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Morphological and farmers cognitive diversity of barley (*Hordeum vulgare* L. [Poaceae]) at Bale and North Shewa of Ethiopia

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Abstract

Twenty two accessions of barley landrace/farmers' varieties collected from Bale and North Shewa *in situ* conservation zones were characterised using 18 qualitative and quantitative morphological traits. Phenotypic frequencies for individual qualitative characters across *in situ* conservation zones, districts, and strategic sites (localities) have shown mixed and some peculiar patterns. Varieties from Bale conservation zone are predominantly white-yellow seeded whereas varieties from North Shewa are purple-black seeded. White-yellow seeded varieties are more frequent in the lower altitude examined, and the purple-black seeded varieties are more frequent at the highest altitude (≥ 2650 masl). While six row types occur at higher frequencies in almost all the sites in North Shewa, the irregular types are dominant at Bale. The highest frequency of six row types is found at an altitude ≥ 2650 masl, whereas the two rowed and irregular types are found below 2650 masl. Two row types occur at low frequency at both sites. At Bale, glume awn shorter than glume is the most frequent character whereas glume awn longer than glume is more frequent at North Shewa. Glume awn longer than glume appears to increase with increasing altitude. Caryopsis cover is relatively monomorphic with respect to distribution across zones. The covered types are most frequent in almost all altitudinal ranges. Estimates of diversity index (H′) for individual qualitative characters suggest that polymorphism is common in varying degrees for most characters, which indicates the existence of wide range of variation. On the basis of cross validation using discriminant function among the quantitative characters, the landrace varieties from North Shewa seem to be more diverse than the ones from Bale. From the results of multiple regression analysis, the zonal variation is significantly associated with all the quantitative morpho-agronomic characters except plant height. The great majority of the varieties from Bale were perfectly identified and named by farmers. The reliability analysis confirmed that there was a remarkable positive degree of consistency between farmers naming of landrace varieties.

Introduction

A major preoccupation of those concerned today with the conservation of plant genetic resources is the loss of germplasm diversity in farmers' fields. Farmers have several socio-economic incentives to replace varieties that evolved within their traditional agricultural system with modern introduced varieties in many regions of the world (Louette et al. 1997). Maintaining genetic diversity in *ex situ* genebanks, on the other hand, has arrested the complex interaction of genetically diverse traditional cultivated varieties (farmer varieties) with their associated pests and pathogens. This also fails to retain traditional farmer knowledge associated with landraces, knowledge which can be instrumental in utilisation and development of new crop varieties from original farmers varieties. To circumvent the disappearance of locally evolved varieties in farmers fields, some have proposed *in situ* crop conservation as a complementary strategy to *ex situ* conservation of genetic resources in genebanks (Altieri and Merrick 1987; Brush 1991). *In situ* conservation here refers to the conservation in the agrosystem of origin of varieties that are cultivated by farmers, using their own selection methods and criteria. Conservation of landraces by farmers *in situ* at the farm level allows continuing farmer selection, which is interaction with the environment and gene exchange with wild species so that evolution of landraces remain genetically diverse and well adapted to local agro-ecological and socio-cultural conditions (Berg 1992; 1995). This is of primary importance for the majority of the worlds' farmers working in low input, subsistence agriculture.

A strategy was suggested for *in situ* conservation of crop genetic resources whereby conservation projects are likened to rural developments (Altieri and Merrick 1987). In Ethiopia, a project entitled 'A Dynamic Farmer-Based Approach to the Conservation of Ethiopias Plant Genetic Resources' funded by the Global Environment Facility (GEF) of the United Nations has been in place for the last four years. This project has been implemented by the Institute of Biodiversity Conservation and Research (IBCR). It emphasises preservation of traditional farming systems and has succeeded in sustaining production by relying on maintenance of biological and genetic diversity in this system. The project has six sites of different agro-ecology across the country, including Bale and North Shewa. Barley is one of the major crop components of the conservation programme at these two sites.

The geographic centres of the two groups of study sites are separated by more than 500 km. In addition to the geographic separation, there are significant soil and climatic differences between the two sites. Though bi-modal, the annual rainfall varies widely in space and in time in the Bale crop conservation site. This low and erratic nature of the rainfall and occurrence of extreme temperatures has resulted in very low organic matter and nitrogen in the soil because under low rainfall and relatively high temperatures, chemical weathering is limited and soils forming processes curtailed. The North Shewa site has extensive highland areas. The soils in the area are usually stony and vary from red on the hill sides to heavy black on the bottom lands, are generally shallow, and often with a very dense or high clay content stratum some 15 to 20 cm beneath the surface. This clay subsurface is very slowly permeable, and the internal drainage is very low and because of the intense rainy season and short growing season, soils are suitable for growing of the small grain cereals. Despite the relatively long frost spells in some months and poor drainage, the distribution of rainfall is 1000 mm y^{-1} (Meterological research report seriesAddis Ababa, Ethiopia 1996) and with a better fertility than the Bale.

Barley (*Hordeum vulgare* L. ssp. *vulgare*) is a major traditional cereal crop in Ethiopia representing about 18% of the total national cereal production, and on average 1.0 million tones of barley grain is produced annually from an area of about 900000 hectares (Central Statistics Authority of Ethiopia 1996). Over 90% of the barley currently produced by subsistence farmers is landraces (Alemayehu 1997) with no external inputs. The high variation in barley from the highly heterogeneous Ethiopian landscape has shown biological principles under operation (Asfaw 1989). In the south, e.g. Bale, and mid-north, e.g. North Shewa, barley is widely grown, cultivated twice per year.

Cultivated barley does not have a clearly traceable origin or path of descent. Vavilov initially considered Ethiopia to be the centre of origin for barley, but later, as a secondary centre of diversification, because the existence of wild forms has never been confirmed from Ethiopia (Vavilov 1926; 1951; Harlan 1969; Tolbert et al. 1979). Though Takahashi (1955) acknowledged the secondary nature of the Ethiopian centre, others were still not completely convinced (Bekele 1983; Negassa 1985b). Ward (1962) regarded Ethiopia as a centre of concentration for deficiens, irregulare, and short rachilla hair types. Several investigations have nonetheless repeatedly shown the importance of Ethiopian barleys as sources of genes for resistance to various diseases of barley (Qualset and Moseman 1966; Wiberg 1974; Qualset 1975; Alemayehu 1995) and protein quality (Munck et al. 1970; Asfaw 1989). Many promising lines have been used as donors of resistance to commercial varieties in North America and in Europe (cf. Negassa (1985a)). By contrast, within Ethiopia the locally adapted barley germplasm remains under exploited in breeding programmes.

Understanding the diversity within a crop in an area to develop conservation strategy, means understanding the people who grow it just as much as understanding the climate and soils of the region and the distribution of the wild relatives (Guarino et al. 1995). This is because the pattern of diversity in crops is the result of an interaction between the genetic make-up of the plants and not just environmental (e.g. climate, soil) and biotic (e.g. pests), but also human factor. For example, vernacular names of landraces are given by local farmers and vary according to the local language or dialect (Asfaw 1989). Knowing the name in the local vernacular and an associated ethnobotanical profile of a wild species, crop or landrace of interest can significantly facilitate the process of finding and collecting it, especially if it is rare.

Local men and women know which crops and which varieties of each crop are grown in their village or district or are being sold in the local market. Vernacular names of landraces may not always correspond to botanical distinctness, but they are often quite descriptive of the cultivar grown. For example, the vernacular names ‘senef gebse’ (lazy barley) refers to easy dehulling as a result of being partially naked, while ‘gealemie gebse’ (two-month barley) refers to maturation within two months only (Asfaw 1989). Sometimes the local names of landraces can be used to deduce the original sources of varieties. For example, farmers in Bale area believe that the local barley variety called ‘aruso-bale’ was originated in the Arsi-Bale highlands.

In this type of traditional knowledge, problems may occur with synonyms or when the same name and/or a single name is given to more than one morphological entity. It would be helpful to examine and record how the local people of an area identify one variety of a crop (landrace) from the other, and the existing variability within a crop in the *in situ* crop conservation sites through an analysis of the pattern of variation in naming their varieties.

To be able to define precisely the objectives, limits, and means for implementing *in situ* conservation, it is necessary to obtain a better understanding of the structure of polymorphism within farmers varieties, how it evolves with farmers practices, and the methods and mechanisms for managing this source of diversity (cf. Louette et al. (1997)). This paper presents and examines the extent of morphological, and farmers cognitive, diversity of barley varieties under conservation at the Bale and North Shewa *in situ* crop conservation zones of Ethiopia.

Materials and methods

All the districts within the two zones (see Figure 1 for collection sites) were surveyed together with elderly knowledgeable farmers who provided vernacular names and explained specific features and purposes of the landrace varieties. On the average 300 matured spikes of each of thirteen and nine landrace varieties were collected from farmers’ field at Bale (six sites) and North Shewa (three sites) *in situ* crop conservation sites respectively (see Annex 1.) using random sampling technique. These samples were planted in the Bale zone-Addis Alem Mana site (Latitude 07° 01′N, Longitude 040° 23′E, Altitude 2030 m above sea level), with soil pH range of 6–6.5. Five rows of 2.5 m long plots (area of a plot being 2 m^2) in three complete blocks were used, and Randomised Complete Block Design (RCBD) was applied. Blocks, rows and plots were given spacing of 2 m, 0.2 m, and 0.4 m between blocks, rows and plots respectively, and seed was sown at a rate of 100 kg ha^{-1}. On average, from 20 plants from each farmers’ varieties, a total of 435 spikes were characterised for 18 qualitative and quantitative morpohological traits. A list of nine qualitative traits, their short forms and their respective classes with their codes are provided in Table 1.

The collection sites were grouped into five altitudinal groups. The proportion of different classes for each character, varieties, regions, districts, *in situ* strategic sites and altitude were calculated. The Shannon-Weaver diversity index, which has been widely used in diversity of germplasm collections (Jain et al. 1975; Bekele 1984; Tesemma et al. 1991; Engels 1991; Demissie and Bjørnstad 1996), was used to analyse the phenotypic frequency data of nine qualitative traits. The diversity index, H′, is defined as:

$$H' = -\sum_{i=1}^{n} pi\log_e pi \qquad (1)$$

where n is the number of phenotypic classes per character and pi is the proportion of the total number of plants in the ith class. H was standardised by converting to the relative index, H′.

$$H' = H/H_{max} \qquad (2)$$

where,

$$H_{max} = \log_e(n). \qquad (3)$$

Canonical discriminant analysis frequently used in germplasm characterisation (e.g. Spagnoletti Zeuli and Qualset (1987)), was used to assess on multivariate basis from nine quantitative traits, differences, and hence distinctiveness among the farmer varieties collected from the two *in situ* crop conservation sites

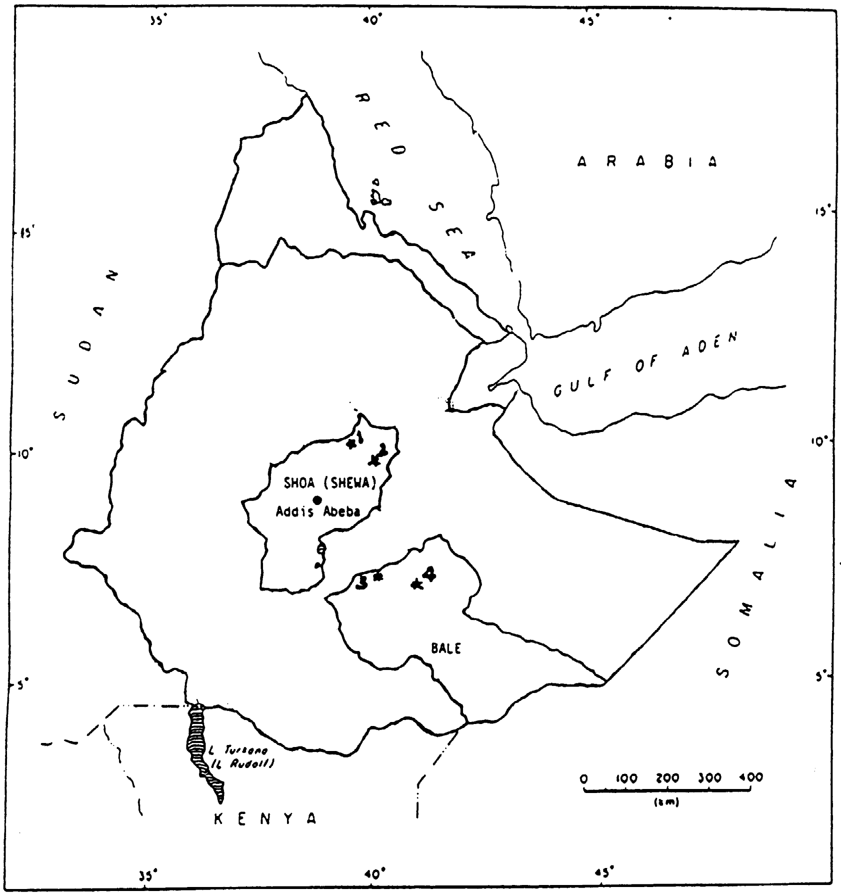

Figure 1. Map of the study area: Bale and North Shewa zones, * Districts: 1-Ensaronawayu, 2-Ankober, 3-Agarfa, 4-Goro.

(Bale and North Shewa). The first two significant canonical functions were used to plot the farmers varieties. The quantitative morphological and agronomic traits recorded were days to heading (DTH), days to maturity (DTM), grain filling period (GFP), tiller number (TN), spikelets per spike (SPS), spike length (SL), barley neck length (BNL), awn length (AL), kernel number (KN) and plant height (PH). Multiple linear regression was applied taking altitude and zonal variation (*in situ* crop conservation sites-Bale and North Shewa) as an independent and the qualitative morpho-agronomic characters as dependent traits. To investigate the similarity or otherwise in the pattern of geographic variation of characters, a correlation coefficient analysis was calculated.

To address the problem of describing a cultural system in cases where informants disagree in identifying varieties based on the local names (i.e. cognitive diversity among informants), and identifying the best traits for the specific varieties, 31 farmers from Bale were interviewed. Data were collected by guiding informants one by one through the field, stopping at each plot and asking, what the barley variety was. The data obtained from the interview were treated in the form of binary data (presence or absence) and subjected to a reliability analysis to quantify the variation among the informants and the varieties. The analysis was carried out using SPSS for MS WINDOWS (1994) Release 6.1.

Results

Qualitative character distribution

Table 2 summarises the phenotypic frequencies for individual characters across *in situ* crop conservation zones, districts (depending on size, a district contains several localities) and strategic sites (localities).

- Farmer varieties from the Bale *in situ* crop con-

Table 1. Qualitative characters used and their respective states and their codes.

Characters	Character states	Codes
1. glume awn length (GAL)	longer than glume	1
	equal to glume	2
	shorter than glume	3
2. spike shape (SS)	parallel	1
	broad	2
	triangular	3
	club	4
3. kernel colour (KC)	white-yellow	1
	purple-black	2
4. glume hairiness (GH)	glabrous	1
	hairy	2
5. spike density (SD)	lax	1
	intermediate	2
	dense	3
6. rachilla length (RL)	short	1
	long	2
7. spike attitude (SA)	completely erect	1
	intermediate	2
	extremely bent	3
8. kernel row number (KRN)	6 rows	6
	2 rows	2
	irregular	1
9. caryopsis type (CT)	covered	1
	naked	2

servation site are predominantly white-yellow seeded (91%), unlike varieties from North Shewa, particularly from Teter Amba and Abaya villages, where the purple-black seed colours are dominant (60%).

- At a character level, white-yellow kernel colours is the predominant character in both zones (82%) as the purple-black type consisted of only 18%.
- Parallel ear shape is more frequent than the alternate variants in both zones except in Teter Amba where the broad spike type reached about 33%.
- The intermediate spike density is the prevalent character in all the sites, districts and zones. At site level, Lay Gorebela in North Shewa exhibited the highest frequencies of dense spikes (70%). Dense spike types occur at a low frequency in almost all of the sites reaching a maximum of 33% in the relatively drier sites of the two zones, Ambentu (Bale) and in Teter Amba (North Shewa).
- Long rachilla is the predominant phenotypic class in both sites except in Ensarona Wayu district (North Shewa), being only 7%. The highest frequency of short rachilla is recorded for Abaya (93%) and at district level, Ensarona Wayu (93%).
- While six row types occur at higher frequencies in almost all the sites in North Shewa, the irregular ones are dominant at Bale. Two row types occur at low frequency, except in Waltaye Gobu (Bale) reaching a maximum of 57%.
- Almost in all the strategic sites and districts (in Bale), glume awn shorter than glumes is the most frequent character. In the contrary, in North Shewa except in Teter Amba site, glume awns longer than glume are more frequent and reached a maximum of 55%.
- Hairy glumes is the most prevalent character state in Bale. Glabrous types were found at highest frequencies at Lay Gorebela (North Shewa), reaching 48%.
- The intermediate spike attitude types are found to be dominant in all the strategic sites at more or less similar frequencies. Extremely bent types were found in Asano Genet site (Bale) reaching 60%.
- Caryopsis cover is relatively monomorphic with respect to distribution across localities in both sites. Almost all strategic sites and districts displayed covered types except the varieties from Waltaye Gobu (Bale) where the naked types were found and reached a maximum of 52%.

Altitudinal trait distribution

Table 3 shows the phenotypic frequencies for individual characters and altitude classes as percentage of the number of farmers varieties from each altitude classes. Glume awns longer than glume appear to increase with altitude. The second variant (glume awn equal to glume) showed a more or less similar trend while the third variant (glume awn length shorter than glume) tended to concentrate at lower elevation. Parallel spike shape is relatively a dominant trait in all the altitudinal ranges. The frequencies of white-yellow and purple-black kernel colour tend to follow an opposite clinal pattern where the former decreased with altitude. Similarly the glabrous and hairy glumes followed an opposite clinal pattern, where the latter decreased with increasing altitude. Short rachilla appears to increase with altitude unlike the longer ones followed the opposite direction. The highest frequency of six rows type is found at an altitude of ≥ 2650 m above sea level (masl) whereas the two rowed and irregular types are found bellow 2650 masl. The covered types are the most frequent types in almost all the altitudinal ranges (1850–2900 masl). Intermediate spike density tends to increase with altitude while the lax ones concentrated below 2650 masl.

Table 2. Phenotypic frequencies for individual qualitative characters cross *in-situ* conservation zones, districts (depending on size, a district contains several localities) and strategic sites (localities).

		Bale									North Shewa					
Char.	Code	Strategic sites Deyu Abergeda	Waltaye Gobu	Chaffa Mana	District Goro	Strategic sites Ambentu	Galema Hunsho	Asano Genet	District Agarfa	Zone Bale	Strategic sites Lay Gorebella	Teter Amba	District Ankober	Strategic site Abaya	District Ensarona Wayu	Zone North Shewa
GAL	1	20	31	20	23	40	32	25	33	28	55	25	42	55	55	45
	2	20	17	7	13	20	15	35	20	16	18	10	15	12	12	14
	3	60	52	73	4	40	53	40	47	56	26	65	43	33	33	41
SS	1	98	95	100	98	84	87	85	86	93	100	67	86	100	100	89
	2	0	5	0	1	13	3	5	6	4	0	33	14	0	0	11
	3	2	0	0	1	0	8	10	6	3	0	0	0	0	0	0
	4	0	0	0	0	3	2	0	2	1	0	0	0	0	0	0
KC	1	98	50	98	84	100	100	100	100	91	73	40	78	40	40	69
	2	2	50	2	16	0	0	0	0	9	27	60	22	60	60	31
GH	1	27	29	17	23	20	28	25	25	24	48	8	31	45	45	34
	2	73	71	83	77	80	72	75	75	76	52	92	69	55	55	66
SD	1	53	50	18	37	40	45	35	42	39	11	39	23	45	45	27
	2	40	38	52	45	27	48	50	43	44	70	28	52	40	40	50
	3	7	12	30	18	33	7	15	15	17	19	33	25	15	15	23
RL	1	20	19	13	83	20	47	40	38	26	55	12	37	93	93	34
	2	80	81	87	4	80	53	60	62	74	45	88	63	7	7	66
SA	1	2	5	7	59	13	10	5	10	7	23	33	27	15	15	24
	2	65	67	48	37	74	35	35	46	53	32	44	37	78	78	46
	3	33	28	45	36	13	55	60	44	40	45	23	36	7	7	30
KRN	6	28	10	60	30	13	3	30	11	25	71	57	65	65	65	65
	2	27	57	13	34	23	35	15	28	29	2	5	3	0	0	3
	1	45	33	27	34	64	62	55	61	46	27	38	32	35	35	32
CT	1	98	48	100	84	100	100	100	100	91	100	100	100	100	100	100
	2	2	52	0	16	0	0	0	0	9	0	0	0	0	0	0

Table 3. Phenotypic frequency for individual qualitative characters and altitudinal classes.

	Characters																							
	GAL			SS				KC		GH		SA			RL		CT		KRN			SD		
Altitudinal range (masl)	1	2	3	1	2	3	4	1	2	1	2	1	2	3	1	2	1	2	1	2	3	1	2	3
1850–2050	28	12	60	78	22	0	0	70	30	17	83	22	53	25	15	85	78	22	37	27	36	43	32	25
2051–2250	20	7	73	100	0	0	0	98	2	17	83	7	48	45	13	87	100	0	60	12	27	18	52	30
2251–2450	29	20	51	92	6	1	1	99	1	24	76	7	69	24	20	80	99	1	21	26	27	47	34	19
2451–2650	39	19	42	93	2	4	1	85	15	38	62	10	39	51	59	41	100	0	34	16	50	36	51	13
>2650	67	14	19	100	0	0	0	48	52	43	57	38	55	7	57	43	100	0	91	0	9	7	74	19

Diversity index

Table 4 provides the estimates of diversity (H′) for individual qualitative characters, and each of the farmers varieties. The highest mean diversity pooled over traits was shown by farmer varieties from Bale (H′ = 0.70) and the lowest (H′ = 0.39) from North Shewa, but these values are not significantly different from each other (t = 3.52, P > 0.18). High variation was observed for kernel row number (H′ = 0.95), spike density (H′ = 0.95), rachilla length (H′ = 0.94), glume awn length (H′ = 0.91) and spike attitude (H′ = 0.91) (Table 5). The lowest variation was obtained for ear shape (H′ = 0.26) and caryopsis type (0.29). At the *in situ* conservation zone level, the highest (H′ = 0.72) mean diversity was obtained from North Shewa and the lowest (H′ = 0.68) from Bale and are significantly different (t = 35.00, P < 0.05). The overall diversity (H′) of both these crop conservation sites are 0.75. Between zones, only glume hairiness exhibited significant difference on the analysis of variance of diversity (H′) for individual traits (Table 7).

On district level, both the highest (H′ = 0.71) and the lowest (H′ = 0.59) mean diversities were obtained from North Shewa, Ankober and Ensarona Wayu, respectively which showed the existence of significantly different (t = 10.83, P < 0.1) variation between districts. Between districts only spike shape and glume hairiness exhibited significant difference on the analysis of variance of diversity (H′) for individual traits (Table 7). At a strategic site level, the

Table 4. Diversity index (H′) estimates for each character in each farmers' varieties.

	Characters									
Farmers' varieties	GAL	SS	KC	GH	SD	RL	SA	KRN	CT	Mean H′ ± SE
1. Aruso Bale1	0.91	0.14	0.29	0.25	0.51	0.72	0.47	0.63	0.29	0.47 ± 0.08
2. Aruso Bale2	0.99	0.23	0.33	0.81	0.85	0.72	0.67	0.81	0.33	0.64 ± 0.09
3. Aruso Bale3	0.91	0.5	0.33	0.72	0.61	0.81	0.46	0.73	0.33	0.60 ± 0.07
4. Aruso Bale4	0.91	0.44	0.33	0.88	0.82	0.81	0.85	0.18	0.33	0.62 ± 0.10
5. Aruso Bale5	0.98	0.37	0.33	0.81	0.91	0.97	0.75	0.89	0.33	0.70 ± 0.09
6. Kinkicho1	0.81	0.17	0.33	0.93	0.89	0.72	0.63	0.63	0.33	0.60 ± 0.09
7. Kinkicho2	0.58	0.17	0.33	0.72	0.21	0.47	0.61	0.63	0.33	0.45 ± 0.07
8. Gedebo1	0.78	0.17	0.33	0.72	0.61	0.61	0.84	0.38	0.33	0.53 ± 0.08
9. Cheneka1	0.70	0.17	0.29	0.90	0.85	0.68	0.62	0.18	0.33	0.53 ± 0.09
10. Gedebo2	0.36	0.17	0.29	0.47	0.91	0.47	0.86	0.63	0.33	0.50 ± 0.08
11. Cheneka2	0.85	0.35	0.33	0.81	0.61	0.33	0.85	0.61	0.33	0.56 ± 0.08
12. Bahir Seded	0.72	0.17	0.33	0.72	0.92	0.61	0.63	0.95	0.33	0.60 ± 0.09
13. Feres Gama1	0.51	0.17	0.33	0.88	0.86	0.61	0.63	0.78	0.33	0.57 ± 0.08
14. Feres Gama2	0.99	0.17	0.33	0.47	0.72	0.61	0.36	0.18	0.33	0.46 ± 0.09
15. Netch Feres Gama	0.92	0.17	0.33	0.61	0.78	0.72	0.58	0.47	0.33	0.55 ± 0.08
16. Tikur Mawge	0.70	0.17	0.33	0.44	0.57	0.68	0.71	0.43	0.33	0.48 ± 0.06
17. Netch Mawge	0.85	0.17	0.33	0.72	0.56	0.88	0.58	0.21	0.33	0.51 ± 0.09
18. Mawge	0.85	0.17	0.72	0.47	0.82	0.33	0.17	0.63	0.33	0.46 ± 0.09
19. Workeye	0.82	0.17	0.33	0.47	0.63	0.47	0.85	0.75	0.33	0.54 ± 0.08
20. Demoye	0.30	0.17	1.00	0.47	0.56	0.61	0.91	0.58	0.33	0.55 ± 0.09
21. Lige Alkiso	0.67	0.17	0.33	0.29	0.21	0.47	0.86	0.21	0.33	0.39 ± 0.08
22. Kesele	0.18	0.17	0.33	0.72	0.46	0.61	0.68	0.46	0.33	0.44 ± 0.07

NB: Source of varieties 1 to 13 Bale (B), 14 to 22 North Shewa (NS).

Table 5. Mean diversity index (H′) of each qualitative character in the conservation zones, districts (depending on size, a district contains several localities) and strategic sites (localities).

	Characters									
Site	GAL	SS	KC	GH	SD	RL	SA	KRN	CT	Mean H′ ± SE
Deyu Aberga	0.86	0.07	0.14	0.84	0.81	0.72	0.66	0.97	0.14	0.58 ± 0.12
Waltaye Gobu	0.91	0.14	1.00	0.87	0.88	0.70	0.71	0.83	0.99	0.78 ± 0.09
Chaffa Mana	0.67	0	0.14	0.66	0.92	0.56	0.82	0.84	0	0.51 ± 0.12
Goro	0.81	0.08	0.63	0.78	0.94	0.66	0.74	0.99	0.63	0.58 ± 0.13
Ambentu	0.96	0.37	0	0.72	0.99	0.72	0.69	0.81	0	0.70 ± 0.13
Galema Hunsho	0.90	0.37	0	0.86	0.82	0.99	0.84	0.70	0	0.61 ± 0.13
Asano Genet	0.98	0.37	0	0.81	0.91	0.97	0.75	0.89	0	0.63 ± 0.13
Agarfa	0.95	0.39	0	0.81	0.92	0.96	0.86	0.82	0	0.63 ± 0.13
BALE	0.89	0.25	0.44	0.80	0.94	0.83	0.81	0.97	0.15	0.68 ± 0.10
Lay Gorebella	0.90	0	0.84	1.00	0.74	0.99	0.97	0.61	0	0.67 ± 0.13
Teter Amba	0.78	0.46	0.97	0.40	0.99	0.53	0.97	0.76	0	0.65 ± 0.11
Ankober	0.92	0.29	0.76	0.89	0.93	0.95	0.99	0.68	0	0.71 ± 0.12
Abaya	0.86	0	0.97	0.99	0.92	0.37	0.60	0.59	0	0.59 ± 0.13
Ensarona Wayu	0.86	0	0.97	0.99	0.92	0.37	0.60	0.59	0	0.59 ± 0.13
NORTH SHEWA	0.91	0.25	0.99	0.92	0.94	0.92	0.97	0.68	0	0.72 ± 0.12

Zone in bold capital, district in bold, strategic sites (localities)-normal.

highest (0.78) and the lowest (0.51) mean diversity were obtained in Bale zone, Waltaye Gobu and Chaffa Mana, respectively, and these values are not significantly different ($t = 4.75$, $P > 0.10$).

The highest mean diversity index pooled over traits for altitudinal classes was shown at the range of 1850–2050 masl ($H' = 0.78$) and the lowest ($H' = 0.51$) at 2051–2250 masl (Table 6). These values are not significantly different ($t = 4.78$, $P > 0.1$).

Canonical discriminant analysis

A proportion of 98.8% and 92.4% from Bale and North Shewa collecting sites respectively were cor-

Table 6. Mean diversity index (H′) of each qualitative character in the five altitudinal classes.

	Characters									
Altitude (masl)	GAL	ES	KC	GH	SPA	RL	CT	KRN	SD	Mean H′ ± SE
1850–2050	0.84	0.38	0.88	0.66	0.92	0.61	0.76	0.99	0.98	0.78 ± 0.07
2051–2250	0.67	0	0.14	0.66	0.82	0.56	0	0.84	0.92	0.51 ± 0.12
2251–2450	0.93	0.24	0.08	0.80	0.71	0.72	0.08	0.94	0.94	0.60 ± 0.12
2451–2650	0.65	0.23	0.61	0.96	0.86	0.98	0	0.92	0.89	0.71 ± 0.12
>2650	0.78	0	0.99	0.99	0.80	0.99	0	0.28	0.66	0.61 ± 0.14

Table 7. Mean squares for variation between conservation zones, altitude, district, and strategic sites from analysis of H′ for qualitative characters.

	Between				Within			
Characters	Zones (df = 1)	Altitude (df = 4)	District (df = 3)	Strategic site Strategic site	Altitude (df = 20)	Altitude (df = 17)	District (df = 18)	Strategic site (df = 21)
CT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SS	0.03	0.01	0.04**	0.02	0.01	0.01	0.01	0.01
GAL	0.03	0.02	0.04	0.05	0.05	0.06	0.05	0.06
GH	0.26*	0.01	0.11	0.06	0.03	0.05	0.03	0.03
KC	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
KRN	0.17	0.05	0.07	0.05	0.05	0.06	0.06	0.06
RL	0.02	0.02	0.02	0.04	0.03	0.03	0.03	0.02
SD	0.11	0.05	0.06	0.06	0.04	0.04	0.04	0.04
SA	0.01	0.05	0.02	0.05	0.04	0.03	0.03	0.02

rectly classified as belonging to their actual sites of origin, on the basis of a cross validation classification, using the discriminant function computed from nine quantitative characters of the 22 farmers varieties. The first three canonical functions accounted for 93.4% (55.3%, 21.1% and 16.0% respectively) of the total variability. The percent of misclassified landraces was slightly higher in North Shewa than the Bale *in situ* crop conservation site. Farmers varieties collected from Bale had negative first canonical function, whereas farmers varieties from the North Shewa site appear to be more diverse than those from Bale (Figure 2).

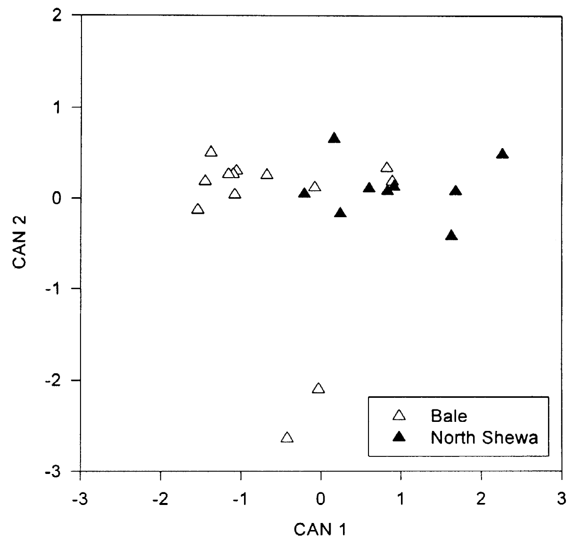

Figure 2. Canonical discriminant analysis of 22 barley farmers' varieties collected from Bale and North Shewa *in situ* crop conservation sites.

Multiple regression analysis

Table 8 summarises the variation observed in the quantitative morpho-agronomic characters, and this variation could be associated with variation in altitude. The magnitudes of these associations varied among characters, the highest being for grain filling period (19%) and the lowest for tiller number (0%). The zonal variation is significantly associated with all the characters, $P < 0.01$, except tiller number, $P < 0.05$, and plant height which showed no significant association respectively.

Correlation coefficient analysis

In order to investigate the similarity in the pattern of geographic variation of characters, correlation coefficient analysis between characters was carried out, and data presented in Table 9. This also indicates common elements of epigenetic control and/or similar response of characters to selection pressure (cf. Bekele (1996)). Pairs of the correlation coefficients of the two sites (zones) do not show consistency. This may be due to natural selection occurring under natural conditions without the intervention of man or artificial selection imposed by farmers. Response to selection, on the other hand, depends on the environmental circumstances in which the individual varieties live, and also the genetic make-up of the individual varieties.

Reliability analysis

Reliability analysis was carried out to quantify the rate of farmers disagreement in naming their landrace varieties. The reliability analysis (Table 10) revealed that there was no significant difference between informants in naming the landraces suggesting remarkable degree of consistency between farmers naming of landrace varieties.

Discussion

A striking preponderance and a more or less similar intermediate frequency of the white phenotypic class over the other variants were reported previously by Demissie and Bjørnstad (1996) and Negassa (1985b) respectively. Moreover, both studies used a third (blue) and forth (purple) as independent categories unlike this study in which only two (white-yellow and purple-black). In this study, high frequency of the

Table 8. Relationship of quantitative morpho-agronomic characters with altitude and conservation zones.

Characters	Altitude r^2	Zones r^2
Awn length	0.01^{ns}	0.03**
Barley neck length	0.02*	0.10**
Days to heading	0.04**	0.04**
Days to maturity	0.12**	0.30**
Grain filling period	0.19**	0.47**
Kernel number	0.01*	0.23**
Spiklets per spike	0.02*	0.16**
Spike length	0.06***	0.03**
Tiller number	0.00^{ns}	0.01*
Plant height	0.04**	0.00^{ns}

* $P < 0.05$, ** $P < 0.01$, ns-non significant.

Table 9. Correlation coefficients of characters in North Shewa and Bale *in situ* crop conservation zones respectively.

Cha.	DTH	DTM	GFP	BNL	AL	KN	SPS	SL	TN	PH
DTH		.70**	−84**	.08^{ns}	.14^{ns}	.28**	.24**	−.44**	−.75**	−.10^{ns}
		.50**	−.65**	.02	−.02^{ns}	.19**	.09^{ns}	−.33**	.21**	.27**
DTM			−.19**	.16*	.02^{ns}	.11^{ns}	.09^{ns}	−.23**	−.55**	−.17**
			.08^{ns}	−.11^{ns}	.06^{ns}	.13*	.20**	−.10^{ns}	.04^{ns}	.19**
GFP				.00^{ns}	−.19*	−.30**	−.26**	.43**	.61**	.01^{ns}
				−.10^{ns}	.10^{ns}	−.07^{ns}	−.03^{ns}	.23**	.06^{ns}	−.53**
BNL					.21**	−.07^{ns}	−.09^{ns}	.00^{ns}	.07^{ns}	−.14^{ns}
					.11^{ns}	−.18**	−.24**	.07^{ns}	−.24**	−.41^{ns}
AL						.01^{ns}	.00^{ns}	−.11^{ns}	−.11^{ns}	−.04^{ns}
						.10^{ns}	.17**	.15**	−.03^{ns}	−.14^{ns}
KN							.92**	.20**	−.03^{ns}	−.18*
							.77**	.35**	.42**	.05^{ns}
SPS								.18**	.01^{ns}	−.16*
								.37**	.27**	.10^{ns}
SL									.34**	−.03^{ns}
									.02^{ns}	n−.03^{ns}
TN										.23**
										.19**

* P < 0.05, ** P < 0.01, ns-nn significant. DTH = Days to heading, DTM = Days to maturity, GFP = Grain filling period. BNL = Barley neck length, AL = Awn length, KN = Kernel number, SPS = Spikelets per spike, SL = Spike length. TN = Tiller number, PH = Plant height.

white-yellow and purple-black seed colour types were found in Bale and North Shewa conservation sites respectively. It was suggested that human selection for barley against the pigmented strains may be one of the factors responsible for the highest frequency of the white kernel types (Demissie and Bjørnstad 1996). However, Bechere et al. (1996) found that the distribution of three seed colours, brown, white, and purple, in wheat across various regions, and thus confirmed Ethiopian wheat farmers have not been selecting against the purple seed colours because of market prices or other reasons. More than half (52%) of the spike collections of wheat from the major tetraploid wheat production zone, the central highlands, were purple-grained (Tesemma et al. 1991). These were perhaps the various seed colour types which are used for different traditional consumption purposes (Asfaw 1989; Belay et al. 1995). Farmers in the study area noted that whitish kernel varieties are preferred for 'injera' (thin spongy bread), porridge, 'atmit', (soup-like), and 'besso' (fine flour moistened with water). These varieties, for example, are 'work-eye', 'aruso-bale', 'kinkicho', 'gedebo' and 'nech-mawge'. It is generally believed that the natural white colour increases the appetite of the consumers. Preferences for the black-grained types are mainly for 'tela' (local bear-undistilled), 'arake' (local spirit-distilled) and medicine (for broken leg/bone and mother who delivers a child). The black-grained varieties used for these purposes in the study area are 'kesele' and 'tikur-mawge'. Gugsa (1975) also reported that white kerneled barleys are used for human consumption, the others for beverage production in Ethiopia.

White-yellow seeded varieties are more frequent in the lower altitude groups examined in this study, and the purple-black seeded barley varieties are more frequent at the highest altitude (≥ 2650 masl). However, Demissie and Bjørnstad (1996) found no clear association of the different seed colours with the altitude groups although Ceccareli et al. (1987) found

Table 10. Results of the reliability analysis of vernacular names given by 31 farmers to 22 farmers varieties of barley.

Source of Variation	DF	SS	MS	F
Between farmers varieties	21	91.39	4.352	53.31***
Between farmers	30	3.282	0.109	1.34^{ns}
Residual	630	51.428	0.082	

* P < 0.05, ** P < 0.001, *** P < 0.001, ns-non significant.

the preponderance of the black seeded in the drier environment for their specific character of adaptation to dry conditions. However, Belay et al. (1995) found a low frequency of purple seeded wheat varieties at lowest altitude, and suggested that it is an indication of poor adaptation, i.e., the purple seeded wheat has earlier maturity and higher tillering capacity than the other two seed colour groups, white and brown, which are better suited to the waterlogged soil conditions of high altitude areas. Such a growing environment is less prevalent in the Bale *in situ* conservation site with altitudinal range of 1800–2500 masl with an eratic and unevenly distributed rainfall pattern where the white-yellow seed examined in this work was predominant.

Kebebew et al. (submitted for publication) discussed grain colour as one of the morphologic characters and/or methods used by farmers in Ethiopia in classifying barley landrace varieties. Among the thirty landrace varieties classified by the local farmers, varieties such as 'nech-gebse', 'mawge', 'demoye', 'feresgama', and 'kesele' were also characterised by their white, ivory white, red, purple and black seed colours respectively.

The overall shape of the spike is determined in part by the spacing of the mature kernels on the rachis, which in turn is greatly influenced by the length of the rachis internode. In another study by Kebebew et al. (submitted for publication), it was reported that farmers distinguish the barley varieties by morphologic characters such as spike length, spike density and spike attitude, among others. Thus, varieties 'bukura', 'sentereji', 'wokye', 'tegadme' and 'demoye' are identified by the farmers as having short spike, very lax spike density, very dense spike, inclined spike attitude and erect type respectively. Likewise, in a study made on durum wheat by Kebebew et al. (submitted for publication), it was found that the landrace variety called 'tikur-sinde' from Bale is characterised by its dense spike. Although the adaptive significance of spike density is not known, it is one of the traits used by farmers to identify their varieties. Also from Asfaw (1989) findings, spike density showed both monogenic and complementary gene actions. Under arid Syrian conditions, dense spikes were predominant in wheat (cf. Belay et al. (1993)), as in Ambentu site (Table 2) which is generally considered as moisture deficit site. Farmers in North Shewa use size and shape of spike in classifying their wheat landrace varieties. For example, Barley farmers' varieties differ in the position of the spike at maturity, and they may be erect or nearly so, or they may be bending. Farmers in areas where periodic frost problems encountered as at the North Shewa site, have found frost tolerant varieties having bending spikes.

Although the adaptive importance of rachilla length is not known, it is among the best taxonomic characteristics in barley. Apparently, there is no any selection for this character by farmers or in any barley breeding programmes in the country. The phenotyic trait, short rachilla, is very abundant (67%) in Ethiopian materials (Negassa 1985b). An increasing trend of the short rachilla is observed with increasing altitude (Table 3), and similar other results were reported by Asfaw (1989), and (Demissie and Bjørnstad 1996).

The two rowed and irregular forms are the dominant types in the Bale *in situ* crop conservation site. However, the highest frequency of six row types was found in Arsi-Bale highlands (Negassa 1985b). This may be due to the distinctiveness of the sites sampled and the small sample size used in the present study, while the six rowed and irregular ones were treated under a single class by Negassa (1985a). Demissie and Bjørnstad (1996) indicated the contribution of high amount of precipitation and low temperature for the occurrence of high frequency of the six rowed types in central and south-eastern part of the country. Such an environment is prevalent in the North Shewa *in situ* crop conservation site where the six row types are more frequent (Table 2), and it has been suggested that the high concentration of the six row types in these higher altitude site is due to their genetically based frost resistance (Negassa 1985b).

Barley glumes may be covered with hairs or be without hairs. Teshome et al. (1997) found that farmers in North Shewa and South Welo of Ethiopia use glume hairiness, among another 8 characters, to distinguish sorghum (*Sorghum bicolor* [L.] Moench) landrace varieties. Glume hairiness is a heritable genetically controlled character, and sometimes associated with other traits, e.g. the association of this trait with resistance to kernel bunt (Warham 1988), and powdery mildew (Negassa 1985a) have been reported. In Bale zone, farmers identify and characterise a wheat landrace variety called 'Arendeto' by its distinctive glume hairiness. In the present study, percentage of phenotypic frequencies for glume hairiness across *in situ* conservation sites (Table 2) showed the prevalence of this trait in all the sites. However, although the extent of application of this trait by farmers in North Shewa and Bale requires further investigation, it undoubtedly has some value in identifying and classifying landrace barley varieties.

The restricted occurrence of the naked types in this study is consistent with several other studies (Negassa 1985b; Engels 1991; Demissie and Bjørnstad 1996). For example, no naked forms were found below 3000 masl by Asfaw (1989). Two forms of the naked types, which have black and white kernels, were found at both zones. Low yield, small grain size, lower hardyness and higher selectiveness in growth requirements are characteristics of naked barleys and this appears to explain why they have been grown unsuccessfully up to now in Ethiopia (Asfaw 1989; Negassa 1985a).

Estimates of diversity of the Ethiopian barley have been presented by several authors such as Negassa (1985b), Engels (1991) and Demissie and Bjørnstad (1996) and showed discrepancies in the overall mean diversity with each other. This may be due to inadequate sampling and/or dissimilar and insufficient numbers of characters (Demissie and Bjørnstad 1996). Because of the small sample sizes and areas sampled and dissimilar traits included in this study, comparing the overall mean diversity estimates may not be appropriate. Nonetheless, the overall mean diversity estimates for both the *in situ* crop conservation sites at Bale and North Shewa, districts and strategic sites are high.

With respect to diversity of individual traits (H′), glume hairiness has shown significant differences both between zonal and district groups, whereas spike shape showed a significant difference between district group only (Table 7). Over the long geographical distance, more than 500 km between the two *in situ* crop conservation sites (with minimum seed diffusion) there is distinct agro-ecological conditions, and hence differences in natural and artificial selection pressure operating at both sites may have resulted in this variation. However, the altitudinal classification and the classification based on the strategic sites, did not seem to distinguish any clear-cut pattern. Nonetheless, maximum morphological diversity was found at altitude range of up to 2650 masl, as was reported similarly by Engels (1991) and Demissie and Bjørnstad (1996). The reduction of diversity at altitude beyond 2650 masl may be due to natural selection, such as frost, and the impact of many generations of growing by farmers, i.e. artificial selections.

The barley landraces collected from Bale and North Shewa *in situ* crop conservation sites had distinct agronomic and morphological traites, although they overlapped to some degree (see Figure 2). In an area with environment with more favourable climatic conditions Pecetti and Damania (1996) found less misclassified durum wheat landraces than reported in this paper in material found in the North Shewa *in situ* conservation site which has more favorable climatic conditions than Bale. A similar situation was also found by Jaradat et al. (1991) in wheat from driest districts of Jordan, in which he had less misclassified durum wheat landrace genotypes collections.

The association indicated by the multiple regression analysis, altitude, and collection sites with morphology could be the result of selective accumulation of certain genes at high or low elevations and in varied agroecological conditions. The concentration of some morphological groups at high or low elevations, and different sites as well, could result from farmer selection of morphotypes based on their selection criteria to the prevailing climatic and edaphic conditions. The selection criteria considered by farmers include morphological, agronomic, and gastronomic qualities. The morphological criterion includes field performance of crop stands considering plant height, tillering potential, colour of grain, grain yield and fodder yield. The agronomic criterion consists of length of maturity period, soil requirement, ability to compete with weeds, resistance to stresses such as diseases, pests, drought, frost, water logging and birds attack. The gastronomic aspect includes factors such as taste, colour of resultant food product, cooking time and quality, suitability for use in multiple food products and/or drinks, shelf-life of cooked product, ease of processing (shelling, milling, etc.) and storability. Such selections are common practices in Ethiopia because farmers have rich experience enabling them to tell apart morphotypes that are suited to the different traditional agroclimatic zones, which are based on altitudinal variation, or even to a given soil type as classified by themselves (Asfaw 1989).

The correlation analysis of characters on the two *in situ* crop conservation sites showed inconsistency for most of the traits. This is probably due to significant differences in natural and artificial selection pressures operating at each site. However, some characters (Table 9) showed consistent correlations. This could also be due to what Falconer (1989) suggested, i.e. natural selection between individuals within a population may change the genetic constitution of the population, but the mean fitness will not change if the population is already at the limit of carrying capacity of its environment.

The vernacular names of the barley varieties in the area are mostly associated with their exhibited characters such as hull character, awn length, seed and glume colour, specific uses, and the name of the places where the varieties come from, and some of them are also named without known meanings related to them. For example, the vernacular name 'cheneka' or 'senef gebse' (lazy barley) refers to the easily dehulling as a result of being partially naked and can be consumed in the form of 'kolo' (roasted grain); 'feresgama' (mane of horse) refers to its long awnd and spike; 'kesele' (blakish) refers to its black coloured seed and glume, and highly specilialzed for making local bear and spirit, it also has medicinal value; 'aruso-bale' refers to the place Arsi-Bale highlands where the variety come from.

The great majority of the barley farmers varieties from Bale were perfectly identified and named by the farmers (informants) while the varieties were in plots at the experiment site in Bale zone. Thus, for the most part, informants had no problem of identifying and providing names for the varieties collected from Bale. However, there were a number of varieties collected from North Shewa *in situ* crop conservation site where the informants were unable to identify and name them, because they were distinctively different from the ones in Bale. The variation between these two sites might have resulted from a number of factors, largely the geographical distance between the sites which could curtail seed exchange, the different climatic selection factors experienced by the landraces including edaphic, rainfall, and altitude, and the purpose for which the barley varieties are grown including preference by the inhabitants. Very often farmers tend to stick to their own seed stock unless external conditions (e.g. drought) force them to change (Asfaw 1989).

The evidences from the results of the analysis of both qualitative and quantitative characters suggest that there is significant morphological diversity between the barley varieties found in North Shewa and Bale *in situ* conservation sites. Distinctive differences were also observed between barley varieties in North Shewa and Bale. This is because farmers' selections for desirable agronomic traits are major forces in shaping the dynamic of the crop plant population on farmland. The farmers in Bale were consistent in naming their varieties. This shows that farmers know best their landrace varieties and what genetic traits they posses. Since farmers are in constant interaction with the environment, the conservation and selection of genetic resources is in a dynamic process. Their keen observation and selection activities generate and provide genetic traits valuable to their needs and beyond to the world.

Annex

Annex 1 List of farmers' varieties, zone, district and strategic sites (localities).

No	Farmers' varieties	Zone	District	Strategic sites	Altitude
1	Aruso-bale1	+	Goro	Deyu Abergeda	2450
2	Aruso-bale2	+	Goo	Waltaye Gobu	1850
3	Aruso-bale3	+	Agarfa	Ambentu	2350
4	Aruso-bale4	+	Agarfa	Galama Hunsho	2490
5	Aruso-bale5	+	Agarfa	Asano Genet	2490
6	Kinkicho1	+	Goro	Deyu Abergda	2450
7	Kinkicho2	+	Agarfa	Ambentu	2350
8	Gebebo1	+	Goro	Chaffa Mana	2130
9	Cheneka1	+	Goro	Waltaye Gobu	1900
10	Gedebo2	+	Goro	Chaffa Mana	2110
11	Cheneka2	+	Agarfa	Galama Hunsho	2500
12	Baher-seded	+	Goro	Chaffa Mana	2130
13	Feresgama1	+	Agarfa	Galama Hunsho	2500
14	Feresgama2	+ +	Ankober	Lay Gorebella	2650
15	Nech-Feresgama	+ +	Ankober	Lay Gorebella	2650
16	Tikur-mawge	+ +	Ankober	Lay Gorebella	2900
17	Nech-mawge	+ +	Ankober	Lay Gorebella	2900
18	Mawge	+ +	Ensarona-wayu	Abaya	2650
19	Workeye	+ +	Ankober	Teter Amba	1900
20	Demoye	+ +	Ankober	Teter Amba	1900
21	Lige-alkiso	+ +	Ankober	Teter Amba	1900
22	Kesele	+ +	Ensarona-wayu	Abaya	2650

+ Bale Zone, + + North Shewa zone.

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