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Assessment of on-farm diversity of wheat varieties and landraces: Evidence from farmer's fields in Ethiopia

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Analysis of spatial diversity, temporal diversity and coefficient of parentage (COP) were carried out along with measurements of agronomic and morphological traits to explain on-farm diversity of modern varieties or landraces of wheat (*Triticum aestivum* L. and *Triticum durum* L.) grown by farmers in Ethiopia. Farm level surveys showed low spatial diversity of wheat where only a few dominant varieties appeared to occupy a large proportion of wheat area. The five top wheat varieties were grown by 56% of the sample farmers and these varieties were planted on 80% of the total wheat area. The weighted average age of wheat varieties was high with an average of 13.8 years for bread wheat showing low temporal diversity or varietal replacement by farmers. The COP analysis showed that average and weighted diversity of bread wheat was 0.76 and 0.66, respectively variance component analysis showed significant variations for agronomic characters such as plant height, grain yield, and yield components (kernels spike^{-1}, thousand seed weight) among modern varieties and/or landraces. The principal component analysis explained better the variation among varieties and landraces. Cluster analysis based on agro-morphological traits grouped modern varieties and landraces into separate clusters. The present study describes the diversity of wheat crop available on the farm using different indicators. The variation among modern varieties and landraces offered opportunities for using genotypes with desired agronomic characters in plant breeding to develop varieties suitable for different agro-ecological zones in the country.

Key words: Ethiopia, wheat, genetic diversity, spatial diversity, temporal diversity, coefficient of parentage, landraces.

INTRODUCTION

Crop genetic diversity refers to variation within a plant, within a crop, between crops of the same species and between different crop species (Almekinders et al., 1995). It is argued, however, that the definition of diversity across disciplines could be problematic because the criteria and scales for measurements and their relationships are weak (Smale et al., 1996). Smale et al. (1996) noted that biological scientists measure diversity using genealogical

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analysis or indicators (coefficient of parentage), analysis of agronomic or morphological characters using G×E interactions, and indices of gene frequencies using biochemical or molecular tools; whereas social scientists use the number of varieties within a given crop species (numerical), proportion of area planted to cultivars (spatial) and the rate of variety replacement over time by farmers (temporal) using both farm level surveys and/or secondary data.

Spatial diversity indicates the number of varieties grown or the proportion of area occupied by each variety per unit farm, area, community or region. Temporal diversity indicates changes in crop varieties (or sequential varietal releases by plant breeders) assessing changes taking place over time through introduction or withdrawal of varieties by individual farmers or farming communities. At present a combination of different approaches and tools are used to analyze the genetic diversity of crops (Duvick, 1984; Brennan and Byerlee, 1991; Smale et al., 1996). According to Duvick (1984) there are at least three kinds of diversity: diversity in space, diversity in time and diversity in reserve (genotypes in breeding pools, breeding materials exchanged, etc.). Moreover, genetic diversity of crops can be measured through examining cultivar morphology (Souza and Sorrells, 1991), molecular markers (Cox et al., 1985) or origin or parentage analysis (Martin et al., 1991) or a combination of these tools (van Beuningen and Busch, 1997a,b; Almanza-Pinzón et al., 2003). The coefficient of parentage (COP) was used to measure genetic diversity in wheat (Souza et al., 1994) and rice in Nepal and India (Witcombe et al., 2001). The weighted average age (WA) of varieties is also a very useful tool for measuring the temporal diversity of the crop (Brennan and Byerlee, 1991; Smale et al., 1996).

Ethiopian highlands are considered the ‘center of diversity’ for wheat (Demissie and Habtemariam, 1991; Tesemma and Belay, 1991). Tesemma et al. (1991) reported the morphological diversity of durum wheat landraces from the central highlands of Ethiopia. Since the establishment of the National Agricultural Research System (NARS) in the mid-1960s (ICARDA et al., 1999), several modern varieties including selections from landraces were released for commercial production in Ethiopia (Geberemaraim, 1991b; Tesemma and Belay, 1991). The extent of adoption and diffusion of modern varieties for wheat has been described in Ethiopia (Bishaw, 2004). To date, there is great concern over the loss of genetic diversity, particularly with the substitution of a diverse set of genetically variable crop landraces with few genetically uniform modern varieties particularly in centers of genetic diversity such as Ethiopia. Although the loss of biodiversity is largely due to replacement of landraces by ‘modern’ varieties, population pressure, urbanization and environmental degradation such as recurrent droughts, overgrazing and desertification are also contributing to the decrease in natural genetic diversity.

Abundant information is available on classical diversity studies for crop genetic resources/core collections (Demissie and Habtemariam, 1991) or for quantifying variation within and between geographic regions and populations (Kebebew et al., 2001a) or for specific agronomic (Belay et al., 1993) or morphological (Tesemma et al., 1991) traits. However, information on the status of varietal diversity at the farm level is rather limited (Witcombe et al., 2001; Souza et al., 1994). Some diversity studies were reported particularly on Ethiopian wheat (Kebebew et al., 2001a) but information is rather limited on on-farm diversity. Benin et al. (2003) reported that using named varieties and ecological indices of spatial diversity (richness, evenness, and inverse dominance), they found that a combination of factors related to agro-ecology of a community, its access to markets, and the characteristics of its households and farms significantly affect both the inter- and infra-specific diversity of cereal crops. The present study, however, aimed at assessing the on-farm wheat diversity using different approaches and tools. Therefore, the main objectives of this study were to: (i) Investigate the spatial and temporal diversity of wheat varieties planted by farmers, and (ii) Investigate the agronomic and morphological traits diversity of wheat varieties used by farmers in Ethiopia using different approaches.

MATERIALS AND METHODS

Field surveys

A total of 304 wheat farmers were interviewed in major wheat growing regions as part of a wheat seed system study (Figure 1). A stratified sampling procedure based on the proportion of wheat area in each region, was followed by random sampling of farmers, as described by Bishaw (2004). Four regions were included covering 81 villages in nine districts in south eastern, central and north western parts of the country. Farmers were asked about wheat varieties or landraces they grew and their perception and source of the varieties and area under each variety. After the interview, a seed sample of about 1 kg was collected from each farmer from the seed lot planted or intended for planting for field experiments.

Field experiments

From 304 wheat seed samples collected from farmers, 50 samples representing 13 bread wheat (7 modern, 6 obsolete or landraces) and 12 durum wheat (1 modern, 11 landraces) were selected and planted for two seasons during the 1998/1999 and 1999/2000 cropping seasons to assess the wheat genetic diversity using agronomic and morphological traits. The study was conducted in a randomized complete block design (RCBD) with three replications. The bread wheat included recommended varieties (Dashen, ET13, HAR1685, HAR1709, HAR710, K6295, Pavon76), obsolete varieties (Batu, Israel, Kenya) and landraces (Goli, Menze, Rash, Zombolel). All durum wheat, except Boohai were landraces (Baghede, Baherseded, Enat sende, Gojam gura, Gotoro, Key sende, Legedadi, Nech shemet, Shemet).

Bread and durum wheat varieties were planted separately to study the genetic diversity among modern varieties and landraces using agro-morphological characteristics. The experiment was planted at an altitude of 2250 masl at the Gonde seed farm (8.0°N and 39.1°E) in southeastern Ethiopia. The soils in Gonde are termed as ignimbrite (consolidated lava flows), volcanic ash and pumice. The soil texture is light clay with clay (44 to 47%), silt (28 to 32%) and sand (23 to 27%)

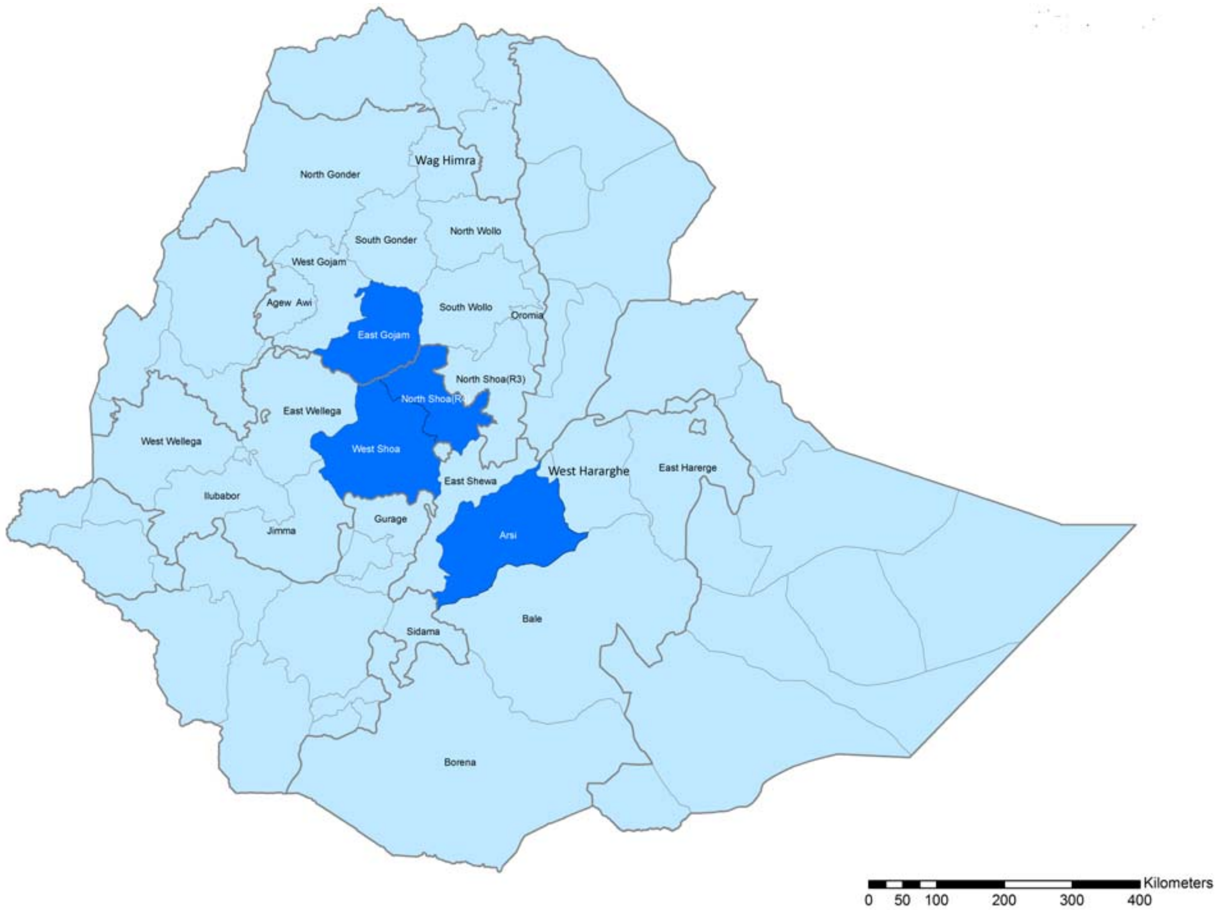

Figure 1. Wheat seed system study areas (shaded) in Ethiopia

(Bishaw, 2004). The agro-morphological characteristics were recorded on a plot basis in the field and after harvest. Agronomic characters measured included days to flowering, days to heading, days to maturity, grain yield, biomass yield, plant height, spike length, number of spikelets spike^{-1}, number of kernels spike^{-1} and thousand seed weight. Morphological characters were measured visually on a plot basis or on a group of plants as described by UPOV (1981 and 1988) defining the methods, scales and crop growth stages for scoring. The following agronomic and morphological characters were recorded during the field experiments:

(i) Agronomic characters (on a plot basis or on 10 randomly selected plants)
Days to heading (days): Number of days (counted from first effective date of rainfall to) when 75% of the plants were heading in the plot;
Days to flowering (days): Number of days (counted from first effective date of rainfall to) when up to 50% of the plants flowering in the plot;
Days to maturity (days): Number of days (counted from first effective date of rainfall to) when 90% of plants reaching physiological maturity in the plot;
Grain filling period (days): Number of days to maturity minus number of days to heading;
Plant height (cm): Length of randomly selected plants measured from the ground (excluding the awns) at maturity;
Number of tillers plant^{-1}: Number of tillers of randomly selected plants counted at maturity;
Grain yield (g): Grain weight of four middle rows harvested at maturity and measured after threshing and cleaning;
Biomass yield (g): Biomass (straw and grain) weight of 4 middle rows harvested and weighed at maturity;
Spike length (cm): Length measured from base of spike to top excluding the awns at maturity;
Number of spikelets spike^{-1}: Number of spikelets on randomly selected plants counted at maturity;
Number of kernels spike^{-1}: Number of kernels counted on randomly selected plants per spike at maturity;
Thousand seed weight (g): Weight of 1000 seeds calculated at 12% moisture content.
(ii) Morphological characters (observed on plot basis or 10 randomly selected plants)
Growth habit: Scored as prostrate, semi-prostrate, intermediate, semi-erect, erect;
Plant characters: Hairiness of uppermost node (HUN), glaucocity of ear neck (GN), zigzagness of neck (ZICN);
Leaf characters: Auricle coloration, glaucocity of leaf sheath and lower leaf blade;
Glume characters: Glume color (GC), beak length (BL), shoulder shape (SHSH), shoulder width (SHW);
Ear characteristics: Ear shape (ES), ear color (EC), awn condition (presence or absence), awn color (AC);
Grain characters: Grain color (GC), grain shape (GS), brush hair (BRH).

Some of the morphological qualitative characters were measured on a scale of 1 to 9. For example, for growth habit the score was erect (1), semi-erect (3), intermediate (5), semi-prostrate (7) and prostrate (9). The qualitative characters were measured on a discontinuous basis such as absent (1) or present (2). For ear shape, it could be scored as tapering (1), parallel (2), semi-clavate (3), clavate (4) or fusiform (5).

Data analysis

Survey data

Farm surveys were conducted as part of a seed system earlier (Bishaw, 2004) in Ethiopia. Farmers were asked about wheat varieties they grew and their perceptions, source of the varieties, area under each variety. The number of varieties grown by each farmer and the proportion of area under each variety was used to measure the spatial diversity on the farm. The weighted average age of varieties was calculated to estimate the temporal diversity of the varieties (Brennan and Byerlee, 1991) grown by sample farmers. Moreover, measuring the varietal diversity also requires information on the genetic relatedness between varieties. The matrix of coefficients of parentage (COP) among released wheat varieties was generated using the International Wheat Information System version 4 computer program (Payne et al., 2002). The COP measures the theoretical genetic relationship between two varieties based on the analysis of their pedigrees. St. Martin (1982) defined the algorithm for calculating COP: (i) the COP of each unique wheat variety with itself is one, and two varieties without common parentage is zero; (ii) each parent contributes equally to the progeny, and any unrelated parents has a relationship of 0.5 with the progeny; and (iii) each variety without a known pedigree is unrelated (COP=0). The average diversity is the average value of the COP among all cultivars (including the COP of a cultivar with itself) grown within each year and region subtracted from 1 (Souza et al., 1994). The weighted diversity is determined from a matrix of the COPs where each cell in the matrix is weighted by the proportion of the area grown to each variety and the weighted mean COP is subtracted from 1 (Witcombe et al., 2001).

Experimental data

The data from field experiments was statistically analyzed using the residual maximum likelihood estimation (REML Genstat 6.1) to test the significance of variation among the genotypes and to estimate variance components. Moreover, the data was pre-standardized to overcome differences in measurement units used for recording data before carrying out the multivariate analysis. Principal component analysis was performed using the correlation matrix to define the patterns of variation among the varieties or landraces or the collection sites based on the mean of agronomic and phenotypic traits measured during the study using the SPSS 11.1 statistical software and the graph plotted with NTSYS pc 2.1 software. Clustering was made using the hierarchical cluster analysis. Euclidean distance was used as cluster distance measure and the clustering method was unweighted pair group using arithmetic average using NTSYS pc 2.1. The actual data matrix was compared with a calculated cophenetic value matrix to evaluate the degree of fitness between the two matrices (r) performing Mantel test (Mantel, 1967).

RESULTS AND DISCUSSION

The average rainfall for 1998/1999 and 1999/2000 were 794 and 682 mm, respectively, showing some variation in the amount and distribution at the experimental site between the two seasons (Table 1). In both years, exceptionally high and extended rainfall during crop maturity and at harvesting period resulted in lodging and loss of grain yield of modern wheat varieties and landraces. In the 1999/2000 crop season, high incidence of yellow rust was observed particularly on landraces leading to substantial yield loss.

Spatial diversity of wheat varieties

Farmers grow different crops and varieties from agro-ecological, agronomic, economic, and socio-cultural context to maximize on-farm productivity and ensure household food security. It was reported that relatively higher speciesdiversity on the farm where most farmers grew a wide range of cereal, legume and oilseed crops in Ethiopia (Bishaw, 2004). Wheat farmers either grew bread wheat (83.2%), durum wheat (7.9%) or a combination of both wheat types (8.9%). Table 2 shows the number of bread and durum wheat varieties grown per farm. The number of wheat varieties grown by an individual farmer was low showing low levels of varietal diversity. If both bread and durum wheat varieties are considered together 72, 24 or 4% of farmers grew one, two or three varieties per farm, respectively. In case the two wheat species considered separately, the number of farmers growing one variety will be 70% for bread wheat (n=280) and 82% for durum wheat (n=51). Similarly, farmers growing two varieties dropped from one-third to one quarter for bread wheat and to 16% for durum wheat.

In Arsi, relatively more farmers had better choice and access to newly released varieties due to proximity to agricultural research stations and seed suppliers and as a result grew more than two varieties. In other regions more farmers grew modern bread wheat varieties as they were newly introduced to the regions along with durum wheat landraces. Lack of availability of varieties with different agronomic characteristics would be one possible cause of growing less number of varieties by farmers. Similar results were also reported where 73% of farmers grew one wheat variety in southeastern Ethiopia (Ferede et al., 2000). However, this is contrary to Negatu et al. (1992) where over 50% of farmers grew more than one variety in the central highlands of Ethiopia (although no distinction between bread and durum wheat) and Stanelle et al. (1984) who found that 32% of farmers planted two varieties and 27% planted three or more wheat varieties in the USA. The latter could be attributed to the availability of many wheat varieties with diverse morphological characteristics to reduce the risk of wheat production. The general assumption that small-scale farmers are growing diverse crop varieties fitting to different niches is not clearly evident both for wheat or other crops grown by farmers. However, at the community level farmers were growing relatively more varieties as in 62 out of 81 villages where sample farmers were growing from 2 to 4 different wheat varieties or landraces. Given the fact that farmers are planting even one variety on different plots in the village one could possibly find a mosaic of fields with different varieties/landraces at a time showing some degree of spatial diversity on the farm. About 40 modern varieties and landraces of bread and durum wheat were grown in the

Table 1. Average monthly minimum and maximum temperature and rainfall in 19998/89 and 1999/00 crop seasons at Gonde basic seed farm, Ethiopia.

Months	1998/1999				1999/2000			
	Rainfall mm	Max ºC	Min ºC	Average ºC	Rainfall mm	Max ºC	Min ºC	Average ºC
January	82	22.18	9.55	15.9	3.5	22.31	7.38	14.8
February	80.4	23.75	11.18	17.5	4.5	25.47	8.65	17.1
March	28.8	25.13	11.4	18.3	27	24.36	10.73	17.5
April	45.8	26.73	12.45	19.6	26.7	26.36	11.31	18.8
May	78.5	25.7	12.4	19.1	60	25.43	11.38	18.4
June	66.2	24.58	11.76	18.2	98.3	24.08	11.18	17.6
July	96.1	20.2	11.3	15.8	96.1	22	12.03	17.0
August	67.8	20	10.9	15.5	148.6	21	11.7	16.4
September	164.5	21.3	11.1	16.2	112.7	na	na	na
October	81.2	21.5	10.7	16.1	104.4	na	na	na
November	2.6	21.88	9.8	15.8	0	na	na	na
December	0	21.71	na	15.6	0	na	na	na
Total/mean	793.9	22.9	11.1	15.6	681.8			

Note: na= data not available because of malfunctioning of the equipment.

Table 2. Number of bread and durum wheat varieties grown by sampled farmers (n=331) in Ethiopia.

Number of varieties	Arsi		West Shoa		North Shoa		East Gojam		Total	
	Farmers	%	Farmers	%	Farmers	%	Farmers	%	Farmers	%
All wheat										
1	75	53	55	77	56	93	53	90	239	72.2
2	55	39	14	20	4	7	6	10	79	23.9
3	11	8	2	3	-	-	-	-	13	3.9
Total	141	100	71	100	60	100	59	100	331	100
Bread wheat										
1	75	53	44	81	30	97	48	89	197	70.4
2	55	39	9	17	1	3	6	11	71	25.4
3	11	8	1	2	-	-	-	-	12	4.3
Total	141	100	54	100	31	100	54	100	280	100
Durum wheat										
1	-	-	11	65	26	90	5	100	42	82.4
2	-	-	5	29	3	10	-	-	8	15.7
3	-	-	1	6	-	-	-	-	1	2.0
Total	-	-	17	100	29	100	5	100	51	100

Note: - = no farmers growing.

survey areas in south eastern, central and northwestern regions of the country (Figure 1) by sampled farmers from 1994/1995 to 1997/1998 crop season. The total number of wheat varieties grown slightly decreased because some landraces were dropped as farmers were adopting new bread wheat varieties instead. The total number of wheat varieties grown by sampled farmers dropped from 40 in 1994 to 31 in 1997 and these included durum landraces such as Atekere, Agere, Bire, Boydo and Wasma. Figure 2 shows the pattern of the top ten wheat varieties grown by farmers over a four-year period from 1994/1995 to 1997/1998 crop season. During the four year period, the five major bread varieties were grown by 44.9% (lowest in 1996) to 66% (the highest in 1997) of wheat farmers. In 1994, the bread wheat varieties Pavon, Enkoy, Dashen, Batu and Israel were planted by 62.1% of farmers. In 1997,

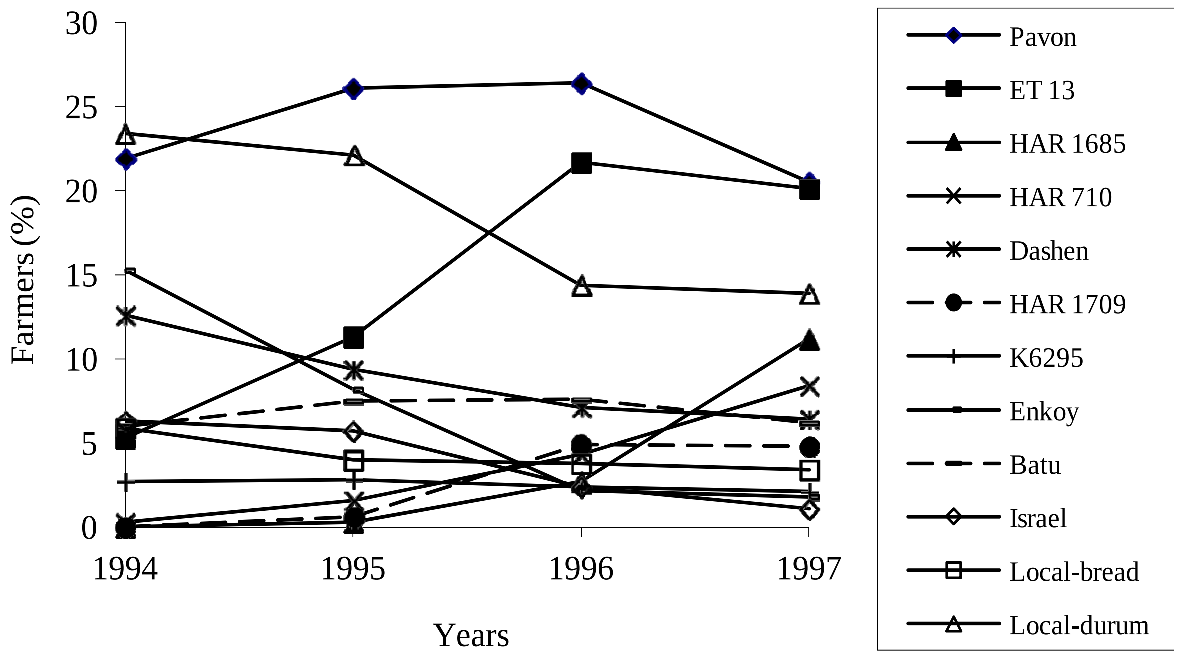

Figure 2. Patterns of bread and durum wheat varieties grown by sample farmers in Ethiopia.

the top five varieties altogether were planted by 66.2% of farmers, among which Pavon and ET13 were grown by 40.6% of the farmers, followed by HAR1685 (11.2%), HAR710 (8.4%) and Batu (6.2%). The average over four year period was 56%. In 1997, about 86% of sampled farmers grew bread wheat varieties whereas the remaining 14% planted durum wheat varieties. The proportion of farmers growing Dashen and Enkoy dropped from nearly one third in 1994 to less than 10% in 1997. On the other hand, the percentage of farmers' growing Pavon and ET13 showed an upward trend increasing from 27.2 to 40.6%, in the same period as the two older varieties Dashen and Enkoy become susceptible to rust and less popular with farmers. Throughout the period Pavon appeared to be a single dominant variety planted by over 20 to 25% of the farmers. Batu also remained among the top five bread wheat grown by sample farmers.

The percentage area of top ten wheat varieties grown by farmers over a four-year period is shown in Figure 3. There was a steady increase of area allocated for wheat production by sampled farmers over the years (almost by 50%). This happened due changes in adoption rates as most of the farmers were introduced to modern varieties and at the same time growing their landraces in decreasing proportion. The five top wheat varieties on average occupied 80% of the wheat area planted during the four year period. In 1994, *Pavon, Enkoy, Dashen, Batu* and *Israel* in decreasing order accounted for nearly 80% of the wheat area planted by farmers. In 1997, *Pavon* and *Batu* still remained at the top whereas the older varieties or landraces such as Dashen, Enkoy and Israel were replaced by the new varieties. The newer 'HAR' varieties accounted for over one fifth of wheat area. Pavon remained dominant occupying 40 to 50% of the wheat area grown by sampled farmers over the four year period. Negatu (1999) also reported that in central Ethiopia three modern wheat varieties were grown on 53% of the wheat area and the most widely grown variety ET13 was planted by 74% of sample farmers on 51% of the wheat area. In another survey it was reported that six dominant varieties covered 92.5% of the total wheat area grown by sample farmers in Arsi region (Ferede et al., 2000). Much higher level cultivar concentration was reported from South Asia where a single wheat variety occupied up to 70% in Pakistan and 75% in Bangladesh (CIMMYT, 2001). The area allocated to bread and durum landraces declined over the years from 18.3 and 14.4%, respectively in 1994 to 12.6 and 7.6% in 1997 in the same order. Kotu et al. (2000) found that wheat farmers in southeastern Ethiopia are decreasing the area of landraces compared to modern varieties.

The important features observed from the survey were: (a) decline in the proportion of bread and durum landraces; (b) decrease in previously most popular varieties such as *Dashen* and *Enkoy* as they became susceptible to diseases; (c) increase in the proportion of previously less popular varieties such as *Pavon* and *ET13*; and (d) a continuous increase of newly released '*HAR*' varieties which was not evident in previous surveys. Negatu et al. (1992) also found that 94% of sampled farmers in predominantly durum wheat production zones in the central highlands grew only few modern bread and durum wheat varieties. About 63% of these farmers were formerly used

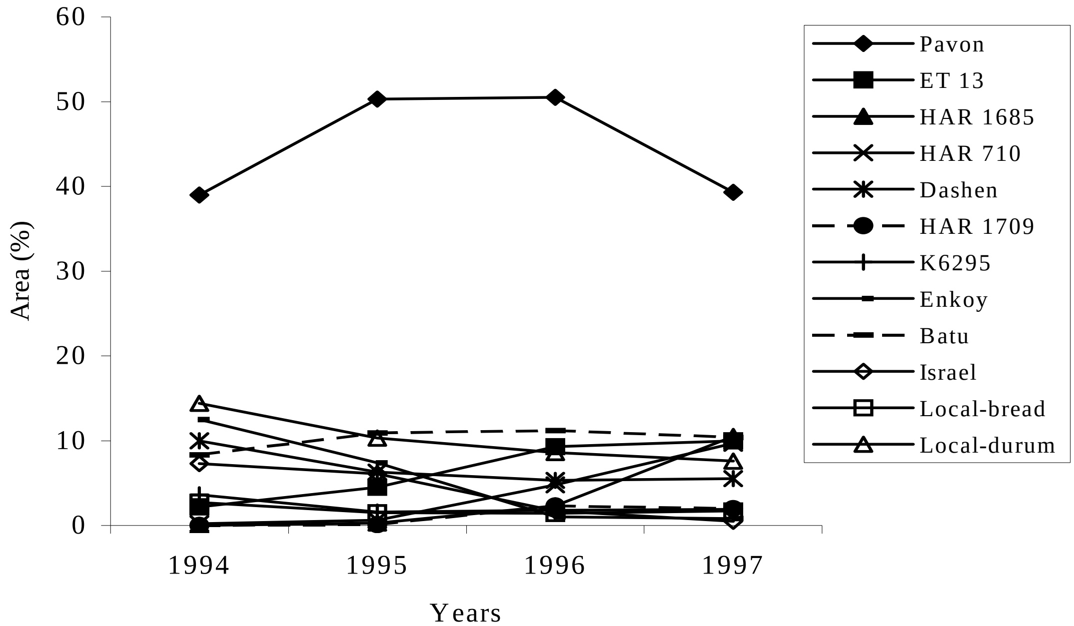

Figure 3. Patterns of area allocation for bread and durum wheat varieties by sample farmers in Ethiopia.

to grow as many as 27 durum landraces, but abandoned them primarily due to lack of seed availability and their susceptibility to plant diseases and insect pests. Hailye et al*.* (1998) also found that farmers in northwestern Ethiopia had formerly reported mostly growing 13 durum landraces, which were abandoned because of their susceptibility to rusts, moisture stress and low soil fertility.

It should be noted that the number of varieties grown by individual farmers was rather low given the number of released wheat varieties and landraces cultivated in Ethiopia. Moreover, a small number of varieties occupied the highest proportion of area allocated to wheat and they were also grown by a large number of farmers. Varietal concentration indicates the percentage distribution of crop area by cultivar (spatial diversity) and measured by the area planted to a dominant cultivar and the area planted to the top five cultivars. Accordingly, these results indicate high varietal concentration reflecting low on-farm diversity of bread wheat in Ethiopia. On the other hand, there was not a single landrace which substantially dominated the area of wheat production. Different durum landraces were grown quite evenly across the districts.

Temporal diversity of wheat varieties

During the last five decades, several modern bread (49) and durum (16) wheat varieties were recommended or released (Gebremariam, 1991; Tesemma and Belay, 1991; NSIA, 2000) with an average of 13 varieties per decade for the highly diverse agro-ecological regions of Ethiopia (Figure 4). Among these, eleven bread and three durum varieties were released during the survey year. The average wheat varietal release was 1.3 modern varieties per year from 1950 to 2000. There is substantial difference in the average release per year between durum (0.3) and bread wheat (1.0) varieties, indicating more choices for bread varieties. During the wheat seed survey sample farmers grew nine bread wheat varieties on the recommended list compared to one durum variety. Souza et al*.* (1994) reported an average release of 1.5 varieties per year in the Yaqui valley of Mexico. The performance of the Ethiopian Wheat Research programme appeared satisfactory given the average annual total wheat releases of 80 varieties per year by NARS of developing countries between 1986 and 1990 (Evenson and Gollin, 2003).

The availability of recommended varieties alone would not imply varietal diversity, if they were not available at the farm level and grown by farmers. The weighted average age (WA) of varieties is used to estimate the rate of varietal replacement, based on the average age of varieties grown by farmers in a given year since release, weighted by the area planted to each variety in that year (Brennan and Byerlee, 1991). In 1997, the WA calculated for modern bread wheat showed a low level of varietal turnover of 13.4 years (Table 3) similar to WA of 13 and 11 years reported for bread wheat varieties, respectively in central (Beyene et al*.,* 1998) and northwestern Ethiopia (Hailye et al., 1998). These figures indicate that although Ethiopian farmers are growing modern varieties of bread wheat, they are slow in changing to new varieties released in recent years or having difficulty to get quick access to improved seeds. The present WA was closer to 13 years (Smale et al., 1996), but lower in contrast to 16 years of varietal

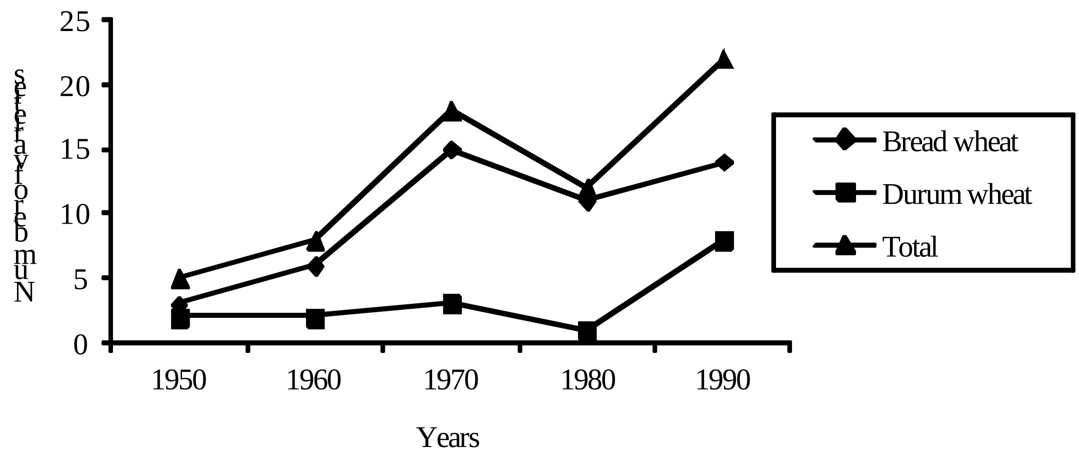

Figure 4. Modern bread and durum wheat varieties released from 1950 to 2000 in Ethiopia.

Table 3. Weighted average age (WA) of bread wheat varieties grown by farmers in Ethiopia.

Variety	Year variety released	Years since release	Mean area (ha) in 1997	WA
Dashen	1984	13	0.80	1.09
Enkoy	1974	23	0.39	0.94
ET13	1981	16	0.46	0.77
HAR 1685	1995	2	0.87	0.18
HAR 1709	1994	3	0.38	0.12
HAR 710	1995	2	1.06	0.22
K6295	1980	17	0.86	1.53
Pavon	1982	15	1.78	2.80
Batu	1984	13	1.57	2.14
HAR 416	1987	10	0.75	0.79
Kenya	1954	43	0.61	2.75
Total				13.35

replacement reported by Moya and Byerlee (1993). Ethiopian farmers had long seed retention period (Bishaw, 2004) which had a negative impact on adoption of new varieties (Gamba et al., 1999) thus increasing the WA of varieties on the farm. The slightly lower WA could be attributed to the release of new varieties and farmers willingness to adopt them replacing most popular 'old' generation wheat varieties such as *Dashen* and *Enkoy* which become susceptible to yellow rust and stem rust, respectively. *Enkoy* variety remains dominant in terms of area coverage for over two decades in major wheat production regions of the country. The breakdown of resistance induced farmers to promoting varietal replacement and increasing the temporal diversity at the farm level similar to what was reported elsewhere (Souza et al., 1994; van Beuningen and Busch, 1997a; Hailye et al., 1998). In general high WA is a combination of many factors reflecting slow rate of variety development by the agricultural research, ineffective variety release and registration system, poor promotion or popularization of new varieties or unavailability or lack of access to seed of new varieties (Bishaw, 2004; Hailye et al., 1998).

Although several modern durum wheat varieties were released by the national agricultural research system none of them were encountered in Arsi region where bread wheat is most popular among farmers because of its high yield potential. Moreover, only a single improved variety was found in traditionally durum wheat growing areas of the country in central and northwestern regions reflecting lower adoption of modern varieties on the farm. This indicates the underlying failure of the crop improvement program in developing modern varieties that meet farmers' adoption criteria or the weakness of national seed system in providing seed of these varieties to farmers. On the other hand, sample farmers were growing a wide range of durum wheat as many as 15 landraces across the regions. It is estimated that over 80% of durum wheat area in Ethiopia is covered by landraces consisting of mixtures

Table 4. Coefficient of parentage matrix of modern bread wheat varieties in Ethiopia.

Variety	Batu	Dashen	Enkoy	ET 13	HAR 416	HAR 710	HAR 1685	HAR 1709	K6295	Pavon 76
W[1]	0.115	0.061	0.009	0.111	0.002	0.107	0.116	0.022	0.021	0.436
Batu	1	0.184	0.007	0	0.147	0.071	0.144	0.073	0	0.152
Dashen		1	0.008	0	0.231	0.096	0.383	0.116	0	0.297
Enkoy			1	0.5	0.009	0.005	0.008	0.005	0	0.01
ET 13				1	0	0	0	0	0	0
HAR 416					1	0.091	0.197	0.281	0	0.274
HAR 710						1	0.083	0.045	0	0.122
HAR 1685							1	0.098	0	0.274
HAR 1709								1	0.5	0.137
K6295									1	0
Pavon										1

Note: W[1] = proportion of area occupied by each variety used for calculating the weighted diversity; COP values for ET 13 and K6295 are assumptions.

that exhibit genetic variation for quantitative and qualitative traits (Tesemma and Bechere, 1998). It is believed that such landrace mixtures constitute the major on-farm diversity of durum wheat in Ethiopia (Belay et al., 1993; Kebebew et al., 2001a) where 20 or more morphotypes (agrotypes) still exist all in one field (Tesemma and Bechere, 1998).

At present a significant proportion of the total wheat area in developing countries is planted to modern varieties, including early generation tall improved varieties and/or second-generation short stature modern varieties (Pingali, 1999). However, the rate of varietal replacement of the old generation improved varieties is slow where farmers could not benefit from investment made in developing new varieties with superior yield potential owing to time lag between the release of the variety and its adoption by farmers. A rapid rate of varietal replacement in farmers' fields not only leads to higher returns to plant breeding research programme by increasing adoption but also increase genetic diversity if varieties are from diverse parentage (Brennan and Byerlee, 1991).

Coefficient of parentage of wheat varieties

During the field survey it was found that the majority of the sampled farmers extensively grew modern bread wheat varieties compared to the landraces. Most of these varieties, however, were introductions from CIMMYT, Kenya or selections from Ethiopian landraces with some common parents or ancestors. Table 4 presents the COP which measures the degree of relatedness among varieties (Payene et al., 2002). The COP values vary from as low as 0.071 (between Batu and Enkoy) to 0.383 (between Dashen and HAR 1685) excluding the non-related varieties (COP values = 0). Most of the recently released wheat varieties not only related to each other, but also to the recommended or 'obsolete' varieties still grown by farmers. Pavon, the most widely grown variety has high COP values of 0.274 each with HAR 416 and HAR 1685 and Dashen (0.297). HAR 1709 has high COP value with HAR 416 (0.281). Dashen also had the highest COP values with HAR 1685 followed by Pavon and HAR 416. The COP data and the proportion of area occupied by each variety were used to measure the average diversity and the weighted diversity of bread wheat varieties deployed in farmers' fields (Souza et al., 1994; Witcombe et al., 2001).

First, the COP data was used to measure the average diversity of bread wheat varieties in farmers' fields. Here bread wheat varieties with unknown association with current varieties (e.g. Kenya) or those considered landraces or the origin could not be traced (e.g. Israel) were excluded, although some of them occupied more than 0.1% of the total wheat area in the 1997/1998 crop season. The most popular bread wheat variety ET13 has Enkoy as one parent and therefore a maximum COP value of 0.5 was assigned between the two varieties assuming they are from unrelated parents. Likewise, K6295 also has Romany Back Cross as one parent similar to HAR1709 and therefore a COP value of 0.5 was assumed between the two varieties. However, these figures appeared high and it is unlikely that the parents of these varieties came from unrelated ancestors. The average wheat diversity among cultivars grown in an area is measured by subtracting the mean coefficient of parentage from 1 (Souza et al., 1994; Witcombe et al., 2001) and higher values indicate higher diversity. Accordingly, the average diversity of wheat varieties of known parentage calculated from the COP matrix would be 0.76, if ET 13 and K6295 were excluded from the matrix. If ET 13 and K6295 are, however, kept in the matrix with COP values of 0.5 with Enkoy and HAR 1709, respectively and unrelated to all other varieties the average diversity of wheat varieties grown by farmers would be 0.81 showing slight increase (6%) in diversity. These results are comparable to similar diversity studies for crops such as barley (Martin et al., 1991).

Table 5. Mean, minimum, maximum and standard error of mean for nine agronomic traits of bread and durum wheat varieties.

Agronomic characters	Bread wheat			Durum wheat		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Number of tillers plant^{-1}	2	10	4.2 ± 0.2	2	10	4.3 ± 0.1
Days to heading (d)	49	97	67 ± 1.0	51	78	67 ± 0.4
Days to maturity (d)	114	147	131 ± 1.1	114	147	132 ± 0.8
Grain filling period (d)	21	82	64 ± 1.4	47	84	66 ± 0.8
Plant height (cm)	72	128	94.3 ± 1.3	65	115	90.9 ± 0.9
Grain yield (kg ha^{-1})	1050	7590	3702 ± 109	250	5550	2381 ±121
Biomass yield (kg ha^{-1})	3750	10000	7343 ± 123	3000	12500	6425 ± 129
Number of grains spike^{-1}	19	53	36.0 ± 0.8	5	57	30.4 ± 0.9
Thousand seed weight (g)	22.8	45.7	33.5 ± 0.5	8	53.09	27.2 ± 0.8

Second, the COP data and the proportion of area occupied by each variety were used to measure the weighted diversity of bread wheat varieties. The weighted diversity measures not only the relatedness but also the area occupied by the varieties; and therefore robust criteria to measure the diversity at the farm level. The bread wheat varieties with known COP values and with the proportion of area of more than 0.1% were included for calculating the weighted diversity. The varieties Batu, Dashen, Enkoy, ET 13, K6295 and the 'HAR' series, altogether accounts for nearly 90% of the total wheat producing area during the 1997/1998 crop season. We calculated the weighted diversity by the formula (d= 1-WRW´) where the COP (R) value in each cell in the matrix is weighted by the proportion of area occupied by each variety (where W is a vector and W′ a transpose). Accordingly, the weighted diversity of bread wheat varieties was 0.66. The weighted diversity is expected to be lower than the average diversity particularly if higher number of varieties is related (because of high average COP values) as seen from the COP values in Table 4. It should be noted that, however, fewer varieties dominated the wheat production area. Pavon is predominantly grown by nearly 40% of the farmers in 1997/1998 crop season and closely followed by ET 13 which is less related to most of the recommended and newly released varieties. Witcombe et al. (2001) found that both the average and weighted diversity increased following participatory variety selection approaches with farmers where previously a single variety predominates the crop area and thus lower the diversity at the farm levels. They also reported that weighted diversity has increased from 0.26 to 0.61 due to releases and adoption of unrelated and diverse varieties following the participatory variety selection in India.

Agro-morphological traits diversity

Table 5 presents the summary of descriptive statistics including the means, minimum and maximum values, standard error of mean of bread and durum wheat varieties. The number of tillers plant^{-1} ranged from 2 to 10 with an average of 4 for both bread wheat varieties. Tillering is the most important yield component of wheat varieties and most liked by farmers because of the potential it offers for better weed control. Although the average number of days to heading appeared to be similar, the bread wheat varieties had a slightly longer period to heading than durum wheat materials. There was a clear distinction in plant height with local bread wheat varieties such as Menze, Zombolel, Goli and ET 13 (selection from Ethiopian germplasm) having the highest plant height (over 100 cm) and modern varieties such as Batu, Dashen, Pavon, Enkoy and 'HAR' showing shorter plant height (< 100 cm). The average grain filling period between bread and durum wheat appears to be similar, but bread wheat varieties had wider range than durum landraces with short gain filling period similar to that reported by Belay et al. (1993). Tarekegne et al. (1996) also found that in bread wheat varieties plant height was reduced significantly, while days to anthesis was significantly increased over the period of varietal releases since 1949.

Among the bread wheat varieties Pavon gave the highest grain yield followed by varieties K6295 and Enkoy whereas Boohai (the modern variety) was the highest yielder among durum wheat close to the expectations farmers gave during field survey (data not shown). The yield at experimental stations ranged from 5 to 7 tonnes ha^{-1} were reported earlier for modern wheat varieties (Tarekegne, 1996). The number of kernels spike^{-1} and the thousand seed weight among bread and durum wheat appeared to be also different. Almost all bread wheat varieties had higher number of kernels spike^{-1} and highest thousand seed weight than durum wheat varieties and therefore widely accepted by farmers because of high yield potential. Alemayehu et al. (1999) reported substantially higher number of grains per spike but similar results with this study for thousand seed weight for recently released bread wheat varieties. In general durum wheat landraces have low thousand seed weight compared to modern varieties (Belay

Table 6. Simple Pearson correlation coefficient of agronomic traits for bread wheat (matrix above diagonal) and durum wheat (matrix below diagonal).

Variables	TIL	DTH	DTM	GFP	PH	GYD	BYD	NKS	TSW
Tillers plant^{-1} (TIL)	1.00	-0.26	0.03	0.26	-0.18	0.03	0.13	-0.23	0.40
Days to heading (DTH)	0.10	1.00	0.12	-0.99**	0.26	-0.03	-0.03	0.09	-0.63*
Days to maturity (DTM)	0.40	0.28	1.00	0.44	0.24	0.11	0.28	0.03	-0.01
Grain filling period (GFP)	0.09	-0.90**	0.17	1.00	-0.21	0.16	0.08	-0.09	0.64**
Plant height (PH)	-0.16	-0.53	0.07	0.57	1.00	0.23	0.56*	-0.66**	-0.03
Grain yield (GYD)	0.28	-0.86**	0.07	0.91**	0.57	1.00	0.51	-0.11	0.16
Biomass yield (BYD)	0.48	-0.13	0.51	0.37	0.09	0.46	1.00	-0.51	0.37
Number of kernels spike^{-1} (NKS)	0.12	-0.77**	0.21	0.88**	0.70*	0.89**	0.48	1.00	-0.45
Thousand seed weight (TSW)	0.28	-0.77**	0.25	0.90**	0.50	0.94**	0.51	0.91*	1.00

Note: * and ** are significant at P ≤ 0.05 level and P ≤ 0.01, respectively.

et al., 1993).

A wide range in the extreme values of each of the traits studied particularly among the modern varieties will provide farmers an opportunity to make a choice of genotypes that will fit best to their niche environmental conditions. Moreover, the variation that exists among the landraces offers broad opportunities for using the genotypes with desired agronomic characters in the plant breeding program to develop new varieties suitable for different agroecological zones of the country.

Correlation coefficient analysis

The correlation coefficients between agronomic traits are presented in Table 6. In bread wheat correlation among the traits was not only weak but also insignificant with few exceptions. The correlation between days to heading and thousand seed weight was highly significant and negatively correlated (P ≤ 0.01). The longer the days to heading, the lower the thousand seed weight probably due to shorter grain filling period. Grain filling period had a highly significantly negatively correlated with days to heading and a highly significantly positively correlated with thousand seed weight. Similarly, plant height was significantly negatively correlated with number of kernels per spike (P ≤ 0.01) and a significantly positively correlation with biomass yield (P ≤ 0.05). The negative association between plant height and number of kernels was due to the modern bread wheat varieties with short plant height had long spikes and thus more grains as compared to tall landraces with short spike length associated with a low number of kernels spike^{-1}. A positive association is expected between plant height and biomass yield because the taller the plants the more is the biomass yield. Moreover, some of the modern bread wheat varieties had high tillering capacity and therefore produced more biomass yield comparable to the landraces.

In durum wheat, days to heading were significantly negatively correlated with grain yield and yield components such as the number of kernels spike^{-1} and thousand seed weight. Grain filling period had highly significantly positively correlated with grain yield, number of kernels plant^{-1} and thousand seed weight, but highly significantly negatively correlated with days to maturity. However, grain yield was significantly (P ≤ 0.01) correlated with the number of kernels per spike and thousand seed weight. Moreover, the number of kernels spike^{-1} was positively and significantly correlated with thousand seed weight. The findings are similar to what Belay et al. (1993) reported in that days to heading had significantly negatively correlated with grain yield, number of kernels and thousand seed weight; and the grain yield had significant positive correlation with number of kernels and thousand seed weight in durum wheat landraces from central Ethiopia. They also found a highly significant negative association between grain filling period and days to maturity, but a positive association with thousand seed weight which is similar to present findings. The kernel weight was reported as an important yield component in durum wheat landraces (Belay et al., 1993).

Variance component analysis

Variance component analysis revealed little significant differences among the bread and durum wheat varieties for agronomic characteristics except for days to heading for bread wheat and thousand seed weight for durum wheat and qualitative characteristics such as growth habit, grain color and grain shape for both wheat types (data not shown). The estimates of variance components showed the contribution of collection sites towards the patterns of variation that existed among the genotypes which is more pronounced for durum landraces compared to modern bread varieties. This is well understood given the recent introduction of modern varieties to their collection sites and where any variation is expected from the genotypes than the effect of collection sites. Estimates of variance components showed that the patterns of variation among

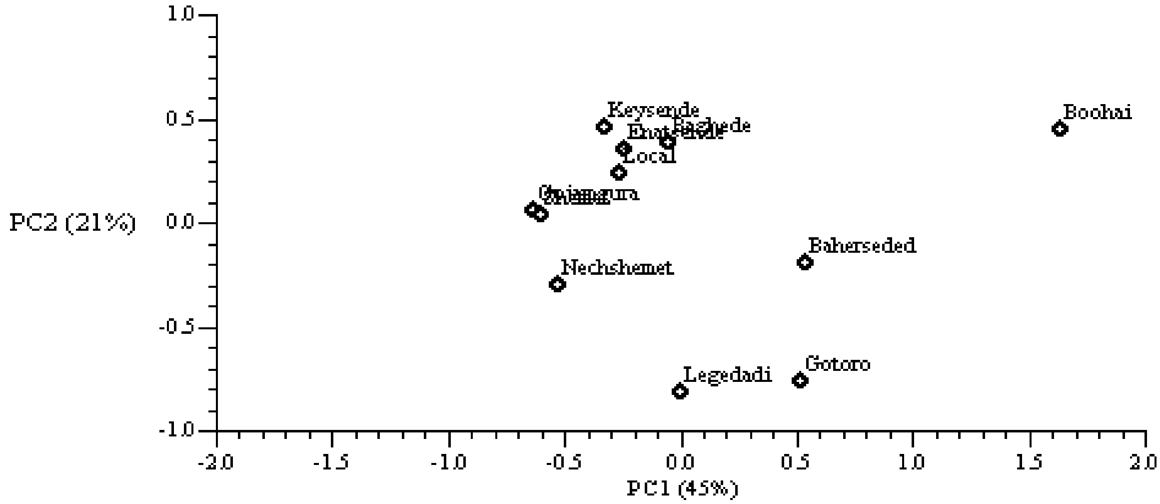

Figure 5. Principal component plot of durum wheat varieties based on 12 agronomic and phenotypic traits.

the genotypes were attributed to the collection sites (provinces and districts) from the lowest of 36% for grain yield to 74% of the variation for plant height among the durum varieties and landraces, although this is not significant in all cases. Tesemma et al. (1991) also found that diversity among durum landraces from central Ethiopia was attributed to their collection sites (districts) than variation within the populations. There was no significant difference among all the estimates of mean diversity for the populations and districts except for glume pubescence.

However, by dropping the collection sites from the model, almost all the agronomic characters measured such as plant height, grain yield, biomass yield, number of kernels spike^{-1} and thousand seed weight showed remarkable significant variation among the genotypes. Therefore, there was a significant difference ($P<0.001$) among bread wheat varieties for tillers plant^{-1}, days to heading, grain yield, number of kernels spike^{-1} and thousand seed weight. Days to maturity and biomass yield were not significant among bread wheat varieties. Likewise, durum wheat varieties showed significant differences ($P \leq 0.001$) for days to heading, grain yield, and thousand seed weight. Number of kernels spike^{-1} was significant at $P \leq 0.01$. The number of tillers plant^{-1}, days to maturity and biomass yield was not significantly different among the durum wheat varieties. On the contrary significant difference on number of tillers plant^{-1} was observed among landraces of wheat collected from central Ethiopia and suggested as useful agronomic trait for crop improvement programs in the country (Belay et al., 1993).

Principal component analysis

The principal component analysis was made to estimate the relative contribution of the different traits studied towards the overall agro - morphological variations among the local durum landraces. The analysis showed that the first three components with eigenvalues more than unity altogether explained 84% of variation among 11 durum wheat landraces for 12 agronomic and phenotypic characteristics studied (data not shown). The first, second and third components each accounted for 45, 21 and 18% of the variation, respectively. Plant height, grain yield, number of kernels spike^{-1} and thousand seed weight were most important agronomic characters contributing to the first principal component. The qualitative morphological characters such as growth habit, ear shape, grain color and grain shape were important for the second component. According to Demisie and Habtemariam (1991) Ethiopian durum wheat landraces exhibited an enormous variation in spike form, spike density, awn size and glume color and glume hairiness. The third component was associated with days to maturity, tillers plant^{-1} and biomass yield. Ayana and Bekele (1999) also found that plant height and days to 50% flowering as important agronomic characters for classifying sorghum germplasm in Ethiopia.

The distribution of durum wheat landraces along the first two axes of the principal components is presented in Figure 5. The first principal component is more important in separating the durum wheat landraces as compared to the second component. The extreme right of the first component was occupied by Boohai, a modern variety developed from germplasm materials introduced from CIMMYT compared to other landraces which are known to be of Ethiopian origin. The first principal component differentiated the low yielding landraces from high yielding modern variety based on grain yield and yield components such as number of kernels spike^{-1} and thousand seed weight. Belay et al. (1993) reported that landraces were late in days to heading and maturity and had lower kernel

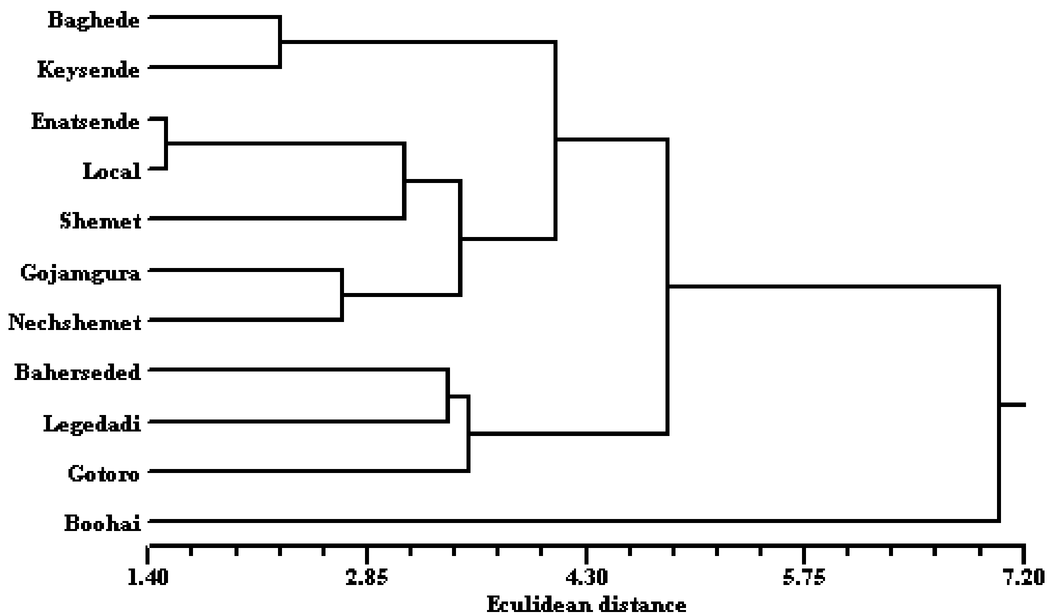

Figure 6. Dendrogram showing clustering of durum wheat landraces collected from farmers in Ethiopia.

weight compared to Boohai, a modern variety. The second component was able to separate early maturing landraces from late maturing genotypes. Gotoro and Legedadi occupied the extreme negative values of the second component and appeared to head earlier compared to other genotypes. Baherseded, Shemet and Nech shemet heads slightly later than other genotypes. Landraces such as Baghede, Enat sende, Gojam gura and Key sende ('red' grain) as the name suggests could be separated from others on the basis of seed color. Belay et al. (1995) reported that local landraces exhibited a wide range of colors from white, red/brown to purple colored grains; and the purple-grain landraces have useful agronomic traits such as early maturity, shorter height, higher fertility, tillering capacity and harvest index. However, most of the modern wheat varieties had amber color (Alemayehu et al., 1999) with few exceptions such as Enkoy and K6295 with red kernels.

Cluster analysis

Clustering based on agro – morphological traits revealed three clusters separating the recently introduced modern variety (Boohai) and long established landraces (Figure 6). The correlation between the cophenetic value matrix and actual matrix data was very high (0.91) indicating a very good fit of the cluster analysis performed. The durum wheat landraces were not all clustered along their region of geographic origin based on the morphological traits. Baherseded, Gotoro and Legedai were collected from West Shoa and were clustered together but differently from Bagehede and Key sende which were collected from the same region. Enate sende, Gojam gura and Shemet all from North Shoa were within the same sub-cluster with another unidentified local landrace from the same region. However, Nech shemet was clustered with Gojam gura instead of Shemet. The durum wheat landraces from North Shoa were heading late, had low grain filling period and low grain yield. Kebebew et al. (2001a) also reported that durum landraces collected from central and southeastern Ethiopia were not clustered along their collection sites or geographic origin. Instead, durum landraces with similar vernacular names collected from different sites or geographic regions were clustered together than those landraces from the same collection sites or geographic regions. Ethiopian durum wheat landraces exhibited tremendous diversity for some phenotypic characteristics such as grain color ranging from white to purple. Landraces such as Baghede, Enat sende, Gojam gura and Key sende ('red' seeded wheat as the name suggests) were grouped together within the same sub-cluster because of their patterns of grain color mixtures. Tesemma et al. (1991) reported that a high proportion of landraces had purple seed color across different districts. Some landraces such as Tikur sende are used for specific purposes such as for brewing local beer or spirits (Kebebew et al., 2001a) while white colored ones are used for social or religious festivities. The prefixes such as *'key'* (red), *nech* (white), *tikur* (black), *sergegna* (white and red mixture) are useful folk taxonomy in classifying landraces based on the proportion of grain color mixtures not only in wheat but also in other crops such as barley (Kebebew et al., 2001b) in Ethiopia. Local names could be used to describe the performance or to indicate the original source of landraces. Moreover, farmers may coin new names for modern varieties and some varieties are better known by their adopted name than their release names. For example a bread wheat variety, HAR 1685 is named popularly by farmers as *Qubsa* because of its high yield.

In case of bread wheat the principal component analysis showed that the first four components with eigenvalues more than unity accounted for 74% (22, 21, 18 and 12%, respectively) of the variation among the varieties (data not shown). The first component was associated with plant height and ear shape whereas the second component was with agronomic characteristics such as days to maturity, grain yield, biological yield and phenotypic characteristics such as ear color and grain color. The third component was associated with agronomic traits such as tiller plant^{-1} and thousand seed weight and the fourth with number of kernels spike^{-1}. Clustering separated the varieties into six clusters (data not shown). Israel, one of the 'oldest' popular bread wheat of unknown origin was placed completely distinct from the rest of the group. The local variety had the highest thousand seed weight and unique phenotypic characteristics in terms of ear shape and awn condition compared to other bread wheat varieties. In Cluster 2 Enkoy and K6295 were grouped together because of their unique red grain color as compared to all bread wheat varieties with white to amber color including local bread wheat varieties (Alemayehu et al., 1999). This is in contrast to durum landraces where variable grain color is most common. ET 13 and Goli had the highest plant height and were therefore grouped together in Cluster 3 while Zombolel, another landrace, stood alone in Cluster 5. However, the clusters did not match the clustering constructed from the COP values.

The Ethiopian farmers are growing durum wheat for millennia and the country was recognized as a center of diversity for tetraploid wheats (Demissie and Habtemariam, 1991) while the bread wheat is comparatively of recent introduction (Gebremariam, 1991). The national bread wheat breeding program has benefited substantially from the introduced germplasm from the International Agricultural Research Centers (IARCs). As a result, plant breeders have made good achievement in developing varieties acceptable to farmers at least in favorable production areas. There is substantial increase in bread wheat area and production in traditionally durum wheat growing regions of central and northwestern Ethiopia. At present, the high adoption and diffusion rate of modern varieties coupled with recurrent drought in traditionally durum wheat growing areas of the country are threatening the existence of landraces and leading to loss of such immense diversity (Bishaw, 2004). Moreover, the predominance of a few bread wheat varieties calls for concern in a country where devastating rust epidemics are common features of crop production. There seems to be an urgent desire for appropriate conservation measures to be undertaken for the durum wheat landraces and at the same time diversify the choice of bread wheat varieties available to farmers.

The diverse agro-ecology and long history of association with the wheat crop and its production under a variety of socio-economic and cultural situations led to the evolution of highly diverse forms of landraces which could be of practical benefit for crop improvement. Several workers reported the diversity of quantitative and qualitative characters of the Ethiopian wheats (Demissie and Habtemariam, 1991; Belay et al., 1993, Tesemma et al., 1991). Durum wheat landraces such as Enat sende and Nech shemet from North Shoa identified by farmers as having frost tolerance (Kebebew et al., 2001a). Moreover, purple seeded wheat matures earlier and has higher tillering capacity than other color types and a good adaptation to water-logged soil conditions in high-altitude areas (Kebebew et al., 2001b). Monomorphism for awn condition (presence or absence) was also reported for landraces which is similar to our findings, a useful trait for tolerance to plant diseases (Tesemma et al., 1991). It was suggested, however, that durum wheat crop improvement would be possible through indirect selection for tiller numbers plant^{-1} and thousand seed weight or direct selection for yield *per se* (Belay et al., 1993). Moreover, alternative breeding strategies led to the development of 'composites' with up to 20 to 25% more yield than local landraces and 10 to 15% more than modern varieties (Tesemma and Bechere, 1998). The study has shown that the few wheat varieties, particularly the durum wheat landraces collected from farmers, were diverse in agronomical and phenotypic characteristics offering greater opportunities for developing germplasm adapted to the varied agroecology and diverse end uses and consumer preferences. This would contribute towards the maintenance of genetic diversity on the farm and counter balance the ensuing genetic erosion.

Conclusion

The Ethiopian highlands are considered the centers of diversity of tetraploid wheats where a considerable wealth of genetic variability and diversity still exists on the farm. The diverse agro-ecology of Ethiopia coupled with a long history of association with the crop under a variety of socio-economic and cultural situations led to the evolution of highly diverse forms of these crops. Until recently this wealth of genetic diversity has been maintained by generation of farmers. However, the introduction of modern agriculture brought a dramatic shift in wheat production practices. There was a remarkable increase in the adoption of modern bread wheat varieties in predominantly durum wheat growing regions of the country as farmers are striving to maximize production and achieve food security from diminishing and meager land resources. The wide spread adoption and diffusion of modern bread wheat varieties could lead to the replacement or displacement of these valuable genetic resources - the loss of durum landraces. The loss of landraces also leads to loss of traditional knowledge in crop improvement and maintenance. It is important to design an innovative and integrated genetic resources conservation, maintenance, enhancement and utilization strategies and approaches that could meet the food security and livelihoods of farmers dependent on these crops. It is desirable that the participation of national governments and all stakeholders in formulating and targeting the interventions required.

The national agricultural research systems made a spectacular progress and achievement in developing modern varieties of bread wheat that meet farmers' preferences. In contrast, there is little headway in crops like durum wheat where landraces still dominate the agricultural landscape. Not only was there a lack of success in developing modern varieties, but farmers also rejected those varieties released by the national programs and the area under improved varieties is negligible. The Ethiopian durum wheat production areas are characterized by highly varied microenvironments such as topography, soil type, soil moisture (water-logging), temperature and frost. In apparent effort to circumvent the failure of conventional crop improvement program alternative breeding strategy is suggested for durum wheat in Ethiopia. Therefore, the national agricultural research systems should introduce and institutionalize participatory approaches as a means of identifying new varieties that farmers prefer and link this with formal plant breeding and seed production activities. Adoption of such varieties by farmers not only enhances productivity, but also maintains and improves on-farm varietal diversity of durum wheat.

The agro - morphological studies revealed a wide range of variation for each of the traits studied particularly among the modern bread wheat varieties that will provide farmers an opportunity to make a choice of genotypes that will fit best to their niche environments. Moreover, the variation that exists among the landraces offers broad opportunities for using the genotypes with desired agronomic characters in the plant breeding program to develop varieties suitable for different agro ecological zones of the country. In Ethiopia, past effort to use exotic germplasm in developing durum wheat varieties with wider adaptation to the local conditions met with little success and the locally adapted germplasm remains under-exploited in the national breeding program. Therefore, the national agricultural research system should incorporate the local landraces into their breeding program and develop location specific varieties that meet farmers' requirements and also increase on-farm diversity.

Spatial diversity, temporal diversity, coefficient of parentage analysis and measurements of agronomic and morphological traits were employed to explain the diversity of wheat varieties or landraces grown by farmers in Ethiopia. While the spatial diversity and temporal diversity indicates the domination of few selected varieties in terms of area coverage, the agronomic and phenotypic measurements showed remarkable variation that existed both among modern varieties and local landraces that would provide broader opportunities for use in crop improvement and production. Since different measurements and scales were used to define diversity it would be difficult to ascertain a set of common indicators and their interrelationships that would satisfy both the biological scientists and social scientists concerned with biodiversity issues. It is imperative that a multidisciplinary approach is undertaken to address the problem and develop a common framework for assessing genetic diversity that would enable policy changes required to enhance the conservation and utilization of these resources to the benefit of farmers and the society at large.

This study was not meant to measure wheat diversity *per se* or intended to investigate the patterns of diversity from the geographic or agroecological context. It was rather an attempt to look into the agronomic and morphological traits diversity of sets of varieties currently used by farmers and any specific traits that are associated with farmers' considerations or preferences for particular group of varieties or landraces.

Conflict of Interest

The authors have not declared any conflict of interest.

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