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The dynamics of on-farm management of sorghum in Ethiopia: Implication for the conservation and improvement of plant genetic resources

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Abstract

On-farm conservation of plant genetic resources for food and agriculture has received strong support worldwide in recent years. It has been justified on appealing assumptions: it complements *ex situ* conservation, allows co-evolutionary interaction of host–pathogens and crop–weed complexes, and involves local knowledge systems. This article illustrates how on-farm conservation being set for its sake is extremely difficult under farmers' dynamic management of plant genetic resources based on sorghum. The dynamics of their management could be explained by continued introduction, displacement, loss and maintenance of aboriginal landraces that have distinct functional attributes, patch-occupancy and relative abundance profiles. Such management and hence the dynamic landrace demography has largely been triggered by co-evolving biophysical stresses, spatial and seasonal variations. The best viable alternative to support farmers' management of genetic resources is to link conservation to crop improvement both to enhance on-farm genetic diversity and make the biophysical environment a comfortable home for the plant genotypes.

Introduction

Over the last four decades, a massive *ex situ* build of Plant Genetic Resources collection has been seen across the globe. The invention of methods for keeping crop seeds viable in genebanks made this mission very successful. Collecting missions have been praised as invaluable rescue operations against threat of crop genetic erosion resulting from technological changes (mainly increased adoption of modern varieties) and agro-ecological destruction (Frankel and Bennett 1970). Germplasm collections have been used primarily as raw materials for the development of modern varieties (Soleri and Smith 1995; Pistorius 1997), but also as start-up stocks or restoration of local seed system in case of total loss of seeds caused by drought, famine and in post-war recovery such as in Ethiopia, Rwanda, Sierra Leone and Somalia, just to mention a few (Worede 1992; Sperling 1997; FAO 1998; Richards and Ruivenkamp 1998; Friis-Hansen and Sthapit 2000).

However, soon after the inception of *ex situ* conservation both biological and social scientists have started questioning the adequacy of *ex situ* conservation strategy mainly on grounds of being static (co-evolutionary dynamics of host–pathogens and crop–weed complexes being frozen) and for detaching the collection from local knowledge systems (Bennett 1970; Frankel and Bennett 1970). As a result, *in situ* conservation has been considered as backup and complementary strategy to *ex situ* conservation and a model for its implementation has been suggested (Maxted et al. 1997 2002). In early times, *in situ* conservation was thought to maintain 'museum farms' (Holden et al. 1993) or pockets of 'primitive' agriculture (Ingram and Williams 1984). But later, it has been inspired as strategy of allowing co-evolutionary processes that shape the genetic diversity and adaptability of plant populations to continue to occur (Frankel and Soulé 1981; Oldfield and Acorn 1987; Brush 1989; Marshall 1989). In recent years, it has been considered as enhanced PGR utilization at the local level and consistent with agricultural development (Worede and Mekbib 1993; FAO 1998; Worede et al. 1999; Feyissa 2000). This inspiration partly has come because of the need to capture new emerging genotypes from the continued crop evolution, mutation, recombination, gene flow, etc. And partly it is because of the continued role of crop landraces in subsistence agriculture and in recognition of farmers' effective management of these landraces in centers of crop origin and in extreme circumstances (Richards 1986; Bellon 1991). For some, however, this management could not qualify to be labeled as 'conservation' at all (Almekinders and De Boef 2000a). Even some note that 'conservation as such may be a concept unknown to farmers' (Bellon et al. 1997, 2003). Their argument is that farmers rarely maintain crop genetic diversity in view of conservation *per se* since their practice as much involves seed exchange and gene flow as it involves discarding (exclusion) of landraces. For Almekinders and de Boef, and other proponents of Participatory Plant Breeding (PPB) such as Witcombe, Sperling, Joshi, Eyzaguirre and many others the best way to encourage, cultivate and use diversity is, in their words, 'to promote on-farm employment of diversity' by using participatory approaches. However, the extent to which PPB approaches enhance or at least maintain existing local diversity remains to be seen since promoting diversity can involve replacing landraces. As it stands now there seems to be a strong support for *de facto* conservation[1] of landraces that farmers have been practicing for centuries as part of their farming system. A number of on-going on-farm conservation activities in different parts of the world (e.g. Almekinders and De Boef 2000b; Friis-Hansen and Sthapit 2000), with support from organizations such as the Global Environmental Facility (GEF) of the World Bank, UNDP, and UNEP show the attention given to *in situ* conservation (Brush 1999; Feyissa 2000; Worede et al. 2000).

Despite the surge of support for on-farm conservation of plant genetic resources on global scale, no agreed set of scientific principles yet exists for its implementation (Wood and Lenné 1997). Some see the conservation of traditional crops on-farm as tantamount to trying to stop crop development (Brush 1999). Hawkes et al. (2000) refers to this as the conservation/development paradox. Brown (1999: 37) notes, 'evidences for the nature, pace and causation of genetic change during on-farm conservation is virtually non-existing'. Soleri and Smith (1995) and Tin et al. (2001) have studied the consequences of *ex situ* and *in situ* conservation based on maize and rice accessions, respectively by measuring variation in morphological and genetic structure between accessions of the 'same' populations kept under static and dynamic condition. Their major findings were that 'genetic shift and drift have occurred *ex situ*' for maize (Soleri and Smith 1995), and 'adaptability is at risk under on-farm conservation' due to natural and intentional selection pressures for rice (Tin et al. 2001). However, without prior knowledge of the original genetic composition of earlier collection, it is difficult to quantify and attribute genetic changes either to difference in conservation strategies or because of being originally distinct populations. This shows that not only the consequences of on-farm and *ex situ* conservation strategies have not been well studied and resolved but also method of researching, understanding and quantifying the complementary role of these strategies have not been well developed. Nor were baseline data on the original genetic composition of landraces available to assess the trend of genetic change in space and time.

This research was aimed at investigating the potentials and consequences of on-farm conservation of plant genetic resources. The objectives of the study were to (1) understand the dynamic

[1]In this chapter, on-farm or *in situ* conservation is perceived as the continued on-farm maintenance of crop landraces under natural and farmer-induced selection pressures, i.e. *de facto* conservation by farmers through direct and continuous use of landraces in the course of meeting biophysical (agro-ecological) and socioeconomic requirements – conservation-cum-utilization. It does not refer to the maintenance of landrace diversity in view of conservation perspective.

nature of farmers' management of sorghum in marginal environments; (2) analyze the implications of this dynamic management for enhancing on-farm conservation and linking conservation to plant improvement. The empirical data were generated by measuring patch-occupancy and relative abundance of genebank-conserved and farmer-managed sorghum landraces in south Welo of Ethiopia.

Material and methods

Description of study locations

The study was conducted in south Welo. Geographically, Welo is situated in northeastern parts of Ethiopia and administratively it is situated within the Amhara Regional State. The geographic features of the study area are characterized by rugged topography with valley bottom being exposed to sedimentation and silt formation due to highly eroded upland and erratic rainfall. The northern highlands were generally the most epicenters of droughts and famines that the country has been facing over the years. In recent years, crop failure due to drought has become a recurrent phenomenon, occurring once in every two years especially in this part of the country (Ethiopian Meteorology Service Agency, unpublished report).

Agriculture in south Welo is characterized by mixed farming systems – crop–livestock interaction. With the exception of few and small irrigated fields along riverbanks and valley bottoms agriculture is entirely rain-fed, where moisture is a serious threat to crop production. Generally, the agricultural land of south Welo can be categorized as very poor because of high nutrient depletion resulting from over cultivation, excessive run-off and removal of crop residues for firewood and livestock feed, and has low carrying capacity due to population pressure (Ezra 1997). In presence of these extreme circumstances, it is the diversity of crops and crop landraces that farmers have, persistently, used more than any other farm level resources to cope with changing dynamics and to meet their daily subsistence. In this regard, sorghum is every thing for Welo farmers and is a leading crop by any standard: in area cultivated, total production, as source of staple food, feed and firewood.

Four districts from south Welo were selected for this study namely; Ambasel, Bati, Dawa-chefa and Kalu. The selection of sorghum and Welo region was based on prior established evidences: (1) Sorghum is one of the crops for which Vavilov has identified Ethiopia as center of its origin and domestication (Vavilov 1951 cited in Stemler et al. 1975). The general consensus, however is that the crop had been originated in northeastern quadrant of Africa, if not within Ethiopia, (De Wet and Harlan 1971; Harlan 1975; Doggett 1988), where it has been evolved in interaction with wild and weedy relatives, and where it still exists in large diversity. (2) Agricultural sample survey reports of the Central Statistical Authority (CSA 2000) of Ethiopia show that Welo is one of the leading sorghum producing regions both in total production and area cultivated to sorghum. Welo is known as the center of sorghum diversity and long history of sorghum production (McCann 1995; Teshome et al. 1997). (3) Farmers of this region have made significant contribution both in volume and content to world sorghum collection such as high lysine and disease resistant sorghums (Gebrekidan 1973; Singh and Axtell 1973; Gebrekidan and Kebede 1979; Doggett 1988). And (4) Welo is generally categorized as risk prone agricultural region mainly because of recurrent droughts and highly degraded agricultural landscapes. Also, the impact of modern agriculture (dependency on high external inputs, fertilizer and seeds) in this area is very much limited. Hence, research in this region may generate farm level evidences that hint at the possibility and consequences of *in situ* conservation of crop genetic resources in extreme circumstances and in an area where modern agriculture has limited impact. Conclusively, the above evidences made re-introducing and tracing of earlier sorghum collection in their original collecting sites fairly possible.

Accession sampling and re-introducing to the original collecting sites

Two sets of sorghum materials were considered for the study: '*enat mashila*' meaning 'mother sorghum' (aboriginal to the study area), and 'introductions' as identified by farmers based on their knowledge of landrace demography. Mother sorghums are those landraces that have been grown by farmers since the time of their ancestors in the study area, south Welo. Introductions consist of landraces (i.e. not aboriginal to the study areas) and improved varieties entered into the study area through local seed systems and/or by government and NGOs interventions between mid-1970 and 2001. Genebank-conserved accessions consist of both aboriginal and landraces introduced between 1979 and 1988.

The Institute of Biodiversity Conservation and Research of Ethiopia (IBCR, the former Plant Genetic Resource Center of Ethiopia-PGRC-E) has by far the most conservation facilities with well-defined and efficiently run programs in east Africa (FAO 1998). At present, the institute holds more than 56,000 accessions of various crop plant species conserved as long and medium-term collections (Worede et al. 2000). The total size of sorghum collection conserved by the Institute's genebank amounts 9530 accessions as per 2001 (Table 1). About 843 of these were collected from Welo (north and south Welo added together). Had it been for incomplete passport data the number of accessions from Welo could have been more than this; as shown on Table 1, collecting sites for 3263 sorghum accessions were unknown. Accessions from north Welo were discarded in this study mainly for logistic reason.

Table 1. Geographic distribution of sorghum accessions conserved in the Ethiopian Genebank.

Region	No. of accessions	%
Arsi	96	1.0
Bale	18	0.2
Eritrea[a]	236	2.5
Gamugofa	403	4.2
Gojam	207	2.2
Gonder	366	3.8
Hararge	812	8.5
Illubabor	394	4.1
Keffa	129	1.4
Shewa	1350	14.2
Sidamo	94	0.9
Tigray	1163	12.2
Welega	156	1.6
Welo	843	8.9
Unknown	3263	34.2
Total	9530	99.9

Source: Institute of Biodiversity Conservation and Research (IBCR) of Ethiopia.
[a]Independent country since 1991.

Since the intention was to re-introduce accessions to their original collection sites as much as possible, care was taken to avoid risk of misplacement (risk of re-introducing accessions to locations different from their original collecting sites) by discarding all accessions obtained from markets and donated by research institutes and agricultural colleges. Accordingly, only accessions collected directly from farmers' fields were considered. From the passport data, information on year, name of district, altitude and source of collection (e.g. farmers' fields, store, market, etc.) were available. However, neither location names nor farmers' names were available in passport data. The earliest year of collection was considered as much as possible since one of the objectives was to assess the present status of long-term genebank-conserved accessions in farmers' fields. No collecting date was available for accessions collected directly from farmers' fields in south Welo prior to 1979. As a result, a total of 20 accessions collected directly from farmers' fields between 1979 and 1988 were obtained from the three districts: Kalu, Bati and Ambsel. No accession from the Dawa-Chefa district was sampled for this study, as there was no accession collected from 'actual farmer's field' documented in the passport for this district.

The sampled genebank accessions were taken back to their respective original sites and were grown by farmers in 2001. Each sampled genebank accession was grown by three to five farmers in their respective districts. Due to absence of collection site names, altitude was used to approximate the collection site in each sampled district. It was also assumed that most of the accessions were collected from along main roads, during early time of collecting expeditions. On the basis of this assumption, sites having altitudes similar to the one recorded for sampled genebank accessions in each district were identified within 5 km radius on both sides of the main highway connecting the capital city – Addis Ababa and Wichale (south Welo).

Farmers interview

A total of 200 farmers from four districts (50 farmers from each district) were randomly drawn and interviewed. These farmers had ages ranging from 35 – 77 (58 on average). An interview, based on semi-structured questionnaires, was mainly focused on exploring farmers' reasons of growing a variety of sorghums and to sketch the demography of each sorghum landrace they have grown over the years. The other important part of the interview was to assess farmers' knowledge and use this knowledge to reconstruct the original bio-sociological identity of genebank accessions collected from their fields more than a decade ago. During an interview mature heads (panicles) of genebank-conserved landraces were shown to each interviewee for physical observation and identification, which, in fact, helped them remember these accessions by name and their functional attributes and also to distinguish existing and lost ones.

Measuring patch-occupancy and relative abundance

A total of 200 sorghum fields, the fields of the interviewed farmers, were sampled for measuring patch-occupancy and relative abundance in the four study districts. Each farmer carefully identified the landraces s/he grew as mixture or in a pure stand. Patch-occupancy and relative abundance of the two sets of sorghum populations were measured by walking through transects. Care was taken to include all micro-niches in each district since sorghum landrace diversity is highly affected by variation in micro-niches resulting from difference in altitude, moisture regimes and (a)biotic stresses (Teshome et al. 1999). The level of patch-occupancy alone can not adequately indicate the risk of loss of landraces maintained on-farm and to decide which conservation strategies best to pursue. The fact is that landraces over large patches could be at risk when they appear in low population size or density per field. Hence, relative abundance (% of total plants sampled) and average relative density (% of plants sampled per field) could supplement and qualify the information on patch-occupancy. This means that high values for each indicator and the sum of the factors decrease the risk of loss of landraces (Tunstall et al. 2001), which in other words, ensures the dependability of maintaining these landraces on farmers' fields and under their management practices for sometime. Conversely, low values signify the risk of loss of landraces maintained on-farm and thus opt more for *ex situ* conservation of these threatened landraces. Hence, sorghum landraces from five quadrants per field (1×1 m taken from every direction of a field and one from the center) were counted to measure the relative abundance of landraces. By this procedure, data on patch-occupancy of landraces (i.e. number of fields on which a particular landrace appeared) and relative abundance (the percentage of the total plants surveyed that belonged to each landrace) were collected. It is assumed that there is a considerable communality in landrace diversity profile between the contiguous study districts being shaped by local seed system and because of biophysical and socioeconomic similarities. On the basis of this assumption the distribution and abundance of all genebank accessions have been tracked and assessed across all the study districts though each accession was taken back to original collecting site.

The reasons why patch-occupancy and relative abundance of sorghum accessions was chosen for this study include: (1) In the first place, there were no baseline biological data that show both genebank-conserved and farmer-managed landraces were originally the same populations. In the absence of such information, it is difficult to analyze the genetic changes and to attribute these changes to a variation in conservation strategies. Consequently, patch-occupancy and relative abundance (distribution and density) of genebank-conserved and farmer-managed landraces were measured on the basis of their physical presence in the field and by using farmers' knowledge.

(2) A common perception that a variety/landrace is purely planted to an isolated field is not applicable to sorghum and Welo farmers, since they grow a number of sorghum landraces as mixture per field/season. The dynamic crop mix in a field is the result of Genotype $\times$ Environment (physical) $\times$ Social Interaction. Hence, the patch-occupancy and relative abundance of landraces in a crop mix provide clues for the type of conservation strategy (*ex situ* or *in situ*) required at the landrace level. Likewise, breeders' recommendation of varieties for monoculture and its adoption over large uniform fields may not always relevant to cropping systems where crop and crop landraces grown as a mixture.

(3) Generally, such type of research could establish a benchmark genetic and morphological information for subsequent studies of the trend of landrace demography, diversity captured, maintained, introduced and lost by *ex situ* and on-farm

conservation strategies in space and time and varieties that need to be supplied by formal plant breeding.

It is worth defining the concept of 'landrace' as used in this paper. A landrace is a ''plant population maintained through conscious selection of farmers for its stable functional attribute(s) and morphological characteristics within a defined biophysical and social environment''. It is a farmer unit of selection whose distinct subject(s) of selection (functional attributes) and morphological characteristics exist as an ensemble. This is to say that a landrace identity could not be explained by its morphological distinctiveness alone since it can not survive farmers' selection pressure by being distinct in these characteristics (color, shape, height, etc.).

Results

Sorghum landrace diversity

From the interview with farmers and the field survey in the four districts a total of 55 discrete landraces were identified by their vernacular names when sweet-stalk sorghums counted as one (Table 2). These discrete landraces can be grouped into five clusters based on their functional attributes namely staple sorghums, sweet-grain sorghums (*ye-eshet ehil*), sweet-stalk sorghums (*tinqish*), segregating genotypes (e.g. *morgage, gomezaze*) and wild relative (e.g. *qilo*). All 55 discrete landraces are known by 75 vernacular names, which means that some of these landraces have more than one name. Moreover, about 45 names of sweet-stalk (*tinqish*) landraces were recorded during the interview and from the field survey, but they were counted as one as their common characteristic is the sweetness of their stalk (Tunstall et al. 2001), although they vary in morphology, sweetness and juiciness and some of these landraces are also reputed by farmers for their grain quality for making local beverage. Teshome et al. (1997) reported that the names given to accessions by the farmers are consistent and highly dissimilar. They have come to this conclusion based on the analysis of the genetic distance between five named landraces. Based on our observations, we however argue that if Teshome et al. had included in the analysis all named landraces and local languages (Amharic and Oromo language) spoken in the study areas they would have found multiplicity of names for some landraces. Even though some staple sorghum landraces can be consumed green by roasting during time of scarcity, only those landraces grown for green consumption purpose were counted as sweet-grain sorghums. Also, crops like maize, haricot bean and sesame, etc. were apparently found inter-cropped with sorghum but their presence in a mix was not analyzed although they may have impact on population size of a companion crop-sorghum.

Thirty-six percent (20 of 55) of the total discrete landraces were found to be specific among the districts. Thirty-three percent of landraces were grown in two of the four districts and 11% were grown in three of the four districts. The remaining 20% of the landraces were commonly grown in all districts studied (Table 2). Among the districts, Kalu and Ambasel districts grow higher number of landraces, 34 and 33, respectively, while Dawachefa and Bati grow 30 and 21 landraces, respectively.

Virtually all farmers grow crop mixtures where a particular field ubiquitously planted to a range of sorghum landraces and other crop species. Growing a variety of staple sorghum landraces (i.e. sorghums mainly used for making staple food, *injera*) as mixture reported to have started around mid- 1970s with the advance of drought, stalkborer and diminishing farm size. But, perhaps, growing staple sorghum mixed with sweet-stalk and sweet-grain sorghum has been started much earlier. The number of landraces counted per field/season ranged from 1 – 19, and six on the average, when *tinqish* (sweet-stalk) landraces counted as one. In earlier research by Teshome and his colleagues in east Shewa and south Welo regions of Ethiopia, the number of landraces per field/season were reported to be as many as 24 (Teshome et al. 1999).

Landrace diversity varies mainly with altitude, cropping season and heterogeneity of micro-niches and it is well in conformity with the findings of Teshome and his colleagues (Teshome et al. 1999). The diversity is greatest in mid-altitude and decreasing towards both higher and lower elevations (Figure 1). This is mainly due to adaptive selection, where highland environment favors landraces that are adapted to cooler climate, whereas lowland favors landraces adapted to

Table 2. List of sorghum landraces grown in the study districts, south Welo.

No.	Landrace name	Ambasel	Bati	D/chefa	Kalu	Total appearance
1	*abaere*	✓	✓	✓	X	3
2	*abdoke*[a]	X	X	✓	✓	2
3	*abola*	X	X	X	✓	1
4	*ahiyo*	✓	X	X	✓	2
5	*anchro (wincho)*	✓	✓	✓	✓	4
6	*areri*[a]	X	X	✓	X	1
7	*baqelo*[a]	✓	X	X	X	1
8	*belalo*[a]	X	X	✓	X	1
9	*boresh*	✓	X	X	X	1
10	*cherekit (mera)*[a]	X	✓	✓	✓	3
11	*chigero (Debesso)*	✓	X	X	✓	2
12	*chimego (ye genfo ehil)*	X	X	✓	✓	2
13	*chiqite*	X	X	✓	X	1
14	*chome*	X	X	X	✓	1
15	*dalecho*	✓	X	X	X	1
16	*dawe*[a]	✓	✓	✓	X	3
17	*dhangale (Tengele, dagalit)*	✓	✓	✓	✓	4
18	*fereje*[a]	X	✓	X	X	1
19	*gadido*[a]	X	✓	X	X	1
20	*ganseber*	✓	X	X	✓	2
21	*gorad*	✓	X	✓	✓	3
22	*goronjo*[a]	X	X	X	✓	1
23	*humera (Esmael, subhan, ajaebe)*[a]	✓	✓	✓	✓	4
24	*jamiyo*[a]	✓	✓	✓	✓	4
25	*jirgite*[a]	✓	✓	X	X	2
26	*jiru*[a]	✓	✓	✓	✓	4
27	*limat*[a]	X	✓	✓	✓	3
28	*marbaksa*	X	✓	✓	X	2
29	*marchqe (Borchoqe)*	✓	✓	✓	✓	4
30	*milte*	✓	X	X	✓	2
31	*mokake*[a]	X	✓	✓	✓	3
32	*morgage (dologom, gomzaze)*	✓	✓	✓	✓	4
33	*mote*	✓	X	X	✓	2
34	*q.ehil (afesso)*[a]	✓	✓	✓	✓	4
35	*qilo*	✓	✓	✓	✓	4
36	*qi.ayefere*	X	X	✓	✓	2
37	*rayo*[a]	✓	✓	X	X	2
38	*shilime (game- na-qonjo)*	✓	X	X	✓	2
39	*shole (tate)*	✓	X	X	✓	2
40	*shuleka*	✓	X	X	X	1
41	*shumiye*[a]	X	X	✓	X	1
42	*tambak*	✓	X	X	X	1
43	*tinqish*	✓	✓	✓	✓	4
44	*tiqureta*	✓	X	X	X	1
45	*tuba*	X	X	X	✓	1
46	*utala*[a]	X	X	✓	X	1
47	*wanase (gubete, hamote, tringo)*	✓	X	X	✓	2
48	*watigala*	X	X	X	✓	1
49	*wefibelash*	X	X	✓	✓	2
50	*w.beguchu*	✓	X	✓	X	2
51	*wegere*[a]	X	X	✓	✓	2
52	*yebaglat (ye wisha girat)*	✓	X	X	X	1
53	*yelemdeha*	✓	X	X	X	1
54	*y.mendaye*	X	X	✓	✓	2
55	*zengada (jange)*	✓	✓	✓	✓	4

[a]Introductions; ✓ = found; X = not found.

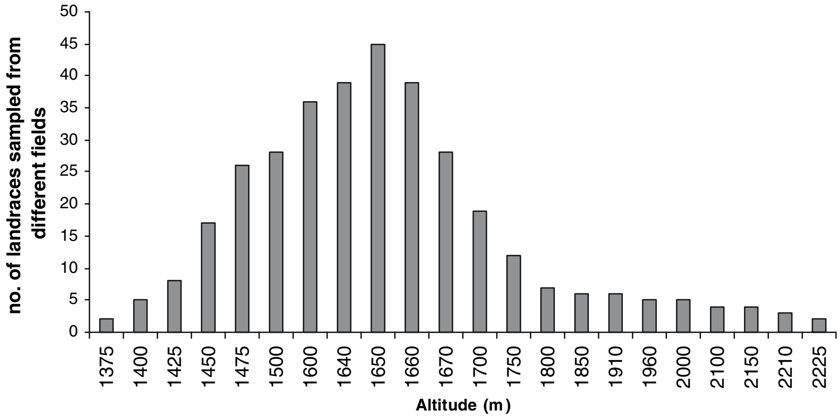

Figure 1. Number of landraces sampled from different fields per altitude (m asl).

moisture stress condition, i.e. tolerate or escape drought. With regard to cropping season variation, landrace diversity and number of landraces per field decreases as one goes from a field planted to short duration sorghum in June to a field planted to long duration sorghum in March/April. This is partly due to the fact that risk of crop failure resulting from (a)biotic stresses such as dry spells and associated insect pest incidences were more common in long-duration than in short-duration sorghums. But, also, it is due to limited availability of sorghum landraces for short season mix (Gebrekidan 1982; Ayana and Bekele 2000). The other reason could be due to the availability of other crop species for short season planting, e.g. tef.

At field level, land quality and (a)biotic stresses were the major factors for farmers to grow a variety of landraces and to grow them as a mixture. For instance, fields of poor soils or infested with striga dominantly planted to landraces adapted or tolerant to these stresses. Similarly, fields with better soil fertility were planted to high yielding landraces. Some have suggested that there is a positive correlation between field size and landrace diversity (Cromwell and van Oosterhout 1999; Teshome et al. 1999). They argue that farmers with larger size may spare extra land for maintaining landrace diversity. It is also tenable to say that with larger farm size a higher seed rate is used which creates a possibility of constituting seeds of various landraces. Conversely, as field size decreases seed rate also decreases. This as a result will reduce the number of landraces constituting a mixture. In the study area like in any other parts of the country, land is a very scarce resource and there is no hope that it will improve in the future, either. This is partly due to population pressure causing repeated land redistribution and partly because the land suitable for crop cultivation was used for human habitation. The size of farmland presently owned by farming households is very small (ranged from 0.5 to 1 ha, 0.75 ha on average). Since this is the case for all farmers involved and across all study districts, farm size is a weak factor to explain the difference between farmers in the number of landraces they manage. Our field account is that landrace diversity varies more with field quality and (a)biotic stresses than field size although the latter factor can not completely be ignored due to reasons mentioned above. Apart from field quality, landraces' tillering ability has a direct impact on determining the type and number of landraces to be included in a mixture. Farmers repute some landraces such as *gorad*, *dhangali*, *zangad* as having high tillering ability. During time of seed scarcity, landraces with high tillering ability are preferred in order to maintain the required population density/field. This will have a negative selection pressure on landraces with less tillering ability.

Landrace demography

Not all landraces presently grown in the study area are originated and cultivated since ancestral time of the present day farmers. Some are introductions from close or distant areas through local seed systems (market, gift, and seed exchange) or government and NGOs interventions. Studying landrace demography is important to understand, among other things, the role of local seed systems, dynamics of seed migration and the agronomic characteristics of landraces sought by farmers over space and time. Understanding reasons of seed migration is especially beneficial for deciding what to maintain on-farm and what not, and what to back up the local gene pool from a genebank and formal plant breeding institutions. The results of this study show that there is tremendous seed migration between farmers and regions mainly associated with the advance of drought, striga, insect pests and soil fertility decline since over the past three decades or so (Table 3). They were introduced to the study area since mid-1970s. Except varieties known by one common name-*limat*, all introductions are farmers' landraces mainly obtained through local seed systems and markets. The earliest introductions were *jiru* and *jamiyo*, both from northeast Shewa, central Ethiopia. The latest influx of landraces were introduced after mid-1990s namely *humera*, *abdoke*, *limat*. As shown on Table 2, 36% of the total discrete landraces recorded in the field (20 out of 55) were introduced genotypes. From this evidence, two groups of landraces can be identified in view of temporal diversity: aboriginal (*enat mashila* – 'mother' sorghum) and introduction (Table 4). The aboriginal landraces are grown since ancestral time and reputed for their agronomic potential and socioeconomic importance. These were landraces with goose compact panicle that belong to durra race as established by scientific classification. In fact, the durra race is the most economically important race of sorghum and that has a long history of domestication in Ethiopia (Stemler et al. 1975). The introduced genotypes were particularly reputed by farmers for their tolerance against various stresses such as drought, striga and stalk borer, soil fertility decline and short duration.

Re-constructing the original identity of genebank-conserved accessions

Of the 20 accessions taken back to Welo farmers in 2001 for the stated research objectives five accessions, represented by six landraces were lost or no more remembered by farmers of all age groups. These were accessions collected in 1979 namely: acc.no.69209, acc.no.69210, acc.no.69211, acc.no.69214 and acc.no.69216 (Table 5). Five accessions were found to be mixtures, each consisting of at least two landraces distinguished at least by their grain color. The 20 genebank accessions fall under 16 landraces, i.e. 10 discretely named landraces according to farmers' classification (*aba-ere*, *ahiyo*, *dhangale*, *fereje*, *jamiyo*, *jirgite*, *milte*, *tinqish*, *yelemdeha* and *zengada*) and six unidentified or lost landraces. Of the 10 named landraces, seven were aboriginal and the remaining three (*jamiyo*, *fereje* and *jirigite*) were introductions. In this particular case, this study asserts the following: (a) Some of the earlier collections had been rescued from being eroded as a result of *ex situ* conservation in the genebank, which would have been lost otherwise. (b) few accessions were

Table 3. Landrace migration in space and time in south Welo.

Landrace name	Geographic source	Area where dissemination has occurred	Seed migration in space (km)	Seed migration in time	Reason for introducing
jiru	Jihur, Northeastern Shewa	Qobo and Zobel districts, North Welo	430 – 460	Mid-1970's	Yield potential and grain quality
jamiyo	Jama, North Shewa	Same as above	460 – 460	Late 1970	Decline of soil fertility
mera	Merabite, Northeastern Shewa	Same as above	400 – 460	Late 1980s	Advance of striga and other stresses
rayo	Raya-Azebo, North Welo	Daawaa-Chaffaa district, south Welo	220 – 235	Early 1990s	Same as above
yeju	South Welo	Shewa Robii, northeastern Shewa	230 – 250	Not precisely known	Soil fertility decline
humera	Humera, from Sudan border	Same as above	545 – 615	Mid-1990s	Advance of drought
limat (released variety)	Melkassa (Research center)	South Welo	300 – 400	Mid-1990s	Short duration
wegere	West Hararghe	Daawaa-Chaffaa, Kalu	300 – 350	Mid-1990s	Yield and grain quality

Table 4. The sedentary status and functional attributes of some selected landraces in south Welo, 2001.

Name of landrace	Sedentary status		Adaptation zone	Functional attributes
	Aboriginal	Influx		
abaere	✓		Midland	Staple, high yielding potential and milling recovery
abdoke		✓	Lowland	Short cycle, consumed green by roasting
ahiyo	✓		Midland	Tolerant to striga, bird
anchro (wincho)	✓		Highland &waterlogged	Tolerate to bird, waterlogged field, poor yielding
areri		✓	Lowland–midland	Sweet-grain
baqelo		✓	Midland	Sweet-grain
boresh	✓		Midland	Staple, high yielding potential and milling recovery
cherekit (mera)		✓	Midland	Tolerant to poor soil, striga
dalecho	✓		Midland	Staple, high yielding potential and milling recovery
dawe		✓	Lowland–midland	Short cycle, escape drought
dhangale (tengele)	✓		Midland	Staple, high yielding potential and milling recovery
fereje		✓	Lowland	Short cycle, escape drought
gadido		✓	Lowland–midland	Short cycle, escape drought
gorad	✓		Midland	Staple, high yielding potential and milling recovery
goronjo		✓	Midland	Tolerant to striga and stalkborer
humera (esmael, subhan)		✓	Lowland–midland	Tolerant to striga, stalkborer, poor soil
jamiyo		✓	Midland	Medium maturing, adapted to poor soil, with better grain yield
jirgite		✓	Lowland–midland	Medium maturing, adapted to poor soil
jiru		✓	Midland	Staple, high yielding potential and milling recovery
limat		✓	Lowland–midland	Short cycle improved variety
marchuqe (borchoqe)	✓		Midland	Sweet-grain
mokake		✓	Midland	Medium maturing
qi.ayefere	✓		Midland	Tolerant to striga
rayo		✓	Midland	Tolerant to striga and stalkborer
shumiye		✓	Midland	Staple
tambak	✓		Midland	Sweet-grain
tinqish	✓		Low, mid & highland	Sweet-stalk
wefibelash	✓		Midland	Bird tolerant
w.beguchu	✓		Midland	Sweet-grain
y.mendaye	✓		Midland	Sweet-grain
utala		✓	Lowland–midland	Sweet-grain
zengada (jange)	✓		Highland	Preferred for making local beverage

no more adapted to their original collecting sites-fields with altitude ranging from 1540 to 1550 masl (e.g. acc. no.212639, acc. no.212640 and acc. no.212643). These were sorghum landraces that belong to *zangada* group and there were collected between 1985 and 1988. They are known as highland sorghum, i.e. adapted to high altitude (areas with greater than 1700 masl), cooler temperature and are long duration sorghums, up to 270 days. A mid-altitude zone from which *zangada* landraces were originally collected has been facing recurrent drought, which was relatively less problematic to support the growth of these long duration sorghums prior to the time of collecting in the 1980s. The *zangada* group is presently confined to high altitude areas with relatively better rainfall and cooler temperature. This illustrates the difficulty of using some of the earlier collections directly in production. (c) despite the fact that farmers have demonstrated their ability to identify most of the accessions they had provided to the genebank by grain color and shape, and by looking at whole plant while standing in the field, their knowledge of the lost accessions has been lost as well.

Patch-occupancy and relative abundance

At adaptation (altitude) zone and field levels

As noted earlier landrace diversity varies with altitude, quality and heterogeneity of fields. Few discrete landraces such as *zengada*, *wincho*, *tiqureta*, sweet-stalk and sweet-grain sorghums were identified in uplands (Table 6). None of the introduced genotypes was found in upland with higher altitude. As a result, aboriginal landraces

Table 5. Lost and re-gained original identity of genebank accessions as identified by farmers.

Acc. No.	Altitude (m asl)	Site of collection	Year of collection	Vernacular name as identified by farmers
69208	1670	Bati	1979	*kubi tinqish*
69209	1670	Bati	1979	Unidentified (lost)
69210	1640	Bati	1979	Unidentified (lost)
69211	1650	Bati	1979	Unidentified (lost)
69212	1600	Bati	1979	*fereje* and *jamiyo* mixture
69213	1930	Kalu	1979	*zangada* & unidentified white-seeded sorghum
69214	2070	Kalu	1979	unidentified white-seeded sorghum
69215	2070	Kalu	1979	*ahiyo* & unidentified white-seeded sorghum
69216	1970	Ambasel	1979	Unidentified
69217	1830	Kalu	1979	*Jamiyo*
212639	1550	Ambasel	1985	*zengada*
212640	1550	Ambasel	1985	*zengada*
212641	1690	Ambasel	1985	*zengada*
212642	1540	Ambasel	1985	*ahiyo*
212643	1540	Ambasel	1985	*zengada*
212644	1540	Ambasel	1985	*jirgite* mixed with unidentified landrace
226046	1660	Bati	1988	*dhangale*
226047	1580	Bati	1988	*aba-ere*
228108	1540	Ambasel	1988	*yelemdeha*
228109	2070	Kalu	1988	*milte*

have had the highest patch-occupancy and relative abundance profiles in this adaptation zone, *zengada* being the highest (data not shown). The result of this study shows that sorghum landrace diversity is limited both in quality (variation in functional attributes or traits) and quantity (only seven landraces were recorded) in high altitude zone. Nor did formal plant breeding and farmers' seed system manage to add genetic diversity adapted to uplands. The highest number of discrete landraces (45) was recorded for mid-altitude followed by lowland (Table 6). Likewise, the distribution of introduced landraces follows similar pattern in these adaptation zones, i.e. there were more introductions in midlands than in the lowlands.

Both aboriginal and introductions were found existing over large patches with patch-occupancy percentage (% of fields in which a landrace appeared) as high as 78 within their adaptation zones and micro-niches. But, there is significant difference between individual landraces in their patch occupancy and relative abundance profiles being imposed by variation in field quality, (a)biotic stresses, seasonal variation, and landrace spillover. For instance, fields with better soil fertility status and high soil moisture retention capacity such as fields in valley bottom or along river banks were planted to few high yielding sorghum landraces (e.g. *dhangale*, *gorad*, *aba-ere* and *dalecho*), unless seed unavailability dictates otherwise. In effect, these landraces maintained high patch-occupancy and relative abundance in these particular fields. Similarly, in fields of poor soils or infested with striga landraces like *cherkit*, *kitiny-ayfere*, *rayo*

Table 6. Landrace distribution by altitude, micro-niches and at field level.

Spatial variation mainly as defined by altitude	Altitude (m asl)	No. of fields sampled	Total area (ha)	No. of discrete landraces	No. of landraces/field
Highland	> 1800	32	17.6	7	1–5 (3)[a]
Mid-altitude	1500–1800	81	76.9	45	2–19 (11)
Lowland	< 1500	47	32.2	26	1–12 (5)
Valley bottom	1450–1610	35	17.5	9	2–8 (3)
Waterlogged field	1375–1520	5	1.5	4	1–3 (2)
Total		200	145.7	55	1–19 (6)

[a]Figures in parentheses represent average number of landraces counted/field.

and *ahiyo* constitute the largest share of 'seed lots' (Louette 1999), which as a result contributed to their high relative abundance in these particular fields. Sites near backyards and forest trees, where birds are causing major problem, were predominantly planted to bird tolerant landraces such as *wef-ayibelash*, *cherkit*, *zengada*, *wincho* and *tikureta*. Furthermore, fields with waterlogged condition (high water-table) were planted to few adapted landraces (e.g. *winho or anchro*) and were found in abundant in that particular field.

Variation in planting seasons (early-March/April and late-June season planting) affects patch-occupancy and relative abundance of landraces in two ways. First, by selecting for specific adaptation zone, it affects farmers' landrace choice. For instance, if early season planting commonly practiced across all adaptation zones failed, then farmers would be forced to rely on late season planting, which is suitable mainly for lowlands with short growing period. Second, as a consequence, late season planting favors mainly short duration landraces. This ultimately reduces patch-occupancy of medium and long-duration landraces, as they are less adapted to late season planting. In short, the number of landraces and their patch-occupancy was increased in early season planting because of variation in field quality and heterogeneity of micro-niches that demand a range of tolerant and adaptive landraces, while late season planting encouraged the opposite. Finally, landrace with potential spillover, i.e. wide adaptation and tolerant to various stresses appeared to have higher patch-occupancy and relative abundance profiles. Some of these landraces include *dhangale*, *yelemdeha*, *ahiyo*-aboriginal and *humera*, *mokake* and *jamiyo*-introductions. Generally, introduced genotypes appeared with better patch occupancy and relative abundance than aboriginal landraces in the fields with moisture stress, poor soil and infested with striga, while the latter were dominant in uplands, in the fields with better soil fertility and moisture retention in the midland and lowland areas. One may question whether this is a stable situation or an indication of the progressive colonization of new introductions on the fact that this finding is a result of a snapshot survey of one cropping season. But, on the other hand, when information from the interviews with farmers on their selection priorities and challenges are taken into account the progressive replacement of aboriginal landraces by new influxes is an imminent case. Moreover, although there was no baseline data on distribution and density status of individual accessions at the time of collecting, the inclusion of 'introductions' in genebank accessions at that time was presumably because of their rareness. At present, however, these new introductions have become abundant both in distribution and density. Three principal lessons can be noted from this finding. First, replacement of aboriginal landraces has indeed occurred especially in fields that are prone to (a)biotic stresses. At altitude level, replacement was more in lowland than in mid-altitude, none in the uplands. Second, this evidence provides a particular case in which a landrace was replaced by another landrace unlike the commonly stated assumption that genetic erosion occurs as result of adoption of improved varieties (Berg et al. 1991; Cooper et al. 1994). Third, landrace migration in space and time occurred not because of farmers search and impression for morphological distinctiveness of genotypes as argued by some (e.g. Wood and Lenné 1997) but rather because of unique functional attributes (traits), e.g. adaptive to poor soil, tolerant to striga, grain sweetness, etc. possessed by the introduced genotypes.

At district level

Like at field level, landraces have shown similar trend in patch-occupancy and relative abundance profiles at district level because of agro-ecological similarity between study districts. Bati is by far the most vulnerable district of those studied in which influxes and displacement has become conspicuously noticeable. There were more introduced genotypes than aboriginal landraces in this district. Of the existing aboriginal landraces (nine in total), six landraces occupied less than 20% patch-occupancy (Table 7). Whereas 7 of the 12 introduced genotypes have had more than 20% patch-occupancy in the same district. If rescue operation or backing up local genotypes is to be considered this district deserves priority. A more or less similar trend was observed in the Dawa-chefa district. For instance, 9 out of 16 aboriginal landraces in this district occupied less than 20% patch-occupancy. Relatively few introduced genotypes were found in the Ambasel district. But, 12 out of 25 aboriginal landraces in this district have had low patch occupancy percentage (less than 20%). This

Table 7. Patch-occupancy of aboriginal and introduced landraces by district (% of total fields sampled).

District	Landrace category	Patch-occupancy percentage (No. of landraces)				
		< 20%	20 – 40%	41 – 60%	> 60%	Total landraces
Bati	Aboriginal	6	–	2	1	9
	Introduction	5	4	3	-	12
	Total	11	4	5	1	21
Dawa-chefa	Aboriginal	9	5	1	1	16
	Introduction	6	5	3	–	14
	Total	15	10	4	1	30
Ambasel	Aboriginal	12	8	3	2	25
	Introduction	2	3	3	–	8
	Total	14	11	6	2	33
Kalu	Aboriginal	5	7	10	2	24
	Introduction	–	4	2	4	10
	Total	5	11	12	6	34

Table 8. Relative abundance of aboriginal and introduced landraces by district (% of total plants sampled).

District	Landrace category	Relative abundance percentage (No. of landbraces)				
		Very rare < 2%	Rare 2 – 5%	Common 6 – 10%	Abundant > 10%	Total landraces
Bati	Aboriginal	5	1	1	2	9
	Introduction	2	6	3	1	12
	Total	7	7	4	3	21
Dawa-chefa	Aboriginal	5	5	5	1	16
	Introduction	3	5	3	3	14
	Total	8	10	8	4	30
Ambasel	Aboriginal	5	12	4	4	25
	Introduction	1	2	3	2	8
	Total	6	14	7	6	33
Kalu	Aboriginal	7	7	9	1	24
	Introduction	–	3	4	3	10
	Total	7	10	13	4	34

signifies that Ambasel is equally at risk because of low patch-occupancy profile of aboriginal landraces and limited supply of foreign materials. In the Kalu district, larger proportion of both aboriginal and introduced genotypes enjoyed more than 20% patch-occupancy (Table 7). Overall, larger number of aboriginal landraces occupied less than 20% patch- occupancy in all districts, except Kalu. By contrast, larger proportions of the introduced materials occupied greater than 20% patch-occupancy. This clearly illustrates that introduced landraces appeared to be more aggressively encroaching sorghum fields than aboriginal landraces specially when the elapsed time since introduction for some of the landraces such as *humera* is taken into account.

Furthermore, all districts studied exhibit similar trend in relative abundance of landraces (Table 8). Aboriginal landraces have had better relative abundance than patch-occupancy profile. This is perhaps due to farmers conscious selection and allocation of aboriginal landraces to fields to which they are better adapted in order to attain stable total dry matter yield for food and non-food needs.

Discussion

The dynamics of a crop mix

The usual sorghum-based farming system of south Welo can be described as a practice of growing crops and crop landraces in a mixture per field/season. This crop mix is neither a random event nor a 'design' stipulated in 'inter-species ecological complementarity' principle (Richards 1993). It is not a function of gene flow alone, either. It is rather an intentional decision that farmers have taken in response of the need of the moment. Farmers establish appropriate crop mix based on ecological variation (altitude, heterogeneity of micro-niches-soil type, soil fertility, and soil moisture), bio-physical stresses (mainly drought, striga, stalk borer, soil fertility decline) and availability of seeds of the required landraces. The dynamic mix is meant to attain multiple objectives: production, selection (experimentation) and conservation of genetic diversity to maintain options for the future. Thus, their piece of land is not only a place to produce grain for food but also a place for crop selection and conservation as well (Table 9).

The practice of growing crop mixtures on a limited piece of lands (often less than a hectare) has direct impact on the type and size of landraces maintained on-farm. First, small farm-size affects farmers' production objectives, selection (experimentation) and conservation priorities. Consequently, these objectives and priorities determine landraces that constitute a mixture. Second, because of the small farm-size a low number of plants per landrace are planted. A low number of plants when subjected to recurrent (a)biotic stresses would result in a large chance of loss of individual landraces especially susceptible ones. In effect, (a)biotic stresses coupled with small farm size impose selection pressure in favor of tolerant landraces. One option to reduce this risk is to improve farmers' post harvest seed storage methods and facilities, i.e. complementing on-farm conservation of plants with seed storage.

A community seed bank has been initiated by Ethiopian National Genebank with financial support from Global Environmental Facility in the mid-1990s with the objectives of establishing

Table 9. Analysis of farmers' reasons of maintaining sorghum landrace diversity and growing them as mixture per field ($n = 200$).

Reasons	Farmers' explanations	%
Maintaining landrace diversity		
Coping with bio-physical stresses	To distribute risk of crop failure resulting from diseases, insect pests, striga, drought, soil fertility decline, etc over landraces that have varying degree of tolerance/resistance against these stresses	78
Multiple uses	To take advantage of the built-in quality characteristics possessed by landraces such as sweet-grain landraces for offsetting pre-harvest hunger, sweet-stalk landraces for generating cash, others being good for staple, livestock feed and firewood, etc.	62
Sorghum genetic resource conservation	To maintain landraces that could serve as source of important traits for taking advantage of seasonal and micro-niche variations or for use against newly emerging stresses	53
Cropping season variation	To take advantage of the two growing seasons that favor the growth of two groups of sorghum; long-cycle and short cycle sorghums	17
Growing landraces mixture		
Attain harvest security and yield stability	Due to unpredictability of biophysical stresses associated with seasonal variation farmers opted to mix a variety of landraces in order to attain harvest security and yield stability	72
Land shortage	Due to land shortage and problem of storage pests farmers are forced to grow a mixture of landraces that are meant to meet production objectives on one hand and those kept mainly for conservation purpose on the other	63
Seed shortage	Seed shortage is a major problem because of crop failure resulting from drought and associated stresses. In effect, farmers mix seeds of various landraces to maintain the required seed rate	57
Heterogeneity of a field (exploit the potentials)	Few farmers mentioned that their fields favor the growth of different landraces that are responsive to soil fertility variation and moisture retention resulting from field management (e.g. application of manure) and due to field orientation against run-off.	11
For field isolation, to prevent from wind, theft	Farmers mentioned that few landraces are used as wind break because of their sturdy stalk, or to isolate fields because of their unique panicles, to camouflage sweet-stalk or sweet-grain sorghums to prevent from being looted	7

community-based *ex situ* conservation facility for seed reserve and to satisfy farmers' needs by creating access to genetic diversity, etc. (Feyissa 2000; Getahun Mulat personal communication). However, the difficulty of maintaining cold rooms without electric supply in rural farming households and securing funds to cover its cost on sustainable basis; the risk of disrupting local seed systems and farmers' methods of seed storage when farmers are encouraged to depend on community seed banks are among many issues yet to be resolved and remain challenging the realization of community seed banks. At present, the need to support farmers' post-harvest storage methods and facilities seems more compelling than building cold rooms in rural farming communities. Also, in an event of diminishing farm size, it is important to study the effect of size of seed sample on sustaining the inherent genetic diversity when landraces are grown in a mixture.

Farmers' selection criteria

Farmers were asked why they have been growing sorghum landrace diversity and grow them as mixture per field/season over the past three decades or so. It has been found that all farmers interviewed have given more than one reason for keeping sorghum landrace diversity and for including a particular landrace in a mix (Table 9). Farmers make use of the values possessed by each landrace such as grain yield, plant bio-mass for feed and firewood, stress tolerance/resistance, maturity, milling recovery, market value, social or ritual values, etc. Such farmers' multiple selection criteria have been widely acknowledged for being responsible for the type of on-farm diversity as we have it today Richards 1986; Longley and Richards 1993; Bellon 1996; Teshome et al. 1999). Teshome et al. (1999) argue that as the number of selection criteria increased, landrace diversity in the fields increased independent of environmental variables. However, as results of this study indicate, the survival of sorghum diversity on-farm has been resulted more from ecological factors (altitude, heterogeneity of micro-niches-soil fertility, soil moisture), biophysical stresses and resource limitation (land and seed) than from farmers' multiple selection criteria. The fact is that farmers' selection criteria are dictated by changing biophysical and socioeconomic environments. If, for instance, striga continues to be seriously threatening sorghum production in the study area, as it is the case, then farmers' multiple selection criteria will ultimately be reduced to the selection of striga resistant/tolerant landraces. In doing so, those sorghums susceptible to striga will disappear sooner or later, no matter how excellent they are for meeting farmers' criteria for making *injera* (Ethiopia's staple), in their yielding potential and stalk quality for firewood and cattle feed. In the same way, the diversity currently available in intermediate altitude will disappear if drought remained a serious threat to sorghum production. If this situation prevails farmers will eventually be forced to make choice between crop species, let alone within single species (sorghum) or even may give up farming altogether and obliged to seek off-farm opportunities elsewhere. There is already a clear indication that tef (*Eragrostis tef*) is advancing at the expense of sorghum in Ambasel and Kalu districts due to drought. This asserts that farmers' multiple criteria can be outweighed by single biophysical stress prevailing at a particular site. Even if farmers employ multiple selection criteria, they give priority to a landrace that meets multiple selection criteria more than a variety with single superior trait under condition of increased (a)biotic stresses and resource limitations. Thus, it is impossible to envisage the value of crop genetic diversity without maintaining the natural resources base (water, soil and land) and mitigating the complex and co-evolving biophysical stresses, a challenge that can not be solved by employing farmers' multiple selection criteria for yield, grain quality, taste, etc.

Farmers make conscious selection of landraces that meet the need of the biophysical environment. Their principle of landrace evaluation and selection refers to as '*andi-ayshomim*', literally means no one can be elected without contest. In actual practice, this is the employment of a mixture of competing landraces per field. The method of selection is known as '*afesso*', which is equivalent to '*bulk*' in population improvement in formal plant breeding. They select individual landraces on the basis of their distinct functional attributes rather than single superior trait. The bulk seeds are planted to the same field, on a particular soil type, soil fertility gradient and moisture regimes, in presence of weeds, diseases and insect pests of various sorts. This helped farmers evaluate landraces under similar and variable environmental factors occurring at particular space and time. By implication, there is no outright adoption of introduced genotypes by farmers. The important point to emphasize here is that farmers select each landrace on the basis of distinct functional attribute (agronomic, nutritional quality, maturity, and other utility values). For instance, a low yielding but sweet-grain sorghum has a chance of co-existing with high yielding staple sorghum because of its unique functional attribute – being used as sweetener or consumed green. Farmers' selection for functional attributes being distributed over landraces is a point of departure from formal plant breeding in which breeders aggregate desirable traits in single variety under the principle referred to as 'broadening the genetic base' of breeding materials (Cooper et al. 2001). Also, it has been reported that farmers in the study area grow weedy relatives mixed with grain sorghums just to enhance diversity through gene flow (Worede and Mekbib 1993; Teshome et al. 1999). Our observation however is that farmers tolerate the growth of weedy relatives along with staple sorghums for their leaves and stalks to use as cattle feed and firewood and grain for making local beverages. It is this farmer's practice of selecting staple sorghums and weedy relatives for their distinct functional attributes that has contributed to the survival of on-farm sorghum genetic diversity.

Threats to on-farm diversity

The risk of loss of aboriginal landraces was predicted based on vulnerability index computed from patch-occupancy, relative abundance and average density values, where high value for each indicator and the sum of factors decreases the risk of loss of landraces, i.e. render low vulnerability index. Accordingly, sweet-grain sorghums were found to be the most at risk (Table 10) mainly due to the advance of drought over the years. Also, farmers' selection for sweet-grain affected the availability of seeds of sweet-grain landraces, since they are consumed green (at dough stage) before reaching maturity for seed harvest to offset pre-harvest hunger. Among staple sorghum, only three landraces were found with low risk status. The risk of loss of the others was largely because of increasing (a)biotic stresses (mainly drought, striga, stalk borer, and soil fertility decline). This can be understood from the characteristics of introduced genotypes that are reputed for conferring tolerance against (a)biotic stresses. The impact of adoption of improved varieties on local sorghum diversity is limited. The Ethiopian Sorghum Improvement Program released more than 15 short duration varieties adapted to intermediate and lowlands over the past two decades or so. The adoption of these varieties however stands at bare minimum, less than 5% of the total area under sorghum (*forthcoming*). The varieties failed to meet minimum requirement (dual purpose for food and feed) to be taken up by farmers. For that matter, the adoption of these short-duration improved varieties can not be seen as a threat to local sorghum diversity. For one thing, there is little chance of replacement because of reproductive and seasonal isolations between short duration improved varieties and medium-long duration farmers' landraces. Secondly, short duration varieties are in short supply in local sorghum germplasm in its center of diversity. The adoption of these varieties thus illustrates a case in which improved varieties and farmers' landraces co-exist and at the same time challenges the common assumption that introduction of improved variety is a threat to local genetic diversity.

Table 10. Risk of loss of aboriginal landraces based on vulnerability indexes computed from patch-occupancy, relative abundance and average density values.

Risk of loss	Name of landraces (in ascending order of vulnerability index)
Low	*Dhangale, gorad, ahiyo*
Moderate	*tinqish, wef-aybelash, zangada, aba-ere, yelem-deha, boresh, dalecho, milte, tuba, anchro, wati-gala*[a], *mar-baksa*[a], *yiqir-mendaye*[a], *wanase*[a]
High	*mote, qitiny-ayfere, morgage, qilo, abola, shole, shuleka, gansber,tiqureta*
Very high	*Yebag-lat*[a], *chome*[a], *chigero*[a], *chimigo*[a], *chiqite, shilime, marchuqe*[a] *wetet-begunchu*[a], *tambak*[a]

[a]Sweet-grain sorghums.

Conclusion

This study explores the dynamics of farmers' management of sorghum in marginal environments of Ethiopia. In such dynamic management *ex situ* conservation has clearly rescued some landraces which otherwise would have disappeared as result of the changing biophysical environment and farmers' selection pressures. On-farm management, in its part, has remained a source of influx of genotypes mainly as a function of farmers' seed system and gene flow dynamics. There is no static maintenance of a particular landrace over space and time as there is no static biophysical and societal environment. Thus, on-farm conservation of plant genetic resources for food and agriculture can only be a result, not an objective being set for its sake. There are two underlining principles primarily to be agreed upon to invest in on-farm conservation. First, farmers' management of crop landrace diversity is an 'open system' (Wood and Lenné 1997). Second, on-farm conservation needs to lessen the conservation-development paradox (Hawkes et al. 2000) and could be incorporated into agricultural development programs that aim to improve the production of traditional farming systems (Atlin et al. 2000). Any viable package incentives to enhance and sustain the complementarily co-existence of *ex situ* and on-farm conservation should adhere to these underlying principles. These principles could be materialized at least in two ways:

(a) Modifying the biophysical environment (micro-niches) to the requirement of landraces (e.g. fertility restoration, moisture conservation, and other agronomic practices), since otherwise it will be difficult for landraces to remain adaptive to the changing biophysical environment and socio-economic needs. This hints at making the biophysical environment a comfortable home for plant genotypes.

(b) Linking conservation to crop improvement to support farmers' 'maintenance breeding', i.e. to identify landraces for re-introduction or introgression of lost traits, e.g. high lysine, into adapted landraces/varieties that are still needed by farmers. The possibility of keeping genetic diversity on-farm by respecting farmers' multiple selection criteria is becoming elusive in the face of increasing biophysical stresses. An informed genetic manipulation and introgression is required which can not be left for simple mass selection and random mating. Also, the concern must not only to enhance crop genetic diversity on-farm but also to integrate genetic and agro-ecological innovations to sustain processes that create this diversity in open and dynamic system.

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