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Quantitave evaluation of Ethiopian landraces of lentil (*Lens culinaris*)

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Summary

One hundred and fifty-six landrace populations of lentil (*Lens culinaris* Medikus) collected from 10 provinces in Ethiopia were evaluated for a set of six quantitative traits at three sites contrasting in altitude. Consistent regional differences among landraces were found for time to flower and maturity, 100-seed weight, number of seeds/pod and plant height. The regional differences were clarified by a discriminant analysis based on 100-seed weight, time to flower and plant height. The lentil of the West Highlands was early and short, that of the North Highlands was large-seeded, whereas lentils from the Central Highlands were the least distinctive group. Selection for seed size was the result of local human preferences. Humans were probably also responsible for the lack of adaptive value of plant phenology in relation to altitude. Selection for seed yield at the low and middle elevation sites gave a positive response to selection at both sites. However, selection for yield at the highland site did not give a positive response elsewhere, indicating that adaptation to highland conditions differed from that at lower elevations.

Introduction

Lentil (*Lens culinaris* Medikus) is an important highland pulse in Ethiopia (Westphal, 1974). The crop is grown after tef (*Eragrostis tef* (Zucch.) Trotter) or bar- [illegible] sometimes mixed with linseed in highland Ethiopia. In some mountainous parts of Transylvania it was grown mixed with barley (Szabó & Péntek, 1976) and it is often grown in mixed cropping in the Indian sub-continent with barley, mustard, linseed, autumn-planted sugarcane or castor (Saxena, 1981). Barulina (1930) described the lentil of Ethiopia and Yemen as grex *aethiopicae*, an endemic group of short, early plants with small flowers and seeds, and pods with an elongated apex. Although Ethiopian accessions in the ICARDA lentil germplasm collection have been evaluated in Syria (Erskine & Witcombe, 1984), there has been no systematic evaluation of Ethiopian germplasm in Ethiopia.

Lentil improvement in Ethiopia has exploited exotic germplasm more than local genetic resources (Bejiga, 1984). However, the considerable value of Ethiopian crop diversity both nationally and internationally is well known (Hawkes & Worede, 1991). We plan to exploit local lentil germplasm in future plant improvement.

As part of an evaluation of Ethiopian germplasm, we [illegible] among lentil landraces and evaluated landrace performance at three sites contrasting in altitude, in order to plan an effective selection strategy for lentil improvement in Ethiopia.

Materials and methods

A total of 156 lentil landraces were collected from different regions of Ethiopia by the Plant Genetic Resources Center, Addis Ababa (Table 1). Passport data included village, District and Province for 132 accessions; this information was used to derive approximate latitude, longitude and altitude of collection locations. The 156 landraces were evaluated at three sites, namely Chefe Donsa (CD) (8° 48′ N, 39° 0′ E, 2450 m), Debre Zeit (DZ) (8° 30′ N, 38° 54′ E, 1900 m) and

Table 1. Regions of lentil cultivation in Ethiopia and Eritrea, their provinces and the number of accessions collected in each region

Region	Provinces within regions	No. accessions
Northern	Eritrea, Tigray, Gondar	45
Eastern	Arussi, Bale, Sidamo, Harrar	21
Central	Gojjam, Shoa, Wollo	63
Western	Wollega, Illubabor, Keffa, Gemugofa	3
Unknown		24

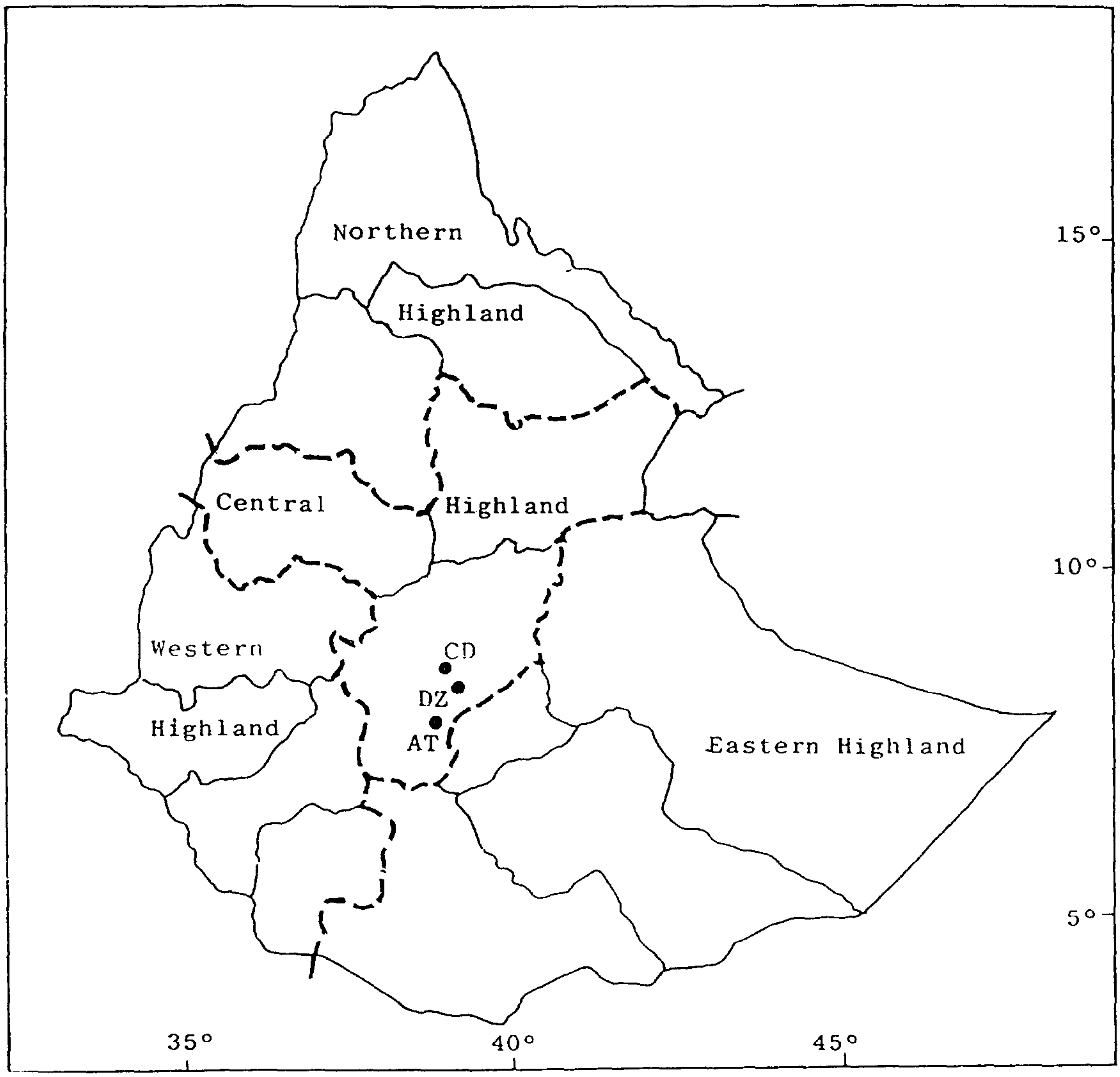

Fig. 1. Map of Ethiopia and Eritrea showing provincial and regional boundaries and the location of the trial sites, Chefe Donsa (CD), Debre Zeit (DZ) and Alem Tena (AT).

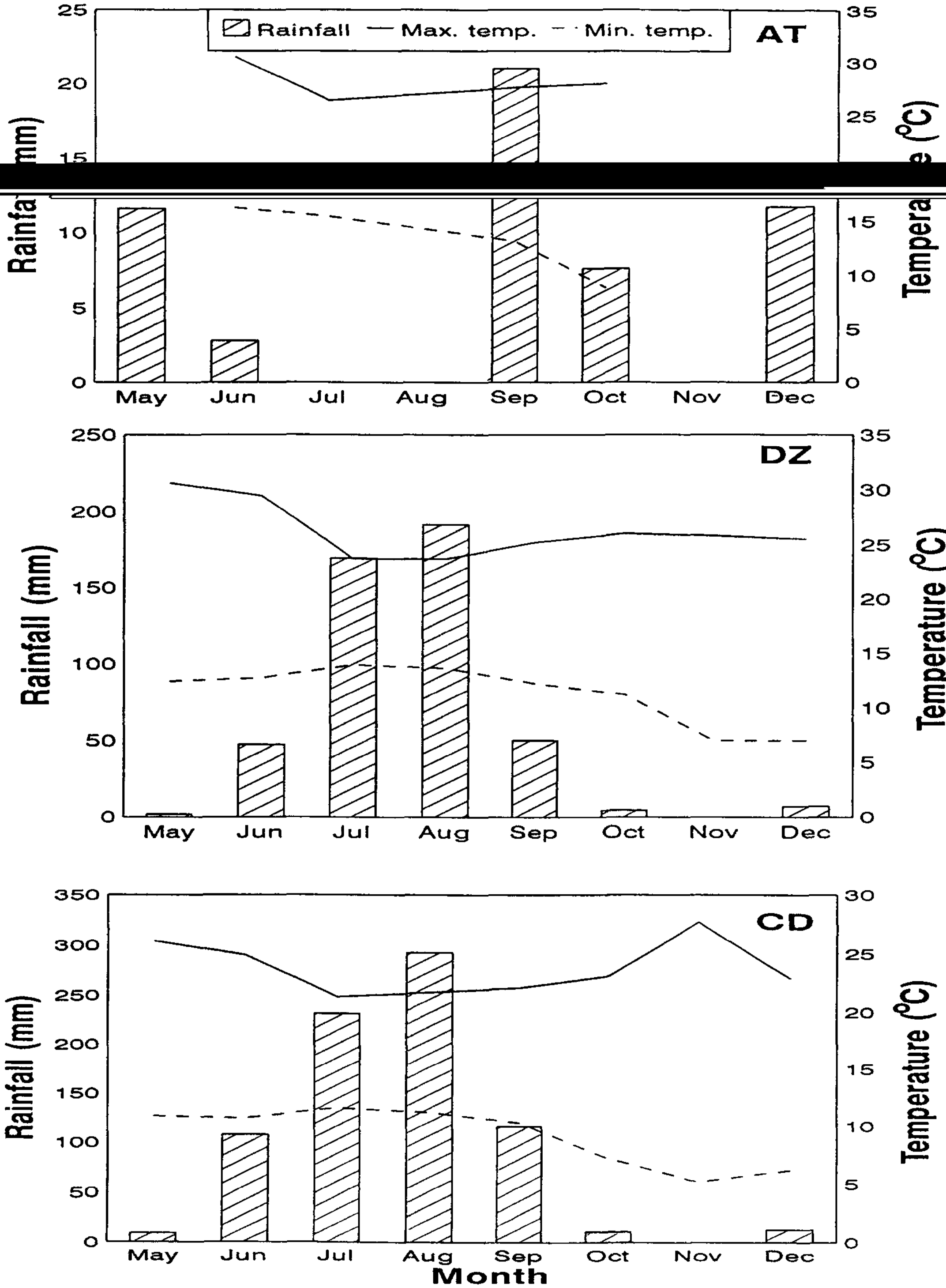

Fig. 2. Seasonal climatic data (monthly rainfall total (mm), mean maximum and mean minimum temperature (°C)) of the trial sites Alem Tena (AT), Debre Zeit (DZ) and Chefe Donsa (CD). At AT some monthly temperatures are missing as is the August rainfall total.

Table 2. Mean (x) and standard errors (SE) of genotypic means overall and by region of origin, together with the F values of analyses of variance by geographic region and correlation coefficients with altitude of the characters: time to flower (d), time to maturity (d), plant height (cm), number of seeds per pod and 100-seed weight (g) of Ethiopian lentil germplasm

Geographic region		Time to flower	Time to maturity	Plant height	Seed no. per pod	100-seed weight
Overall	x	50.8	95.6	32.7	1.60	2.60
	SE	0.18	0.21	0.26	0.02	0.02
	Range	45.3–57.7	85.3–102.0	27.1–49.3	1.23–2.00	2.17–3.17
Northern Highlands	x	50.9	95.8	32.8	1.6	2.7
	SE	0.29	0.34	0.43	0.03	0.02
Eastern Highlands	x	51.5	95.8	32.9	1.5	2.5
	SE	0.45	0.52	0.97	0.04	0.03
Central Highlands	x	50.7	95.6	32.0	1.6	2.6
	SE	0.25	0.28	0.26	0.02	0.02
Western Highlands	x	46.0	91.7	30.2	1.6	2.5
	SE	0.33	3.17	1.89	0.11	0.06
F value B v W*		6.83	3.03	4.05	2.29	13.45
F value B × E v W × E**		4.31	1.01	1.73	<1	<1
Correlation with altitude		0.079	0.009	0.161	0.036	0.323

*degrees of freedom = 3, 128
**degrees of freedom = 6, 256

Alem Tena (AT) (8° 6′ N, 39° 6′ E, 1600 m) which represent highland, medium altitude and lowland sites, respectively, for lentil cultivation (Figure 1). The soils of Chefe Donsa and Debre Zeit are heavy black clays (vertisols), whereas the soil at Alem Tena is sandy loam with poor moisture retention. Seasonal meteorological data for the sites are shown in Figure 2. The trial was hand-sown in 1991 on July 17 at AT, on August 1 at DZ and on August 9 at CD in an augmented randomized complete block design using three checks among every 10 test entries (Federer, 1956). No fertilizer or inoculation was applied but nodulation was good throughout. Plots consisted of 2 rows, 25 cm apart with 2–5 cm between plants in a row, giving a plot size of 2 m^2. Plots were hand-weeded, as necessary.

Observations were recorded on time (d) to 50% flowering and maturity on a whole plot basis. Reproductive duration (time to maturity–time to flower) was calculated. The numbers of seeds per pod and plant height were recorded on five randomly selected plants per plot. Seed yields were determined from a guarded plot size of 1.75 m^2 to avoid border effects.

The unadjusted plot values were used in a combined analysis of variance over sites. The variation among landraces (L) was partitioned into differences between four geographic regions of collection (Table 1 and Figure 1) (B) and differences within regions (W), and the variation of L × Environments (E) was similarly partitioned into B × E and W × E components. To test the hypothesis of regional differences, the mean square for B was tested against that of W, and the mean square of B × E was tested against W × E. Regional differences for those traits showing consistent effects over sites were also examined in a multivariate sense by discriminant analysis (Erskine et al., 1989). Characters for inclusion in the discriminant analysis were selected stepwise to minimize Wilk's lambda between groups. An approximate F-ratio gave a test of significance of the Mahalanobis distance between group centroids. Canonical variate analysis was used to represent the multivariate data on orthogonal axes such that the maximum discrimination was obtained between groups, when tested against variation within groups (Seal, 1964). Cluster analysis of regional group centroids was done using average linkage method.

The effect of altitude of collection was examined in two ways: through the correlations of plant characters with the altitude of collection and through an

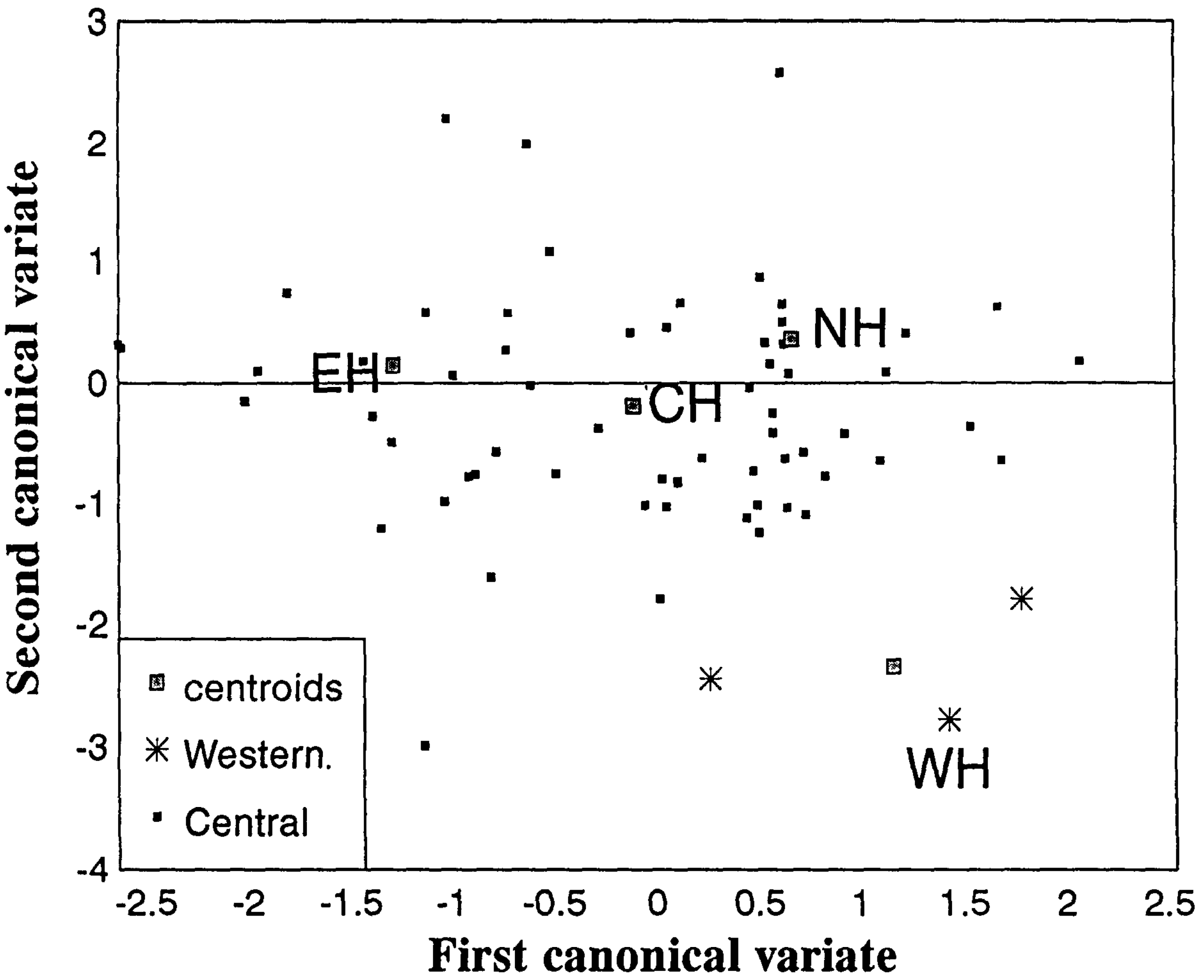

Fig. 3. Scatter diagram of first two canonical variates for the values of the most distinctive (WH) and least distinctive (CH) landrace populations and centroids for the regional groups of Northern Highlands (NH), Eastern Highlands (EH), Western Highlands (WH) and Central Highlands (CH).

analysis of variance on the basis of three altitude groups (1600–2400 m elevation, 2400–3200 m, 3200–4000 m) by replacing the previously-discussed regional groups with those for altitude.

The performance of the top and bottom 10% accessions for grain yield at each site was studied and com-

Results

There were significant differences between geographic regions in time to flower and maturity, reproductive duration, plant height, number of seeds per pod and 100-seed weight in the combined analysis of variance. F-values are given in Table 2. Regional means were consistent over sites for all these characters except time to flower, for which the mean square for B was significantly greater than the mean square for B × E, indicating the greater magnitude of the variance for region differences over the interaction. There were no

the reproductive period and grain yield.

The overall mean for time to flower was 51 days with the earliest landrace flowering in 45 days (Table 2). Early flowering was a feature of germplasm from the Western Highlands. For plant height, the range among landraces was wide from 27–49 cm and the early flowering, Western Highlands group were shorter than the other material, on average. Seed size ranged

Table 3. Wilk's lambda, F-values with degrees of freedom (df) and discriminant functions for the characters used in the discriminant analysis by region

Character	Wilk's lambda	F value	df	Functions 1	Functions 2
100-seed weight (g)	0.760	13.45	3,128	1.073	0.161
Time to flower (d)	0.602	12.25	6,254	−0.755	0.706
Plant height (cm)	0.559	9.20	9,307	−0.014	0.593

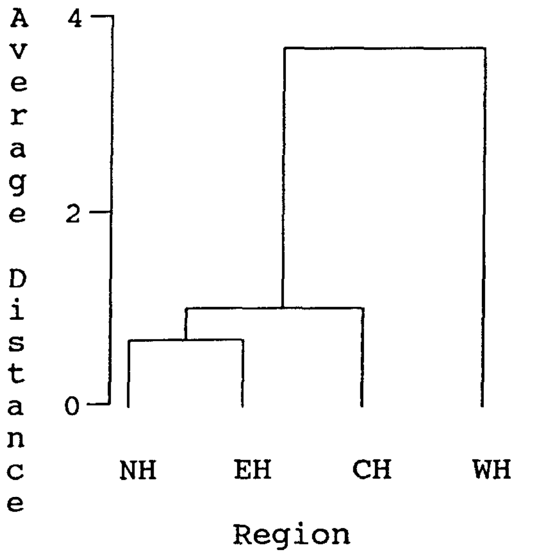

Fig. 4. Dendrogram from cluster analysis of the regional groups of Northern Highlands (NH), Eastern Highlands (EH), Western Highlands (WH) and Central Highlands (CH).

from 2.2–3.2 g/100 seeds over accessions with larger-seeded germplasm originating from the Northern Highlands.

Discriminant analysis revealed large differences between germplasm from different areas. Regional differentiation was based, in descending order of importance, on 100-seed weight, time to flower and plant height (Table 3). Collectively, these characters gave a highly significant F-value from the discriminant analysis of 9.20 with 9 and 307 degrees of freedom.

The canonical variate diagram shows the differentiation between areas (Figure 3). The x-axis (Function 1 in Table 3) represents 100-seed weight, positively, and time to flower, negatively, and the y-axis (Function 2 in Table 3) represents time to flower and plant height. In the canonical diagram the most distinctive group is that of the Western Highlands. This is confirmed by its predicted group membership of 100% in Table 4 and the dendrogram in Figure 4. In contrast, the Central Highlands group, which occupies a central/intermediate position between the other group centroids in the diagram, comprises the least distinct group, as confirmed by its low predicted membership of 36.5% (Table 4). For the accessions of unknown provenance within Ethiopia, the discriminant analysis has given their most probable origins and most of these accessions probably came from the Eastern Highlands (Table 4).

Differences between altitude groups were non-significant as the F values of the tests of mean squares of B v W and B × E v W × E were less than one for all characters. Correlations between the altitude of collection and the various plant traits were non-significant for all characters except 100 seed weight (Table 2).

Positive selection for grain yield at AT, the lowland site, resulted in a correlated response to selection at DZ, the intermediate elevation site, giving a significant mean grain yield advantage of 25.5% over the overall mean, but at CD, the highland site, the same selections from AT did not yield significantly more than the overall mean (Table 5). Positive selection for grain yield at the mid-elevation site (DZ) resulted in a significant correlated response to selection at the lowland site (AT) of 39.3% above the overall mean, but at the highland site (CD) these selections produced the same yield as the overall mean. Selections made at the highland site (CD) yielded poorly at the lower-elevation sites with the negative response to selection for yield reaching the level of significance ($p = 0.05$) only at AT.

Selection for grain yield at the three sites had no effect on phenological characters, 100-seed weight and the number of seeds per pod. However, selection for grain yield at DZ and AT resulted in taller than average plants. The altitude of collection of the landraces had no influence on landrace performance in different sites.

Table 4. Predicted membership of different regions based on discriminant analysis. Figures in parentheses are actual counts

No.	Actual group	No. of cases	Predicted group members (%) 1	2	3	4
1.	Northern Highlands	45	64.4 (29)	6.7 (3)	17.8 (8)	11.1 (5)
2.	Eastern Highlands	21	9.5 (2)	81.0 (17)	4.8 (1)	4.8 (1)
3.	Central Highlands	63	30.2 (19)	28.6 (18)	36.5 (23)	4.8 (3)
4.	Western Highlands	3	0	0	0	100 (3)
5.	Unknown origin	24	20.8 (5)	54.2 (13)	16.7 (4)	8.3 (2)

Table 5. Mean (x) and standard error (SE) of the 156 accessions and 10% top and bottom yields at Chefe Donsa (CD), Debre Zeit (DZ) and Alem Tena (AT), together with the F value from a one-way analysis of variance between groups

Variable		Overall mean	CD Top 10%	CD Bottom 10%	DZ Top 10%	DZ Bottom 10%	AT Top 10%	AT Bottom 10%	F value
Population size		156	16	16	16	16	16	16	
Grain yield at CD	x	3238	4440	1937	3305	3616	3456	3635	19.3
(kg/ha)	SE	59.31	54.87	92.78	180.09	180.01	161.61	160.67	
Grain yield at DZ	x	1894	1696	2035	2484	964	2377	1812	21.0
(kg/ha)	SE	18.70	55.13	51.53	29.42	14.62	63.69	53.81	
Grain yield at AT	x	384	261	336	535	343	737	102	22.6
(kg/ha)	SE	14.43	31.48	31.86	59.98	43.42	31.90	10.54	
Time to flower (d)	x	50.8	49.7	51.5	50.6	50.4	51.1	50.5	1.3
Time to maturity (d)	x	95.6	95.0	92.2	94.5	95.0	94.7	96.5	1.6
Repro. duration (d)	x	44.8	45.3	44.8	43.9	44.7	43.7	46.0	1.9
Plant height (cm)	x	32.7	32.0	32.4	34.1	31.3	34.6	32.7	2.7
Seed no./pod	x	1.6	1.5	1.5	1.6	1.5	1.6	1.5	0.7
100-seed weight (g)	x	2.6	2.6	2.7	2.6	2.6	2.6	2.6	0.8
Latitude of origin (°)	x	11.4	10.6	12.3	10.9	10.8	12.0	10.8	1.2
Longitude of origin (°)	x	38.7	39.0	38.0	39.4	38.4	38.9	39.1	0.9
Altitude of origin (m)	x	2633	2503	2936	2837	2501	2851	2513	1.3

Discussion

This collection of germplasm is valuable because of the genetic erosion occurring in Ethiopia due to drought and also the wide range of sites sampled, spanning ten Provinces and an altitudinal range of 1600 to 4000 m elevation. However, germplasm from the Western region was under-represented and should be collected expeditiously.

On the macro-geographic scale, the germplasm conformed morphologically to the grex *aethiopicae* described by Barulina (1930). This grex is distinguished by a complex of morphological characters common to all the members of the group but not found in other groups. At the same time the group is differentiated geographically. Although we found variation within Ethiopian lentil germplasm, this variation does not represent a centre of diversity of the crop as found, for example, for barley (Negassa, 1985).

Local differentiation was evident within Ethiopian lentil germplasm. The most important character for differentiation was 100-seed weight, a trait affected by human preference and of low adaptive value. In a previous survey of patterns of morphological variation in lentil germplasm from various countries, plant phenology was the key to adaptation on the macro-geographic scale (Erskine et al., 1989). On the micro-geographic level of this study, however, time to flower was only the second most important character in differentiation. Germplasm from the Western Highlands was particularly early to flower and short in stature, whereas material from the Northern Highlands was relatively large-seeded. The Central Highlands occupies the middle position both geographically and morphologically, as its germplasm was intermediate for all plant traits and the least distinctive of the regional groups. This implies greatest diversity within germplasm from the Central Highlands and also gene flow between the Central Highlands and the other regions. In Ethiopian barley landraces, regional differentiation has also been found for some phenotypic traits with a concentration of variation in the Arussi-Bale area (Eastern Highlands) (Negassa, 1985).

The crop growing period was 82 days at the lowland site AT (elevation 1600 m) and a month longer (113 d) at the highland site CD (elevation 2450 m), emphasizing the major influence of environment on maturity. The testing environments at different altitudes contrasted primarily in temperature. The major disparity in the length of the growing period at different elevations suggested that times to flower and maturity might be adaptive characters in relation to altitude. However, selections made for yield made at sites contrasting in altitude did not differ in their mean time to flower and maturity. Furthermore, correlations between the altitude of collection, on the one hand, and both time to flower and reproductive duration, on the other hand, were non-significant. This shows that plant phenology is of no value in adaptation to different altitudes within the Ethiopian production region. In lentil germplasm from Yemen, there was also no relationship between plant morphology and the altitude of collection (Erskine & Choudhary, 1986). The lack of evidence for selection for altitude/temperature adaptation through plant phenology is probably due to human influence. Sowing date at any location varies seasonally according to the timing of the rains, and seed may be moved to different altitudes within a region. Both these effects dilute selection pressure on the length of the growing period.

For the future exploitation of the assembled local variation for grain yield, we made a preliminary study of adaptation. The results for grain yield showed similar adaptation to conditions at AT and DZ indicating that selection may be effectively conducted in either environment with the expectation of a response to selection at the other site. However, selection at AT and DZ was ineffective in the highland site CD, and *vice versa*. Data from a single season show that performance under highland conditions differed from that in both mid-altitude and lowland conditions.

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