Growth and development of narbon vetch (*Vicia narbonensis* L.) genotypes in the semi-arid central Turkey

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Abstract

In order to investigate the growth and yield potential of narbon vetch (*Vicia narbonensis* L.), to elucidate the possible associations of plant traits, to inquire the basics of responses shown by genotypes across years through examining of genotype × year interaction effect, and to extrapolate the nature of adaptation, 27 accessions were evaluated for yield and yield related characters over four subsequent cropping seasons (1994-98) in the central Turkey. Days to harvest, biomass, seed yield, and harvest index were measured, and the results were analyzed by multiple statistical procedures: principal component analysis, linear regression analysis, cluster analysis, descriptive statistics, analysis of variance and additive and multiplicative model analysis. Four year effects were grouped into three classes (good, fairly-good and poor). Seed yield was positively correlated with days to harvest in the first ($p < 0.05$) and fourth ($p < 0.001$) years, and with biomass in all years, which made them plastic and fixed traits respectively. For seed yield, the 27 genotypes were separated into four groups, and year and interaction effects were found to be highly significant ($p < 0.001$). Certain genotypes behaved differently; G25 and G11 were more suitable for specific adaptation, while G2, G4, G6 and G27 were best for broad adaptation. These selected genotypes could be used as a set of reference lines in the evaluation of narbon vetch germplasm for better yield and adaptation. The enhanced developmental flexibility through adjusting plant growth-longevity combined well with higher biomass and harvest index is the primary form of narbon vetch adaptation to the semi-arid central Turkey and similar environments in the Mediterranean area.

Additional key words: AMMI model; biomass; days-to-harvest; harvest index; seed yield; specific and broad adaptation.

Resumen

Crecimiento y desarrollo de genotipos de la Veza de Narbona (*Vicia narbonensis* L.) en la Turquía semiárida central

Con el fin de investigar el crecimiento y el rendimiento potencial de la Veza de Narbona (*Vicia narbonensis* L.), dilucidar las posibles asociaciones de caracteres de las plantas, investigar los fundamentos de la respuesta mostrada por los genotipos a través de los años mediante un examen del efecto de la interacción genotipo × año, y extrapolar la naturaleza de la adaptación, 27 accesiones fueron evaluados para rendimiento, y los caracteres relacionados con el rendimiento evaluados durante cuatro temporadas (1994-98). Se midieron los días a cosecha, la biomasa, rendimiento de semillas e índice de cosecha. Los resultados se analizaron por varios procedimientos estadísticos: análisis de componentes principales, análisis de regresión lineal, análisis de grupos, estadística descriptiva, análisis de varianza y AMMI. Los efectos de los 4 años se agruparon en tres clases (buenos, bastante buenos y malos). El rendimiento de

semillas se correlacionó positivamente con los días a cosecha en el primer ($p < 0,05$) y cuarto ($p < 0,001$) año, y con la biomasa todos los años, lo que les hace caracteres plásticos y fijos, respectivamente. Los 27 genotipos se diferencian en cuatro grupos según el rendimiento de semillas, y los efectos del año y su interacción fueron altamente significativos ($p < 0,001$). Ciertos genotipos se comportaron de manera diferente, G25 y G11 son más adecuados para una adaptación específica, mientras que G2, G4, G6 y G27 fueron mejores para una adaptación amplia. Estos genotipos pueden utilizarse como referencia para la evaluación de germoplasma de Veza de Narbona para un mejor rendimiento y adaptación. Una mayor flexibilidad en el desarrollo del crecimiento de las plantas combinada con mayor biomasa e índice de cosecha es la forma primaria de adaptación de la Veza de Narbona en la Turquía central semiárida y ambientes similares del área mediterránea.

Palabras clave adicionales: adaptación específica y amplia; biomasa; días a cosecha; índice de cosecha; modelo AMMI; rendimiento de semillas.

Introduction

Vicia narbonensis L. (narbon vetch), one of the 59 *Vicia* species identified in the natural flora of Turkey (Davis & Plitman, 1970), is mostly cultivated in the Mediterranean countries. Due to its high seed production, narbon vetch is more suitable to be grown as a grain feed, which has been determined as an appropriate ruminant feed (van der Veen, 1960; Mateo-Box, 1961). The seed of some lines with no anti-nutritional components would also have potential for poultry feeding (Francis *et al.*, 1999). Moreover, its high green biomass and ability to fix large amount of nitrogen into the soil make it a valuable green manure crop (Özyazıcı & Manga, 2000; Avcıoğlu *et al.*, 2009). Narbon vetch has a great potency in Turkey (Fırıncıoğlu *et al.,* 1997), although its growing area has been restricted to only few provinces. However, the feed requirements for an expanding livestock population in Turkey necessitate the introduction of forage legumes into crop rotations (Fırıncıoğlu *et al.*, 2007).

The success of growing annual forage legumes in central Turkey largely depends on the degree of resistance to biotic (*i.e.,* diseases and insects) and abiotic (*i.e.,* freezing temperatures in winter, low and uneven distribution of rainfall during growth period, and high temperature at maturity) stress factors (Fırıncıoğlu *et al.*, 1997, 2009a,b). Narbon vetch is well adapted to adverse conditions (Abd El Moneim, 1992) in Waest Asia Region and can be planted in autumn, and is a reasonably winter hardy species, but its plant growth period is restricted to a relatively short duration, falling between early spring and late June, while it stays dormant during winter months (Fırıncıoğlu *et al.*, 1997; Açıkgöz, 1988, 2001). In such an arid environment, selecting for yield is complex as the climatic conditions are inconsistent and quite variable within and between years (Fırıncıoğlu *et al.*, 2009a).

In continental Mediterranean highlands the success of agricultural production is mainly contingent on either overcoming or avoiding of major constraints such as low air temperature and seasonal drought (Keatinge *et al.* 1991). The effectual assessment of environmental influences on genotypic responses is possible through the studies on yield and yield-related characters (*i.e.* phenology, biomass, and harvest index) (Fırıncıoğlu *et al.*, 2009a,b, 2010). Therefore, to improve adaptation and yield in narbon vetch, it is essential to have insights into the magnitude of responses of growth and yield to production environments.

Vicia species have usually revealed genotype × environment interaction (GEI) in multi-environmental trials (Abd El Moneim *et al.,* 1988; Abd El Moneim*,* 1992; Siddique *et al.*, 1996, 1999), which has breeding merits for developing improved varieties (Allard & Bradshaw, 1964; Eberhart & Russell, 1966). After recognizing the importance of GEI analytical methods have been developed to measure and describe them (Cooper & DeLacy, 1994). There are several methods available to assess the adaptability and yield stability for a set of genotypes. Among them universal methods for additive effects such as stability analyses, based on linear regression (Finlay & Wilkinson, 1963; Eberhart & Russell, 1966; Verma *et al.,* 1978; Cucolotto *et al.,* 2007) have been widely used. Alternatively, to enumerate the effect of GEI caused by each genotype, the statistical model AMMI as the combination of both additive main effects and multiplicative interaction effects has been used (Gauch, 1992).

In narbon vetch, GEI was explained by the soil properties such as high soil pH and clay content (Siddique *et al.*, 1999), and was defined by the tolerance to low rainfall (Abd El Moneim, 1992). Moreover, GEI may

invoke some chances for the selection of genotypes showing positive associations with the environmental conditions (*i.e.* specific adaptation) or of genotypes with low frequencies of poor yield (*i.e.* yield stability) (Simmonds, 1991; Ceccarelli, 1996) as cited in Annicchiarico (2002). In addition, Wade *et al.* (1999) reported the use of the known responsiveness of a set of genotypes to certain environments is as an indicator set to classify environmental conditions. Furthermore, the three major components of yield (time required from planting to harvest, accumulation of biomass and harvest index) are controlled by GEI (Wallace *et al.*, 1993).

Growth and development malleability of narbon vetch to varying environmental conditions can display its adaptive and productive limits. However, there has been only few published data available on yield and yield components of narbon vetch (Çakmakçı *et al.*, 1999; Büyükburç & İptaş, 2001; Yücel, 2004; Yılmaz, 2008). Therefore, this investigation was aimed to: (1) determine the growth and yield potentials of selected *V. narbonensis* lines; (2) elucidate possible associations between seed yield and yield-related characters; (3) examine the basics of responses shown by genotypes across environments through analysis of genotype × year interaction (GYI) effects; and (4) enlighten the nature of its adaptation.

Material and methods

Variety performance tests were conducted from 1994 to 1998 at the Research Farm of the Central Research Institute for Field Crops (CRIFC) in Haymana, which is located 44 km south-west of Ankara. The experimental site has clay loam soil texture with high lime content, low organic matter, is slightly alkaline and poor in phosphorous and nitrogen but it has adequate potassium. Twenty-seven genotypes of *V. narbonensis* L. were studied, a genotype G1 from a local population and 26 accessions (G2 to G27) selected in previous years from the ICARDA (International Center for Agricultural Research in the Dry Areas, Aleppo, Syria) Narbon Vetch International Adaptation Trials. The study site, which is located in central Turkey, represents the major vetch seed production area (Açıkgöz, 1988, 2001). The trials, depending on local weather conditions, were established in the first half of October in 1994, 1995, 1996 and 1997. The weather conditions were quite variable through the four cropping seasons, therefore, for simplicity each trial season was considered as an individual year and thus represented four-experimental years (Y1 to Y4).

The experiments were laid out in a completely randomized block design with three replicates. For all sowings, the previous crop was a cereal. Plots were 1.5 m wide (consisting of six, 5 m rows, 25 cm apart) and were sown by a sowing-machine with a density of 90 seeds m^{-2}. Although not a common practice in the region, 100 kg ha^{-1} of composite fertilizer, di-ammonium phosphate (DAP-18 43%), to provide optimum growth conditions for genotypes were added into experimental plots during sowing (Avcıoğlu *et al.,* 2009). Weeds were controlled by a post-planting pre-emergence herbicide (Linurex) spray and in the spring by hoeing and hand.

Seed yield (SY) and three yield-related characters were evaluated in the experiments: (1) days-to-harvest (DH), number of days from sowing to harvest (when seeds become brown and hard); (2) biomass (BI) of plants at full maturity, cut by a reaping hook in each plot of a 6.0 m^2 area (6 rows, 1.5 m wide, 4 m long), weighed (kg ha^{-1}); (3) harvested plants were thrashed for seed, weighed and recorded as SY (kg ha^{-1}); (4) harvest index (HI) was assessed in each plot by dividing SY by BI.

Cropping seasons (*i.e.* year effect) were described and characterized by employing principal component analysis (PCA). PCA, based on correlation matrices, was performed on both biological data of accession means of each trial and environmental data across the years, and was used to construct a biplot (*i.e.* loading and score plots overlapped) of genotypes (*i.e.,* cropping years). Four climatic variables were March, April and May mean temperatures (MarT, AprT and MayT) at the vegetative stage and rainfall at the reproductive stage (RSR) (June), while biological attributes were DH, BI, SY and HI.

Cluster analysis (CA) was carried out on the mean seed yield of 27 accessions in each trial in order to group the genotypes into groups (GGrs). As Annicchiarico (2002) recommended for the analysis of adaptation trials, clustering was performed with the use of average linkage method (*i.e.* four clusters) on the standardized data of genotypes mean SY across years with squared Pearson distance measure. In addition, descriptive statistics (DS) [mean, standard error of means (SEM), coefficient of variation (CV), and minimum (Min) and maximum (Max) values] were calculated for each GGr, because after data transformation, most data of DH, BI and HI did not satisfy the assumption of variance homogeneity.

The relationships of SY with yield components (*i.e.* DH, BI and HI), across years were investigated. Simple linear regression with groups (SLRG) analysis, a useful method of depicting trends across cropping years, was performed jointly on the G means of each trial. SLRG was used in this study, because there were factors as well as varieties in the set of explanatory variables in the data set. In the analysis, SY, yield components and years were taken as response, explanatory and factor respectively. Based on the variable × year interactions, the slope (*b*) significances of each year separately (*i.e.,* fitted terms: year + yield component + yield component × year) and differences from the reference year (Y1) (fitted terms: constant + yield component + year + yield component × year) were estimated. The Y1 was selected because it was the best production year.

Analysis of variance (ANOVA) was used to enumerate sources of variation, and SY data were statistically analyzed. The combined ANOVA was conducted on genotypes for all trials, and the model included genotypes as fixed effect and years as random effect (Annicchiarico, 2002). To identify the yield differences between GGrs across four cropping years, an accumulated ANOVA with the unbalanced structure design was performed, since each GGr contains different number of accessions. The comparisons of means were done using LSD test, on the basis of significance at $p < 0.05$ level. Before conducting ANOVA SY data were transformed to square root data (SQRT) to satisfy the assumption of homogeneity of variance.

In order to evaluate the magnitude and significance of GYI effect and to determine the breeding merits of narbon vetch genotypes, the additive and multiplicative model (AMMI) was performed on the seed yield data of genotypes across four years. AMMI makes the combination of both ANOVA and PCA into a single analysis with both additive and multiplicative parameters and the percentage of the treatment sum of square (SS) was employed as a useful summary statistic to assess the overall goodness of fit (Gauch, 1992). In the AMMI analysis, genotypic differences in yield stability and adaptability to varying environmental conditions can be evaluated quantitatively (Pacheco *et al.,* 2005). Moreover, the construction of biplots by plotting the main *vs.* interaction effects (scores) and IPCA-1 *vs.* IPCA-2 scores facilitates greatly to visualize the GYI effects.

PCA, CA and DS were carried out using the MINITAB vers. 14.0 (Minitab Inc.), GENSTAT Discovery vers. 3.0 (VSN Int) was used for the analysis of SLRG, ANOVAs' and AMMI model.

Results

Climatic conditions and characterization of cropping seasons

In this study, weather conditions were dominant factors controlling plant growth and development, and thus the four cropping seasons affected narbon vetch growth and production differently. During winter months, Table 1 shows that mean minimum temperatures were lower in December of Y1 and in February of Y3 (–2°C, –4°C, respectively), compared to the long-term average (–1 and –2°C). At the vegetative stage (March to May), average temperatures in Y1, Y2 and Y3 were higher (17°C) than the long-term average (16°C), while it was greater only in Y1 (21°C) at reproductive phase (June). Reproductive stage in all cropping seasons followed more or less the same temperature pattern. However, in Y4 April mean minimum (7°C) and maximum (19°C) temperatures were considerably higher, and May mean maximum temperature (21°C) was lower, compared to those of Y1, Y2 and Y3. Hence, narbon vetch was exposed to excessive temperature fluctuations during the vegetative growth stage in Y4. Across the cropping seasons, the rainfall received during the vegetative growth period was 25, 30, 23 and 24% higher, respectively, compared to the long-term average. However, at the reproductive stage 95% less and 71% more rainfall were received in Y2 and Y3, respectively, than the long-term average (36 mm). Therefore, high variation in air temperature at the vegetative stage in Y4 probably made this cropping season relatively stress prone for crop growth and development.

The PCA characterized the cropping seasons successfully. Table 2 shows that the first three PCs produced eigenvalues greater than 1, and explained 85% of the total variation (TV) together. The scores on the PC_1, which accounted for 39% of TV alone, were correlated positively with SY, HI and MayT, but negatively with DH and AprT. The PC_2, 25% of TV, was associated positively with BI, SY, MarT and AprT but negatively with DH. Therefore, the four cropping seasons are effectively separated by the first two PCs' axes, which accounted for the major portion of TV (64%). The biplot of PCA, based on factor loadings (vectors) and scores of PC_1 *vs.* PC_2 (Fig. 1) illustrates how different attributes

Table 1. Climatic data for long-term (1982 to 2006) and for four successive cropping seasons (years, Y); March to May (vegetative stage) and June (reproductive stage)

Temperature (°C)		O	N	D	J	F	M	A	M	Mean[1]	J
1982-2006	Average	13	6	2	1	1	5	11	16	11	20
	Maximum	19	12	6	4	6	11	17	22	17	26
	Minimum	7	2	−1	−2	−2	0	6	9	5	13
1994-95 (Y1)	Average	16	5	0	3	5	6	10	17	11	21
	Maximum	22	9	3	7	10	11	15	23	16	28
	Minimum	10	2	−2	0	0	2	4	10	5	14
1995-96 (Y2)	Average	11	3	3	1	4	4	9	17	10	20
	Maximum	17	7	6	4	9	7	14	24	15	26
	Minimum	6	0	0	0	0	0	3	11	5	12
1996-97 (Y3)	Average	11	8	6	2	0	3	7	17	9	20
	Maximum	17	15	10	6	6	9	12	23	15	26
	Minimum	7	2	4	−1	−4	−1	3	11	4	14
1997-98 (Y4)	Average	13	7	4	2	3	4	13	16	11	20
	Maximum	18	12	7	6	8	9	19	21	16	25
	Minimum	9	2	1	−1	−1	0	7	10	6	14

Precipitation (mm)	O	N	D	J	F	M	A	M	Total[1]	J
1982-2006	31	37	39	34	35	36	54	49	139	36
1994-95 (Y1)	30	67	20	34	11	92	61	30	183	61
1995-96 (Y2)	28	61	22	30	38	79	36	83	198	2
1996-97 (Y3)	44	9	65	37	18	15	91	72	178	123
1997-98 (Y4)	60	36	65	11	53	47	71	64	182	47

[1] Mean and total indicate the mean temperature and total precipitation at vegetative stage.

Table 2. Principal component analysis of four biological and four climatic characters associated with 27 narbon vetch (*Vicia narbonensis* L) lines grown in four successive cropping seasons (1994-98)

Variables	PC1	PC2	PC3	PC4
Days to harvest (DH)	**−0.369**	**−0.420**	0.205	**0.378**
Biomass (BI)	−0.045	**0.450**	**0.568**	0.173
Seed yield (SY)	**0.316**	**0.304**	**0.410**	**0.448**
Harvest index (HI)	**0.448**	−0.215	−0.262	**0.333**
Reproductive stage rainfall (RSR)	0.111	−0.176	**0.488**	**−0.682**
March mean temperature (MarT)	0.084	**0.598**	**−0.348**	−0.211
April mean temperature (AprT)	**−0.483**	**0.303**	−0.192	0.074
May mean temperature (MayT)	**0.556**	−0.033	−0.050	−0.026
Eigenvalue	3.125	2.007	1.699	0.993
Proportion of variation (%)	39.1	25.1	21.2	12.4
Cumulative proportion of variation (%)	39.1	64.2	85.4	97.8

Factors with heavy loadings (more than 3.00) in PC's are accentuated by bolding. The data matrix consisted of 108 rows (*i.e.,* 27 genotypes replicated over four years) and 8 columns of variables.

are related, and provides a scheme for the evaluation of these relations across the years. The importance of these attributes in PCs' is indicated by the strength (*i.e.,* length) and direction of the arrows. Biplot vectors show that PC$_1$ mainly separated the years through the G re-

sponses based on SY, HI and MayT, which was strongly contrasted with DH and April T, whereas PC$_2$ discriminated the years on the basis of BI, SY, MarT and AprT, which was sturdily contrasted with DH (Fig. 1). In the first two PCs', RSR was the only variable which
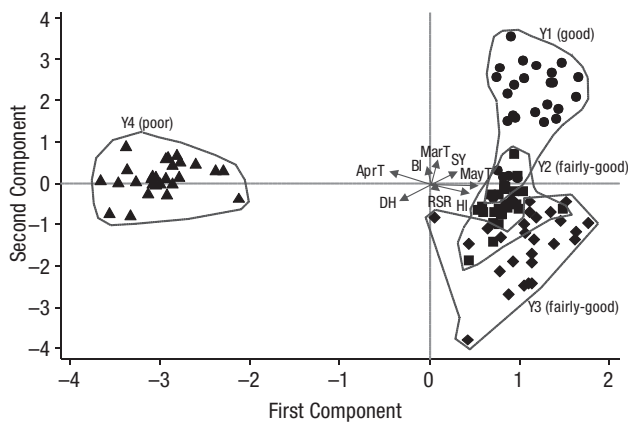
Figure 1. Year effect characterization; the bi-plot of the first *vs* second PC on the basis of biological data [days to harvest (DH), biomass (BI), harvest index (HI) and seed yield], and climatic data [reproductive stage (June) rainfall (RSR), March mean temperature (MarT), April mean temperature (AprT), and May mean temperature (MayT)] in 27 narbon vetch genotypes grown in consecutive cropping years [1994-95 (Y1:●), 1995-96 (Y2:■), 1996-97 (Y3:◆) and 1997-98 (Y4:▲), circled with the dashed lines].

did not make a significant effect on years. Accordingly, the genotypes in the four years were scattered differently in the biplot. The genotypes in Y1 and Y3 were located on the upper and bottom right quadrants of biplot respectively, while in Y2 they were gathered between them. Contrarily, these genotypes in Y4 were situated around the left-end of x-axis. Therefore, in terms of genotypic responsiveness, the genotypes became more similar in Y1, Y2 and Y3 than in Y4.

Relationships of seed yield with yield components

The relations of SY with DH, BI and HI, which could be used as selection criteria, were investigated to assess the effects of yield components on productivity (Fig. 2). As the genotypic responses to the production environments varied, the trends of these associations differed largely. The mean SY of genotypes was significantly increased as the DH was lengthened in Y1 ($p < 0.05$) and Y4 ($p < 0.001$), while only the slope (*b*) of regression line in Y3 was significantly different from that of the reference level (*b* in Y1) (Fig. 2a). Furthermore, BI was related significantly and positively with SY across all years, and the slopes of regression line in Y2, Y3 and Y4 were not significantly diverted from that of the reference level (Y1) (Fig. 2b). As HI increased, SY significantly decreased in Y1 ($p < 0.001$), and significantly increased in Y4 ($p < 0.01$). However, the slopes (*b*) in Y3 and Y4 were significantly different from that in Y1 (Fig. 2c).

Grouping of genotypes for seed yield and yield components of genotype groups

Dendrogram derived from CA illustrates that the similarity levels of each GGr were quite high and in general as the similarity level increased the number of genotypes included in cluster groups also increased (Fig. 3). In terms of SY production, at 85% similarity
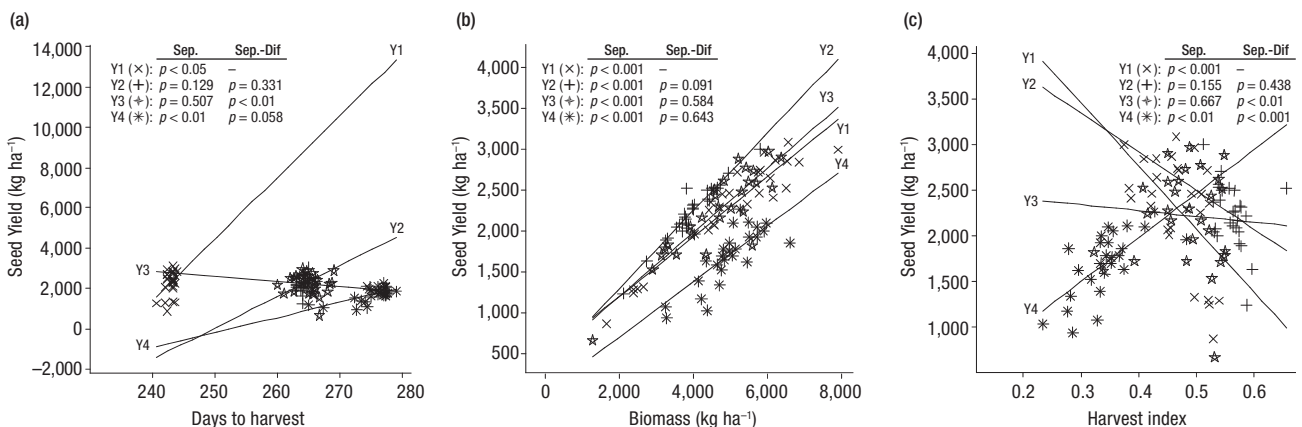

Figure 2. Relationships of seed yield with (a) days to harvest, (b) biomass and (c) harvest index of 27 narbon vetch genotypes grown in four years [Y1 (×); Y2 (+); Y3 (✦); Y4 (✳)]. Significance of slopes (*b*) for groups: separated (Sep.) and estimated, and separated and estimated for differences (Sep-Dif.) from the reference level (Ref.Lev. = Y1) in interactions. The estimated variances, accounted for, are 28.1, 84.3 and 33.6% for the respective variables, and the significance of interactions in the Sep. and Sep-Dif. analyses were $p < 0.001$ and $p < 0.05$ for DH, $p < 0.05$ and $p=0.310$ for BI, $p < 0.001$ and $p < 0.001$ for HI, respectively.
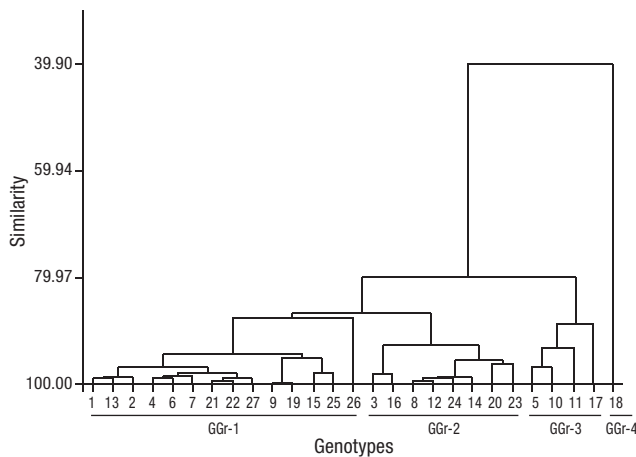
Figure 3. Dendrogram for genotype grouping (GGr) based on the mean seed yield data of the 27 narbon vetch lines grown in four years.

265 days in Y3 and 264 days in Y2, and was 243 days (shortest) in Y1. GGrs responded similarly to plant growth-longevity across years. However, BI varied largely, ranging between 5,054 kg ha^{-1} in Y1 and 4,001 kg ha^{-1} in Y2. Over the years, the BI production was highest and lowest (5,274 and 2,071 kg ha^{-1}) in GGr-1 and GGr-4, respectively, while GGr-1 had the highest BI in all years. HI was largest (0.56) in Y2, was reduced to 0.49 in Y3, 0.47 in Y1 and 0.34 in Y4. Over-all years GGr-4 had highest HI (0.50), followed by GGr-3 (0.48), and GGr-2 (0.46) along with GGr-1. The HI of GGr-4 was highest (0.59) in Y2, while it was lowest (0.31) for GGr-2 in Y4.

Seed yields of genotypes and genotype groups

ANOVA revealed that main effects of G, Y and GYI effects, and GGr and GGrYI effects for seed yield were highly significantly different ($p < 0.001$) (Table 4).

The SY of genotypes and GGrs across cropping years are given in Table 5. The mean SY ranged from 2,304 kg ha^{-1} in Y1 to 1,699 kg ha^{-1} in Y4. Over the four years, nine genotypes (G1, G2, G13, G15, G21, G22, G25, G26 and G27) were in the highest yielding group, while three genotypes (G1, G2 and G27) produced greatest SY in all years. Mean SYs of four genotypes

level, 27 narbon vetch genotypes could be grouped into four GGrs. GGr-1 and GGr-2 had 14 and 8 entries while GGr-3 and GGr-4 had 4 and 1 accessions, respectively. According to the similarity levels, it appeared that GGr-1 and GGr-2 were more alike than GGr-3, while GGr-4 (only one entry) was quite distinct.

The descriptive statistics of GGrs across four cropping years for DH, BI and HI are given in Table 3. The mean DH was 275 days (longest) in Y4, followed by

Table 3. Descriptive statistics of 27 genotypes (Gs) and four genotype groups (GGr) for the yield components (DH: days to harvest, BI: biomass (kg ha^{-1}) and HI: harvest index); mean and standard error of means (± SEM), coefficient of variation (CV%) and minimum–maximum values for narbon vetch grown across four cropping years (Y)

Varia-bles	GGrs	N	Y1			Y2			Y3			Y4			GGrs Mean ± SEM
			Mean ± SEM	CV (%)	Min – Max	Mean ± SEM	CV (%)	Min – Max	Mean ± SEM	CV (%)	Min – Max	Mean ± SEM	CV (%)	Min – Max	
DH	GGr-1	14	243 ± 0.20	0.3	242-244	265 ± 0.19	0.3	264-266	265 ± 0.54	0.8	263-269	276 ± 0.25	0.3	274-277	262 ± 1.64
	GGr-2	8	243 ± 0.23	0.3	242-244	264 ± 0.30	0.3	263-265	265 ± 0.80	0.9	261-268	274 ± 1.36	1.4	267-279	262 ± 2.11
	GGr-3	4	243 ± 0.65	0.5	241-244	264 ± 0.29	0.2	263-264	264 ± 1.50	1.1	260-266	273 ± 2.83	2.1	265-277	261 ± 2.97
	GGr-4	1	242			264			267			274			262 ± 6.91
	Gs	27	243 ± 0.15	0.3		264 ± 0.17	0.3		265 ± 0.43	0.9		275 ± 0.60	1.13		
BI	GGr-1	14	6068 ± 240	14.8	4510-8010	4344 ± 163	14.0	3657-5860	5352 ± 15	10.2	4610-6443	5332 ± 140	9.8	4070-6040	5274 ± 12
	GGr-2	8	4993 ± 242	13.7	4447-6280	3913 ± 148	10.7	3330-4587	3775 ± 32	23.6	2910-5647	4945 ± 271	15.5	4173-6687	4407 ± 16
	GGr-3	4	2481 ± 64	5.2	2383-2660	3451 ± 282	16.4	2743-4010	4795 ± 50	20.8	3947-6207	4197 ± 329	15.7	3293-4867	3731 ± 27
	GGr-4	1	1643			2110			1260			3270	-		2071 ± 44
	Gs	27	5054 ± 308	31.6		4001 ± 139	18.0		4651 ± 230	25.7		4973 ± 151	15.8		
HI	GGr-1	14	0.450 ± 0.01	11.7	0.37-0.52	0.55 ± 0.01	6.5	0.51-0.66	0.49 ± 0.01	8.6	0.42-0.55	0.37 ± 0.01	13.0	0.29-0.48	0.46 ± 0.01
	GGr-2	8	0.47 ± 0.01	4.5	0.45-0.51	0.56 ± 0.00	1.9	0.54-0.57	0.48 ± 0.03	17.5	0.32-0.55	0.31 ± 0.01	13.1	0.23-0.34	0.46 ± 0.02
	GGr-3	4	0.52 ± 0.01	3.1	0.50-0.54	0.59 ± 0.01	1.6	0.58-0.60	0.48 ± 0.03	10.7	0.41-0.52	0.33 ± 0.03	15.0	0.28-0.37	0.48 ± 0.03
	GGr-4	1	0.53		0.53	0.59			0.53			0.33			0.50 ± 0.06
	Gs	27	0.47 ± 0.01	10.4		0.56 ± 0.01	5.3		0.49 ± 0.01	11.62		0.34 ± 0.01	14.8		

The list of genotypes included in GGrs is given in Table 5 and Figure 3.

Table 4. ANOVA on seed yield data (SQRT transformed) across four cropping years for 27 genotypes (a) and 4 GGrs (b), degree of freedom (df), sum of squares (SS), mean square (MS)

Source of variation	df	SS	MS	*F*-value	*F*-pr.
(a) for genotypes					
Genotypes (G)	26	6,337	243.7	6.16	< 0.001
Year (Y)	3	2,332	777.3	59.93	< 0.001
G × Y interactions	78	3,086	39.6	3.05	< 0.001
Block [Y]	8	179	22.3	1.72	< 0.095
Residuals	208	2,698	12.97		
Total	323	14,631			
(b) for genotype groups					
Genotype groups (GGr)	3	5,508	1,835.9	116.48	< 0.001
Year (Y)	3	2,332	777.3	49.31	< 0.001
GGr × Y interactions	9	1,884	209.3	13.28	< 0.001
Block [Y]	8	179	22.3	1.42	0.189
Residuals	300	4,729	15.8		
Total	323	14,631	45.3		

Table 5. Mean seed yield (kg ha^{-1}) of the 27 genotypes (Gi) and four genotype groups (GGrs) in four cropping years (Y)

		Square rooted					Actual				
		Y1	**Y2**	**Y3**	**Y4**	**Mean**	**Y1**	**Y2**	**Y3**	**Y4**	**Mean**
G1		53.38	50.66	53.85	45.14	**50.76**	2,850	2,567	2,903	2,053	**2,593**
G13		54.45	48.23	52.59	45.82	50.27	2,970	2,330	2,777	2,110	2,547
G2		53.28	50.00	50.98	**47.56**	50.46	2,843	2,530	2,603	**2,267**	2,561
G4		49.60	48.69	47.75	44.70	47.69	2,463	2,373	2,280	2,000	2,279
G6		51.33	48.71	47.90	41.97	47.48	2,647	2,393	2,297	1,763	2,275
G7		48.47	47.49	51.16	42.91	47.51	2,353	2,267	2,620	1,860	2,275
G21		49.06	50.20	52.20	43.81	48.82	2,410	2,523	2,737	1,930	2,400
G22		47.77	52.06	50.58	43.89	48.58	2,327	2,713	2,597	1,927	2,391
G27		52.13	50.11	50.09	44.02	49.09	2,720	2,523	2,513	1,963	2,430
G9		52.38	44.66	49.30	41.22	46.89	2,743	2,000	2,437	1,700	2,220
G19		50.12	45.03	49.57	41.22	46.49	2,523	2,040	2,483	1,700	2,187
G15		49.50	45.59	53.61	45.78	48.62	2,457	2,083	2,887	2,103	2,383
G25		**55.50**	45.34	**54.53**	45.68	50.26	**3,087**	2,080	**2,977**	2,097	2,560
G26		54.68	**54.78**	47.18	40.29	49.23	2,997	**3,003**	2,243	1,623	2,467
	GGr-1	51.55	48.68	50.81	43.86	48.72	2,671	2,388	2,597	1,935	2,398
G3		44.86	45.13	41.45	31.89	40.83	2,013	2,050	1,720	1,030	1,703
G16		45.58	43.67	42.66	36.52	42.11	2,090	1,913	1,820	1,340	1,791
G8		47.88	46.28	39.14	39.83	43.28	2,297	2,143	1,533	1,593	1,892
G12		49.61	47.55	41.34	40.54	44.76	2,463	2,277	1,710	1,647	2,024
G24		45.23	46.50	41.93	38.97	43.16	2,070	2,173	1,783	1,523	1,888
G14		47.32	45.82	42.38	42.21	44.43	2,257	2,107	1,830	1,783	1,994
G20		53.60	49.85	44.23	43.00	47.67	2,873	2,497	1,963	1,860	2,298
G23		52.00	49.95	40.90	37.10	44.99	2,723	2,497	1,720	1,390	2,083
	GGr-2	48.26	46.84	41.75	38.76	43.90	2,348	2,207	1,760	1,521	1,959
G5		35.88	43.35	45.23	40.45	41.23	1,290	1,890	2,060	1,637	1,719
G10		35.94	48.12	46.52	42.15	43.18	1,297	2,317	2,170	1,780	1,891
G11		36.34	46.97	50.25	34.09	41.91	1,323	2,217	2,527	1,173	1,810
G17		35.18	40.37	46.39	30.28	38.06	1,247	1,637	2,170	940	1,498
	GGr-3	35.84	44.70	47.10	36.74	41.09	1,289	2,015	2,232	1,383	1,730
G18	GGr-4	29.48	35.21	25.88	32.72	30.82	870	1,240	670	1,073	963
Mean		47.43	47.05	46.65	40.88	45.50	2,304	2,236	2,223	1,699	2,116

In SQRT data Lsd$_{(0.05)}$. for G; Y = 1.116, G = 2.898, G × Y = 5.797, and Lsd$_{(0.05)(averaged)}$ for GGr: Y = 1.228, GGr = 1.818, GGr × Y = 3.585, Bolded and underlined values indicate the highest yielding G and in highest ranking group in corresponding variables, respectively.

(G5, G10, G11 and G17) in GGr-3 were relatively lower in Y1 (a good year), compared to those in Y2 and Y3, whereas the reverse was true for G23 and G20. Moreover, G9, G19 and G23 were among the high ranking genotypes (2,743, 2,523, and 2,723 kg ha^{-1} respectively) in Y1 while they significantly reduced their ranking order (1,700, 1,700 and 1,390 kg ha^{-1} respectively) in Y4.

Over the four years, GGr-1 produced the highest SY (2,398 kg ha^{-1}), followed by GGr-2 (1,959 kg ha^{-1}), while GGr-4 had the lowest (963 kg ha^{-1}). GGr-1 had the highest SY in all years (2,671, 2,388, 2,597 and 1,935 kg ha^{-1}, respectively), whereas GGr-2 was in the best yielding group in Y1 (2,348 kg ha^{-1}), while GGr-4 had the lowest SY in all cropping years (870, 1,240, 670 and 1,073 kg ha^{-1}) respectively.

Genotype × year interaction

The results of ANOVA, based on AMMI model, are presented in Table 6. The analysis revealed that narbon vetch SY was significantly influenced by G, Y and GYI effects ($p < 0.001$). The treatments SS captured 80% of the total SS, was proportioned to 54% of the G-SS, 20% of the Y-SS, and 26% of the GYI SS. A large yield variation explained by genotypes suggested that the genotypes were quite diverse. Therefore, though G-SS is pretty large, the GYI-SS is greater than the Y-SS, so GYI effect is important. In addition, in the AMMI model the first three interaction principal components (IPCAs') were found to be highly significantly different ($P < 0.001$, $P < 0.001$ and $P < .0.05$, respectively), and IPCA-1 (52%) along with IPCA-2 (29%) jointly explained the major portion of interaction effect (81%), while IPCA-3 accounted for only 19%. Therefore, the use of the first two IPCAs' for the construction of biplots provided clear evidence to explain the interaction efficiently, and on the basis of these two axis it could be prudent to conclude either general or specific adaptability and breeding merits of these genotypes.

Figure 4a shows both the G and Y main effects on the abscissa, and the IPCA-1 scores of GYI effect on the ordinate. Displacements along the abscissa show differences in main effects, while displacements along the ordinate indicate differences in interaction effect. The IPCAs' scores of genotypes: closer to zero indicate appropriateness for the general adaptation whereas farther from zero exhibit aptness for the specific adaptations (Ebdon & Gauch, 2002). The genotypes were scattered from right to left along abscissa as they were grouped by CA (Fig. 3). The four genotypes with high SY (G1, G2, G13 and G25) overall years (Table 5) and with low IPCA scores were gathered on the right-end of abscissa, in contrast G18 (GGr-4) with low SY was located in the left-end (Fig. 4a). Though the GYI effect was quite high for Y1 and Y3, it was very low for Y2 and Y4 (Fig. 4a). The biplot of IPCA-1 *vs.* IPCA-2 depicted the two ways of interaction pattern jointly (Fig. 4b). The four genotypes (*i.e.,* G2, G27, G16 and G3) being gathered near to the origin revealed the greatest yield stability, whereas G18, G10, G11, G17, G25 and G23 behaved highly interactively. As being the extreme genotypes, G25 yielded highest in Y1 and

Table 6. AMMI analysis of variance for seed yield data (SQRT transformed) of 27 genotypes grown across four cropping years, degree of freedom (df), sum of squares (SS), mean square (MS)

Source of variation	df	SS	MS	*F*-value	*p*-value	
Total	323	14,631	45.3			
Treatments	107	11,755	109.9	8.47	**0.00000**	% of treatment SS
Genotypes (G)	26	6,337	243.7	18.79	**0.00000**	53.91
Year (Y)	3	2,332	777.3	34.82	**0.00000**	19.84
Block [Y]	8	179	22.3	1.72	0.09509	0.02
G × Y interactions	78	3,086	39.6	3.05	**0.00000**	26.25
						% of GYI SS
IPCA 1	28	1,604	57.3	4.42	**0.00000**	51.98
IPCA 2	26	907	34.9	2.69	**0.00005**	29.39
IPCA 3	24	575	24.0	1.85	**0.01199**	18.63
Residuals	0	0				
Pooled error	208	2,698	13.0			

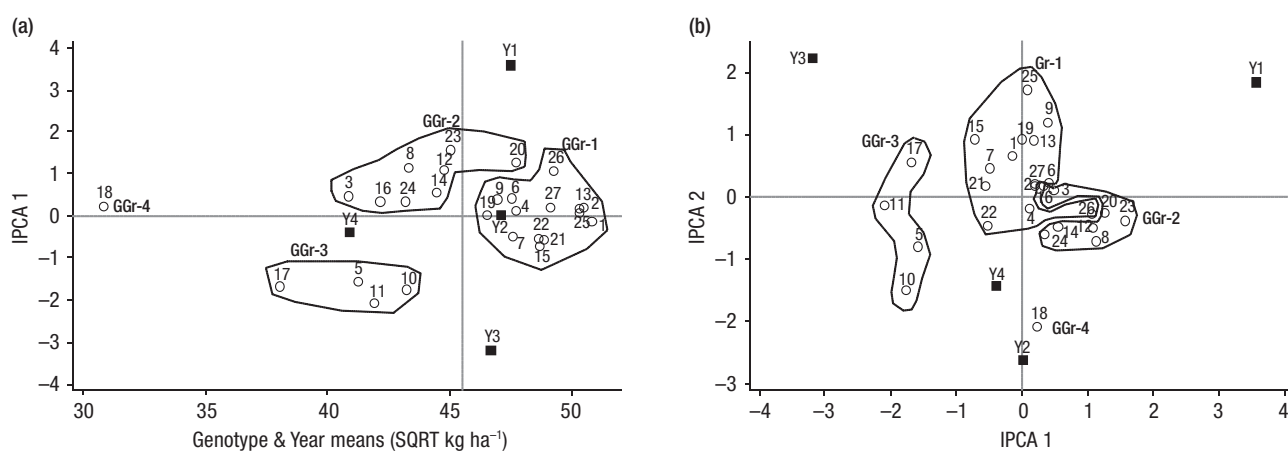Bold *p*-value = significant differences.

Figure 4. Biplots: (a) genotype & year means *vs* IPCA1, and (b) the first two ordination scores (IPCA 1 *vs.* IPCA 2) for the seed yield of 27 genotypes (individual numbers) and across cropping years (the empty circles and filled squares denote genotypes and years respectively). Four genotype groups (GGr) identified by CA are GGr-1, GGr-2, GGr-3 (circled with the dashed lines) and GGr-4.

Y3 (Table 5), and was placed between them along x-axis in upper right quadrant (Fig. 4b), while G18 performed poorly in all the years (Table 5), and was located between Y2 and Y4 (Fig. 4b).

Discussion

This study has demonstrated the adaptive responses of 27 narbon vetch genotypes to various climatic conditions in the four consecutive cropping seasons in the semi-arid central Turkey. Highly significant GYI effect for SY occurred due to the alterations in the ranking order of genotypes across production years. The genotypes had the greatest effect on the SY variation, but GYI effect was higher than the Y effect. Therefore, understanding of the yield performances of genotypes, based on GYI effects, is critical to elucidate the nature of adaptation.

PCA characterized four cropping years successfully and produced consistent results. Both biological (*i.e.,* yield and yield components) and climatic (*i.e.,* monthly men temperature and monthly rainfall) variables across cropping seasons have revealed that how these attributes associate and contribute to narbon vetch adaptation and productivity (Table 2, Fig. 1). Although the seed size of narbon vetch accessions was not studied in this study, its fundamental role in adaptation and yield has been well recognized. Explicitly in *V. narbonensis*, large seed size provides high seedling vigor, which enables this species to flower and mature relatively early, and helps it to avoid the terminal drought on seed filling (Abd El Moneim, 1992; Berger, 2000). In the present study, the

variation of the G performances was associated largely with the climatic conditions. MarT, AprilT and MayT experienced during vegetative stage in Y1 increased BI, SY and HI, and shortened DH, while MayT prevailed in Y2 increased SY and HI, but MarT and AprilT lengthened DH. Contrarily, high April and low MayT experienced in Y4 considerably reduced SY and HI and prolonged DH. Vacillating temperature combined with high rainfall at vegetative stage was likely to have delayed maturity in Y4, while an increase in air temperature in May and June also increased SY, BI and HI in Y1. More importantly, the variation in climate substantially influenced the plant growth period, and in the present study the effect of higher air temperature appeared to be more preponderance on seed yield than rainfall. The extreme dry weather experienced at reproductive stages of Y2 did not affect SY considerably, because the sufficient water was accumulated in soil during vegetative growth stage. Similarly, narbon vetch lines were exposed to the exceeding wet conditions did not suffer from yield losses. In this context, Abd El Moneim (1992) reported that yield in *V. narbonensis* was weakly related with rainfall pattern, which varied between 195 and 504 mm in a four-year study. In this study, however, in Y4, narbon vetch became quite sensitive to the low and high temperatures combined with high rainfall prior to bud initiation and flowering, which were likely to have caused to prolonging of growth longevity, flowering-delay and further flower-abortions. Hence, it appeared that the year's effect on the growth and development of narbon vetch could be described as to be good in Y1, fairly-good in Y2 and Y3, and relatively poor in Y4.

Berger *et al.* (2002) grouped plant characters in two categories; (1) fixed traits (*i.e.,* positively associated with yield under all conditions) and (2) plastic traits (*i.e.,* variable among environments to optimize yield). In terms of DH and HI, genotypes became more responsive in two contrasting cropping years; Y1 (good) and Y4 (poor). Hence, as SY was increased, DH in Y1 and Y4, and HI in Y4 were also increased significantly. Contrarily, HI in Y1 was considerably reduced (Figs. 2a and 2c), and thus indicating that as growth and developmental plasticity, narbon vetch genotypes are able to respond to environmental changes by adjusting growth longevity and dry-matter portioning to sources and sinks. In fact, *V. narbonensis* genotypes are able to exploit favorable and high rainfall environments efficiently because they are able to make best combinations possible among plant traits (Berger *et al.*, 2002). Therefore, it suggested that the short growth period in Y1 led to proportion more dry-matter into the seed mass, while it was contrary in Y4. As a result, it allows narbon vetch to optimize its adaptation and yield. Moreover, the high responsiveness in phenology optimizes crop adaptation to different environmental conditions through early and late flowering (Berger *et al.*, 2002). As a result, weather conditions experienced in Y2 and Y3 lessened the phenological responsiveness and hence, DH and HI, which varied widely across environments, became plastic traits. Büyükburç & İptaş (2001), and Yücel (2004) have also reported the positive relations of SY with BI and HI in narbon vetch. Similarly, in this study, BI which had a strong positive association with SY in all environments made it a fixed trait, thus suggesting its enhancive potential for SY improvement.

In terms of SY, 27 narbon vetch genotypes, based on similarity levels, could be grouped by CA into the four GGrs (Fig. 3). This grouping was quite efficient and was affirmed by the results of SY and yield components (Table 3, Table 5 and Fig. 4). Although the DH of GGrs was similar across cropping years, BI and HI varied substantially (Table 3). These alterations made each individual GGrs more peculiar and responsive to changing environmental conditions. In the larger-seeded *Vicia* species, the combination of seedling vigor, which relates with productivity and huge morphological diversity, bring reduces the influence of phenology on yield in Mediterranean climates, and thus this strategy would lead to better yield stability (Berger *et al.*, 2002). As a response to good (*i.e.,* short growth longevity) and poor (*i.e.,* expanded growth longevity) conditions, the mean SY was highest (2,304 kg ha^{-1}) in Y1, and significantly reduced to 1699 kg ha^{-1} in Y4 (Table 5).

The mean SY of genotypes also differed significantly, but these differences were not consistent across the four cropping years. The GYI effect influenced the ranking order of genotypes, and was intricate. Certain genotypes performed better than others; for example, G1 (2,593 kg ha^{-1}), G2 (2,561 kg ha^{-1}) and G27 (2,430 kg ha^{-1}) were among the highest yielding genotypes in all the four years, while G18 produced the lowest SY (963 kg ha^{-1}) (Table 5). In this study, therefore, superior genotypes expressed their high yielding potentials best in a productive environment such as in Y1, while their SY is limited as a number of lines increased in the first ranking group under stress conditions experienced in Y4. In this context, the higher-ranking genotypes demonstrated growth and developmental flexibility; this was mainly dependent on the environmental quality. In the present study, the cross-over GYI did not occur, by which certain lines become superior in poor environment and *vice versa* in favorable environments as explained in Berger *et al.* (2002).

For SY, the GYI effect was examined by using AMMI model (Table 6 and Fig. 4). Gauch (1988, 1992) and Zobel *et al.* (1988) suggested that the AMMI model could be applicable, if the main effects (genotypes and years) and the GYI effects are significantly different in yield trials. Furthermore, inferences from the biplots constructed from the AMMI results are only relevant, when the first two IPCA could explain a large proportion of variation (Rao & Prabhakaran, 2003). Therefore, the AMMI model used in this study has described the GYI effect well. The results showed that the first two IPCAs with 81% of GYI SS together, successfully captured and delineated GYI effect (Table 6). The biplots (*i.e.,* scattering of genotypes, years, and GGrs) (Fig. 4) also confirmed the grouping identified in CA (Fig. 3). The genotypes, GGrs and years appeared to be quite responsive in biplots, and their direction and magnitude on abscissa and ordinate became crucial to assess the response patterns (Fig. 4). The main effect of genotypes mirrored the breeding merits of experimental material, while the main effect of years reflected overall cropping season quality.

Figure 4a shows both main and interaction effects for genotypes and years though the main effects of three years with above average SY (*i.e.,* Y1, Y2 and Y3) were similar, their GYI effects differed greatly. In addition, Y2 and Y4 were more alike for GYI effect, while they differed largely for the main effect. Thus, these high GYI effects in Y1 and Y3 indicated that genotypes expressed best performances by adjusting their responsiveness to environmental conditions dif-

ferently (Fig. 4a). However, the high IPCA scores of Y1 (positive) and Y3 (negative) in ordinate pointed that in these environments relative ranking of genotypes is unstable, and that large interaction effects make them less predictable for variety tests. Although they had similar growth longevity across the years (Table 3), the four GGrs acted differently in both main and interaction effects. IPCA-1 dispersed GGrs well (Fig. 4a); because of greater GYI effect with GGr-1 with above average yield spreading more widely along the ordinate. GGr-1 performed best in Y1, Y2 and Y3, while GGr-2 and GGr-3 did well in Y1, in Y2 and Y3 respectively. Contrarily, GGr-4 (only G18) was the most distinct, thus exhibiting very low main and interaction effects (Fig. 4a). Figure 4b shows the cross-validation of GYI effect for 27 narbon vetch genotypes in the four cropping years. For breeding advancement, the selected genotypes should be able to combine both high and stable yield. Therefore, G2, G4, G6 and G27 (all in GGr-1), with above-average SY and being stayed near to the origin had a good performance and high stability (Fig. 4b). The extreme genotypes, which became the preferential lines for their respective cropping years, had strong specific adaptation. Among those, G9 and G25 in GGr-1 showed best adaptation to Y1 and Y3, while G11 performed well in Y3 (Fig. 4b). G18 showed poor yields in all environments, but performed best in Y2 and Y4 (Fig. 4b).

In conclusion, narbon vetch is an ideal legume species for grain and straw production, especially useful for sheep feeding during winter-indoor time. Although narbon vetch is regarded as cold and drought tolerant, its SY is quite sensitive to high temperature fluctuations coalesced with high rainfall prior to flowering stage. Considering the relations of SY with BI, HI and DH early maturity along with greater BI and HI are the characters of interest for selecting vetch lines to improve SY. As a response to varying climatic conditions, narbon vetch is able to highly efficiently regulate plant growth and development. The GYI effect in this study has certain implications such as broad and specific adaptations. The selected genotypes can be used as a set of reference lines in the evaluation of narbon vetch germplasm for better yield and adaptation. Finally yet importantly, the enhanced developmental flexibility through adjusting plant growth-longevity combined well with higher BI and HI is the primary form of narbon vetch adaptation to the semi-arid central Turkey and similar environments in the Mediterranean area.

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