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Phenotypic variation of autumn and spring-sown vetch (*Vicia sativa* ssp.) populations in central Turkey

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Abstract

In central Turkey, common vetch (*Vicia sativa* ssp. *sativa*) is traditionally grown in spring. Frequent droughts cause crop failures. Autumn sowing can give higher yields, but then winter plant death is a major problem. The objective of this research was to explore and quantify variation available in *V. sativa* ssp. germplasm for winter hardiness, yield and adaptability. Eleven plant characters were evaluated in 164 vetch populations in autumn and spring sowings over two years, and their inter-relationships were analyzed. Mean winter death was 27% and was greater in the second, colder year, though the magnitude of the coefficient-of-variation was similar in both years (27 and 28%). Autumn-sown plants produced more standing biomass (17%) than spring-sown plants. Winter death was strongly related to other characters, particularly in the colder year. Principle component analysis proved to be efficient at simplifying the results by classifying the eleven variables into three main groups on the basis of seed size, maturity and winter hardiness. There is wide, exploitable phenotypic variation, and enhanced adaptation for autumn sowing could be achieved by selecting for large seeds and early maturity combined with reasonable winter survival.

Additional key words: common vetch, Pearson correlation, plant metric characters, principle component analysis, variety development, winter hardiness.

Resumen

Variación fenotípica en poblaciones de veza (*Vicia sativa* ssp.) del centro de Turquía, sembradas en otoño y primavera

La veza (*Vicia sativa* ssp. *sativa*) crece tradicionalmente en el centro de Turquía y las cosechas sufren pérdidas importantes en las frecuentes temporadas de sequía en primavera. La siembra en el otoño puede conducir a rendimientos más altos, pero las plantas pueden sufrir una mortandad elevada en el invierno, lo que representa un problema mayor. El objetivo de nuestra investigación fue explorar y cuantificar la variación para el vigor, el rendimiento y la adaptabilidad en una colección de germoplasma de *V. sativa* ssp. Se analizaron once caracteres vegetativos y sus inter-relaciones en 164 poblaciones de haba en siembras de otoño y primavera durante dos años. La mortalidad media en invierno fue un 27% superior en el segundo año, aunque la magnitud del coeficiente de variación fue similar en ambos años (27% y 28%). Las plantas sembradas en otoño produjeron más biomasa (17%) que las de primavera. La mortalidad registrada en invierno estuvo fuertemente relacionada con otros caracteres, particularmente con el índice de heladas anual. El análisis de componentes principales demostró su eficiencia para la simplificación y clasificación de las once variables en tres grupos principales sobre la base del tamaño de la muestra, madurez y resistencia al frío. Existe una amplia variación aprovechable y se demuestra la posibilidad de incrementar la adaptación en la siembra de otoño, con una razonable supervivencia en invierno, mediante la selección de plantas con semillas de mayor tamaño y madurez temprana

Palabras clave adicionales: análisis de componentes principales, caracteres métricos de planta, correlación de Pearson, variación adaptativa, vigor invernal.

Abbreviations used: CHT (Central Highlands of Turkey), CRIFC (Central Research Institute for Field Crops**)**, CV (coefficient of variation), DF (number of days from planting to flowering), DH (number of days from planting to harvest), ICARDA (International Center for Agricultural Research in Dry Areas**)**, KE (cultivar Kara-Elçi), N (*V. sativa* ssp. *nigra*), NP (number pods $plant^{-1}$), NS (number stems $plant^{-1}$), NSP (number seeds pod^{-1} $plant^{-1}$), PC_1 (first principle component), PC_2 (second principle component), PC_3 (third principle component), PCA (principle component analysis**)**, PCs (principle components), PL (pod length pod^{-1} $plant^{-1}$), R (resistant), S (*V. sativa* ssp. *sativa*), SA (crosses of *V. sativa* ssp. *sativa* × *V. sativa* ssp. *amphicarpa*), SB (standing biomass), Se (sensitive), SE (variety Sarı-Elçi), SL (stem length), SM (seed mass), Swt (seed weight), T (tolerant), TV (total variation), WD (winter deaths).

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Introduction

Common vetch (*Vicia sativa* ssp. *sativa*) is one of the most important annual forage legumes in the world because of its multiple uses (*i.e.* hay, grain, straw, silage and green manure), its high nutritional value, and its ability to grow over a wide range of climatic and soil conditions. Turkey is the centre of domestication of vetch (Harlan, 1971). Several species of the genus *Vicia* have been cultivated from ancient times (Zohary and Hopf, 1988), and their use as feed crops dates back to antiquity. Gençkan (1983) reported cultivation of common vetch as a forage crop by the Hittites of Anatolian civilizations.

According to Davis (1970), 150 species of *Vicia* grow as wild populations in various parts of the world, and 59 of them occur in Turkey. Açıkgöz *et al*. (1998) recorded that wild, weedy forms of vetch exist in almost every part of Turkey at altitudes from sea level to 2,200 m. *Vicia sativa* L. as wild, cultivated and a cosmopolitan plant is one of the genetically and phenotypically most variable species of *Vicia* (Davis, 1970). *Vicia sativa* ssp. *amphicarpa* exists in northwest and central Anatolia on rocky slopes and in fallow fields, *V. sativa* ssp. *nigra* is scattered throughout Turkey, mainly in the east, on agricultural lands, rocky slopes and in meadows (Açıkgöz *et al*., 1998). Subterranean vetch (*V. sativa* ssp. *amphicarpa*) can express its winter hardiness, drought tolerance and persistence under heavy grazing (Alınoğlu and Durlu, 1970), whilst common vetch (*V. sativa* ssp. *sativa*) grows well under favourable conditions (Abd El-Moneim, 1992). Sabancı (1997) reported considerable diversity among common vetch populations, collected from different regions of Turkey.

Production of common vetch is greatest in countries of the former Soviet Union, Eastern Europe and on the Anatolian plateau, where there is a need to conserve fodder, or grain, to meet shortages over the freezing winter months (Firincioğlu *et al*., 1997a; Francis *et al*., 1999). Increased feed requirements for an expanding Turkish livestock population necessitate the introduction of forage legumes into crop rotations (Fırıncıoğlu *et al*., 2007). Among annual forage legumes common vetch occupies the largest area, of 320,000 ha in Turkey (Anonymous, 2006). The bulk of the crop is cultivated in the Central Highlands of Turkey (CHT), where it is traditionally spring sown. This makes the growing season rather short. Besides, the frequent incidence of drought causes crop failures in the region.

An initial study showed that, if successful, autumn-sown vetches had greater yield potential (Fırıncıoğlu *et al*., 1997b). However, winter death is a major problem in common vetch growing regions with a continental climate (Açikgöz, 1982). Abd El-Moneim and Cocks (1993) reported that cold tolerance is a prime requirement for establishing cool season annual forage legume species in medium to high elevation areas of West Asia and North Africa. For that reason, agricultural production in continental Mediterranean highland environments can only be increased if the major constraints of low temperatures and drought can be either overcome or avoided (Keatinge *et al.,* 1991). Appropriate plant material is very crucial for any plant breeding program aimed at developing new cultivars (Tyler, 1987). Humpreys (1991) reported that if phenotypic measurements are taken from adequately large samples and plant traits display sizeable differences among populations, they can give realistic depictions of overall genetic performance.

To improve resistance to stress factors, it is imperative to know the magnitude of variability present, as this would provide a basis for efficient selection. From available germplasm, it should be possible to develop common vetch cultivars with better adaptation and greater yield. Thus, the objectives of this research were to explore and quantify variation in *Vicia sativa* ssp. germplasm for its utilization in improving agronomically important characters such as winter hardiness and drought tolerance, and to ensure higher yield.

Material and methods

Experimental material and management

These experiments were conducted during the 1998-1999 and 1999-2000 cropping seasons at the Ikizce Research Station, Central Research Institute for Field Crops (CRIFC) located 44 km south-east of Ankara. The soil was a clay loam with a high lime content and low organic matter. It was slightly alkaline, poor in phosphorous and nitrogen but had adequate potassium. Meteorological conditions for the two growing seasons, with long-term means, from the local weather station in Ankara, are shown in Figure 1. Compared with long-term climate data (Figure 1a), winter in 1998-1999 was mild (Figure 1b), while winter was cold in 1999-2000 (Figure 1c).

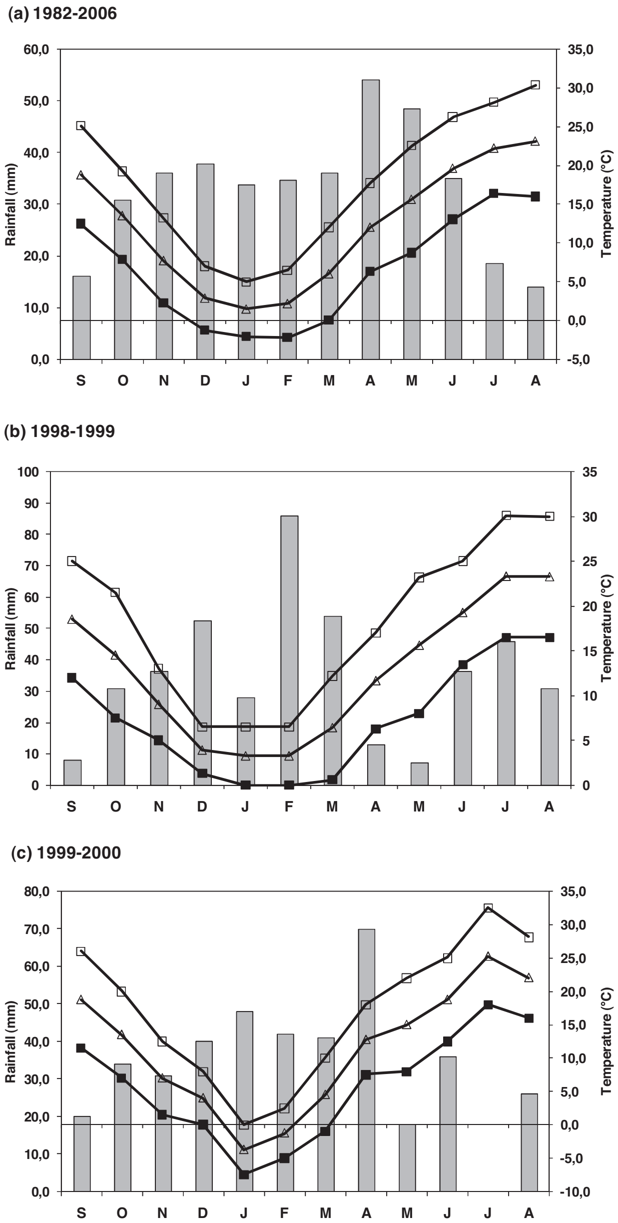

Figure 1. Monthly rainfall (column) and monthly average (△), maximum (□) and minimum (■) temperatures in (a) long term (1982-2006), (b) 1998-1999 and (c) 1999-2000.

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. The total of 164 lines of the *Vicia sativa* ssp. accessions, tested in the trails, consisted of four segregating populations (F_6 and F_8) from crosses of common vetch (*Vicia sativa* spp. *sativa*) × subterranean vetch (*Vicia sativa* ssp. *amphicarpa* Dorth.), two local checks, cvs. Kara Elci and Sarı Elci, 11 lines of *V. sativa* ssp. *nigra*, and the remainder were from *V. sativa* ssp. *sativa*. The subspecies (*nigra* or other) were tentatively identified; they remain for clarification in a later taxonomic study.

The experiments were established in both autumn and spring. One hundred and fifty seeds of each accession were hand sown in 2 m long drills 0.35 m apart. For autumn sowing trials in the first and second years were sown on 1 October 1998 and 13 October 1999, respectively. For spring sowing after sowing on 26 April 1999, very little rain fall was received (Figure 1b), so the trial was irrigated to field capacity. In the following year, it was sown on 5 April 2000.

Measurements

Eleven plant characters were evaluated, and their relationships investigated.

(1) *Days-to-flowering*: the number of days from sowing to flowering (the date when 50% of plants had flowered in the plant rows);

(2) *Days-to-harvest*: the number of days from sowing to seed harvest. For each season, the longest number of days to harvest was subtracted from the least to calculate maturity time span. This was divided by three, and lines falling in the first, second and third parts of this period were regarded as early, mid and late maturing respectively.

(3) *Winter deaths:* estimated by scoring on a 1–9 scale soon after winter. Mean values of 1.0 - 3.0 were defined as resistant with no visible symptom of permanent damage in the row, 3.1 - 6.0 as tolerant, some foliar injury and up to 25% of plants killed, and 6.1 - 9.0 as susceptible, severe foliar damage and up to 100% plants killed.

The following five traits were measured on six randomly selected plants, from each accession at full maturity:

(4) *Stem length (cm)*: length of the main stem from crown to stem tip,

(5) *Number of stem:* plant^{-1} arising from the crown,

(6) *Number of pods plant^{-1},*

(7) *Pod length (mm):* measured on 3 randomly selected pods,

(8) *Number of seed pod^{-1}:* number of seeds from 3 randomly selected pods,

(9) *Standing plant biomass (g row^{-1})*; at full maturity,

(10) *Seed mass (g row^{-1}):* the weight of seed threshed from standing biomass of each accession,

(11) *1000-seed weight (g).*

In addition, vetch lines were arbitrarily grouped for seed size based on the 1000-seed weight as very large (> 60.1 g), large (50.1 to 60.0), medium (40.1 to 50.0 g), small (30.1 to 40.0 g), and very small (< 30.1g).

Data management and statistical procedure

The mean, standard error of means, coefficient of variation (% CV), and range of each characters were separately calculated for each growing season. Principle component analysis (PCA) was used to classify the vetch material. From the PCA, the first two components were produced. To check the scores were plotted for the second principal component (y-axis) versus the scores for the first principal component (x-axis). Component coefficients with greater values than 3.0 were considered as having a major contribution to total variation (Brown, 1991). Negative values designate the direction of the relationship between the variable and component (Seiler and Stafford, 1985; Veronesi and Falcinelli, 1988). Pearson correlation analysis was performed to seek relationships among plant characters. For all statistical analysis the Minitab-14 statistical package was used.

Results

Phenotypic variation

The data revealed that there was considerable variation and good potential for enhancement of high yielding vetch lines (Table 1).

There was high variation in winter deaths among the 164 lines. Both means and CVs were higher in the second year (4.4% and 28.4%) than in the first year (3.2% and 26.7%) (Table 1). Among phenological variables there was more variation in spring than in autumn sowings. In the first spring sowing the vetch lines flowered 25 days earlier than in the second spring sowing. There was higher variation in days-to-harvest for both sowing times (3.1% and 7.2%) in the first cropping season than in the second year (2.7% and 6.9%), respectively.

Table 1. The mean, standard error of the mean (SEM), coefficient of variation (CV%) and range of 11 quantitative characters in 164 vetch (*Vicia sativa* spp.) accessions from various sources sown in autumn and spring of the 1998-99 and 1999-00 growing seasons at the İkizce Research Farm of the CRIFC, Ankara.

		First cropping season (1998/99)			Second cropping season (1999/00)		
Variables	**Sowing season**	**Mean ± SEM**	**CV (%)**	**Range**	**Mean ± SEM**	**CV (%)**	**Range**
Winter deaths (1-9)	Autumn	3.26 ± 0.07	26.72	7.0	4.47 ± 0.10	28.44	6.50
	Spring	-	-		-	-	-
Days to flowering	Autumn	220.30 ± 0.65	3.75	35.0	214.54 ± 0.56	3.35	33.0
	Spring	45.58 ± 0.58	16.12	32.0	70.12 ± 0.61	10.97	57.0
Days to harvest	Autumn	258.36 ± 0.64	3.16	32.0	253.74 ± 0.55	2.73	28.0
	Spring	76.52 ± 0.44	7.23	25.0	99.15 ± 0.55	6.93	25.0
Stem length (cm)	Autumn	32.65 ± 0.58	22.73	42.8	37.43 ± 0.73	25.09	47.0
	Spring	35.29 ± 0.46	16.46	30.0	36.40 ± 0.62	21.57	42.7
Stems plant^{-1}	Autumn	1.70 ± 0.03	23.98	2.2	1.46 ± 0.02	19.62	1.30
	Spring	1.63 ± 0.04	30.76	2.3	1.53 ± 0.04	28.74	2.30
Pod plant^{-1}	Autumn	3.83 ± 0.10	34.11	7.0	4.47 ± 0.16	46.97	14.2
	Spring	5.81 ± 0.18	38.84	11.7	5.51 ± 0.20	44.96	14.0
Pod length (mm)	Autumn	41.19 ± 0.38	11.84	30.7	41.13 ± 0.39	12.27	23.3
	Spring	35.94 ± 0.45	16.07	27.6	38.81 ± 0.45	14.56	37.9
Seeds per pod^{-1}	Autumn	5.31 ± 0.06	14.38	4.6	5.27 ± 0.07	15.76	4.30
	Spring	4.97 ± 0.07	18.11	4.4	5.00 ± 0.09	22.63	6.60
Standing biomass (g row^{-1})	Autumn	188.21 ± 6.14	41.79	350.0	212.24 ± 7.43	44.72	455.0
	Spring	195.48 ± 3.64	23.71	290.	137.18 ±5.35	49.16	295.0
Seed mass (g row^{-1})	Autumn	49.28 ± 2.12	55.01	105.6	77.44 ± 3.02	49.74	186.0
	Spring	48.40 ± 1.72	45.29	175.0	35.47 ± 2.00	70.93	91.7
1000-seed weight (g)	Autumn	58.23 ± 1.25	27.39	68.8	58.23 ± 1.33	29.31	72.0
	Spring	46.54 ± 0.85	23.23	46.8	48.40 ± 0.91	23.82	52.5

Spring-sown vetch lines matured 23 days earlier in the first year than in the second (Table 1).

There was great variation in yield components (Table 1). Stem lengths were similar at both sowing times in both years. Variation was greatest (25.1%) in the second autumn and the least in the first spring sowing (16.5%). Although mean stem number plant^{-1} did not vary much in plantings and years, its variation ranged from 19.6%, in the second autumn, to 30.8% in the second spring. Diversity in pod number plant^{-1} among lines was greater for both sowings (47.0% and 45.0%) in the second cropping season than in the first year sowings (34.1% and 38.8%). In autumn-sown plants, pods were longer (41.2 and 41.1 mm in years 1 and 2) than in spring-sown plants (35.9 and 38.8 mm). Seeds pod^{-1} varied from 5.0 in the second spring sowing to 5.3 in the first autumn sowing (Table 1).

Of all the measured plant characters, seed mass showed the highest variation, followed by plant biomass. Spring sowing, in the second year, generated the greatest variations in seed mass (70.9%) and standing plant biomass (49.2%). Mean plant biomass in the autumn sowing was much higher in the second year (212.2 g row^{-1}) than in the first (188.2 g row^{-1}). While vetch lines had the greatest seed mass (74.4 g row^{-1}) in the second autumn sowing. The 1000-seed weight differed considerably over planting times, but not between years (Table 1).

Relationships among plant characters

In the correlation matrices, most plant characters showed significant correlations (Tables 2, 3). For autumn sowing, winter deaths were positively, significantly, correlated with days-to-harvest and negatively, significantly related to standing biomass and seed mass (Table 2). Winter deaths increased with increased days-to-harvest in the first (*r*=0.291***) and second (*r*=0.550***) years, but winter hardiness significantly improved standing biomass (P<0.05 and P<0.001) and seed mass (P<0.01 and P<0.001) in both years (Table 2). However, while seed size increased with the increased winter damage in 1998/99 (*r*=0.230**) the reverse was true in 1999/00 (*r*=-0.666***) (Table 2). Accessions with large seeds matured earlier (P<0.001),

Table 2. The correlation coefficients for various plant metric characters measured on 164 autumn sown vetch accessions; 1000-seed weight (1000-Swt), and winter deaths (WD), days to flowering (DF), days to harvest (DH), stem length (SL), stem number (NS), pod number (NP), pod length (PL), seeds pod^{-1} (NSP), standing biomass (SB) and seed mass (SM)

Cropping Season		WD	DF	DH	SL	NS	NP	PL	NSP	SB	SM
1998/99	WD	—									
	DF	0.127									
	DH	0.291***	0.909***								
	SL	-0.311***	0.263**	0.280**							
	NS	-0.199*	0.048	0.097	0.210**						
	NP	-0.202*	0.349***	0.384***	0.591***	0.564***					
	PL	-0.196*	0.080	0.088	0.574***	-0.004	0.184*				
	NSP	0.178*	0.456***	0.453***	0.169*	-0.046	0.091	0.512***			
	SB	-0.381***	-0.062	-0.060*	0.718***	0.281***	0.469***	0.471***	-0.077		
	SM	-0.455**	-0.117	-0.156*	0.626***	0.280***	0.400***	0.438***	-0.096	0.933***	
	1000-Swt	0.230**	-0.628***	-0.585***	0.274***	0.008	-0.041	0.424***	-0.326***	0.508***	0.530***
1999/00	WD										
	DF	0.648***									
	DH	0.550***	0.865***								
	SL	-0.080	0.320***	0.512***							
	NS	-0.051	0.217**	0.351***	0.234**						
	NP	0.342***	0.578***	0.685***	0.600***	0.380***					
	PL	-0.135	0.158*	0.364***	0.537***	0.180*	0.22**8				
	NSP	0.404***	0.643***	0.658***	0.384***	0.211**	0.424***	0.499***			
	SB	-0.685***	-0.459***	-0.263**	0.381***	0.180*	-0.090	0.432***	-0.194*		
	SM	-0.698***	-0.560***	-0.385***	0.218**	0.145*	-0.176*	0.366***	-0.291***	0.938***	
	1000-Swt	-0.666***	-0.694***	-0.547***	0.006	-0.057	-0.371***	0.221**	-0.583***	0.663***	0.754***

*, **, ***: significant at P<0.05, 0.01, 0.001, respectively. Other values are not significant

Table 3. The correlation coefficients for plant metric characters measured on 164 spring sown vetch accessions; 1000-seed weight (1000-Swt), days to flowering (DF), days to harvest (DH), stem length (SL), stem number (NS), pod number (NP), pod length (PL), seed pod^{-1} (NSP), standing biomass (SB) and seed mass (SM)

Cropping Season		DF	DH	SL	NS	NP	PL	NSP	SB	SM
1998/99	DF	—								
	DH	0.829***								
	SL	-0.011	0.173*							
	NS	0.339***	0.406***	0.056						
	NP	0.103	0.231**	0.259**	0.540***					
	PL	0.488***	0.534***	0.265**	0.269**	0.070				
	NSP	0.427***	0.360***	0.062	0.171*	0.046	0.704***			
	SB	-0.196*	-0.088	0.519***	0.017	0.240**	0.096	-0.166*		
	SM	-0.253**	-0.226**	0.398***	-0.098	0.065	0.032	-0.087	0.564***	
	1000-Swt	-0.444***	-0.281***	0.331***	-0.063	0.058	0.032	-0.366***	0.553***	0.429***
1999/00	DF	—								
	DH	0.813***								
	SL	-0.035	-0.186*							
	NS	0.151	0.283***	-0.115						
	NP	-0.077	0.034	0.053	0.490***					
	PL	0.075	0.027	0.561***	0.020	0.090				
	NSP	-0.288***	-0.410***	0.346***	-0.049	0.077	0.513***			
	SB	-0.447***	-0.535***	0.647***	-0.126	0.049	0.310***	0.403 ***		
	SM	-0.653***	-0.691***	0.421***	-0.126	0.068	0.146	0.313***	0.857***	
	1000-Swt	-0.259***	-0.103	0.031	0.090	0.079	0.160*	-0.153	0.166*	0.309***

*, **, ***: significant at $P<0.05$, 0.01, 0.001 respectively. Other values are not significant

had fewer seeds pod-1 ($P<0.001$), and produced more standing biomass and seed mass ($P<0.001$) (Table 2).

In spring sowings, there were stronger associations among characters in the first than in the second spring (Table 3). Plant phenological characters were significantly correlated with most plant yield components. Earliness increased seed mass in both years ($P<0.01$ and $P<0.001$), and accessions with larger seeds had higher standing biomass (r=0.553*** and 0.166*) and seed mass (r=0.429*** and 0.309***), respectively (Table 3).

Principal component analysis

For sowing time and cropping season, the result of the PCA, based on the highly correlated 11 plant characters, showed great diversity among the 164 accessions of *V. sativa* subspecies. In all trials, except in PC_3 of the 1999/00 autumn sowing, the first three principle components (PCs), gave Eigen values greater than 1.0 and together explained 76, 80% and 71, 70% of the total variation in the data set, respectively (Tables 4 and 5).

In the first autumn sowing, scores on the first principal component (PC_1), which accounted for 35% of the total variation (TV), were highly correlated with stem length, pod length, standing biomass and seed mass. The second principal component (PC_2), 28% of TV, was associated with days to flowering and harvest, seed pod^{-1} and the 1000-seed weight (Table 4). In the second autumn sowing, scores on PC_1, which accounted for 44% of TV, were significantly associated with winter deaths, days-to-flowering and harvest, seed pod^{-1} and seed mass. The second principal component accounted for 28% of the TV. It was correlated with stem length, pod length, standing biomass, seed mass and 1000-seed weight.

In the first spring sowing, PC_1 accounted for 32% of the TV and was mainly loaded by characters related to days-flowering and harvest, pod length, seed pod^{-1} and the 1000-seed weight, PC_2, explained 25% of TV and was determined mainly by stem length, pods $plant^{-1}$, standing biomass, seed mass, and the 1000-seed weight. In the second spring season, stem length, seed pod^{-1}, standing biomass and seed mass were the principal contributors to PC_1, accounting for 37% of the TV, while

Table 4. Principle component analysis of characters associated with vetch lines (*Vicia sativa* spp.) sown in autumn of the 1998/99 and 1999/00 growing seasons at the Ikizce Research Farm of the CRIFC

Autumn	1998-1999			1999-2000		
	PC1	PC2	PC3	PC1	PC2	PC3
Eigen value	3.8464	3.0394	1.4763	4.8529	3.0532	0.9324
Proportion of variation	0.350	0.276	0.134	0.441	0.278	0.085
Cumulative proportion of variation	0.350	0.626	0.760	0.441	0.719	0.804
Variable	**Eigen vectors**					
Winter deaths (1 to 9)	0.281	-0.120	-0.145	0.358	0.201	0.032
Days to flowering	0.031	-0.528	0.025	0.415	-0.080	0.037
Days to harvest	0.030	-0.536	0.035	0.388	-0.208	0.002
Stem length (cm)	-0.413	-0.198	-0.086	0.120	-0.458	0.060
Stem plant^{-1}	-0.200	-0.102	0.527	0.119	-0.252	-0.763
Pod plant^{-1}	-0.296	-0.281	0.367	0.291	-0.262	-0.312
Pod length (mm)	-0.312	-0.108	-0.548	0.044	-0.452	0.449
Seed pod^{-1}	0.003	-0.365	-0.465	0.328	-0.208	0.333
Standing biomass (g row^{-1})	-0.473	0.021	0.013	-0.277	-0.411	-0.017
Seed mass (g row^{-1})	-0.460	0.066	0.014	-0.324	-0.351	-0.045
1000-seed weight (g)	-0.297	0.376	-0.201	-0.169	-0.380	0.005

days to flowering and harvest, stem length, stem and pod plant^{-1} and pod length provided the main portion of TV to PC_2, and explained 18% of the TV, and the 1000-seed weight (Table 5).

The scatter diagrams of the first two PCs for each sowing time (Figure 2, 3) displays the phenotypic variation among accessions of *V. sativa* ssp. for seed size and subspecies, maturity and winter hardiness. The accessions are widely scattered along both PCs axes. The dispersion strongly supported delimitation of the accessions based on observations of seed size, maturity and winter hardiness for autumn (Figure 2) and spring-sowings (Figure 3). For autumn sowing, in both years, there was a gradient along the first and second PC axes with the plant characters of seed size, maturity and winter death (Figure 2). This gradient was more distinct in the second year (1999/00) because of the effect of the colder winter on plant survival and its resultant contribution to the PCs (Table 4). Accordingly, the subspecies *nigra* and crosses of *sativa* and *amphicarpa* with small or very small seed sizes were on the right side of the scatter plots in both years (Figure 2). The standard cultivar Kara Elci and the variety Sarı Elci were in left half in the first year, however, in the second year although Kara Elci retained the same place, Sarı Elci, supposedly cold tolerant, moved to the right half near to *V. sativa* ssp. *nigra*. In the second year the cross populations remained near the *V. sativa* ssp. *nigra* lines.

In spring sowings, although no clear seed size grouping appeared (Figure 3), a distinct maturity gradient formed along the PC_1 from early to mid and to late in 1998/99. There was an opposite ranking order in 1999/00. In terms of maturity, spring-sowings displayed more distinct formations than autumn sowing, but they did not show any apparent congregation of subspecies grouping (Figure. 3).

Discussion

In this study, analysis of phenological, morphological and agronomic traits showed pronounced variation existed among 164 vetch populations. Despite the presence of great phenotypic variation, we have ascertained some characters that would be useful to improve vetch cultivars. The PCA, based on 11 metric characters, classified accessions into seed size, maturity and winter hardiness groups.

As Buddenhagen and Richards (1988), Richards (1989) and Shorter *et al.* (1991) explained, the first step towards maximizing crop yield by agronomy or plant breeding is to ensure that crop phenology is well fitted to the available resources and existent constraints in the production environment. For both days-to-flowering and harvest, spring sown crops showed much greater variation than autumn sown crops, indicating that the shorter

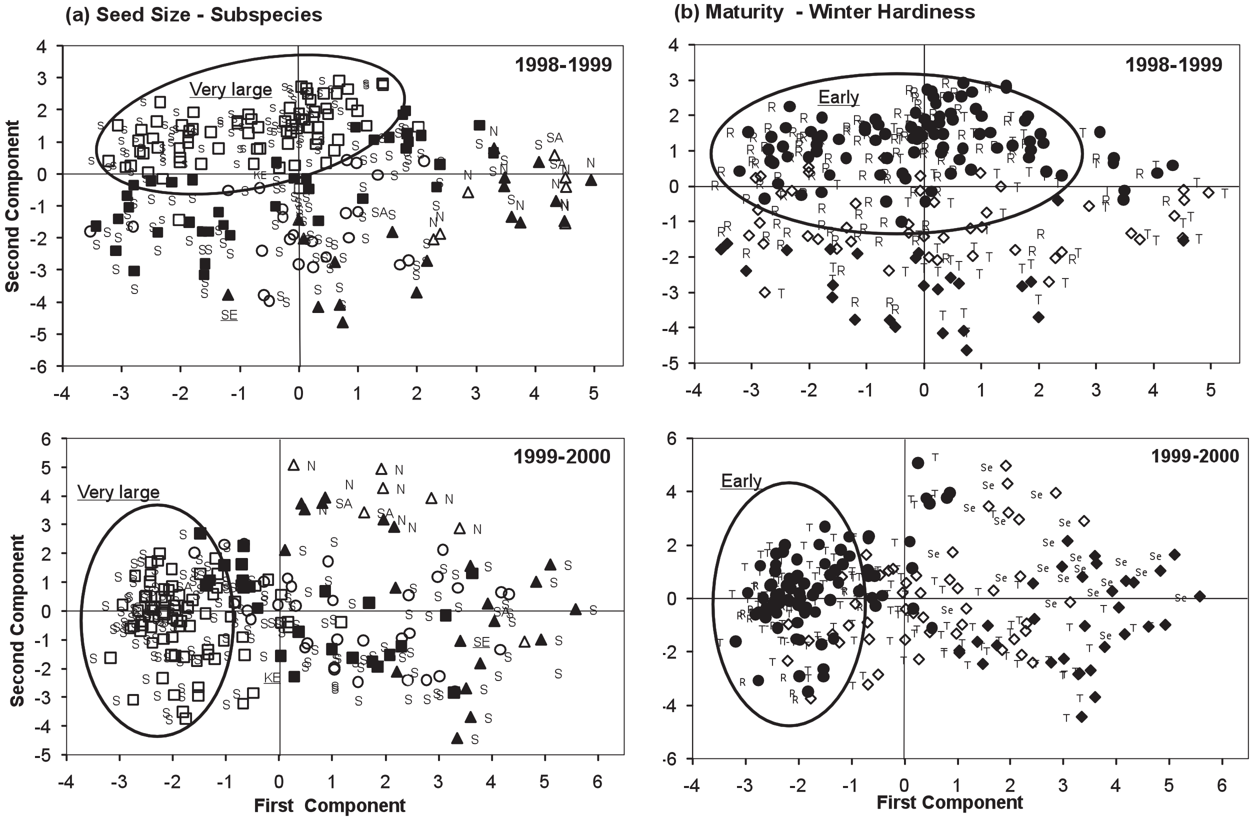

Figure 2. The score plots of the first two principle components in autumn sowings in the 1998-1999 and 1999-2000 cropping seasons of different vetch populations: (a) seed size group: [very large (□), large (■), medium (○), small (▲), very small (△)], and sub-species group: [*V. sativa. i.e. sativa* (S), *nigra* (N), and crosses of *sativa* × *amphicarpa* (SA), standard cultivar, KE Kara Elçi, and a variety, SE Sari Elçi] and (b) maturity group: [early(•), mid (◊), late (♦)] and winter-hardiness group [resistant (R), tolerant (T) and sensitive (Se)].

spring growing period is a response to environmental stress with increased phenological diversity. In this context, Bunting (1975) pointed out that the duration from sowing to flowering is very important, if crops sown in the proper time are to have the potential to yield well in a certain environment. The superiority of autumn-sowing is evident from the fact that, on average of the two years and evaluation of 164 genotypes, autumn-sown trials produced 17% more standing biomass than spring sowings. When a genotype is already phenologically adapted to an environment, high dry matter production is likely to be a major requisite for a high seed yield (Siddique *et al*., 1993). Interestingly, there were only slight differences among 1000-seed weights of the same sowing times in both years. However, the 1000-seed weights of autumn sowings, in both years, were 20% heavier than those of the spring sowings. This indicates the superiority of autumn over spring sowing. Autumn sown populations have a greater growth duration. In spring autumn sown crops start to grow from seedlings stage while spring-sown crops are emerging from dry seed. Early flowering permits a long seed-fill period during which leaves remain green and seed fill is improved. High yields in common vetch may be related to rapid seed filling characteristics, therefore, vetch adaptation could be improved through selection of early flowering genotypes (Siddique *et al*., 1999).

An effective screening method was considered a prerequisite for selection of winter-hardy material. Differences in winter hardiness, among accessions, may be in part associated with origin-inherited adaptation. Winter vetch survival usually necessitates tolerance not just to freezing temperatures but also to freeze-thaw cycles, frost-heave, and water-logging. Winter deaths were strongly related to other characters, which were more potent in the cold year. Levit (1972) states that when a relationship between winter hardiness and morphological characteristics occurs, it is indirect because of

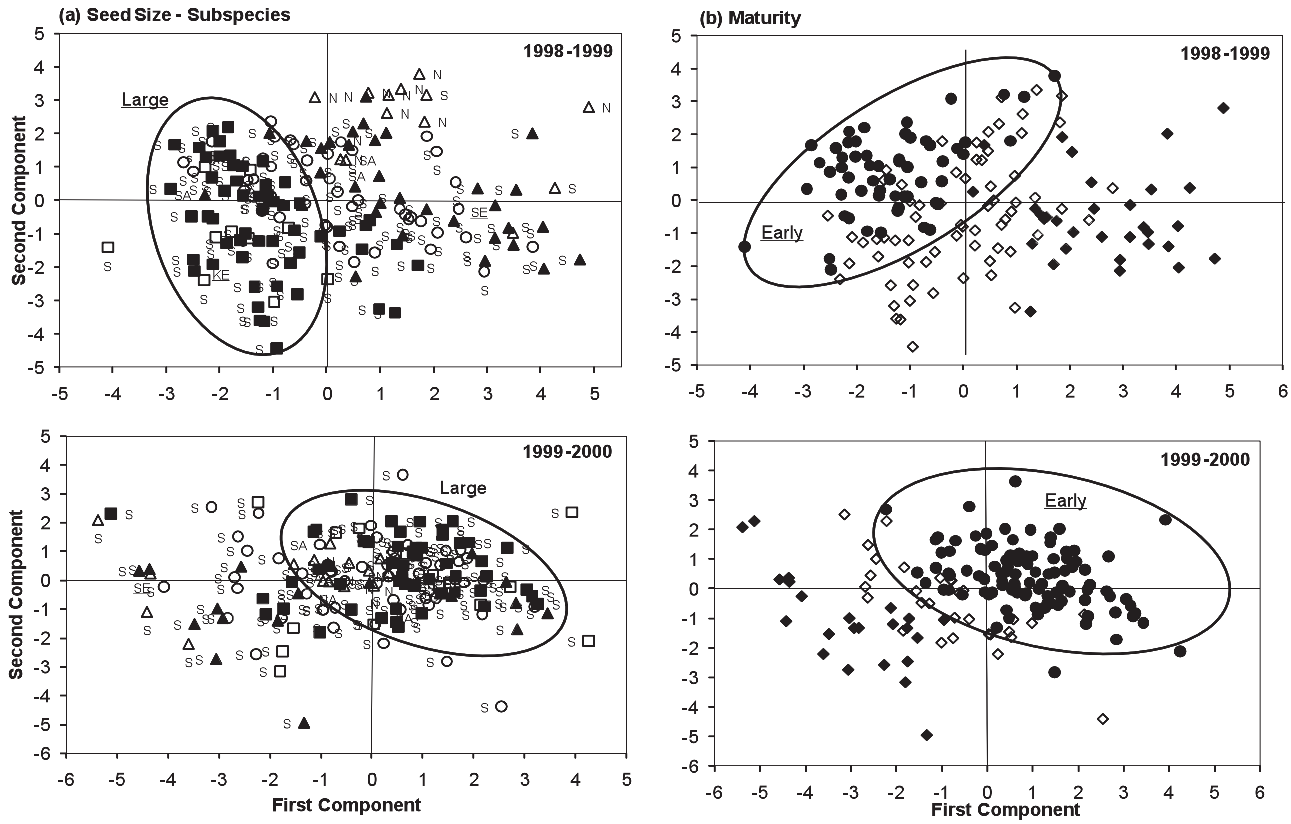

Figure 3. The score plots of the first two principle components of spring sowings in the 1998-999 and 1999-2000 cropping seasons of different vetch populations: (a) seed size group: [very large (□), large (■), medium (○), small (▲), very small (△)] and sub-species group: [*V. sativa. i.e. sativa* (S), *nigra* (N), and crosses of sativa × amphicarpa (SA), standard cultivar, KE Kara Elçi, and a variety, SE Sari Elçi], and (b) maturity group: [early(•), mid (◊), late (♦)].

accompanying physiological factors. The strong association of winter hardiness with 1000-seed weight was the most conspicuous: the bigger the seed size the greater the winter survival (Table 2). Further, the large variation in 1000-seed weight could also be useful in selecting populations with higher seedling viability as larger seeded populations have greater viability (Bullitta *et al.,* 1994). Açıkgöz (1982) pointed out that heavier seeds of common vetch grew faster and produced less shoot relative to roots than lighter seeds. Hence, it appears that greater winter-hardiness might have occurred due to larger seed size and resultant stronger seedling establishment in the autumn. In arid central Turkey, these results implied that for high and sustained vetch yield the crop should be autumn sown and early flowering. This would ensure a lengthy productive period to produce more biomass.

The PCA proved to efficient by grouping the 11 variables measures into 3 main components, further clarifying the multivariate structure indicated by the simple correlation coefficients and describing the variation of the germplasm analyzed. Further, considering the loadings relative to PC_1 and PC_2, it can be inferred that yield characters together with phenology and winter survival are major sources of diversity. Vetch lines with the greatest winter survival were from the very large seed size group in the second year (Figure 2), and irrespective of their origin, fairly high yielding populations were most likely to have been selected. Shorter maturity, with larger seed size and satisfactory winter survival should be the primary form of vetch crop adaptation to Mediterranean type environments like that of the Central Highlands of Turkey.

In conclusion, this study contributes increased knowledge of *V. sativa* ssp. germplasm available in Central Turkey. Vetch populations had developmental plasticity to year-to-year climatic variation and selecting for more rapid crop development is likely to increase

Table 5. Principle component analysis of characters associated with vetch lines (*Vicia sativa* spp.) planted in spring 1998/99 and 1999/00 growing seasons at the Ikizce Research Farm of the CRIFC

Autumn	1998-1999			1999-2000		
	PC1	PC2	PC3	PC1	PC2	PC3
Eigen values	3.232	2.525	1.317	3.659	1.800	1.487
Proportion of variation	0.323	0.253	0.132	0.366	0.180	0.149
Cumulative proportion of variation	0.323	0.576	0.708	0.366	0.546	0.695
Variables	**Eigen vectors**					
Days to flowering	0.478	-0.032	0.055	-0.375	-0.348	0.242
Days to harvest	0.457	-0.149	-0.047	-0.415	-0.326	0.055
Stem length (cm)	-0.020	-0.493	0.127	0.311	-0.393	0.234
Stem plant^{-1}	0.273	-0.209	-0.532	-0.116	-0.340	-0.563
Pod plant^{-1}	0.111	-0.307	-0.613	0.032	-0.342	-0.553
Pod length (mm)	0.356	-0.293	0.374	0.199	-0.549	0.191
Seed pod^{-1}	0.386	-0.081	0.365	0.304	-0.254	0.209
Standing biomass (g row^{-1})	-0.202	-0.486	0.031	0.458	-0.086	0.025
Seed mass (g row^{-1})	-0.237	-0.382	0.211	0.467	0.109	-0.146
1000-seed weight (g)	-0.321	-0.347	0.020	0.131	0.025	-0.397

yield of this species. From a plant breeding point of view, the existence of wide diversity appears to be of great interest in providing valuable materials. Especially, the genetic variability for winter survival should be utilized in breeding programs. Selection, for further yield tests, from the very large seeded, early maturing lines with reasonable winter survival should produce enhanced adaptation for autumn sowing in the CHT.

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