category	Bati	Borkena	Epheson	Hayk	Merewa Adere
Dry grain	16 (69.57 %)	19 (44.19 %)	24 (68.57 %)	7 (41.18 %)	19 (59.38 %)
Fresh green immature	3 (13.04 %)	10 (23.26 %)	5 (14.29 %)	3 (17.65 %)	7 (21.88 %)
Sweet stalk	3 (13.04 %)	13 (30.23 %)	5 (14.29 %)	7 (41.18 %)	5 (15.63 %)
Wild relative	1 (4.35 %)	1 (2.33 %)	1 (2.86 %)	00.00	1 (3.13 %)
Total	23 (100 %)	43 (100 %)	35 (100 %)	17 (100 %)	32 (100 %)

Table 14 Sorghum landrace compositions and uses at agricultural landscape level in 2011/2012 cropping season

Sorghum landrace use category	Bati	Borkena	Epheson	Hayk	Merewa Adere
Dry grain	29 (69.05 %)	25 (53.19 %)	22 (64.71 %)	11 (78.57 %)	19 (70.37 %)
Fresh green immature	7 (16.67 %)	6 (12.77 %)	4 (11.76 %)	00.00	3 (11.11 %)
Sweet stalk	5 (11.90 %)	15 (31.91 %)	7 (20.59 %)	2 (14.29 %)	4 (14.81 %)
Wild relative	1 (2.38 %)	1 (2.13 %)	1 (2.94 %)	1 (7.14 %)	1 (3.70 %)
Total	42 (100 %)	47 (100 %)	34 (100 %)	14 (100 %)	27 (100 %)

Farmers who do not have home-saved seeds but with financial means go to the local market and buy the seed stock they need for a particular field and growing season using their cash. The cash may be obtained through the sale of surplus grain and/or livestock. A case example is Epheson where 40 and 24 % of the farmers used seeds obtained from local market to meet the sowing needs in 2011/2012 and 2000/2001 cropping seasons, respectively. In Merewa the percentages of farmers who used seeds from local market have increased from 14 % in 2000/2001 to nearly 30 % in 2011/2012 cropping seasons. The seed stocks purchased by the farmers in the local markets are all landraces. Farmers who planted seed stock mixtures obtained from local markets have reported the appearances of unexpected sorghum varieties and at times wild-relatives. Thus, markets do not only serve as sources of seed materials but also as one of the mechanisms of differentiation and intraspecification when the purchased seed materials are planted at different agro-ecological niches in farmers' fields.

Exchange of seeds is a common practice among farming communities in North Shewa and South Wollo. Exchange is primarily conducted if the farmer does not have the type, quantity and quality of the seed material he/she would like to plant in his/her field. Exchange of seed materials (both interspecies and intraspecies) are also practiced to test performance and adaptability of newly acquired crop populations. Exchange, as the primary seed source is more frequently practised in the highland agricultural landscape of Hayk (20 % in 2000/2001 and 7.46 % in 2011/2012 cropping seasons, respectively), where a variety of non-sorghum crops (*wheat*, *barley*, *fava bean*, *lentils*, *peas*, *chick pea* and *vetch*) abound for farmers to exchange either in the market or at home for desirable sorghum seeds adapted to the local cool temperatures, frost and long growing season. Exchange of seed sources involves not only the exchanges of intraspecific sorghum landrace seeds but also exchange of sorghum for other crops and vice versa. Variable percentages of farmers in the other agricultural landscapes have employed exchanges in combination with other seed sources to meet the seasonal planting seasons of 2000/2001 and 2011/2012 cropping seasons (Table 15).

Borkena is the only agricultural landscape where two community seed banks are available to serve the communities as seed sources in times of seed insecurity. The Community seedbanks are components of an *in situ* conservation strategy and an active seed selection and farming practices. They are also used as cultural, exchange, and learning centres. The percentages of farmers who used community seed bank as primary seasonal seed source have increased from 2.3 to 4 % in 2000/2001 and 2011/2012 cropping season, respectively. Farmers in Borkena use seeds from the community seed bank to augment home-saved seeds to reduce risks of seed insecurity in times of environmental stress such as drought and dry sells (18 and 3.80 % of farmers used home-saved seeds + community seed bank seeds in 2000/2001 and 2011/2012 cropping season, respectively).

The rank of seed sources to obtain seeds for cultivation is dynamic, changing from season to season in all agricultural landscape (Table 15). The empirical evidence demonstrates that a single seed source cannot meet the amount, quality and diversity of farmers' desired seed stocks for seasonal sowing and resowing of diverse sorghum landraces in heterogeneous agroclimatic fields. The diversity of landraces and seed sources are reflection of the heterogeneity of farmers' selection criteria and the agroclimatic resources on which the landraces are cultivated on a seasonal basis for food, seed, livelihood and environmental security. Diversity of seeds sources is also a reflection of the social network functioning in the production system (McGuire 2008).

Table 15 Seed sources and percentages of farmers in 2000/2001 and 2011/2012 cropping seasons

Seed sources	Bati % farmers		Borkena % farmers		Epheson % farmers		Hayk % farmers		Merewa Adere % farmers	
	2000/2001	2011/2012	2000/2001	2011/2012	2000/2001	2011/2012	2000/2001	2011/2012	2000/2001	2011/2012
Home-saved	70.27	70.00	61.24	66.00	33.00	60.00	53.00	73.00	49.00	32.00
Market	00.00	00.00	7.00	6.00	40.00	24.04	10.00	6.00	14.00	29.00
Exchange	00.00	0.00	00.00	0.00	8.00	00.00	20.00	7.46	00.00	00.00
Community seed bank	00.00	0.00	2.38	4.00	00.00	0.00	00.00	00.00	00.00	00.00
Home-saved + market	16.22	21.00	00.00	16.00	00.00	00.00	00.00	00.00	00.00	26.00
Home-saved + exchange	2.75	6.00	2.00	1.56	4.00	2.50	00.00	5.50	00.00	5.71
Exchange + market	00.00	00.00	00.00	00.00	00.00	2.98	2.00	00.00	2.25	00.00
Exchange + home-saved	00.00	00.00	00.00	00.00	00.00	7.50	15.00	5.50	2.58	00.00
Home-saved + community seed bank	00.00	0.00	17.83	3.80	00.00	00.00	00.00	00.00	00.00	00.00
Home-saved + gift	00.00	0.00	00.00	00.00	00.00	00.00	00.00	00.00	2.75	0.00
Market + home-saved	00.00	2.56	5.43	2.34	15.00	2.98	00.00	2.54	20.00	5.71
Gift + market	3.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
Other sources	6.98	00.00	4.12	00.00	00.00	00.00	00.00	00.00	9.42	1.58
Total (%)	99.22	99.56	100.00	99.70	100.00	100.00	100.00	100.00	100.00	100.00

Implication and conclusions

This paper and earlier publications on sorghum diversity research project (Teshome 1996, 2001; Teshome et al. 1999b, 2007; Tunstall et al. 2001) have demonstrated that the spatio-temporal dynamics of the generation and maintenance of sorghum landrace genetic diversity on-farm is influenced by both human and natural factors.

Among natural factors, altitude, field attributes (location, distance from homestead, aspect, size, heterogeneity, fragmentation, and continuity), soil (type, fertility, texture, and water holding capacity), and climate (rainfall and temperature and their distribution and effectiveness through time and space) have all been demonstrated to influence the inter- and intra-specific diversity of crop genetic resources on-farm (Teshome 1996; Teshome et al. 2001, 2007).

The farmers, as the primary creators, users and conservers of crop genetic resources on-farm, influence the levels, status and dynamics of both inter- and intra-specific diversity through their decision-making processes, selection criteria, strategic management practices, storage systems, seed sources, local markets, cultural exchange mechanisms, and diversity of processing and consumption choices at the household and community levels. Other human factors, including markets, gender and socioeconomic factors, population size and growth, ethnic and linguistic diversity, government policies related to land ownership and the conservation and uses of genetic resources also have consequences for the magnitudes and diversity levels of both inter- and intra-specific crop genetic resources on-farm (Teshome 2001; Tunstall et al. 2001; Teshome et al. 2007).

Farmers grow numerous sorghum landraces whose names do not change but their genetic make up is evolving over time due to introduction of new alleles through gene substitution, gene mutation, migration, selections, exchange and mixture cropping. Varietal names as named by farmers are critical for understanding how well varieties are adapted to variable environmental conditions and farmers' preferences. Farmers' selection criteria are therefore the de facto sources of information on the adaptive performance of sorghum landraces in highly variable agroclimatic conditions. The amount of sorghum landrace diversity within each agricultural landscape is estimated and is accessible, owned, managed and used by the farmers to improve their livelihoods. Farmers in the research area recognize the true value of the crops and crop varieties they manage and use and have increased the diversity to 77 landraces over time through diversification, selections, breeding and exchange practices.

The presented research results demonstrate clearly that over the 11-year period from the 2000/202001 to the 2011/2012 cropping season, the spatio-temporal dynamics of sorghum landraces, farmers' selection criteria and the field sizes have changed substantially. Less than 32 % of the landraces were identified clearly as generalist genotypes that are cultivated across most of the agricultural landscape of the research area. These landraces are considered as widely adapted to the agro-ecological, market, cultural, and socioeconomic conditions of the five agricultural landscapes. Most of these landraces are flourishing in terms of their richness. The majority of the landraces (68 %) are currently used as niche-specific genotypes grown across one or two of the agricultural landscapes. Low patch occupancy (Teshome 2001; Tunstall et al. 2001; Teshome et al. 2007) could be a challenge for many, but not all, of these landraces. For sure, many of these niche-specific landraces could be grown more widely due to their inherent plasticity and the abundance of suitable niches beyond those that they currently occupy, in their local or neighboring agricultural landscape.

Landraces occupying restricted cultural, end-use, market and agroecological conditions are niche-specific. The vulnerability of a niche-specific landrace to being displaced and lost probably depends on the type of cultural and agronomic niche that is being filled. Sorghum landraces that occupy unique cultural and agronomic niches that are highly valued by the farm family are likely to stay in the production system without facing risks of loss or displacement due to their faithful relationship with the farmers in both favorable and unfavorable cropping seasons (Teshome 2013). Many of the niche-specific landraces (Tables 6, 7) could be grown more widely in all agricultural landscapes provided adequate amount of desirable seeds are accessible at the required planting season and agricultural landscape. Land fragmentation due to population pressure and land redistribution policy contributes to the dominance of niche-specific sorghum landraces adapted to narrowly defined farmers' selections and agroclimatic conditions within each of the agricultural landscape. Lack of diverse and adequate desirable seed stocks to maintain a mean viable landrace populations on numerous parcels of land fragmented through land distribution and redistribution policy could be a challenge to numerous farmers growing specialist sorghum landraces. For a dynamic landrace population to be viably grown on seasonal basis, both adequate desirable seeds and diverse and relatively large field sizes are required to reduce the risks of losses or displacement.

Landrace richness at the field level increased significantly in two agricultural landscapes and marginally in one agricultural landscape over the 11-year period. At the same time, some farmers in all agricultural landscapes greatly increased the number of landraces that they grew in an individual field, even though the majority of the field sizes had decreased. The landrace richness, and its range across fields, can be readily appreciated by looking at the standing crop before harvest time. Each farmer has to decide how much of each landrace to harvest for seed, and how much is available for consumption or sale in the local market. Farmers face a challenge in selecting and collecting enough seed materials for the next planting season when cultivating niche-specific landraces. If the field size continues to decrease, the agro-ecologically niche-specific landraces are the most likely to be vulnerable, partly because of competition for space and partly because the specific niche may be transferred to another farmer's ownership. In this processes, the risk of genetic erosion increases as a result of lack of desirable seed and lack of adequate agricultural land to support the current range of crops, each with its own diversity of landraces, in the coming cropping seasons.

Sorghum landraces in the research area vary according to their contributions to seed, food and livelihood security. Dry grain sorghum landrace compositions grown for direct consumption and for income generation were dominant both in 2011/2012 cropping season [47/77 (61 %)] and in 2000/2001 cropping season [38/68 (55.88 %)], representing over 55 % of the landraces cultivated in respective season. Sweet stalk and fresh green consumption sorghum landrace compositions were also represented, respectively, by 25 % and 10–15 % of the landraces cultivated in the cropping season (Table 12). These groups of landrace compositions are critical sources of food and income security between growing and harvesting months. Enhancing landrace composition uses and strengthening the diversity of seed sources, as they are practiced by the farmers, would ensure the sustainable uses and conservation of the landraces for food and livelihood security in light of land fragmentation and climate variation. The sustainable conservation and uses of sorghum landraces on farm go together faithfully. A landrace with relatively low contribution to family food and income security in times of environmental crisis will likely face risk of underrepresentation in the production system. Home-saved seeds as primary seed source need to be strengthened by increasing the number of compatible secondary and tertiary seed sources to ensure diversification and ownership and faithful relationship of farmers and sorghum landrace uses for resilient food and livelihood security.

Risks of diversity losses could be mitigated by embarking on comprehensive programs incorporating factors related to space (farmers' fields), time (seasonality changes), farmers' decision making processes, policy, markets and socioeconomic factors through participatory research for development, and enhancement of the diverse genetic resources on-farm. Through the 1990s the Seeds of Survival program worked with farmers to restore diversity lost due to droughts of the mid 1980s and since 2002 continues supporting community seedbanks, participatory varietal selection and biodiversity-based economic initiatives in Borkena agricultural landscape. It is believed that the community seedbanks in Borkena are helping farmers to maintain a high diversity of crops by backstopping the household seed supply system. Further research to examine the role of the community seedbanks and farmer-led research in the generation and maintenance of the on-farm crop diversity are needed. The potential vulnerability to genetic erosion of the niche-specific landraces identified here should also be carefully considered by *in situ* conservation programs.

The dynamics of the sorghum landraces in all the agricultural landscapes in the eleven intervening years between 2000/2001 and 2011/202012 cropping season demonstrate clearly that sorghum landraces are responsive, versatile, heterogeneous, generalist, specialist and highly plastic crop varieties cultivated in contrasting agroclimatic conditions for their adaptability to short and long maturity and cold and drought resistance attributes. Such wealth of genetic attributes needs to be conserved and used strategically on sustainable basis for livelihood and environmental security.

The Seeds of Survival program has made the farmers more aware of their landraces and of their particular importance. The stepwise increase in the number of selection criteria from 1992/1993 to 2000/2001 to 2011/2012 is an indication of their increased awareness of the many roles that the sorghum and other biodiversity aspects play in their lives.

Programs designed to address the challenges of seed, food and livelihood security, natural resources management, and the sustainable conservation and uses of the diverse crop genetic resources in the research area must, therefore, recognize the importance of on-farm conservation of inter- and intra-species diversity and the associated natural and human factors influencing the generation and maintenance of the on-farm crop diversity.

Farmers should be at the 'heart' of any program initiatives related to the sustainable conservation and uses of their crop genetic resources. The north Shewa and south Wollo sorghum belt is endowed with rich cultivated crop genetic resources (not just of sorghum) that are adapted to the heterogeneous agricultural landscape. These diverse genetic resources are nurtured by the local time-tested experiential knowledge of farming practices, selections, and seed exchange mechanisms. The farmers' wisdom, gained from generations of experience, is critical for success.

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