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Genotype × environment interaction and stability analysis for dry matter and seed yield in field pea (*Pisum sativum* L.)

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Abstract

The objectives of this study were to evaluate dry matter (DM) yield and seed yield of six leafed and semi-leafless pea (*Pisum sativum* L.) genotypes, and to compare them for these traits. Evaluation of genotype × environment (G × E) interaction, stability and cluster analysis were also carried out at eight diverse locations with typical Mediterranean and Mediterranean-type climate during the 2001–2002 and 2002–2003 growing seasons. Significant differences were found among the pea genotypes for DM and seed yield on individual years and combined over years, and in all locations. All interactions which related to G × E interaction showed significance (P>0.001) for DM and seed yield. The highest yield (4789 kg ha^{-1}) was obtained from the leafed genotype 'Urunlu'. However, stability analysis indicated that for DM yield, the leafed genotypes 'Golyazi' and 'Urunlu' should be grown in low yielding and high yielding environments, respectively. Cluster analysis, based on grouping locations, showed that P101 was the preferred variety in low yielding environments, and P98, in high yielding ones. It was suggested that the use of both stability and cluster analyses might give better results. Comparison of cluster and stability analyses showed that the stability analysis fails to recommend cultivars to different regions where yield potential showed significant differences. It seems, however, that cluster analysis could be a powerful tool to examine G × E interaction. If the number of environments was sufficient, a separate stability analysis could be run in each cluster.

Additional key words: adaptation, cluster, leafed and semi-leafless peas, Mediterranean conditions, stability.

Resumen

Interacción genotipo × ambiente y análisis de estabilidad para rendimiento de materia seca y de semilla en guisante (*Pisum sativum* L.)

Los objetivos de este estudio fueron evaluar y comparar el rendimiento de materia seca (DM) y de semilla de seis genotipos de guisante con hojas convencionales y semiafilas. Además, se evaluó la interacción genotipo × ambiente (G × E) y se realizaron análisis de estabilidad y tipo cluster en ocho localidades de clima mediterráneo, durante las temporadas 2001–2002 y 2002–2003. Se encontraron diferencias significativas entre genotipos para rendimiento de DM y de semilla, tanto para años individuales como combinados, así como en todas las localidades. Todas las interacciones G × E fueron

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Abbreviations used: b_i (regression coefficient), CV (coefficient of variation), DF (degrees of freedom), DM (dry matter), G × E (genotype × environment), G × L (genotype × location), G × Y (genotype × year), MS (mean square), S^2d (regression mean square), SE (standard error), Y × G (year × genotype).

significativas (P>0,001) para rendimiento en DM y semilla. Se obtuvo la producción más alta (4789 kg ha^{-1}) con el genotipo de hoja convencional 'Urunlu'. El análisis de estabilidad indicó que, para rendimiento en DM, los genotipos 'Golyazi' y 'Urunlu' deben cultivarse en ambientes de baja y alta producción, respectivamente. El análisis cluster, basado en agrupamiento de localidades, mostró que la variedad P101 fue la mejor en ambientes de baja producción, y la P98 en los de alta producción. Al comparar los análisis de estabilidad y de tipo cluster se vio que el primero falla al recomendar genotipos para las diferentes regiones donde el rendimiento potencial muestra diferencias significativas. Sin embargo, el análisis cluster puede ser una poderosa herramienta para examinar la interacción G × E. Si el número de ambientes es suficiente, se puede efectuar un análisis de estabilidad separado para cada cluster.

Palabras clave adicionales: adaptación, cluster, condiciones mediterráneas, estabilidad, guisantes de hoja convencional y semiafilos.

Introduction

Peas (*Pisum sativum* L.) are grown for hay, pasture or silage production, alone or mixed with cereals, in different parts of the world (McKenzie and Spooner, 1999). The seed is rich in crude protein and mineral elements (Acikgoz *et al.*, 1985), providing the European animal feed industry with a raw, protein-rich material for pigs and poultry (Bourdillon, 1999). Therefore, pea is one of the most important protein crops in Europe, and used as an alternative source of crude protein to soybeans.

High and stable dry matter (DM) and seed yield production are among the main objectives in most forage breeding programs. To be widely accepted, a genotype must show good performance across a range of environments. However, it is often difficult to find such cultivars. Genotypes respond to changes in environmental conditions such as temperature, rainfall, soil type, moisture and so on (Robertson, 1959; Cockerham, 1963; Falconer and Mackay, 1995). Therefore genotypes selected in a breeding program should be tested at various locations for several years, and analyzed appropriately to determine the extent of the genotype × environment (G × E) interaction before being released as cultivars. To determine the extent of the G × E interaction, a simple regression of cultivar mean on the experiment mean was proposed. This technique became extensively used after the studies of Finlay and Wilkinson (1963) and Eberhart and Russell (1966). This method is based on regression analysis of stability parameters for cultivars by analyzing experiments conducted over years and/or locations. Eberhart and Russell (1966) proposed to consider two parameters: the first one is the regression coefficient (b_i) to compare relative responsiveness of a particular cultivar to the mean of all cultivars (environmental index), the second one is the deviation from the regression mean square (S^2d) for measuring how well the predicted response compares with the observed response. When Eberhart and Russell (1966) proposed this analysis, they used cultivar means as the response variable and experiment means as the environmental index.

In previous studies with different pea genotypes, humid conditions and cool temperatures in early spring favored the vegetative development of fall-seeded peas. Thus, very high forage yields, up to 45–50 Mg ha^{-1}, were obtained in fall-seeded plots. However, significant year × genotype (Y × G) interactions were detected in forage yield (Uzun and Acikgoz, 1998; Uzun *et al.*, 2005). Conventional leafed and semi-leafless pea genotypes are widely grown in most European countries for seed production. Until now, the agronomic performances of leafed and semi-leafless forage-type peas have not been studied thoroughly under Mediterranean or Mediterranean-type climatic conditions. There is inadequate information on DM and seed yield performances and the stability of leafed and semi-leafless forage-type pea genotypes in such environments. The main objective of this study was to evaluate DM and seed yield and stability of pea genotypes, and compare leafed and semi-leafless types for these traits.

Material and methods

Six pea genotypes were grown to test the stability of DM and seed yield at eight different locations with typical Mediterranean or Mediterranean-type climate during the 2001–2002 and 2002–2003 growing seasons. The pea genotypes used in this study were developed by the pea breeding program in Uludag University, Bursa, Turkey. The selection criteria to improve pea genotypes were: high forage and seed yield, winter hardiness, early maturity, and indeterminate growth habit. A typical bulk selection was applied in the breeding process. The pea genotypes tested in this study were Kirazli (semi-leafless, purple flowered), Ulubatli (semi-leafless, white flowered), P98, P101, Golyazi and Urunlu (all leafed and white flowered). Kirazli, Ulubatli, Golyazi and Urunlu were officially registered in Turkey in 2007.

The yield trials were carried out in the following locations: Adana, Antalya, Bursa, Diyarbakır, Dogankent, Izmir, Samsun and Tekirdag. With the exception of Diyarbakır, all are situated in the coastal regions of Turkey, with very low altitudes as shown in Table 1.

In general, the soil in these areas was clay loam, slightly alkaline (pH = 7.2–8.0), rich in potassium (527–1100 kg ha^{-1}), medium in phosphorus (22–142 kg ha^{-1}) and containing 1.1–2.4% organic matter. Adana, Antalya and Dogankent have a typical Mediterranean climate while the other locations have a Mediterranean-type climate. Typical Mediterranean climate is characterized with mild and wet winter and spring seasons; and hot and dry summers. Precipitation patterns are similar, but winters are generally cooler in the Mediterranean-type climate.

For the eight locations, long-term average total precipitation varied from 496 mm to 1068 mm $year^{-1}$, with 60–70% of the yearly precipitation occurring during the pea-growing season. Long-term average annual temperature of the locations was 16.4°C, with yearly average temperatures ranging from 13.5°C to 18.7°C, and with the highest temperature recorded exceeding 40°C in most of them. The average winter temperature varied from 3.2°C to 10.9°C between locations, with unusual drops observed in some years (Table 1).

At each location, field experiments were arranged in a randomized complete block design with four replicates. The plot was 14 m^2 (1.4 × 10.0 m) in size, comprising 8 rows spaced 17.5 cm apart. In Bursa and Samsun, sowing was done with an experimental driller. At the other locations, seeds were hand planted. In all the cases seeding rate was 100 viable seeds m^{-2}. Fertilizers were applied before planting at the rate of 30 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5. Experiments were carried out between 11 and 21 November, 2001 and 1 and 27 November, 2002. Throughout the experiment, irrigation was not applied and weeds were controlled by hand.

Forage yield was measured at full flowering stage in an area of 3 m^2, and the remaining part of each plot was harvested for seed yield. The plants were cut from ground level and the forage was dried in the oven at 70°C for 48 h. Based on DM content, DM yield per plot was estimated by multiplication of forage yield by DM content of the plot. At maturity, the remaining area of each plot was harvested, and threshed by hand. Seed yield was measured 15 days after harvest, to allow for stabilization of the seed moisture content.

Analysis of variance (ANOVA) and other statistical analyses were performed with the statistical package JMP 5.0.1 (SAS, 1989-2002). The data were combined over years and locations, using fixed-model analysis. Before combined variance analysis, the data were checked for normal distribution and homogeneity of variances by years and locations. Due to conformity with normal distribution and homogenous variance, transformation was not needed in the analysis of each trait. The techniques presented by Finlay and Wilkinson (1963) and Eberhart and Russell (1966) were used in the stability analysis. In the regression analysis, 16 points (of the mean of 16 experiments in two years and eight locations) were taken as the variable for the environmental index on the *x* axis. Following the concept of sta-

Table 1. Locational and climatic characteristics (long-term average) used for stability analysis of pea cultivars

Location	Latitude	Longitude	Altitude (m)	Prec.[a] (mm)	Temp.[b] (°C)	W. Temp.[c] (°C)	H. Temp.[d] (°C)	L. Temp.[e] (°C)
Adana	36° 59´ N	35° 18´ E	20	647	18.7	10.2	45.6	-11.2
Antalya	36° 53´ N	30° 42´ E	42	1068	18.7	10.9	44.6	-4.6
Bursa	40° 11´ N	29° 04´ E	70	699	14.8	6.5	42.6	-25.7
Diyarbakir	37° 55´ N	40° 12´ E	660	496	15.9	3.2	46.2	-24.2
Dogankent	36° 48´ N	35° 15´ E	12	774	18.3	10.0	40.8	-10.2
Izmir	38° 24´ N	27° 10´ E	25	700	17.6	9.6	42.7	-8.2
Samsun	41° 17´ N	36° 20´ E	44	735	13.5	7.8	39.0	-9.8
Tekirdag	40° 59´ N	27° 29´ E	4	591	13.8	5.6	37.0	-13.5

[a] Total precipitation. [b] Annual average temperature. [c] Average winter temperature for the December–February period. [d] Highest temperature recorded. [e] Lowest temperature recorded.

bility, the *b*=1 hypothesis was tested. Any significant interaction which includes genotype was accepted as representative of a G × E interaction. If the interaction was significant, then stability analysis was carried out. In the case of non-significant interaction, it is very easy to decide the desired genotype for any trait considered. In deciding which cultivars show stability, the first criterion used was significant differences of the regression coefficient (*b*) from one. Any genotype which had a non-significant *b* from one was accepted as stable. A cultivar with a high performance and a non-significant *b* is desired.

In this study, the coefficient of variation (CV) was adopted instead of the S^2_d because CV is the standardized S^2_d and is easier to comment on. S_d^2 or CV is the second parameter used to decide if one genotype is better than another. When b_i is equal to one or not significantly different from one, then a lower S^2_d or CV is the reason to prefer a genotype. Nevertheless, the evaluation of stability should be taken cautiously, because the Eberhart and Russell (1966) method has its own limits: firstly, the decision is valid for the environments where the experiments were conducted and for the cultivars included in the experiments; and secondly, any addition or deletion of an environment or a genotype in experiments can change conclusions easily.

Cluster analysis was performed using the JMP 5.01 statistical software. Clustering was done with the hierarchical Ward method. Data were standardized for clustering by choosing the “Standardize Data” option. In this study, locations and varieties were clustered using DM yield and seed yield because varieties were improved for dual purposes, as forage and seed.

Results and discussion

The highest and lowest average DM yields were obtained from the leafed varieties Urunlu (4789 kg ha^{-1}) and P101 (3840 kg ha^{-1}), respectively. Nonetheless, only the Ulubatli and the P101 yields were significantly different from the highest-yielding variety, Urunlu. Significant genotype × location (G × L) interaction also shows that the same genotype might not give the highest yield in all locations. Urunlu gave highest yield in Samsun and Izmir. P101 exhibited the best performance in Dogankent and Tekirdag. Kirazli (semi-leafless), P98 (leafed), and Ulubatli (semi-leafless) had the highest DM in Adana and Diyarbakir, Bursa, and Antalya, respectively (Table 2). G × L interaction makes it very difficult to chose variety(ies), and in most cases, it is not practical to recommend specific ones for each location. Therefore, further analysis is needed to simplify this interaction. In order to see resemblance among environments, for each year, locations were clustered by DM yield (dendrogram not shown), with Antalya, Diyarbakir and Izmir in Cluster 1; Adana and Dogankent in Cluster 2; and Samsun in Cluster 3. The Tekirdag and Bursa locations were placed in different clusters each year. Cluster 3 represented the highest DM yielding group, and Urunlu was the best variety. Cluster 1 was the normal yielding group and Kirazli, Ulubatli and P98 yielded better than the others in the cluster. Cluster 2 was the low yielding group, and P101 was the best variety for DM yield. With regard to locations, Samsun and Adana had the highest and lowest DM yield, respectively. Multiple comparison of locations showed that these were significantly different from one another. A cluster analysis

Table 2. Mean dry matter yield (kg ha^{-1}) of different pea genotypes at each location over a two-year period

Location	Golyazi	Kirazli	P101	P98	Ulubatli	Urunlu	Average
Adana	2531	2834	2678	2366	2382	2617	2568
Antalya	4341	4542	3888	5145	5898	4088	4657
Bursa	5214	5081	3981	6226	4942	5094	5052
Diyarbakir	4370	5323	2678	4255	4230	3815	4386
Dogankent	3675	3547	4322	3667	2990	3720	3478
Izmir	5790	5840	3267	5994	5362	6225	5438
Samsun	7135	6223	3387	7773	6878	8613	6997
Tekirdag	4389	3643	5358	2788	3312	4143	3686
Average	4685	4614	3840	4779	4490	4789	4486
Cluster 1	3532	3341	4119	2940	2895	3943	3387
Cluster 2	5370	5402	3440	5879	5462	5567	5187

$LSD_{0.05}$ for genotypes: 179 kg ha^{-1}. $LSD_{0.05}$ for locations: 206 kg ha^{-1}.

which takes into account changes of yield from variety to variety might classify locations. Such a cluster gave two main groups: one with Adana, Dogankent and Tekirdag, which could be defined as the low-yielding locations (Cluster 1), and another one with Antalya, Bursa, Izmir, Diyarbakır and Samsun (Cluster 2), which could be defined as the high-yielding locations (Figure 1). Antalya and Bursa were the most similar locations for this trait. An interesting result was observed in the first cluster, because Tekirdag is different from Adana and Dogankent temperature wise. That makes the decision to select a variety for a region–without experimental data–more difficult. Apparently, more climatic and soil data are needed to know which field pea variety should be recommended to a region without experimental data. Another approach could be a decision of variety based on the means of genotypes in Clusters. Average DM yield in low-yielding (Cluster 1) and high-yielding (Cluster 2) locations was 3244 and 5306 kg ha^{-1}, respectively. Genotypes P101 and P98 performed better than the rest in the low and high yield conditions, respectively (Table 2). Alternative genotypes for low yield conditions could be any of the other varieties except P98 and Ulubatli. In high yield conditions, all the varieties, except P101, could be alternatives to P98.

Resemblance of genotypes for DM is shown in Figure 2. P101 was different than the other genotypes, and thus formed a cluster by itself. The other five genotypes were grouped in the second cluster. Within the second cluster, cluster analysis was able to differentiate semi-leafless (Kirazlı and Ulubatli) and leafed (Golyazi, Urunlu and P98) genotypes for DM yield. The average of leafed genotypes, including P101, was 4523 kg ha^{-1}, and that of semi-leafless varieties was 4552 kg ha^{-1}. As previously mentioned, the difference was not significant (P>0.61). In general, semi-leafless genotypes showed around 2% yield advantage over leafed genotypes.

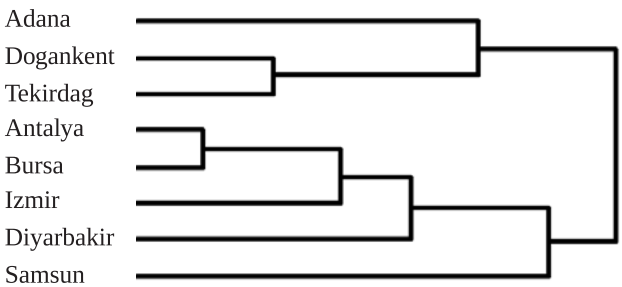

Figure 1. Clusters of eight locations formed by dry matter yield of six pea genotypes.

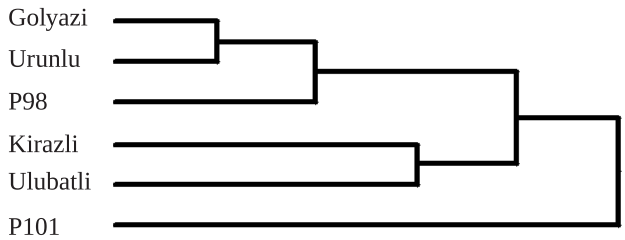

Figure 2. Clusters of six pea genotypes for dry matter yield in eight locations.

Overall, average seed yield indicated that the semi-leafless genotype Ulubatli gave the highest seed yield, and that the yield of the semi-leafless Kirazli was not significantly different from Ulubatli (Table 3). Nonetheless, although Ulubatli performed best in Adana and Bursa, the Kirazli genotype gave the highest yield in the locations of Antalya, Izmir and Tekirdag. The lowest seed yield was obtained from leafed genotypes P101 and P98, but these also gave the highest yields in Samsun (P101) and Diyarbakir (P98). In Dogankent and Samsun, the seed yield of Ulubatli and Kirazli was almost the same to that of Urunlu and P101, respectively. This leads to the conclusion that, in all the locations, with the exception of Diyarbakir, Ulubatli and Kirazli were the best genotypes. It seems that the complexity for seed yield from G × L interaction was less than that for DM yield.

When DM and seed yield were considered, the combined ANOVA indicated significant differences in all components of variance for these traits (Table 4). Genotypes showed different performances across years and locations for DM and seed yield, and all genotype interactions showed significance. The difference between leafed and semi-leafless types was significant for DM yield and seed yield.

Complexity arousing from significant G × L interaction or any other interaction with genotype is well known. The year effect on genotypes cannot be controlled, and thus the genotype × year (G × Y) interaction could be ignored for practicality and/or making the situation simpler, so that only the G × L interaction is evaluated. Ignoring the G × Y interaction, however, does not solve the abovementioned problem. In the case of G × E interaction, a stability analysis was suggested. In a sense, the stability analysis summarizes the G × E interaction. Stability analysis for DM yield showed that only P101 and P98 were not stable (Table 5). The regression coefficient (*b*), which is the main criterion to decide the question of stability, and the average yield of

Table 3. Mean seed yield (kg ha^{-1}) of different pea genotypes at each location over a two-year period

Location	Golyazi	Kirazli	P101	P98	Ulubatli	Urunlu	Average
Adana	2624	2618	2248	2664	3379	2456	2665
Antalya	2961	3360	2834	2997	3006	3024	3030
Bursa	3046	3193	2665	3126	3783	3635	3241
Diyarbakir	2635	2384	2351	2769	2466	2316	2487
Dogankent	2045	1985	2085	2088	2122	2128	2076
Izmir	3025	3311	2458	3034	3293	3240	3060
Samsun	2794	2964	2970	2536	2816	2272	2675
Tekirdag	3251	3356	3047	2101	2577	3229	2927
Average	2798	2896	2545	2664	2930	2788	2770
Cluster 1	2525	2488	2414	2514	2696	2293	2488
Cluster 2	3071	3305	2751	2815	3165	3282	3065

$LSD_{0.05}$ for genotypes: 109 kg ha^{-1}. $LSD_{0.05}$ for locations: 126 kg ha^{-1}.

genotypes were combined and visualized in Figure 3. In this case, Golyazi and Urunlu were the desired varieties due to their high DM yield and stability from a statistical point of view. This figure shows that P98 could only be grown in high-yielding environments. However, this genotype could be very risky in low-yielding environments. Therefore, Golyazi and Urunlu are the varieties that could be recommended to all environments. Another representation of stability analysis is to use the expected yield of varieties, which are estimated by regression equation of each genotype, as seen in Figure 4. This representation suggests that the Urunlu and Golyazi varieties should be recommended. However, stability analysis missed the fact that P101 was the best variety in low-yielding conditions, as pointed out by cluster analysis.

Cluster and stability analyses did not confirm each other. On the other hand, just looking at the G × L interaction proved to be a difficult task in deciding the best variety, and consequently it would be much more difficult in the case of a high number of genotypes and locations. The best approach would be a combination of stability and cluster analyses when the number of locations is high. However, the number of locations in this study was not sufficient to test this approach. Clustering just the locations by ignoring the year effect, recommended

Table 4. Combined analysis of variance for dry matter yield and seed yield

Source of variation	DF[1]	Dry matter yield		Seed yield	
		MS[2]	Prob>F	MS[2]	Prob>F
Year (Y)	1	59445954	0.0001	3931775	0.0007
Location (L)	7	65882955	0.0001	5111743	0.0001
L × Y	7	22362217	0.0001	5473663	0.0001
$Error_a$[3]	32	356085		277770	
Genotype (G)	5	6083386	0.0001	872511	0.0001
Leafed *vs* Semi-Leafless	1	489117	0.6100	2852050	0.0000
G × Y	5	3172834	0.0001	279959	0.0009
G × L	35	2618646	0.0001	471288	0.0001
G × Y × L	35	597495	0.0001	625111	0.0001
$Error_b$[4]	155	192719		71806	
Total	282				
CV (%)		9.8	9.7		
R^2 (%)		96.5	92.2		

[1] DF: degrees of freedom. [2] MS = Mean square. [3] $Error_a$: main plot error. [4] $Error_b$: subplot error.

Table 5. Stability parameters of pea genotypes for dry matter yield

Genotype	*b*	±SE	*a*	CV (%)	R^2	Pr>F
Golyazi	1.02	0.06	63.0	8.5	0.95	0.76
Kirazli	0.88	0.08	642.2	11.1	0.89	0.16
P101	0.47	0.09	1711.6	14.5	0.66	0.00
P98	1.32	0.09	1210.4	12.0	0.94	0.00
Ulubatli	1.12	0.10	564.7	13.9	0.90	0.27
Urunlu	1.20	0.11	641.5	14.7	0.89	0.10

the second highest yielding genotype, P98, which had almost the same average yield of Urunlu. Stability analysis suggested Urunlu and Golyazi.

With regard to the locations, the highest and lowest seed yields were obtained in Bursa and Dogankent, respectively. The genotypes clustered, and two seed yield conditions, high yield and low yield, were recognized. The low yield conditions included the locations of Adana, Diyarbakir, Samsun and Dogankent (Cluster 1), and Antalya, Izmir, Bursa and Tekirdag (Cluster 2) were the high yield locations (Figure 5). The average seed yield of low and high yield locations was 2476 and 3065 kg ha^{-1}, respectively. The highest yielding varieties were Ulubatli, for the low yield cluster, and Kirazli, in high yield conditions. Interestingly, these two varieties could be the alternatives for each other in both these conditions. When 16 environments were clustered for seed yield, 3 clusters were recognized. Only the two-year data from Bursa and Izmir were placed in the same clusters. The others environments were separated in different clusters (not shown). Therefore, it would not be practical to recommend any variety based on these clusters.

Among the genotypes, with regard to seed yield, the leafed variety, P101, formed an independent cluster from others. The rest were divided in two clusters: the leafed Golyazi, P98 and Urunlu in Cluster 1; and the semi-leafless, Kirazli and Ulubatli in Cluster 2. This is an indication that semi-leafless and leafed types might even be separated by seed yield as seen in Figure 6. Significant difference between these two types was another indication for separation. The average seed yield of leafed and semi-leafless types was 2750 and 2913 kg ha^{-1}, respectively, with the semi-leafless types showing around 6% seed yield advantage over the leafed types.

Stability analysis showed that all genotypes were stable (Table 6). P101 and Kirazli had higher CV values which indicated large variability within yield data. Without any graph, it could be said that Urunlu, Kirazli and P101 were subject to recommendation. However, Urunlu had a significantly lower yield than Ulubatli. Ulubatli seemed a variety for high yielding conditions,

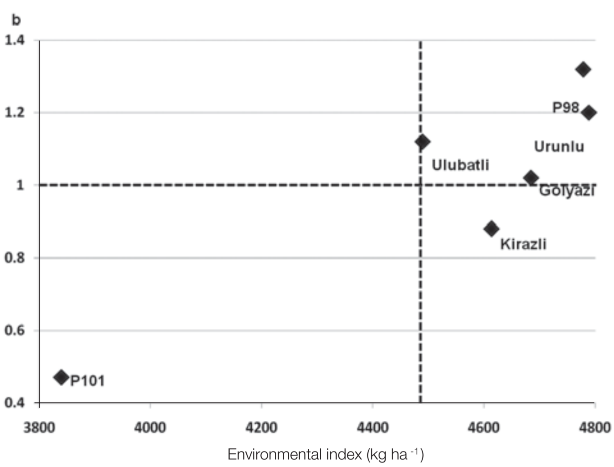

Figure 3. Combination of stability and overall average dry matter yield of field pea genotypes.

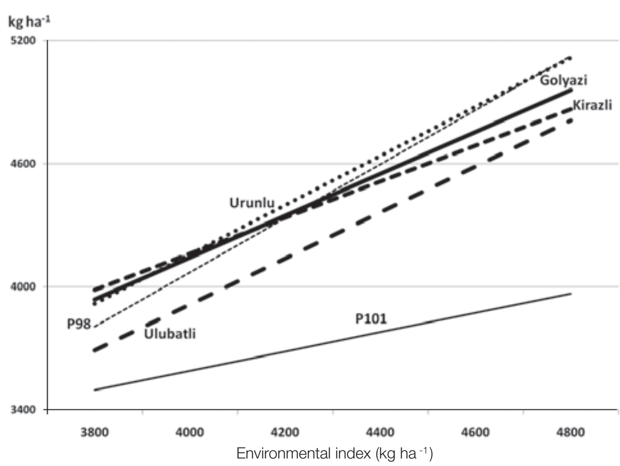

Figure 4. Comparison of field pea genotypes by their expected dry matter yield estimated from their regression (stability) equations.

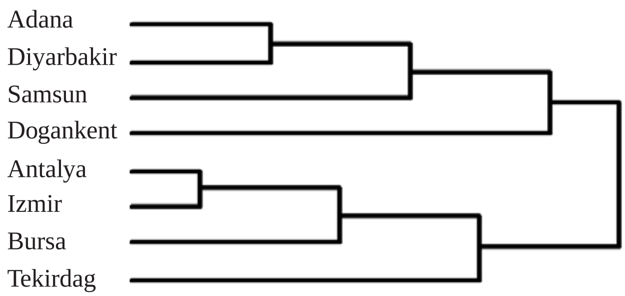

Figure 5. Clusters of eight locations formed by seed yield of six genotypes.

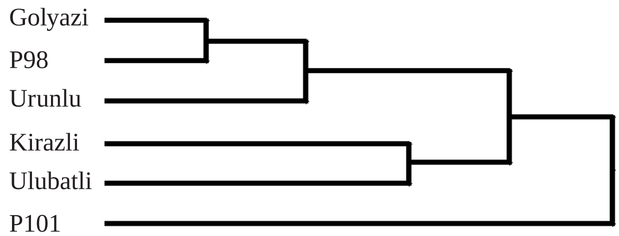

Figure 6. Clusters of six pea genotypes for seed yield in eight locations.

and Kirazli was safer for general recommendation. This case is shown very clearly in Figure 7. Estimated yield of genotypes showed that semi-leafless varieties Kirazli and Ulubatli could be recommended to all locations for seed yield (Figure 8).

Several studies on G × E interaction of annual seed legumes have been done in the past. Abd El-Moneim *et al.* (1988, 1990) found that linear regression accounted for 61% and 82% of herbage and seed yield of vetches (*Vicia* spp.), respectively, and 52% and 57% of forage peas, respectively. In studies with 16 selected lines of chickling (*Lathyrus* ssp.) grown in two locations of Syria during four years, Abd El-Moneim and Cocks (1993) found that the regression lines did not give a good fit (60% and 57%) to the actual herbage and seed yields from the different environments and the usefulness of b_i is limited. Armstrong and Pate (1994) tested reproductive performance of six field pea genotypes, differing in leaf type and growing habit, in three locations in Western Australia. Seed yield increased at the locations depending on rainfall during the growing season. Eleven pea cultivars were grown in 16 Spanish environments for three growing seasons and seed yield differences between cultivars and the G × E interactions were found to be highly significant (Flores *et al.*, 1998). Zubair and Ghafoor (2001) evaluated 12 genotypes of mung bean (*Vigna radiata* L. Wilczek) for stability of grain yield at seven different environments in Pakistan. They reported highly significant G × E interaction with regard to yield. Wamatu and Thomas (2002) tested 10 early maturing genotypes of pigeon pea (*Cajanus cajan* L. Millsp.) at seven environments spread over five regions of Kenya. They found a substantial G × E interaction for grain yield. They also reported that the best genotype at one environment is not the best at other environments. Arshad *et al.* (2003) evaluated 25 genotypes of chickpea for grain yield stability over 12 diverse Pakistani environments. They concluded that the G × E interaction was highly significant and both linear and non-linear components were equally important in yield performance.

The temperature and moisture conditions of early spring favored the vegetative development of the pea crop. Thus, high DM yield values were obtained in all the environments. Average DM yield of pea genotypes was higher than that of previous experiments (Davies *et al.*, 1985; Biederbeck and Boudman, 1994). This study showed that the DM yield advantage of one leaf type over another could be accepted as negligible from statistical point if leafed genotype P101 was not considered. However, stability analysis showed that Urunlu should be the first choice for all environments, and cluster analysis indicated that for DM yield, the leafed Golyazi should be grown in low yielding environments, and leafed P98, in high yielding environments. Whatever the analysis, all recommended cultivars were leafed types.

Table 6. Stability parameters of pea genotypes for seed yield

Genotype	*b*	±SE	*a*	CV (%)	R^2	Pr>F
Golyazi	0.73	0.22	763.3	16.1	0.45	0.24
Kirazli	1.09	0.16	-134.3	11.6	0.77	0.58
P101	1.04	0.20	-314.3	16.0	0.67	0.84
P98	0.79	0.18	461.8	13.8	0.59	0.26
Ulubatli	1.25	0.21	-525.5	15.1	0.71	0.26
Urunlu	1.10	0.16	-251.3	12.2	0.77	0.56

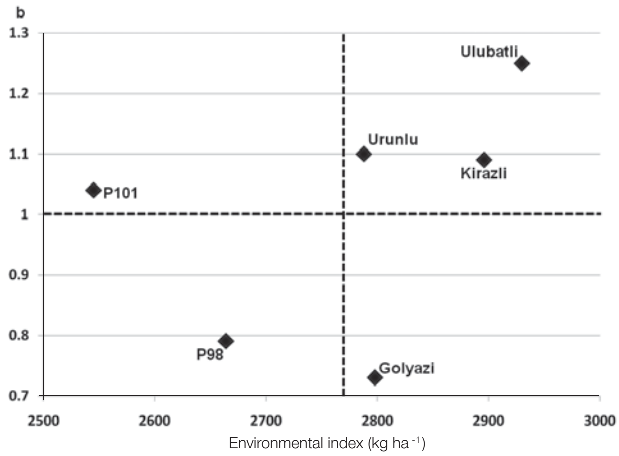

Figure 7. Combination of stability and overall average seed yield of field pea genotypes.

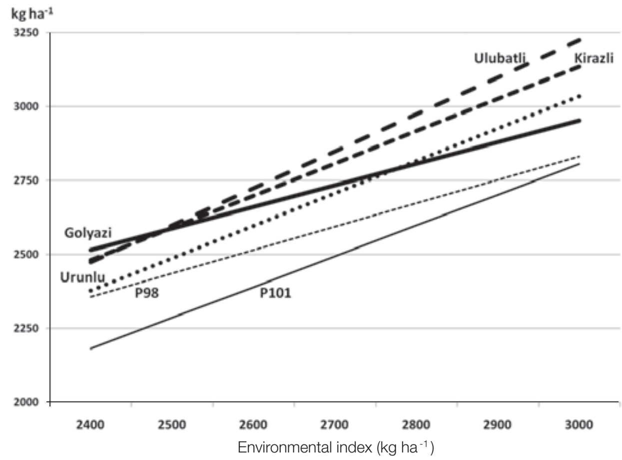

Figure 8. Comparison of field pea genotypes by their expected seed yield estimated from their regression (stability) equations.

It is well known that leafed pea cultivars exhibit severe lodging after flowering (Heath and Heblethwaite, 1985; Stelling, 1997). In this study, lodging scores (1 = severely lodged, 5 = upright) were taken just before cutting for DM yield measurement (data not presented). In close agreement with previous studies (Heath and Hebblethwaite, 1984; Stelling, 1989; Uzun and Acikgoz, 1998) semi-leafless pea genotypes had significantly better standing ability than leafed genotypes. However, semi-leafless genotypes showed instability and slightly lower DM yield.

Overall seed yields in this study were comparable with the average yield of 1.5–2 Mg ha^{-1} in USA and Canada (Davies *et al*., 1985), and experimental seed yields conducted in semiarid Mediterranean-type environments in Jordan (Al-Karaki and Ereifej, 1997; Al-Karaki, 1999) or in the Pacific Northwest, USA (McPhee and Muehlbauer, 1999). However, they were clearly lower than the average seed yield of 3–4 Mg ha^{-1} in Northern Europe (Heath and Heblethwaite, 1984; Davies *et al*., 1985) or experimental yields of 4–7 Mg ha^{-1} (Silim *et al.*, 1985; Stelling, 1989; Biarnes-Dumoulin *et al*., 1996). It is well known that peas are sensitive to high temperatures and drought stress, especially during flowering. Heat stress and water insufficiency resulted in the immediate abortion of reproductive organs and reduced seed number (Davies *et al*., 1985; Guilioni *et al*., 2003). The probable causes for lower seed yield of pea genotypes in the regions with Mediterranean and Mediterranean-type climates were high temperature and very low rainfall during the pod setting and seed filling periods. More than 70% of annual rainfall occurs during the cool winter and early spring in those regions. The pea lines started to flower at the beginning of April, and continued for approximately 15–20 days. Plants were harvested for seed in mid or late June. In those environments, the rapid onset of high temperatures and low rainfall and evaporation in late spring, during pod setting and seed filling of the pea crop, depressed development of pods and seeds. Previous studies in the Bursa region showed that natural precipitation generally satisfied water requirements of the pea crops in the November–February period. Limited or no irrigation was required in March, whereas the rainfall in the April–June period was far below the evapotranspiration demand for pea in this region (Uzun *et al.*, 2005). This severe drought stress during the late flowering and pod filling stages might be the reason for low seed yield in these experiments. In close agreement with these observations, Al-Karaki (1999), and Al-Karaki and Ereifej (1997) indicated that drought accompanied by high temperatures, which occur frequently at flowering and pod formation stages, drastically reduced seed yield under Mediterranean semi-arid conditions.

Conclusion

There were significant G × Y, G × L and G × L × Y interactions for the field pea's DM and seed yield. These interactions are the components of the G × E interaction. Presence of significant interactions makes it difficult for plant breeders to decide the variety(ies) for recommendation. An inadequate number of locations and years can increase the chance of a wrong decision. If the number of genotypes, locations and years was increased, data handling would be a very difficult task, particularly in case of significant interactions.

When, as in the case of seed yield for this study, there was not very much complexity due to significant interactions, a simple evaluation of G × L interaction could lead to a right decision in choosing varieties. However, if the complexity was increased, as in the case of DM yield, evaluation of this interaction could not guide plant breeders to choose the best one or two genotypes. In this case, another available tool would be to perform a stability analysis. Stability analysis, however, missed a good genotype such as P101 for low-yielding environments. Cluster analysis may also be a very helpful tool in complex situations. It was suggested that combination of stability and cluster analyses might give better conclusions. However, the number of years and locations in this study was not sufficient to test this assumption.

Dry matter and seed yield of semi-leafless genotypes were significantly higher than in leafed genotypes. The advantage of semi-leafless types over leafed types was around 1% for DM yield and 6% for seed yield. Without any doubt, the leafed P101 was the best genotype in low yield conditions for DM yield, and Golyazi and Kirazli for areas with high yield potential. Semi-leafless Kirazli and Ulubatli were stable and high seed yielding in all environments. When considering DM yield and seed yield together, the recommended types were Kirazli, for either for DM or seeds, Urunlu for DM and Ulubatli for seeds.

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