ENHANCED WINTER HARDINESS IN COMMON VETCH (VICIA SATIVA L.) FOR AUTUMN-SOWING IN THE CENTRAL HIGHLANDS OF TURKEY

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ABSTRACT

In central Turkey, common vetch is planted in spring, but frequent droughts cause crop failures. Autumn-sown vetch has more yield potential; but then winter killing is a major problem. Therefore, winter hardiness is a central requirement for successful vetch production. This study comprised two phases. First, eighteen lines out of 164 accessions were selected for their superiority, primarily for winter hardiness and earliness in 1999/00. Second, the selected lines along two local checks (var. SarıElçi and cv. KaraElçi) were evaluated for yield performances in multi-year trials established in autumn and spring from 2000 to 2003. Autumn-sown vetch displayed 14.9% greater yield potential than spring vetch. As winter mortality decreased, seed yield increased in two cold environments (r^2=0.41 and r^2=0.54). The two genotypes (L-1430 and L-1548) showed the greatest stability across six environments, while L-581 and L-1544 were the best lines for autumn sowing. In conclusion, the level of variation found in the base populations did clearly show potential for further development, and multi-environment trials singled out the V. sativa genotypes with enhanced winter hardiness.

Key words: Adaptation, Cold tolerance, Drought, Genotype x environment interaction, Seed yield, Yield stability

INTRODUCTION

Increased feed requirements for an expanding Turkish livestock population necessitate the introduction of forage legumes into crop rotations [12]. Common vetch (Vicia sativa ssp. sativa), a major annual forage legume in Turkey, is grown over the largest area, some 320.000 ha [24]. The bulk of the crop is cultivated in Central Highlands of Turkey (CHT), mostly for straw and seed [5, 9], and grain vetch is used as a supplementary concentrate feed when stock are housed indoors in winter [4, 10].

The success or failure of growing annual forage legume species in harsh environments like CHT is largely dependent on the degree of resistance to biotic and abiotic stress [11]. In such arid environments, freezing temperatures in winter, low and inconsistent distribution of annual rainfall, and high temperatures at maturity are all important abiotic stress factors. In CHT, common vetch is traditionally sown in spring, but frequent droughts cause crop failures. Earlier studies showed that autumn-sown vetches had more yield potential than spring vetch [11]. However, winter killing is a major problem [3]; for example, cold tolerance is a central requirement for establishing cool season annual forage legumes in the medium to high elevation areas in West Asia and North Africa [2]. Therefore, successful agricultural production in continental Mediterranean highland environments can only be achieved if the major constraints of low temperatures and seasonal drought can be either overcome or avoided [15].

The importance of the use of genetic resources to enhance genetic potential of the crop and in alleviating biotic and abiotic stress has been well recognized [23]. To improve winter hardiness and adaptation in common vetch, it is imperative to know the magnitude of genotypic variability present, as this will provide the basis for efficient selection. If phenotypic observations are based on adequately large samples and the visible traits measured show significant differences among populations, they can provide a reasonable representation of overall genetic performance [13].

The evidence currently available indicates the autumn-sown common vetch with sufficient winter hardiness would improve adaptation and increase yield potential. Depending on cold intensity and crop susceptibility, the winter effect may range partial forage damage, causing small yield losses, to complete death resulting in total crop failure [20]. Studies of winter hardiness on common vetch in Turkey is very limited, although other legumes have been investigated in more detail. In common vetch, relationships between relative cold tolerance and morphological and physiological traits of seeds or seedling may become pronounced at different growing and harvesting regimes [3]. Cold hardiness was associated with better germination, emergence and smaller seedling and slower growth in field pea (Pisum sativum L.) [22]. In lentil (Lens culinaris Medik.), the inheritance patterns of winter hardiness appeared to be quantitative on the basis of frequency distributions and the lack of discrete segregation classes [14], and an effective field screening method was considered a prerequisite to select for winter hardy material, both in segregating and exotic germplasm [16]. Selecting for yield, however, is complex: weather conditions are unpredictable and drastically varying within and between years. The interactions occur as the result of differential responses by genotypes to different environments [21]. Therefore, analysis of genotype-environment interactions (GxE) is important in determining adaptation and yield stability.

On the basis of available germplasm, it should be possible to develop common vetch cultivars with sufficient winter hardiness. Breeding for such a purpose, therefore, the trials described here were designed to: (1) evaluate and select the superior genotypes for sufficient winter hardiness and seed yield, (2) determine the nature of G x E interaction, and (3) study the nature of adaptation.

MATERIAL AND METHODS

Experimental material and management

The study, comprising two consecutive phases: (1) line selection and (2) adaptation and variety performance tests, was conducted from 1999 to 2004 at the Research Farm of the Central Research Institute for Field Crops (CRIFC), which is located on 44 km south-west of Ankara. For the line selection, experimental plant material was based on accessions from ICARDA (based in Aleppo, Syria) Gen Bank and Feed Legume Breeding Program, and CRIFC's Annual Forage Legume Program. For line selection, 150 seeds of each of the 164 Vicia sativa ssp. accessions were sown in rows (1.5 m long and 0.35 m apart) in the first half of October in the 1999/2000 cropping season. Subsequently, 18 of these lines were selected for their superiority of winter hardiness, early maturity, biomass and large seed size to test further in yield trials. Also included were a line (L-582) selected previously for its cold tolerance and the two local checks (a verity SarıElçi and a cultivar KaraElçi) as the controls. These experiments were established in the first half of October (i.e. autumn-sowing) in 2000/01, 2001/02, 2002/03 and 2003/04, and in early spring (i.e., from mid-March to first week of April) in 2001/02 and 2002/03 cropping seasons. Therefore, the experimental material was subjected to six different environments.

The adaptation and variety performance tests were established in a completely randomized block design with four replicates. For all sowings, the previous crop was a cereal. Plots were 1.5 m wide (consisting of 6 rows, 25 cm apart) by 5 m long, and were sown by hand into drills. Seed rate was calculated as density of 300 seeds per square meter. A dose of 100 kg/ha of composite fertilizer, Di-Ammonium Phosphate (DAP-18 and 43%), was applied into experimental plots during sowing. Weeds were controlled soon after planting by a pre-emergence herbicide (Linurex) and in spring by hoeing.

Soil and climatic conditions

The experimental site has clay-loam soil with high lime content, low organic matter, is slightly alkaline and is poor in phosphorous and nitrogen but it has adequate potassium.

Monthly average, minimum and maximum temperatures and monthly total rainfall for each year, obtained from the local Weather Station in Ankara, are illustrated in Figure 1. The long-term (1982–2006) average annual rainfall was 397 mm (Fig. 1a). While monthly average minimum temperatures were below zero from December to March), total monthly rainfall was highest in April and May. The annual rainfall of 2000/01 and 2002/03 seasons was 23 and 22 % less than these of long-term average respectively (Fig. 4c,e). In this region, spring rain (March to June) is critical for plant growth. There was a drought in spring of 2002/03, which received 36 % less rainfall than the long-term average. In the line selection year (1999/00), precipitation was near normal (4.5% more than long-term), particularly in winter months (Fig. 1b).

In the first test season (2000/01), the winter was very mild, whereas in the second season (2001/02), the winter was quite cold, and January monthly average minimum temperature approached -10 ^{0}C (Fig. 1d). The third (2002/03) and fourth (2003/04) cropping seasons were cold enough for evaluating winter hardiness.

Measurements

In line selection phase, for the 164 accessions, the three plant characters evaluated in accession rows were: (1) winter mortality estimated by scoring on a 1–9 scale soon after winter: 1.0-3.0= resistant, no visible symptom of permanent damage in row, 3.1-6.0 = tolerant, some foliar injury and up to 25% plant killings, 6.1-9.0 = susceptible, severe foliar damage and up to 100% plant killings; (2) the days-to-flowering, the number of days from sowing to flowering date (the date on which flower emerged on 50% of the plants in a row); and (3) days-to-harvesting, the number of days from sowing to seed harvest. The following two traits were measured on six randomly selected plants from each accession at full maturity: (4) the stem length (cm), length of the main stem from crown to stem tip; (5) number of pods per plant. For the seed harvest, all plants in a row were harvested to determine (6) the standing biomass (g/row), (7) the seed mass (g/row), and (8) 1000-seed weight (g).

In the multi-year yield trials, winter mortality score were estimated as in the line selection. Severe winter killings occurred in plots in 2001/02 and most of the plants were killed so only winter-killing scores were recorded and assessed in this season. In each plot, the 6.0 m^2 area (i.e. six rows; 1.5 m wide, 4 m long) was harvested by hand at full maturity (i.e. when pods near ground become brownish and seeds were hard), and following thrashing the acquired seed was weighed and recorded as the seed yield for that plot.

Data management and statistical procedure

To determine the differences between the 18 selected lines and 164 accessions, a t-test was performed for those measured plant characters. In addition, comparisons were made by generating the frequency histograms, with normal curves superimposed, and by using descriptive statistics of mean and coefficient of variation (CV).

Due to differences in sowing time and climate over the years, each yield trial was considered as an individual environment, giving to the six environments: i.e. four autumn (Ea1, Ea2, Ea3 and Ea4) and two spring plantings (Es5 and Es6). To seek possible interactions, combined analysis of variance was performed. Means were separated by using Student's t.

Regression analysis were performed between seed yields in two environments (Ea3 and Ea4) and mean winter mortality scores of those two environments in order to display the cold effect of these two test years on genotypes.

The two stability parameters described by Finlay and Wilkonsin (1963))[8], Eberth and Russel (1966) [7] were calculated: (1) the regression coefficient (b) is a linear regression of genotype mean yield on the average of all genotypes and its significance was determined using the Student's t-test [25], and (2) the mean square deviation from the regression (S^2d). Coefficient of determination (r^2) was computed from linear regression analysis of each genotype [19]. Analysis of variance components [7] was also computed for seed yield when stability parameters were estimated.

The analysis for the descriptive statistics, t-test, and regression analysis were performed in Minitab version 14.0, and J.M.P 5.01 of SAS institute was employed for the analysis of variance and mean separations.

RESULTS

Line selection

Figure 2 illustrates the frequency distributions of eight plant metric characteristics with normal curves superimposed, drawn separately for the 18 selected lines and 164 accessions (base lines). The cold winter of 1999/00 cropping season made it a good test for winter hardiness (Fig. 1b). Winter mortality score was significantly 32% less in selected lines than in base lines ($P<0.001$). Moreover, on average the selections flowered and matured 5.6 and 5.1 days earlier than base lines did respectively ($P<0.001$). Coefficients of variation for all characters were smaller in selected lines than in base lines. Though they statistically possessed similar stem length and number of pods per plant, the selections had significantly higher standing biomass (35% more), seed mass (38% more) and 1000-seed weight (28% more) than did baselines ($P<0.001$). Because these 18 lines were superior for winter hardiness, earliness, biomass and seed mass, they were selected and taken to the multi-year trials for further tests for adaptation and yield performances.

Adaptation and variety performance

Winter mortality and seed yield

Variance components for winter mortality score and seed

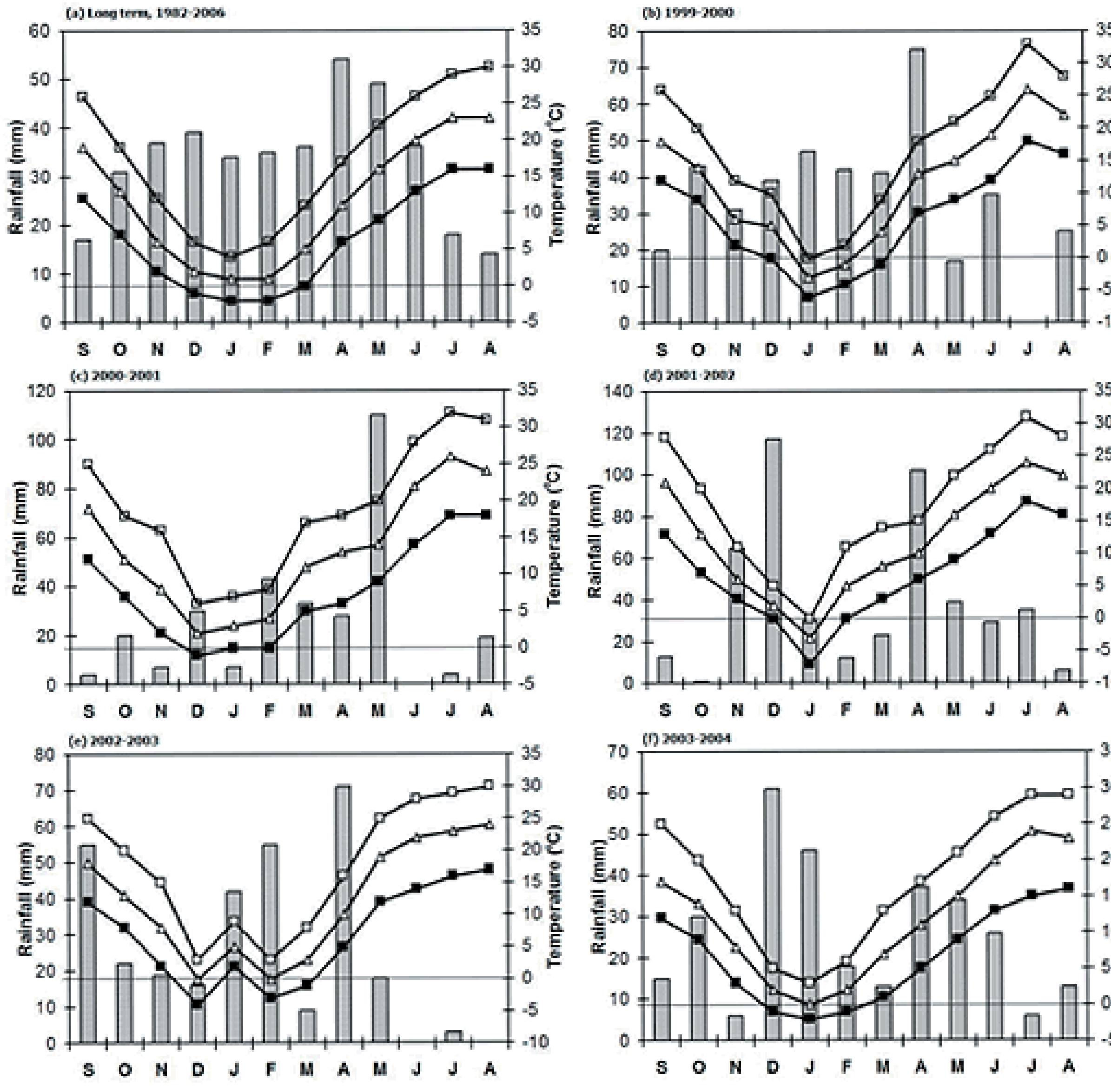

Figure 1 Total monthly rainfall (column), and mean monthly maximum (□), average (Δ), and minimum temperatures (■), (a) long term means: 1982/2006, (b) 1999/00, (c) 2000/01, (d) 2001/02, (e) 2002/03, and (f) 2003/04.

yield from combined analysis of twenty-one genotypes of common vetch grown at five environments were presented in Table 1. For both winter mortality score and seed yield, there were highly significant differences between genotypes, environments and genotype x environment interactions (P<0.001) (Table 1)

On average, across the environments winter mortality (Table 2) score ranged from 3.00 in Ea1 (i.e. very mild winter in 2000/01) to 8.65 in Ea2 (i.e. severe winter in 2001/02). All genotypes had the same winter mortality score (3.00) in Ea1, while almost all plants in the experimental plots died as the result of freezing temperatures during the winter of Ea2. The Ea3 (2002/03) and Ea4 (2003/04) were appropriate test environments for winter mortality, which clearly displayed the range of winter hardiness among the studied genotypes. In Ea3 the three genotypes (L-1500, L-1540 and L-1544) had the lowest mortality (5.25) together, while in Ea4

Table 1. Variance components for winter mortality score and seed yield from combined analysis of variance for the 21 genotypes of common vetch (*Vicia sativa*).

	Winter mortality			Seed yield		
Variance source	d.f.	Sum of Square	Mean Square	d.f.	Sum of Square	Mean Square
Genotype	20	44.56	2.23***	20	8879243	443962***
Environment	3	1410.31	470.10***	4	59759549	1493987***
Genotype x Environment	60	35.38	0.59***	80	17061638	213271***
Error	249	77.30	0.31	312	12489987	40032

***: significant at $P< 0.001$.

Table 2. Winter mortality scores (1-9) of the 21 genotypes in the yield trials established in autumns (Ea1, Ea2, Ea3 and Ea4) at Ikizce Research Farm of the CRIFC, Ankara

Genotype	2000/01	2001/02	2002/03	2003/04	
	Ea1	Ea2	Ea3	Ea4	Mean
L-1430	3.00	8.00 de	6.50 bcd	6.63 def	6.03 fgh
L-1431	3.00	8.25 cd	6.50 bcd	6.88 bcde	6.16 defg
L-1439	3.00	8.50 bc	6.25 bcd	6.88 bcde	6.16 defg
L-1442	3.00	9.00 a	6.75 abc	7.25 bcd	6.50 bcd
L-1453	3.00	9.00 a	7.50 ab	7.50 ab	6.75 ab
L-1469	3.00	8.75 ab	7.00 abc	6.88 bcde	6.41 bcdef
L-1475	3.00	9.00 a	7.00 abc	7.00 bcd	6.50 bcd
L-1477	3.00	9.00 a	6.75 abc	7.13 bcd	6.47 bcde
L-1500	3.00	8.25 cd	5.25 d	6.25 efg	5.69 hi
L-1501	3.00	9.00 a	6.25 bcd	7.00 bcd	6.31 cdef
L-1503	3.00	9.00 a	6.00 cd	7.00 bcd	6.25 cdef
L-1526	3.00	9.00 a	6.25 bcd	7.00 bcd	6.31 cdef
L-1540	3.00	9.00 a	5.25 d	6.00 fg	5.81 ghi
L-1543	3.00	9.00 a	6.00 cd	7.25 bcd	6.31 cdef
L-1544	3.00	7.75 e	5.25 d	5.75 g	5.44 i
L-1548	3.00	8.25 cd	6.50 bcd	6.88 bcde	6.16 defg
L-1551	3.00	8.00 de	6.50 bcd	6.75 cde	6.06 efgh
L-292/1	3.00	9.00 a	7.00 abc	7.38 abc	6.59 abc
L-581	3.00	8.00 de	6.00 cd	6.00 fg	5.75 ghi
KaraElci	3.00	9.00 a	8.00 a	8.00 a	7.00 a
SarıElci	3.00	9.00 a	7.25 abc	7.13 bcd	6.59 abc
Mean	3.00 d	8.65 a	6.46 c	6.9 b	6.25

Means followed by the same letter are not significantly different

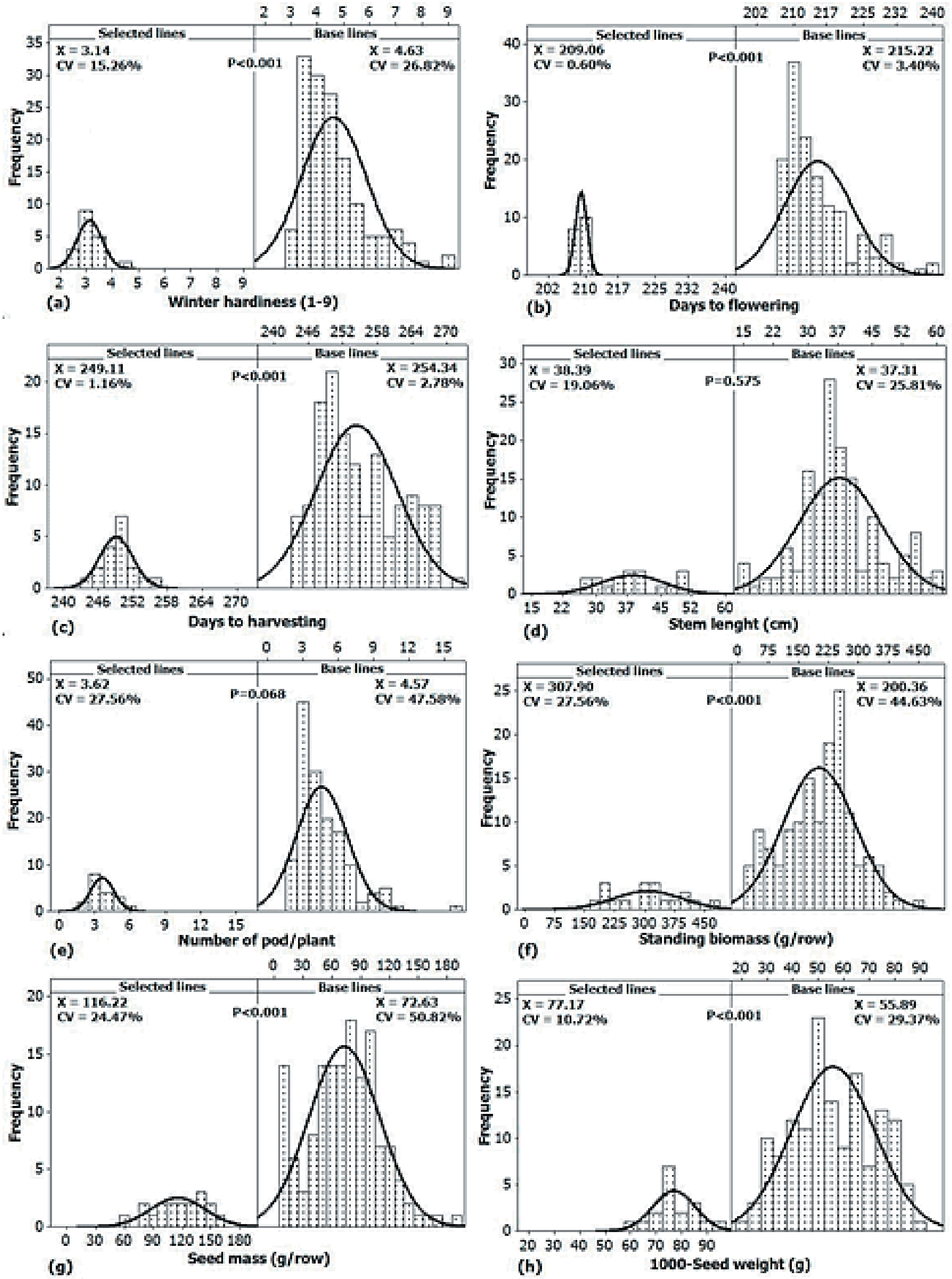

Figure 2 Frequency distributions of the eight plant metric characters, with normal curves superimposed: significant difference between means (X) of the selected lines (n=18) and base lines (n=164 accessions), and coefficient of variation (CV %) for (a) winter hardiness, (b) days-to-flowering, (c) days-to-harvesting, (d) stem length, (e) number of pod/plant, (f) standing biomass, (g) seed mass, and (h) 1000-seed weight.

Table 3. Seed yield (kg ha^{-1}) of the 21 genotypes in the yield trials established in autumn (Ea1, Ea3 and Ea4) and spring (E5 and E6) at Ikizce Research Farm of the CRIFC, Ankara.

Genotypes	Autumn				Spring			Overall mean
	2000/01	2002 /03	2003/04		2001/-02	2002/03	Mean	
	E1	E3	E4		E5	E6		
L-1430	2100^{a}	638^{cd}	821^{abcde}	1186	1296^{ab}	498^{cd}	897	1071^{abc}
L-1431	2000^{abc}	503^{def}	933^{abc}	1146	1246^{abc}	596^{abc}	921	1056^{abcd}
L-1439	1381^{gh}	405^{def}	542^{defgh}	776	1156^{abcde}	654^{abc}	905	828^{gh}
L-1442	1456^{fgh}	257^{f}	238^{h}	650	1225^{abcd}	442^{cd}	834	724^{h}
L-1453	1888^{abcd}	268^{f}	344^{gh}	833	1134^{abcde}	767^{a}	950	880^{efg}
L-1469	1813^{bcd}	870^{abc}	485^{efgh}	1056	1008^{defgh}	467^{cd}	737	929^{efg}
L-1475	1550^{efg}	723^{bcd}	650^{cdefg}	974	814^{hi}	479^{cd}	647	843^{fgh}
L-1477	1250^{h}	485^{def}	629^{cdefg}	788	1235^{abcd}	773^{a}	1004	874^{efg}
L-1500	1488^{fgh}	1030^{ab}	850^{abcd}	1123	863^{ghi}	485^{cd}	674	943^{defg}
L-1501	1388^{gh}	1021^{ab}	515^{defgh}	974	920^{efgh}	371^{d}	645	843^{fgh}
L-1503	1275^{h}	883^{abc}	615^{cdefg}	924	1072^{bcdefg}	727^{ab}	900	914^{efg}
L-1526	2044^{ab}	720^{bcd}	761^{bcdef}	1175	889^{fghi}	485^{cd}	687	980^{bcde}
L-1540	944^{i}	627^{cde}	927^{abc}	833	1139^{abcde}	804^{a}	971	888^{efg}
L-1543	1688^{def}	1016^{ab}	621^{cdefg}	1108	1108^{abcdef}	527^{bcd}	818	992^{bcde}
L-1544	1675^{def}	1177^{a}	1021^{ab}	1291	1111^{abcdef}	475^{cd}	793	1092^{ab}
L-1548	1488^{fgh}	897^{abc}	838^{abcd}	1074	1015^{cdefgh}	542^{bcd}	778	956^{cdef}
L-1551	1750^{cde}	391^{def}	690$^{bcdef h}$	943	1317^{a}	808^{a}	1063	991^{bcde}
L-292/1	1313^{gh}	455^{def}	667^{cdefg}	811	1288^{ab}	800^{a}	1044	904^{efg}
L-581	2106^{a}	729^{bcd}	1100^{a}	1312	1260^{ab}	446^{cd}	853	1128^{a}
KaraElci	1394^{gh}	291^{ef}	475^{fgh}	720	1088^{abcdefg}	440^{cd}	764	737^{h}
SarıElci	863^{i}	260^{f}	450^{fgh}	524	676^{i}	0.13^{e}	338	450^{i}
Mean	1564a	650c	675c	963	1089b	552c	820	906

Means followed by the same letter are not significantly different

L-1544 possessed the lowest mortality score, which was followed by the accessions L-581 (6.00), L-1540 (6.00) and L-1500 (6.25). In overall environments, the three accessions (L-1544, L-581 and L-1500) acquired the least mortality scores (5.44, 5.69 and 5.81), whereas the two local checks (SarıElçi and KaraElçi) produced the highest mortality scores (6.59 and 7.00), respectively.

The average seed yield (Table 3) varied between 1564 kg/ha in Ea1 (following the mild winter in 2000/01) and 552 kg/ha in Es6 (following the drought in late spring of 2002/03). For the autumn plantings, the accessions (L-581 and L-1430) produced the greatest seed yields (2106 and 2100 kg/ha) in Ea1, while in Ea3 and Ea4 L-1544 and L-581 did the best (1177 and 1100 kg/ha), respectively. For the spring sowings, L-1551 possessed the highest seed yields in Es5 (1317 kg/ha) and in Es6 (808 kg/ha). Over the environments, L-581produced the greatest seed yield (1128 kg/ha), and followed by L-1544 (1092 kg/ha), whereas local check SarıElçi acquired the lowest seed yield (450 kg/ha).

Relations of the seed yield with winter mortality

Mean winter mortality scores of 21 genotypes in two cold environments (Ea3 and Ea4) were linearly associated with the seed yields: Ea3 ($P<0.01$ and $r^2=0.41$), Ea4 ($P<0.001$ and $r^2=0.54$) (Fig. 3). Furthermore, in conjunction with these relations in both cold years among 21 genotypes, three accessions (L-581, L-1500 and L-1544) scored as the superior lines in winter survival, were located on upper part of the regression lines (i.e. highest seed yielding), while two checks (cv. KaraElçi and var. SarıElçi) gathered on the right bottom quarter (i.e. lowest seed yielding) (Fig. 3). In addition, linear regression lines of these two cold environments appeared to be very similar (Fig. 3).

Genotype adaptation

An analysis of variance for stability for seed yield (Table 4) showed significant differences between genotypes as well as among environments ($P<0.01$). The mean square due to genotype–environment interactions was found to be significant ($P<0.01$) (Table 4). Genotype-

Table 4. Analysis of variance estimated over stability parameters for seed yield

Source of variation	df	Mean Square
Genotype (G)	20	110993**
Environments (E) (linear)	1	14901914**
Environment (E) + (Gx E)	84	228634**
G x E (linear)	20	83309*
Pooled deviation (residual)	63	41861**
Pooled error	315	10313

*, **: significant at *P*< 0.05, 0.01, respectively. Error mean square was divided by the number of replications (4) since the error sum of square estimated over replications.

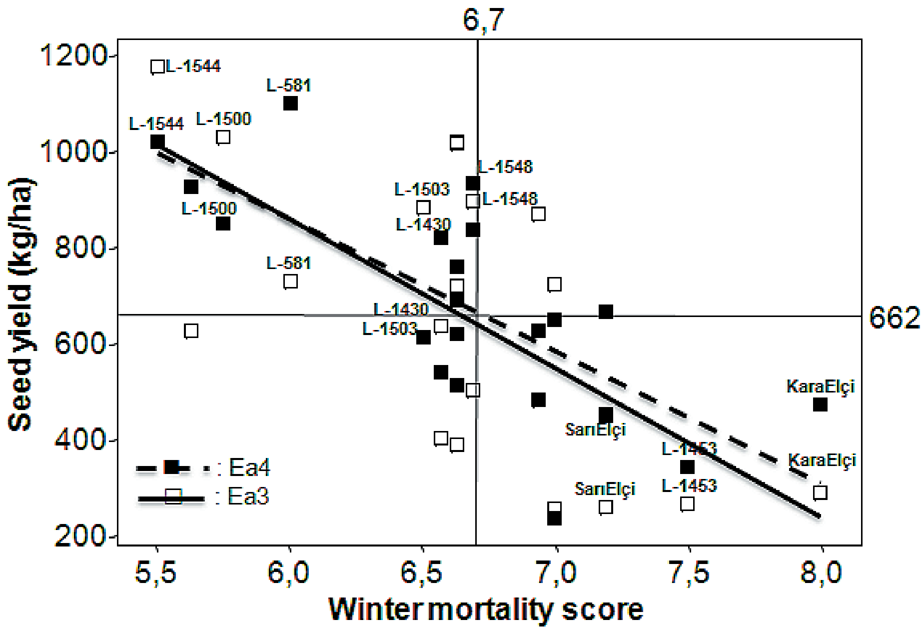

Figure 3. Relations between mean winter mortality score (1-9) and seed yields (kg/ha) of the 21 genotypes in two environments (Ea3 (☐): Y=2738-313.1X, r^2=0.41, P<0.01; Ea4 (■): Y=2504-274.1X, r^2=0.54, P<0.

environment (linear) interactions and deviation around the regression lines were significantly different (P<0.05), P<0.01 respectively) (Table 4). Estimates of stability parameters (S^2d and r^2) for overall seed mean (Table 5) show a large variation in coefficient of determination (r^2), ranging from 0.29 to 0.99. Linear responses to changes in environment (b) ranged from 0.24 to 1.53 (Fig. 4). Regression coefficients (b) of the three lines (L-1442, L-1503 and L-1540) showed significant differences from 1.0, whereas ten genotypes had an average stability (regression coefficient did not differ significantly from 1.0) with seed yield above the grand mean (Fig. 4). Among these ten genotypes, lines L-1430 and L-1548 possessed S^2d values not significantly different from zero (Table 4).

The four genotypes (L-1430, L-581, L-1431 and L-1526) with the greatest regression coefficient and mean seed yield appeared in the right upper quarter of the scattered plot, whereas the accessions L-1544, L-1548 and L-1500 with low mean regression coefficients and above average seed yield were placed in the right lower quarter (Fig. 4). The var. SarıElçi mapped towards the end of left lower quarter with coefficient less than 1.0 and far below mean seed yield, whilst cv. KaraElçi had above average coefficient, but below mean yield (Fig. 4).

DISCUSSION

This study demonstrates a considerable enhancement in winter hardiness of common vetch through identifying superior genotypes in multi-year trials. The level of variation found in the base populations did clearly show potential for further development, and multi-environment trials singled out the V. sativa genotypes with enhanced adaptation. As a first step, we evaluated

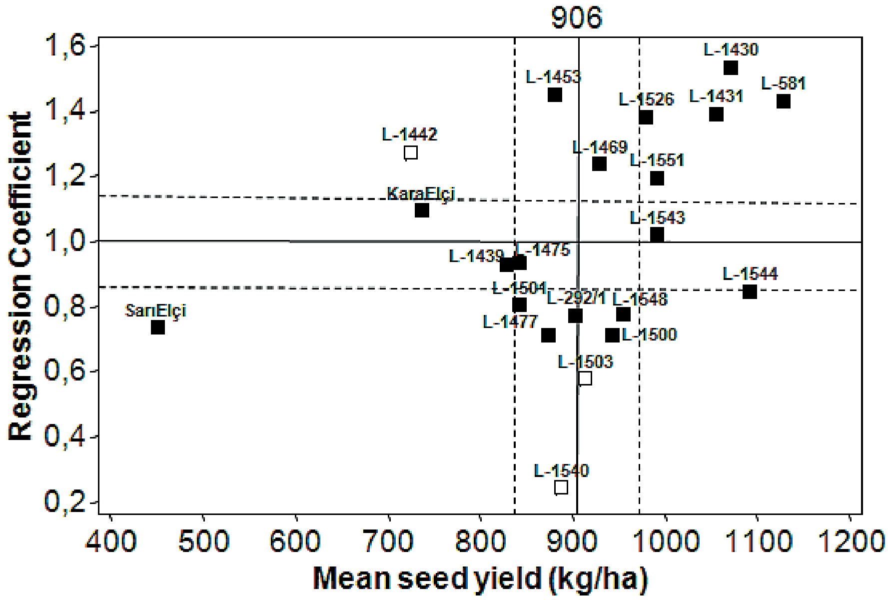

Figure 4. The relationship between the regression coefficient of individual seed yields on mean environment yields (b) of the 21 genotypes of common vetch. Estimates of (b) were significantly different from 1.0 (P<0.05) only for those entries indicated by ☐. The brake-lines indicate confidence limits for mean seed yield (906 ± 67.95) and for regression coefficient (1.00 ± 0.16).

the vetch germplasm for winter hardiness, maturity and biomass. In comparison with the base populations, selections substantially improved the winter survival and consequent yield.

Basically breeding for winter hardiness is a breeding for adaptation, and as the winter conditions vary considerably even within and between years, new cultivars should possess tolerance to the various winter stress factors. Test for cold hardiness in multi-environment trials seems to give the best indication of overall wintering ability for vetch genotypes. Subsequently, a few environments can be appropriate for detection of superior genotypes. In different test winters, specific components may be critical for survival [18]. In the winter of 2001/02 freeze-thaw cycles in early spring, and prolonged freezing temperatures were the main causes for winter mortality. In autumn-sowings, three accessions (L-1500, L-1544 and L-581) had the lowest winter mortality scores (i.e. tolerant), which was significantly less than that of checks (cv. KaraElçi and var. SarıElçi). Twenty-one genotypes responded to increased rainfall and mild winter temperature in 2000/01 (Ea1), with an overall increase in seed yield of 38% compared with overall mean of autumn plantings. Autumn-sown vetch showed 15% greater potential for seed yield than spring vetch (Table 3).

Early flowering can permit a long grain-filling time during which photosynthetic components remain green; in consequence, it improves grain filling. This early flowering and podding combined with vigorous early growth resulted rapid canopy development and dry matter production [26], which laid the potential for a larger total biomass and higher seed yield. Therefore, selection for more rapid crop growth in spring is likely to increase the common vetch yield.

Except the second environment (Ea2), autumn-sowings became successful in production. In autumn plantings, three genotypes (L-581, L-1544 and L-1500) produced the highest seed yield (1312, 1291 and 1123 kg/ha), whereas checks (cv. KaraElçi and var. SarıElçi) yielded last in ranking order (720 and 524 kg/ha), respectively, thus indicating an enhanced yield performance for autumn-sown vetch (Table 3). Among the accessions, poor seed yields of cv. SarıElçi in all environments were mainly due to its late flowering and maturity (data not shown). Low seed yield is probably related to the delayed appearance of floral buds, corresponding with the onset of high temperatures resulting in high abortion rates in flowers and young pods after fertilization [1]. Thus adapting crop phenology to water availability has been the main route by which yield has been improved when water is the limiting factor for crop growth [6, 27]. In the 2002/03 cropping season (Ea3 and Ea6), high temperatures in May and June limited crop growth and shortened flowering and seed-filling stages, and reduced

Table 5. Estimates of stability parameters (S^2d and r^2) for the seed yield of the 21 genotypes of common vetch based on the five environments

Genotype	Overall mean	S^2d/1000		r^2
L-1430	1071	18.603		0.99
L-1431	1056	85.538	*	0.94
L-1439	828	92.747	*	0.87
L-1442	724	169.622	**	0.87
L-1453	880	262.999	**	0.85
L-1469	929	119.797	**	0.90
L-1475	843	64.809		0.91
L-1477	874	133.924	**	0.73
L-1500	943	170.253	**	0.68
L-1501	843	208.358	**	0.69
L-1503	914	44.890		0.84
L-1526	980	162.154	**	0.89
L-1540	888	101.876	*	0.29
L-1543	992	116.609	*	0.86
L-1544	1092	226.558	**	0.69
L-1548	956	50.568		0.90
L-1551	991	158.291	**	0.87
L-292/1	904	164.582	**	0.72
L-581	1128	143.082	**	0.91
KaraElci	737	63.249		0.93
SarıElci	450	78.711		0.83
Grand mean	906	125.582		-

Estimates of S^2d were significantly different from 0.0, and *, **: significant at P<0.05, 0.01, respectively.

yield (Table 3). Therefore, it has appeared that winter hardiness and earliness are important traits for sustained seed yield for autumn-sown vetch in CHT.

Among twenty-one genotypes, as winter mortality decreased, seed yield increased in two cold environments (Ea3 and Ea4) (r^2=0.41 and r^2=0.54) (Fig. 3). These consistent results in both environments indicate that the variation in winter mortality and related seed yields of 21 vetch genotypes occurred due to the genotypic rather than environmental differences.

Eberhart and Russel (1966) [7] suggested that an ideal genotype is one which has the highest yield over a broad range of environments, a regression coefficient (b) value of 1.0 and deviation mean square (S_2d) of zero. Langer et al (1979) [17] reported that the regression coefficient is a measure of response to varying environments and the mean square deviation from linear regression is a true measure of production stability. For seed yield, the research results showed that the G x E interaction component is a linear function of the environmental means (Table 4). Therefore, it is possible to judge the stability of 21 genotypes using definition, and to consider their mean performances. Accordingly, two genotypes (L-1430 and L-1548) across all environments were the most stable (their regression coefficients did not differ significantly from 1.0) with above average seed yield and low S_2d values (insignificant from zero) (Table 4). These can be considered the most widely adapted genotypes, their selection for further use is therefore desirable. Two local checks (cv. KaraElçi and var. SariElçi) were found to be stable (low S_2d values), but their yield were low. Two genotypes (L- L-1540 and L-1442) with yield less than the grand mean, and b values significantly different from 1.0, were relatively better adapted to poor environments (Fig. 4). Large variation in the regression coefficients indicated the genotypes responded differently to environments. For example, three genotypes (L-581, L-1500 and L-1544) had the best winter survival and highest seed yield in two cold environments (Ea3 and Ea4). Thus, we concluded that the accessions L-1430 and L-1548 are the most stable across six environments, while two genotypes L-581 and L-1544 are the best for autumn sown vetch in the CHT.

The study results have certain implications for the enhanced adaptation: (1) selection within the vetch germplasm with a wide spectrum of phenotypic variation was an effective tool in identifying lines for use in autumn plantings; (2) the linear decline in winter survival indicates that these two cold environments imposed the same effect on winter survival.

In conclusion, our results have demonstrated the central role of rainfall and temperature on yield. In this type of stress environments 'winter hardiness' was defined in terms of yield under stress as it reflects the yield potential, and positive relation of winter survival with seed yield is a clear indication of that genetic enhancement. Furthermore, we believe that genetic selection continues to be the primary mechanism by which we increase yield and stress tolerance. Eventually, however, empirical selection will give decreasing returns. Therefore, for more precise definition of target traits and more directed breeding, further studies on winter-hardy vetch lines are necessary to analyze physiological, biochemical, and genetic mechanisms controlling hardening process and dormancy in autumn, survival in winter and re-growth in early spring.

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