



Heat Stress Resilience of *Phaseolus* Species in Comparison to Local Cultivars

Phaseolus Türlerinin Sıcaklık Stresine Dayanıklılık için Yerel Çeşitlerle Karşılaştırılması

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Abstract: The global surface temperature in the world has increased by about one degree since pre-industrial period and it is estimated that the temperature increase will continue in the future owing to climate change. Heat-resilient bean species (*Phaseolus* spp.) are required to supply requirements for the near future. The aim of this study is (i) to determine the heat-resilient beans including eight genotypes of *P. acutifolius* A. Gray, two genotypes of *P. dumosus* Macfady, eight genotypes of *P. coccineus* L., five genotypes of *P. lunatus* L., six genotypes of *P. vulgaris* L., and an interspecific hybrid between *P. vulgaris* × *P. coccineus*, (ii) to compare local cultivars to *Phaseolus* species and (iii) to evaluate phenological, morphological and agronomic characteristics using factor and phenotypic correlations. A total of 30 genotypes were subjected to heat stress during reproductive stage under greenhouse conditions. Maximum temperature was rise the 55 °C. The phenological, morphological and agronomical characteristics of *Phaseolus* species were studied using phenotypic correlations and factor analysis. A genotype (PI-319447) of *P. acutifolius* and two registered cultivars (Goynuk98 and Ozayse) of *P. vulgaris* and three genotypes (PI-312198, PI-535202 and PI-535236) of *P. acutifolius* were determined to be earlier-flowered genotypes. A registered cultivar (Goynuk98) and landrace (APN3062) of *P. vulgaris* had the highest seed yield per plant. Seed yield is considered an important character in determining stress tolerance. Heat-resilient genotypes of *P. acutifolius* and *P. vulgaris* were considered to be not only escape ability via earliness but also buffering capability of heat stress. Some local cultivars were considered to grow under heat stress conditions due to high seed yield.

Keywords: Agronomical trait, Bean, Heat, Morphological trait, *Phaseolus*, Phenological trait

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Öz: Sanayi öncesi döneme göre dünya genelinde yüzey sıcaklığı yaklaşık bir derece artmış ve iklim değişikliği nedeniyle de sıcaklık artışının gelecekte de devam edeceği tahmin edilmektedir. Yakın gelecekteki ihtiyaçları karşılamak için sıcaklığa dayanıklı fasulye türlerine (*Phaseolus* spp.) ihtiyaç duyulmaktadır. Bu çalışmanın amacı (i) sekiz *P. acutifolius* A. Gray genotipi, iki *P. dumosus* Macfady genotipi, sekiz *P. coccineus* L. genotipi, beş *P. lunatus* L. genotipi, altı *P. vulgaris* L. genotipi ve *P. vulgaris* × *P. coccineus* türler arası bir melez olmak üzere sıcaklığa dayanıklı fasulyeleri belirlemek, (ii) yerel çeşitleri *Phaseolus* türleriyle karşılaştırmak ve (iii) faktör ve fenotipik korelasyonlar kullanarak fenolojik, morfolojik ve agronomik özellikleri değerlendirmektir. Toplam 30 genotip, sera koşullarında sıcaklık stresine maruz bırakılmıştır. En yüksek sıcaklık 55 °C olarak ölçülmüştür. *Phaseolus* türlerinin fenolojik, morfolojik ve agronomik özellikleri fenotipik korelasyon ve faktör analizleri kullanılarak değerlendirilmiştir. *P. acutifolius*'un bir genotipi (PI-319447) ve *P. vulgaris*'in iki tescilli çeşidi (Goynuk98 ve Ozayse) ile *P. acutifolius*'un üç genotipi (PI-312198, PI-535202 ve PI-535236) daha erken çiçek açan genotipler olarak belirlenmiştir. *P. vulgaris*'in tescilli bir çeşidi (Goynuk98) ve yerel çeşidi (APN3062), bitki başına en yüksek tane verimine sahip olmuştur. Tane verimi stres toleransını belirlemede önemli parametre olarak görülmektedir. *P. acutifolius* ve *P. vulgaris*'in sıcaklığa dayanıklı genotiplerinin, erken olgunlaşmayla sıcaklıktan kaçma yeteneğinin yanı sıra sıcaklık stresine katlanma yeteneğine de sahip olduğu düşünülmektedir. Bazı yerel çeşitlerin ise yüksek tane verimi nedeniyle sıcaklık stresi koşullarında yetiştirilebileceği düşünülmektedir.

Anahtar Kelimeler: Tarımsal özellik, Fasulye, Sıcaklık, Morfolojik özellik, *Phaseolus*, Fenolojik özellik

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INTRODUCTION

The genus *Phaseolus* L. belongs to the Fabaceae family having five cultivated species: tepary bean (*P. acutifolius* A. Gray), runner bean (*P. coccineus* L.), lima bean (*P. lunatus* L.), year bean (*P. dumosus* Macfady), and common bean (*P. vulgaris* L.). It is considered each of independent domestication processes from different wild progenitors (Almeida and Pedrosa-Harand, 2013; Dohle et al., 2019; Tene et al., 2025). Among them, *P. vulgaris* is the most important food legumes in the world. Beans are the oldest cultivated plants of the New World, originating from Central and South America (Broughton et al., 2003). Two gene pools are reported to be Central America (Mesoamerica) and South America (Andean Region) (Angioi et al., 2010; Bitocchi et al., 2012; Borel et al., 2013; Checa et al., 2006; Cortes, 2013; Gepts, 1998; Kwak and Gepts, 2009; Suárez et al., 2021b). The Mesoamerican gene pool stretches from Mexico to Colombia, and the Andean gene pool elasticities from Southern Peru to Northwest Argentina (Aquino-Bolaños et al., 2016; De la Fuente et al., 2012; García-Díaz et al., 2022; Rosario-Arellano Del et al., 2025; Suárez et al., 2021b). They are important food sources in human nutrition with their high content of protein, vitamins A and C, carbohydrates and minerals, and low-fat content. It is consumed both as fresh and dry seeds, and as canned and frozen pods (Asfaw et al., 2017; Basavaraja et al., 2020; Burbano-Erazo et al., 2021; Flores-Sosa et al., 2020; Lioi et al., 2019; Paredes et al., 2009; Pineda Ivars et al., 2023; Reddy Rajasekhar et al., 2024; Suárez et al., 2021b; Yeken et al., 2018a, 2018b, 2018c). Since the bean began to be cultivated, many genotypes have been improved that show differences in agro-morphological characteristics such as seed size, seed quality and growing season, and this variety is used in breeding and expanding the gene pool (Sinkovič et al., 2019). Beans are grown on the five main continents, these locations being East Africa, North and South America, Asia and West-Southeast Europe (Smart, 1992). Among the pulses, beans are the most affected by adverse growing conditions. Although an important legume, about 60% of common bean production occurs under short-term or terminal drought stresses (Asfaw et al., 2017; Omae et al., 2012; Suárez, et al., 2021a). The bean, which is very sensitive to drought stress, is adversely affected by drought stress (Bomers et al., 2022; Burbano-Erazo et al., 2021; Gross and Kigel, 1994). When the temperature is higher than 35 °C, pollen viability is reduced (Mackie, 1943; Tene et al., 2023). The high temperatures that may occur in the summer season can cause significant reductions in the yield of especially sensitive bean genotypes (Gross and Kigel, 1994; Burbano-Erazo et al., 2021).

Although beans are known as heat sensitive legumes, heat stress constraints bean production but the increase in temperature is predicted to rise in future owing to climate change. Global mean surface temperature (GMST) has risen by an average 0.87°C from pre-industrial period to second millennium, and GMST is estimated to increase of 0.15 to 0.20 °C per decade, which will limit bean production in most countries (Martínez-Nieto et al., 2022). Bean producers rely on heat tolerant bean cultivars under this scenario and circumstances.

In the cultivation of beans, *P. acutifolius*, *P. coccineus*, *P. costaricensis*, *P. lunatus* and *P. dumosus* can be used as gene sources to improve their tolerance to heat and drought stresses in the desired direction (Lin and Marhart, 1990; Nurmansyah et al., 2020; Porch et al., 2013). It has been reported that the tolerance of *P. acutifolius* to drought stress depends on the potential of the leaves and roots to minimize water loss, that it can be used as a parent in drought stress resistance studies in different bean genotypes, and that bean genotypes that are resistant to drought stress can be obtained by transferring the combinations used as parents to a single genotype (Mohamed et al., 2005). Due to the ability of *P. acutifolius* to react to high temperature, drought stress and some diseases, it can be used in interspecific hybridization since intraspecific hybridization which is reduced in crop genetic diversity via the utilization of similar parents (Rainey and Griffiths, 2005) and the mentioned characteristics can be transferred from *P. acutifolius* into common bean cultivars (Lin and Marhart, 1990; Nurmansyah et al., 2020).

Heat tolerant bean cultivars are needed to ensure bean production in the future. Like other cultivated plant crops, beans are exposed to two types of high temperature (heat) stress such as moderate (optimum) heat and extreme heat (shock) stresses. Moderate heat stress refers to the temperature values above the optimum temperature demand of the bean plant. Extreme heat, on the other hand, reduces bean growth and ultimately yield with extreme temperatures during the day (Mohamed et al., 2005;

Rainey and Griffiths, 2005). Despite the studies mentioned on heat stress in bean species, comparative studies for evaluation of bean species on extreme heat stresses were limited when searching in Web of Science (2023). The aim of this study is (i) to elucidate heat-resilient bean genotypes that are tolerant to extreme temperatures in cultivated bean species including *P. acutifolius*, *P. lunatus*, *P. dumosus*, *P. coccineus*, (ii) to compare local cultivars to *Phaseolus* species, and (iii) to evaluate phenological, morphological and agronomic characteristics using factor and phenotypic correlations.

MATERIAL AND METHOD

Plant Materials

Thirty bean genotypes including eight *Phaseolus acutifolius*, two *P. dumosus*, eight *P. coccineus*, five *P. lunatus*, one *P. hybrid* and two *P. vulgaris* L. were used in the study. These plant materials were obtained from the United States Department of Agriculture (USDA). Four registered beans (Nihatbey, Goynuk-98, Karacasehir-90 and Ozayse) in Türkiye were used as controls (Table 1).

Table 1. Genotypes and registered cultivars of *Phaseolus acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* and *P. vulgaris* were used in the study.

Çizelge1. Çalışmada kullanılan *Phaseolus acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* ve *P. vulgaris* tescilli çeşitler ve genotipler.

No.	Accession No.	Origin	Species	Information
1	PI 312198	Mexica	<i>P. acutifolius</i>	Genotypes
2	PI 239056	Morocco	<i>P. acutifolius</i>	Genotypes
3	PI 477033	USA	<i>P. acutifolius</i>	Genotypes
4	PI 307802	El Salvador	<i>P. acutifolius</i>	Genotypes
5	PI 309881	Costa Rica	<i>P. acutifolius</i> var. <i>acutifolius</i>	Genotypes
6	PI 535202	USA	<i>P. acutifolius</i> var. <i>acutifolius</i>	Genotypes
7	PI 535236	USA	<i>P. acutifolius</i> var. <i>tenuifolius</i>	Wild
8	PI 319447	Mexica	<i>P. acutifolius</i>	Genotypes
9	PI 325594	Mexica	<i>P. coccineus</i>	Genotypes
10	PI 317580	Guatemala	<i>P. coccineus</i>	Genotypes
11	PI 257222	Colombia	<i>P. coccineus</i>	Genotypes
12	PI 311211	Guatemala	<i>P. coccineus</i>	Genotypes
13	PI 535284	Guatemala	<i>P. coccineus</i> var. <i>coccineus</i>	Genotypes
14	PI 257409	Costa Rica	<i>P. lunatus</i>	Genotypes
15	PI 256820	Ecuador	<i>P. lunatus</i>	Genotypes
16	PI 256423	El Salvador	<i>P. lunatus</i>	Genotypes
17	PI 195341	Guatemala	<i>P. lunatus</i>	Genotypes
18	PI 299389	Brazil	<i>P. lunatus</i>	Genotypes
19	PI 201323	Mexica	<i>P. dumosus</i>	Genotypes
20	PI 311196	Guatemala	<i>P. dumosus</i>	Genotypes
21	PI 413672	Colombia	<i>Phaseolus</i> sp.	<i>P. vulgaris</i> × <i>P. coccineus</i>
22	APN 3081	Italy	<i>P. coccineus</i>	Na
23	APN 3080	Italy	<i>P. coccineus</i>	Na
24	APN 3079	Italy	<i>P. coccineus</i>	Na
25	APN 3062	Türkiye	<i>P. vulgaris</i>	Landrace
26	APN 3015	Türkiye	<i>P. vulgaris</i>	Landrace
27	Nihatbey	Türkiye	<i>P. vulgaris</i>	Registered cultivar
28	Goynuk98	Türkiye	<i>P. vulgaris</i>	Registered cultivar
29	Karacasehir90	Türkiye	<i>P. vulgaris</i>	Registered cultivar
30	Ozayse	Türkiye	<i>P. vulgaris</i>	Registered cultivar

PI: Plant introduction number in USDA GRIN; APN: Akdeniz University collection number; Na: Information not available

Germination Techniques

Pre-germination was carried out for the plant materials due to the fact that the material used in the experiment (especially the wild bean materials) might have germination difficulties (Toker et al., 2007). For this purpose, incisions were made in the seed coat to increase the water permeability of the seeds. Sowing for germination was done on Oct. 10th, 2018, with 3 seeds from each genotype in petri dishes. 20 cc of water was added to each petri dish and the humidity was checked regularly. After the germination process (approximately 20 days), the germinated seeds were planted in pots filled with peat and the first seedlings

developed in the pot. Plants that completed their first seedling development in pots were transplanted into the greenhouse on Nov. 5th, 2018.

Experiment and Experimental Area

The research was carried out in the Venlo Greenhouse of Faculty of Agriculture at the campus of Akdeniz University (30°38' E, 36°53' N, 51 m above sea level), Antalya, Türkiye. The experiment was established in the randomized complete plot/block design (RCPD) with three replications with 70 cm row spacing, 20 cm plant spacing in a row, and three rows per plot.

Agronomical Practices

The weeds in the experimental area were removed by hand during seedling stage. Neither fertilization nor pesticides was applied. A drip irrigation system was regularly applied to get rid of drought stress with a flow rate of 2 L per hour and 20 cm emitter spacing for each plant. Only extreme heat stress was therefore brought about in the experiment.

Phenological and Agro-Morphological Characteristics

Measured and calculated phenological and agro-morphological characteristics were realized as below (UPOV, 2005): days to flowering was recorded as number of days from transplanting to first flowering. Plant height was measured as cm with a ruler from ground to top of plant. Branches per plant was counted as number of main stems per plant. Pods per plant was counted as the number of pods per plant. Pod length was measured as mm with the caliper length of a pod. Pod width was measured as mm with a caliper wide of a pod. The pod diameter was measured as mm with a caliper diameter of a pod. Beak length was measured as mm with a caliper length of beak (top of pod). Seed length was measured as mm with a caliper length of a seed. The seed width was measured as mm with a caliper wide of a seed. The seed diameter was measured as mm with a caliper diameter of a seed. The number of seeds per pod was counted as number of seeds per pod. Seed yield was recorded as g per plant after harvest. 100-seed weight was recorded as g and then the total number of seeds was converted into hundred seeds.

Data Analyses

Data was statistically analyzed for analyses of variance (ANOVA) using MINITAB 17 software (MINITAB, 2014). Factor analysis was performed to evaluate phenological and agro-morphological characteristics (Canci and Toker, 2009).

Temperature and Humidity in Greenhouse

The temperature and humidity of the greenhouse where the experiment was carried out are given in Figure 1. As seen in Figure 1, the maximum temperature in flowering and pod setting periods were recorded between 36-39.8 °C and 39.8-55 °C, respectively. The average humidity for the months was 71.8% thanks to irrigation and climate conditions in greenhouse. Thus, drought stress has never arisen during experiments.

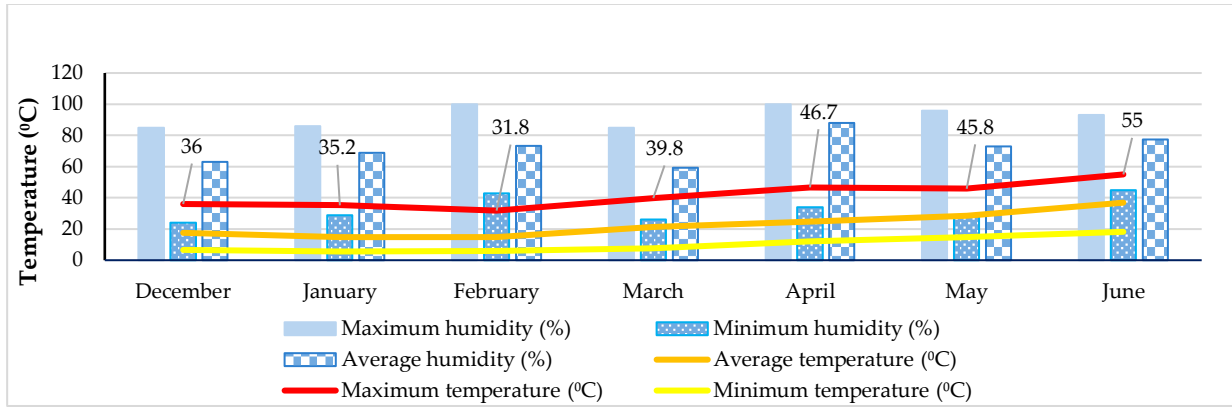


Figure 1. Temperature and relative humidity with minimum, maximum and average values during growing season in greenhouse.

Şekil 1. Yetiştirme sezonunda seradaki minimum, maksimum ve ortalama sıcaklık ve nisbi nem değerler.

Soil Properties in the Experimental Area

Soil properties in the experimental area in greenhouse were detailed in Table 2. The soil characteristics of the research area are as follows. Soil is neutral pH level; it is salt-free, has a loam structure, and it is low in organic matter (Table 2). Similar soil characters are informed by Tene et al., 2023.

Table 2. Soil properties in the greenhouse.

Çizelge 2. Seranın Toprak özellikleri.

Soil Parameters	Results	Interpretation
pH	7.48	Neutral
EC (%)	0.06	No salinity effects
Texture		Loam
Organic matter (%)	1.73	Low
Total N (%)	0.99	Medium
Available P (Kg per da)	3.15	Low
Exchangeable K (Kg per da)	194.00	Optimum

RESULTS AND DISCUSSION

Phenological, Morphological and Agronomical Characteristics

Significant differences were found for plant height, number of branches per plant, 100-seed weight (g), number of seeds per pod, pod length (mm), pod width (mm), pod diameter (mm), beak length (mm), seed length (mm), seed width (mm), seed diameter (mm) and seed yield (g per plant) among the bean genotypes at $p \leq 0.05$, while days to flowering and seeds per pod were not significant (data not shown). Days to first flowering of the genotypes varied from 38 to 117 days. The earliest flowered genotype belonged to *P. acutifolius* (PI-319447), while *P. coccineus* had the latest flowered genotypes (PI-317580 and PI-257222) in Figure 2. Two registered cultivars (Goynuk98 and Ozayse) of *P. vulgaris* and three genotypes (PI-312198, PI-535202 and PI-535236) of *P. acutifolius* were determined as earlier-flowered genotypes (Figure 2). Plant height of genotypes was found between 22 and 355 cm. A genotype (PI-312198) of *P. acutifolius* had the shortest plant height, while a genotype (PI-319447) of *P. acutifolius* had the highest plant height (Figure 3). Branches per plant of the genotypes were detected between 1 and 4 main stems per plant. PI-257409, a genotype of *P. lunatus* had the greatest number of branches per plant (Figure 4). Pods per plant of the genotypes varied from 2 to 63 pods. The most pods per plant was found in Goynuk98, registered variety of *P. vulgaris*, and followed by PI-307802 (*P. acutifolius*) with 57 pods per plant and PI-299389 (*P. lunatus*) with 46 pods per plant (Figure 5). Seeds per pod was between 1 and 6 seeds, and a genotype (PI-319447) of *P. acutifolius* had the most seeds per pod. In general, registered cultivars *P. vulgaris* had higher seeds per pod that of genotypes of *P. lunatus* and *P. coccineus* (Figure 6). The highest seed yield per plant produced in a registered cultivar (Goynuk98) of *P. vulgaris* and followed by landrace (APN3062) of *P. vulgaris* (Figure 7).

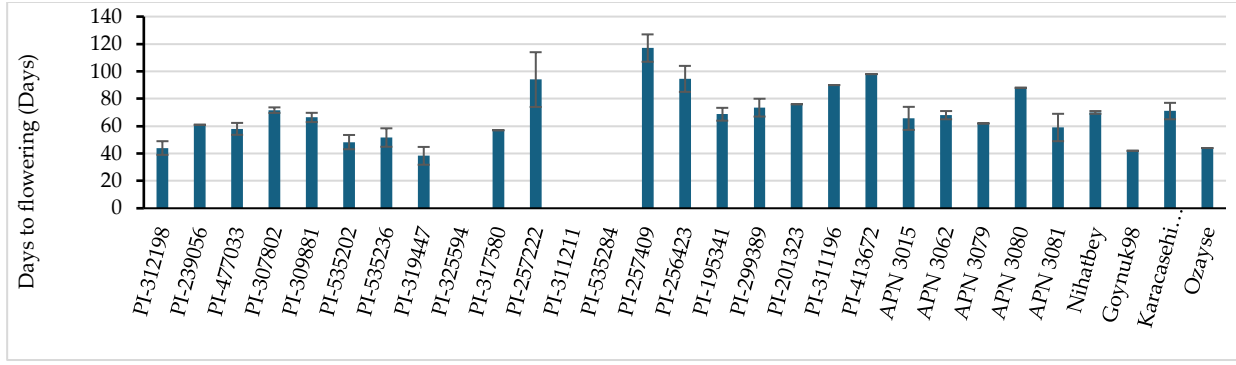


Figure 2. Days to first flowering time, bars indicated means $\pm$ standard errors.

Şekil 2. İlk çiçeklenmegünsayısı, barları $\pm$ standart hataları.

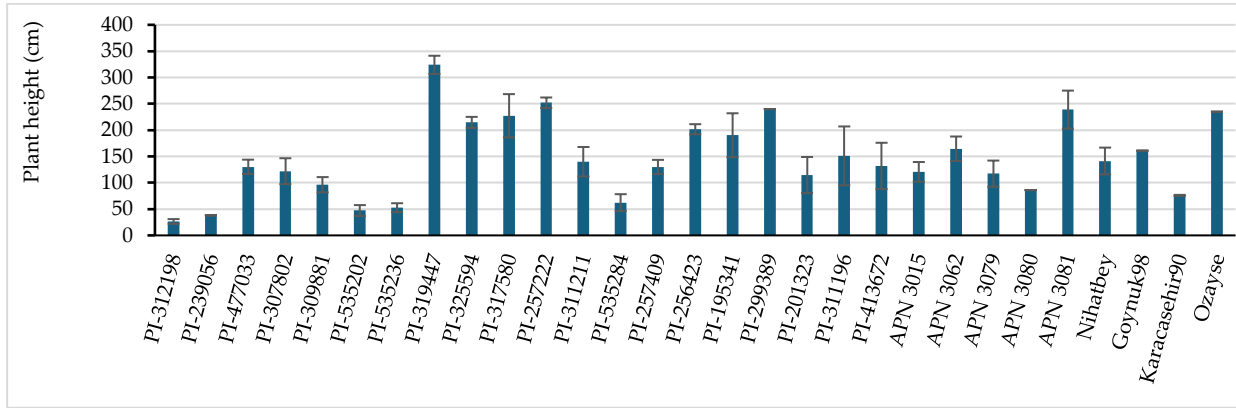


Figure 3. Plant height, bars indicated means $\pm$ standard errors.

Şekil 3. Bitki boyu, barları $\pm$ standart hataları.

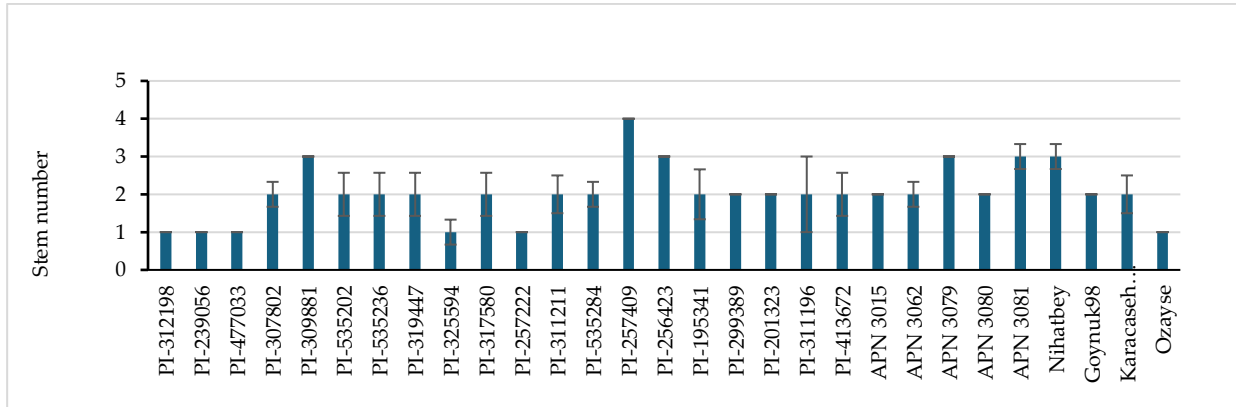


Figure 4. Stem number, bars indicated means $\pm$ standard errors.

Şekil 4. Dal sayısı, barları $\pm$ standart hataları.

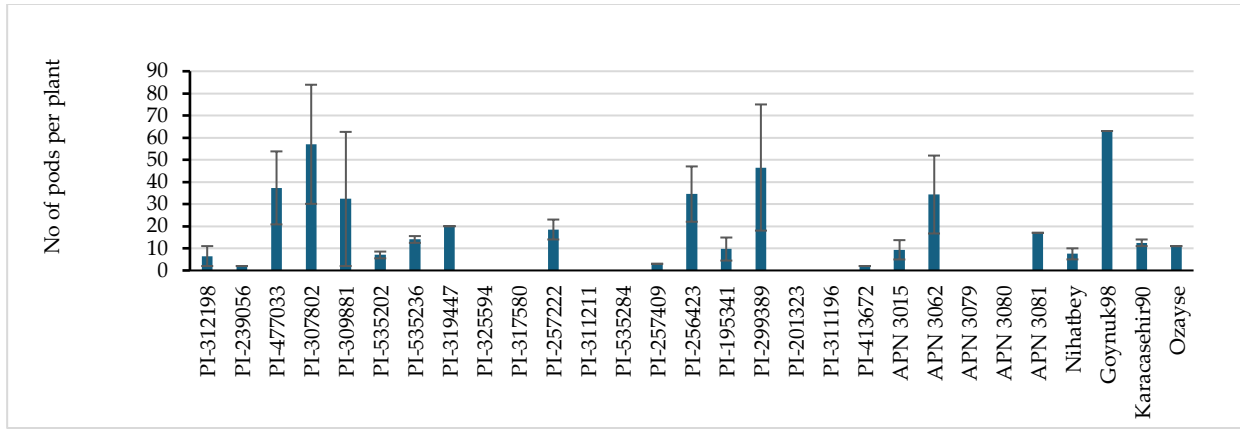


Figure 5. Pods per plant, bars indicated means $\pm$ standard errors.

Şekil 5. Bitki başına bakla sayısı, barları $\pm$ standart hataları.

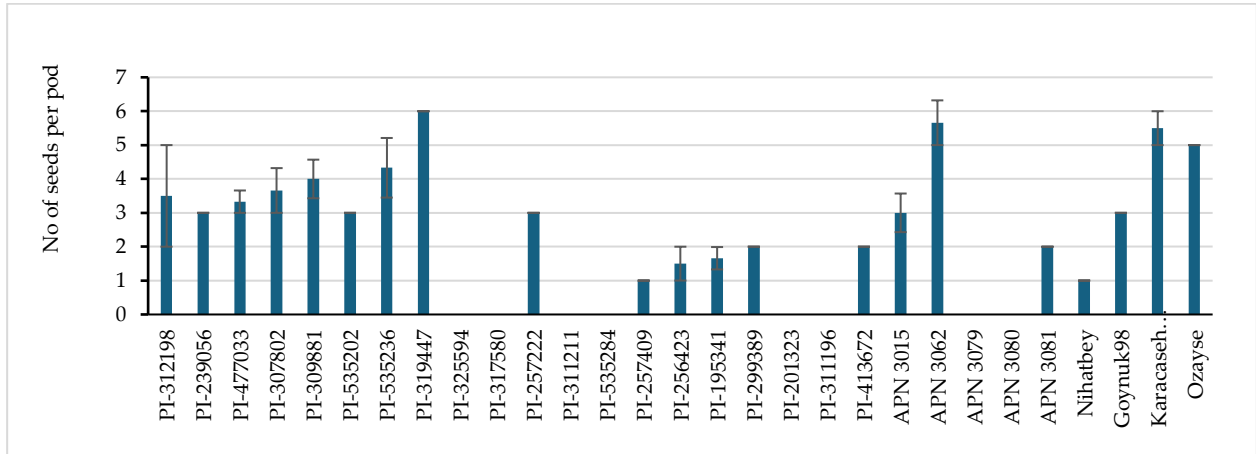


Figure 6. Seed per pod, bars indicated means $\pm$ standard errors.

Şekil 6. Baklada tohum sayısı, barları $\pm$ standart hataları.

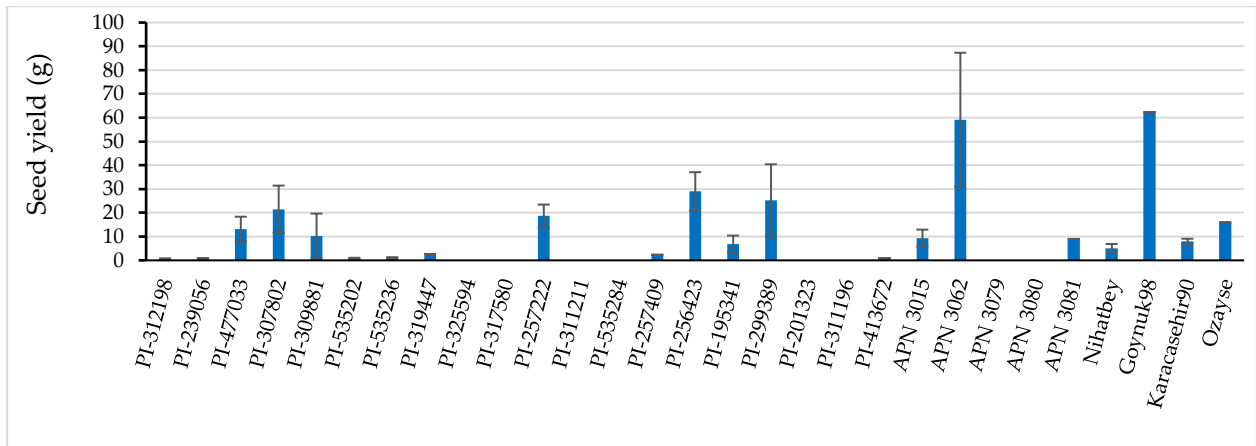


Figure 7. Seed yield, bars indicated means $\pm$ standard errors.

Şekil 7. Tane verimi, barları $\pm$ standart hataları.

In general, pod length of registered cultivars of *P. vulgaris* was longer than that of the other species. Ozayse and APN3062, registered cultivars of *P. vulgaris* had the longest pod having 58.72 mm and 56.36 mm, respectively (Figure 8). Pod width of the genotypes ranged from 2.69 mm in genotype (PI-535236) of *P. acutifolius* var. *tenuifolius* to 8.73 mm in genotype (PI-256423) of *P. lunatus* (Figure 9). As for pod diameter, the genotype PI-257222 (*P. coccineus*) had the widest pod diameter with 4.71 mm (Figure 10). In Figure 11, beak length in pod ranged from 1.13 mm (PI-299389) in *P. lunatus* to 9.69 mm (PI-257222) in *P. coccineus*.

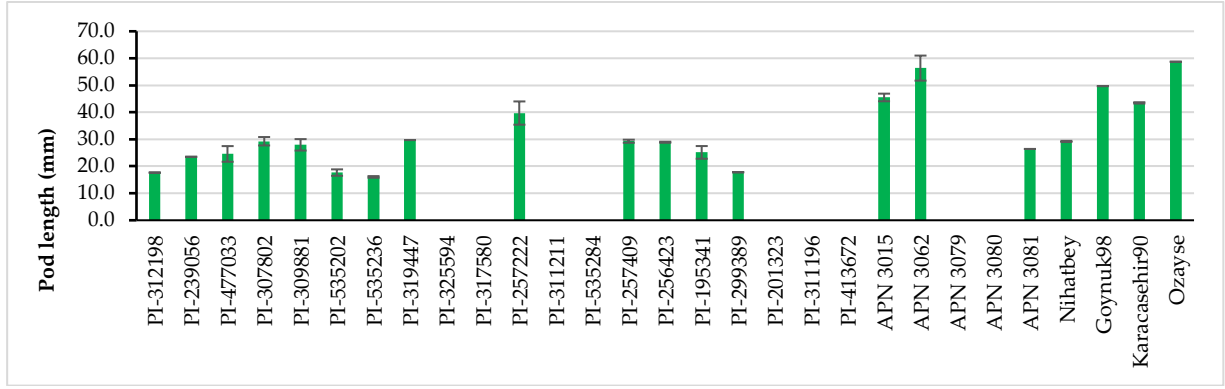


Figure 8. Pod length, bars indicated means $\pm$ standard errors.

Şekil 8. Bakla uzunluğu, barları $\pm$ standart hataları.

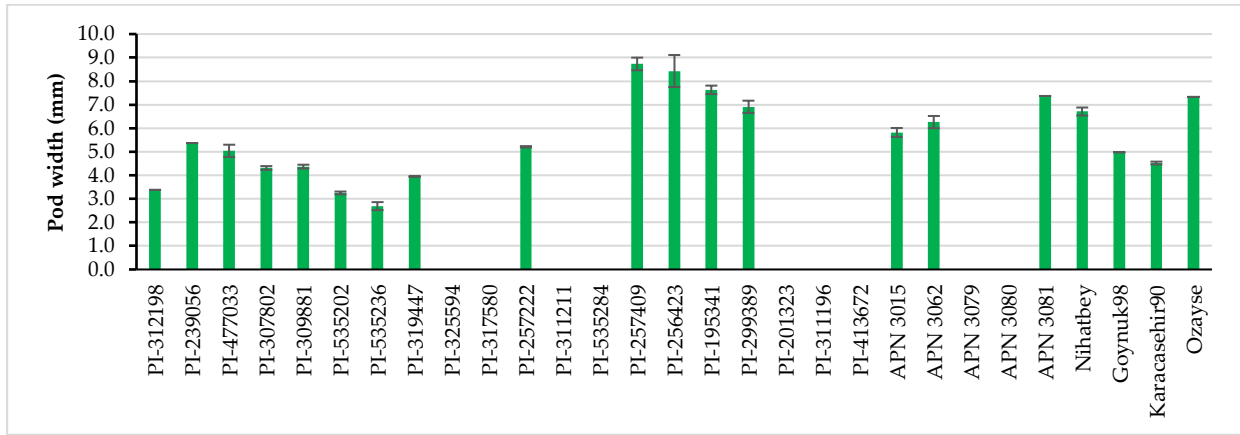


Figure 9. Pod width, bars indicated means $\pm$ standard errors.

Şekil 9. Bakla eni, barları $\pm$ standart hataları.

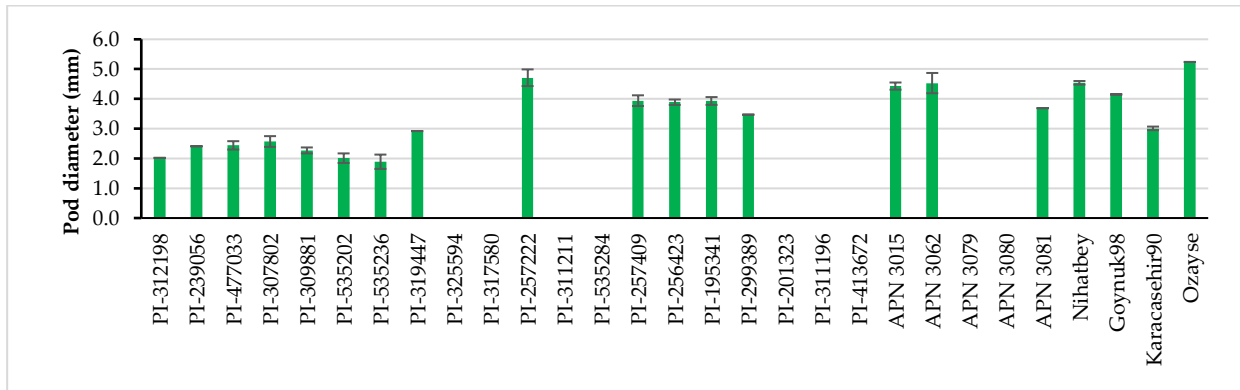


Figure 10. Pod diameter, bars indicated means $\pm$ standard errors.

Şekil 10. Bakla kalınlığı, barları $\pm$ standart hataları.

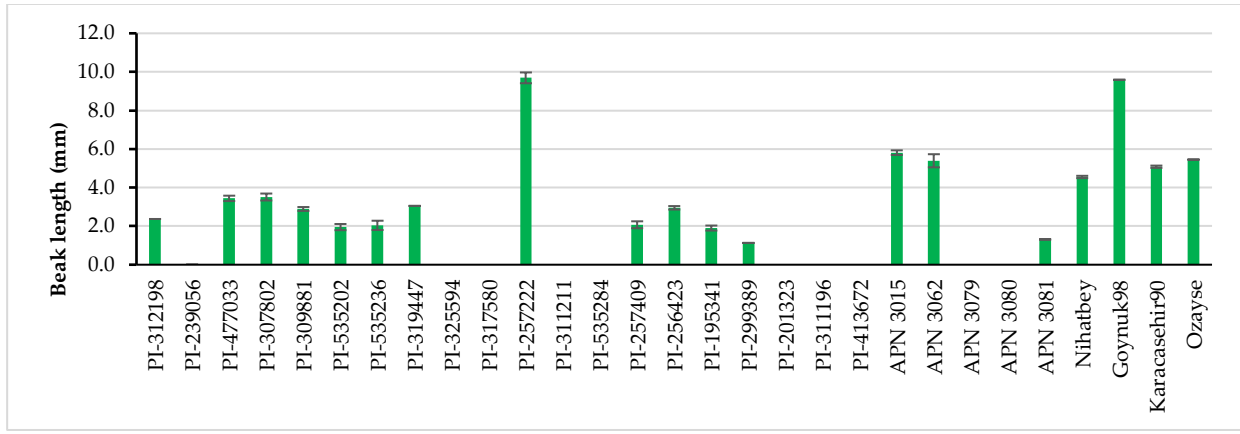


Figure 11. Beak length, bars indicated means $\pm$ standard errors.

Şekil 11. Gaga uzunluğu, barları $\pm$ standart hataları.

The heaviest and the largest seed were detected in a genotype (PI-257409) of *P. lunatus* with 78 g per 100-seed weight, while the lightest and the smallest seed were identified in a genotype (PI-312198) of *P. acutifolius* with 2.82 g per 100-seed weight Figure 12. Seed length of the beans was between 2.28 mm (PI-312198, a genotype of *P. acutifolius*) and 8.92 mm (Goynuk98, registered cultivar of *P. vulgaris*) (Figure 13). Seed width of the genotypes varied from 1.65 mm (PI-535236, a genotype of *P. acutifolius* var. *tenuifolius*) to 5.49 mm (PI-256423, a genotype of *P. lunatus* var.) (Figure 14). In Figure 15, PI-257222 (*P. coccineus*) had the widest seed diameter with 3.97 mm. The cultivars of *P. vulgaris* had wider seed diameter than that of the other species except *P. coccineus*.

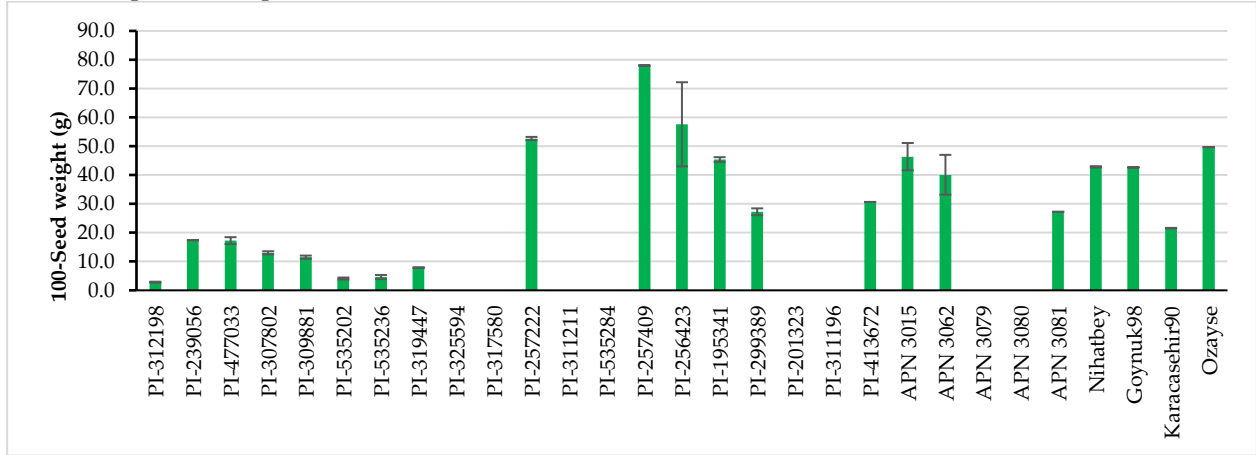


Figure 12. 100-seed weight, bars indicated means $\pm$ standard errors.

Şekil 12. 100 tane ağırlığı, barları $\pm$ standart hataları.

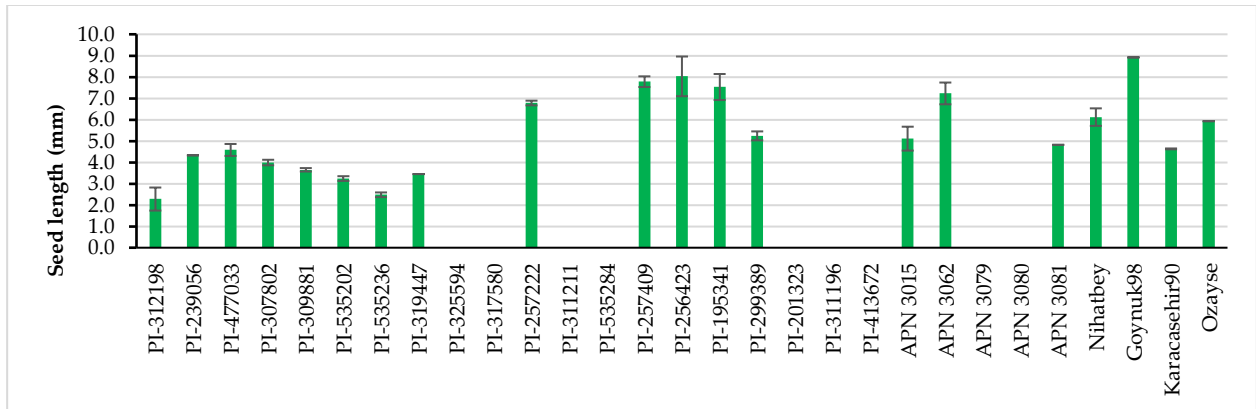


Figure 13. Seed length, bars indicated means $\pm$ standard errors.

Şekil 13. Tane uzunluğu, barları $\pm$ standart hataları.

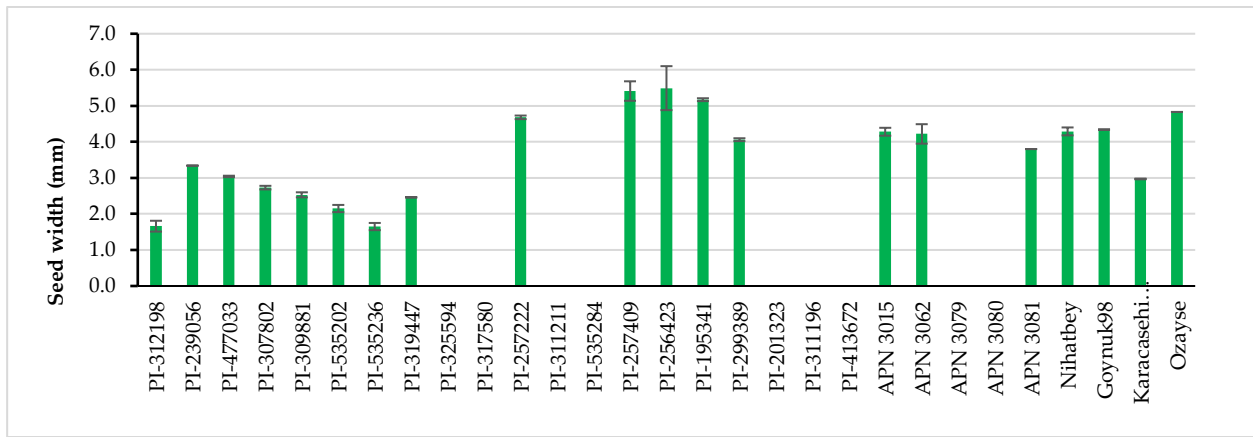


Figure 14. Seed width, bars indicated means $\pm$ standard errors.

Şekil 14. Tane eni, barları $\pm$ standart hataları.

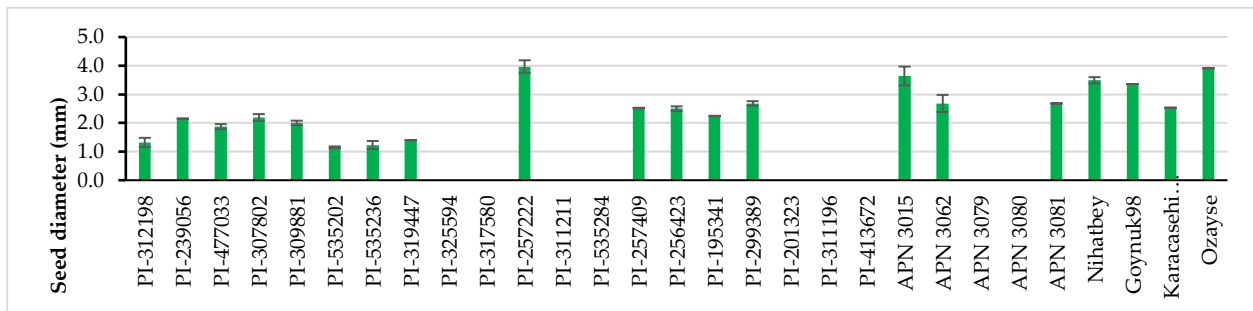


Figure 15. Seed diameter, bars indicated means $\pm$ standard errors.

Şekil 15. Tane kalınlığı, barları $\pm$ standart hataları.

Seeds colors and shapes of genotypes and registered cultivars of *Phaseolus* used in the study (Figure S1). Some flowers of genotypes and registered cultivars of *Phaseolus* used in the study (Figure S2). In Figure S3, some pods of genotypes and registered cultivars of *Phaseolus* used in the study. Some leaves samples of genotypes and registered cultivars of *Phaseolus* used in the study (Figure S4).

Factor Analysis

Three factors are explained with variance of 76.9% having > 1 variance value. Factor 1 consisted of seed width, pod diameter, seed length, 100-seed weight, pod width, seed diameter and seed yield with positive loadings, whereas factor 2 contained beak length of pod, seed per pod, and pod length, with negative loadings, and days to flowering. Factor 3 had three characteristics as pods per plant, plant height and stem per plant with positive loadings (Table 3).

Correlations Analyses

As seen in Table 3, correlation analysis showed that grain yield was significantly and positively correlated with the plant height ($r = 0.132$), stems per plant ($r = 0.047$), and pods per plant ($r = 0.682$) but negatively correlated with the days to flowering ($r = -0.087$). The pod length (mm) was strongly and positively associated with 100-seed weight ($r = 0.897$) and pod width ($r = 0.803$). Beak length was highly and positively related with pod length ($r = 0.701$) in Table 4. Similar results were explained by Tigist et al. 2023 among 15 agro-morphological characters in 144 common bean genotypes.

Table 3. Factor loadings, communalities and phenotypic correlations between seed yield and the studied characteristics in genotypes and registered cultivars of *Phaseolus acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* and *P. vulgaris* L.

Çizelge 3. *Phaseolus acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* ve *P. vulgaris* tescilli çeşitler ve genotiplerin dane verimi ve çalışılan özellikler için faktör analizleri ve fenotipik korelasyonlar.

Variables	Factor 1	Factor 2	Factor 3	Communalities
Seed width (mm)	0.940	0.238	-0.125	0.956
Pod diameter (mm)	0.939	-0.112	-0.126	0.910
Seed length (mm)	0.910	0.068	-0.018	0.833
100-seed weight (g)	0.933	0.205	-0.166	0.939
Pod width (mm)	0.867	0.424	-0.061	0.881
Seed diameter (mm)	0.829	-0.259	-0.156	0.778
Seed yield (g)	0.556	-0.523	0.516	0.849
Beak length (mm)	0.460	-0.764	-0.103	0.806
Seeds per pod (No)	-0.235	-0.736	0.129	0.614
Pod length (mm)	0.627	-0.696	-0.061	0.881
Days to flowering (Days)	0.272	0.660	0.089	0.517
Pods per plant (No)	0.130	-0.253	0.806	0.730
Plant height (cm)	0.288	0.378	0.523	0.499
Stems per plant (No)	0.271	-0.253	0.479	0.521
Variance	6.1	3.1	1.5	10.7
Variance (%)	43.7	22.2	11.0	76.9

Bold data indicate factor loadings each characteristic.

Table 4. Correlations among studied characteristics in genotypes and registered cultivars of *Phaseolus acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* and *P. vulgaris* L. (n=28).

Çizelge 4. *Phaseolus acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* ve *P. vulgaris* L. tescilli çeşitler ve genotiplerin çalışılan özellikler için korelasyon analizleri (n=28).

Characters	Days to flowering (Days)	Plant height (cm)	Stems per plant (No)	Pods per plant (No)	Seed yield (g)	100-seed weight (g)	Seeds per pod (No)	Pod length (mm)	Pod width (mm)	Pod diameter (mm)	Beak length (mm)	Seed length (mm)	Seed diameter (mm)
Plant height (cm)	0.040												
Stems per plant (No)	0.166	0.208											
Pods per plant (No)	0.059	0.081	0.059										
Seed yield (g)	-0.087	0.132	0.047	0.682**									
100-seed weight (g)	0.317	0.396*	0.262	-0.070	0.290								
Seeds per pod (No)	-0.271	-0.204	-0.248	0.127	0.243	-0.403*							
Pod length (mm)	-0.103	0.019	-0.050	0.071	0.601**	0.479**	0.468**						
Pod width (mm)	0.458*	0.365*	0.345	-0.033	0.221	0.848**	-0.500**	0.211					
Pod diameter (mm)	0.216	0.344	0.210	-0.008	0.449*	0.867**	-0.178	0.675**	0.699**				
Beak length (mm)	-0.033	0.047	-0.178	0.128	0.437*	0.386*	0.230	0.701**	-0.073	0.541**			
Pod length (mm)	0.335	0.343	0.199	0.135	0.533**	0.897**	-0.375*	0.450*	0.803**	0.785**	0.356		
Seed width (mm)	0.451*	0.384*	0.263	0.010	0.345	0.947**	-0.456*	0.381*	0.918**	0.835**	0.237	0.929**	
Seed diameter (mm)	0.240	0.254	0.124	0.088	0.378*	0.722**	-0.176	0.637**	0.484**	0.859**	0.686**	0.611**	0.681**

Discussion

Although bean species prefer growing optimum temperature between 20 and 25 °C (Porch, 2006; Porch and Jahn, 2001; Stefanov et al., 2011; Singh et al., 2014; Türkan et al., 2005) beans in this study were subjected to extreme heat stress especially pod setting stage. Plants were survived at extreme temperature

between 39.8 and 55 °C (Figure 1) and produced considerable pods per plant (Figure 2). Cultivated beans were reported to be relatively more sensitive to drought stress and salinity stress compared to other legumes. On the other hand, it has been known that *P. acutifolius* can be widely grown under high temperature and drought conditions for thousands of years. *P. acutifolius* is an important gene source in drought resistance breeding studies (Türkan et al., 2005). *P. acutifolius* was not only drought tolerant but also heat tolerant species (Figure 2). *P. acutifolius* could be gain drought and heat tolerance traits during before domestication since it originated from south of North America. *P. acutifolius* is grown under arid and semi-arid conditions, with high temperatures, low and variable precipitation, and alkaline soils (Lin and Marhart 1990; Dohle et al., 2019). *P. acutifolius* is still predominantly grown only in its region of origin in the warm deserts of Mexico and the USA (Bornowski et al., 2023), although it is the subject of increasing interest in similar agroecological regions of Africa and South Asia (Small, 2014). *P. acutifolius* is a drought-tolerant species so it would cross with wild relatives and common beans (Buitrago-Bitar et al., 2021). *P. lunatus* is grown in the warm humid tropics, important nutrition contents and rich in antioxidant so that's a popular source of protein in many countries (Purwanti and Fauzi, 2019), while *P. coccineus* is grown under cool highland conditions in South America (Mulanya et al., 2019), and it is native for Mexico, Guatemala and Honduras (Jankulovskaa et al., 2021). *P. coccineus* is adapted to primarily in similar cool regions European countries (Hamburdă et al., 2014; Guerra-García et al., 2017; Dohle et al., 2019), and it endures low temperatures (below zero degrees) therefore an alternative for upland (>2400 m) and also tolerates drought conditions (Vázquez et al., 2014). *P. coccineus* is an important bean species that is the third most produced after *P. vulgaris* and *P. lunatus* (Lioi et al., 2019). It is grown as an ornamental plant as well as for fresh and dry consumption. Due to the low temperature requirement during seed germination and plant growth periods, it can be grown in colder production areas than *P. vulgaris* (Spataro et al., 2011). *P. dumosus* is cultivated form of a species that is the result of a naturally occurring hybridization between the progenitors of common and runner bean (Mohamed et al., 2005). Common beans are of mid- to high-land origin, and their productivity is limited by different abiotic stresses like as high temperature (Nadeem and Baloch, 2023). It is an important protein source used in human nutrition in hot and arid production areas where the cultivation of *P. vulgaris* and *P. lunatus* is limited (Almeida and Pedrosa-Harand, 2013). Among the most important characteristics of *P. dumosus*, which has less diversity compared to other bean species, are its adaptation to humid and highland production areas and its resistance to some fungal diseases such as anthracnose caused by *Colletotrichum lindemuthianum* (Sacc. & Magnus) Briosi & Cavara (Mohamed et al., 2005).

In common bean phenological adaptation, plant-water relations, photosynthetic metabolism, and shoot growth are play an important role in tolerance of heat and drought (Hamabwe et al., 2023). According to estimation of the global climate change regime, the temperature will rise in the range of 1.4-5.8 C by the end of 2100 (Shankar et al., 2023). Drought stress leads to decrease in yield to common bean especially with climate change (Landi et al., 2023). During the flowering stage, drought causes important flower and pod deformations therefore cause high yield loss in common beans. Also, this situation has been reported in lots of studies (Papathanasiou et al., 2022). In general, the early flowered genotypes of *Phaseolus* species were found to be more pod length and seeds per pod. In contrast some plant breeders were defended that late maturing bean genotypes have higher yielder than earlier because of nutrients uptake and photosynthesize (Cattel, 1965). Significant correlations have been detected among the seeds per pod, plant type, growth habit and days to flowering agronomic traits in common bean breeding (Mammo et al., 2015). According to Nadeem and Baloch (2023), pod and seed traits that contribute significantly to common bean yield. *Phaseolus* species with the more pods per pod had the more stems per plant with higher plant height. Each factor indicated that one characteristic at least could be considered for high seed yield under moderate heat stress conditions. Thanks to factor analysis, breeders will be assessed with few correlated characteristics instead of many characteristics (Table 3 and 4). Prior to the present study, the use of factor analysis was suggested by (Cagirgan and Yildirim, 1990; Cattel, 1965; Mammo et al., 2015; Marzoghian et al., 2012; Majid et al., 1982; Nemli et al., 2014; Toker, 2004; Toker and Cagirgan, 2004; Sadeghi et al., 2011). As shown in previous studies, seed or pod characteristics in the present study should be handed to elucidate for high yield during selection. Development of new varieties depends on

genetic diversity (Lin and Marhart, 1990). Wild relatives of plants are a potential source of both disease-resistance genes and have greater adaptability to different stresses like biotic and abiotic stresses (Shankar et al., 2023). Seed yield was grouped into the same factor with seed width, pod diameter, seed length, 100-seed weight, pod width, and seed diameter with positive loadings (Table 3) indicating that one of these traits can be evaluated for high seed yield instead of many traits. Prior to this study, Canci and Toker (2009) suggested reducing selection criteria using factor analysis in chickpea. Seed yield was significantly and negatively correlated with the days to flowering (Table 4) explaining that the beans having more seed yield flowered earlier (Figure 2). On the other hand, seed yield was positively correlated with the plant height, stems per plant, and pods per plant showing that high seed yield in beans depended on high plant height, more stems and pods per plant (Table 3 and 4). Under heat stress conditions, beans having high seed yield can be selected via these traits. Pod length and pod weight have considerations for yield improvement by conventional selection breeding. In addition, pod length is positively correlated with seeds per pod and 100 seed weight (Ellis et al., 2021).

CONCLUSION

As a result of the study, PI-319447 (*P. acutifolius*), Goynuk98 (*P. vulgaris*), PI-312198 (*P. acutifolius*) and Ozayse (*P. vulgaris*) genotypes were determined to be the earliest flowering. The genotypes with the highest number of pods per plant were Goynuk98 (*P. vulgaris*), PI-307802 (*P. acutifolius*). The local variety (APN 3062) stands out with its number of seeds per pod, pod length, pod diameter and seed yield. The pod width, seed length and seed width of PI-256423 (*P. lunatus*) were determined at the highest values. *P. acutifolius* and *P. lunatus* are known for their tolerance to high temperature and drought. A registered cultivar had the highest seed yield per plant. Some local cultivars including Goynuk98 and APN3062 *P. vulgaris* were considered to grow under heat stress conditions due to high seed yield. Heat-resilient genotypes of *P. acutifolius* and *P. vulgaris* were considered to be not only escape ability via earliness but also buffering capability of heat stress.

CONFLICT OF INTEREST

We declare that there are no conflicts of interest.

DECLARATION OF AUTHOR CONTRIBUTION

Conceptualization Simru Baş Salan and Hüseyin Çancı; methodology Hüseyin Çancı; software Simru Baş Salan; validation Simru Baş Salan and Hüseyin Çancı; formal analysis Simru Baş Salan; investigation Simru Baş Salan; resources Simru Baş Salan and Hüseyin Çancı; data curation Simru Baş Salan; writing-original draft preparation Simru Baş Salan and Hüseyin Çancı; writing-review and editing Simru Baş Salan and Hüseyin Çancı; visualization Simru Baş Salan; supervision Hüseyin Çancı. Both authors have read and agreed to the published version of the manuscript.

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REFERENCES

- Almeida, C., & Pedrosa-Harand, A. (2013). High macro-collinearity between lima bean (*Phaseolus lunatus* L.) and the common bean (*P. vulgaris* L.) as revealed by comparative cytogenetic mapping. *Theoretical and Applied Genetics*, 126(7): 1909-1916. <https://doi.org/10.1007/s00122-013-2106-9>
- Angioi, S. A., Rau, D., Attene, G., Nanni, L., Bellucci, E., Logozzo, G., & Papa, R. (2010). Beans in Europe: origin and structure of the European landraces of *Phaseolus vulgaris* L. *Theoretical and Applied Genetics*, 121(5): 829-843. <https://doi.org/10.1007/s00122-010-1353-2>

- Asfaw, A., Ambachew, D., Shah, T., & Blair, M. W. (2017). Trait associations in diversity panels of the two common bean (*Phaseolus vulgaris* L.) gene pools grown under well-watered and water-stress conditions. *Frontiers in Plant Science*, 8: 733. <https://doi.org/10.3389/fpls.2017.00733>
- Aquino-Bolaños, E. N., García-Díaz, Y. D., Chavez-Servia, J. L., Carrillo-Rodríguez, J. C., Vera-Guzmán A. M., & Heredia-García, E. (2016). Anthocyanins, polyphenols, flavonoids and antioxidant activity in common bean (*Phaseolus vulgaris* L.) landraces. *Emirates Journal of Food and Agriculture*, 28(8): 581-588. <https://doi.org/10.9755/ejfa.2016-02-147>
- Basavaraja, T., Manjunatha L., Chandora R., Gurumurthy S., & Singh N. P. (2020). Assessment of genetic variability, diversity and trait correlation analysis in common bean (*Phaseolus vulgaris* L.) genotypes. *Legume Research*, 44(3): 252-260. <https://doi.org/10.18805/LR-4208>.
- Bitocchi, E., Nanni, L., Bellucci, E., Rossi, M., Giardini, A., Zeuli, P. S., Logozzo, G., Stougaard, J., McClean, P., Attene, G., & Papa, P. (2012). Mesoamerican origin of the common bean (*Phaseolus vulgaris* L.) is revealed by sequence data. *Proceedings of the National Academy of Sciences*, 109(14): 788-796. <https://doi.org/10.1073/pnas.1108973109>
- Broughton, W. J., Hernandez, G., Blair, M., Beebe, S., Gepts, P., & Vanderleyden, J. (2003) Beans (*Phaseolus* spp.)—model food legumes. *Plant and Soil*, 252 (1): 55-128. <https://doi.org/10.1023/A:1024146710611>
- Bomers, S., Sehr, E. M., Adam, E., von Gehren, P., Hansel-Hohl, K., Prat, N., & Ribarits, A. (2022). Towards heat tolerant runner bean (*Phaseolus coccineus* L.) by utilizing plant genetic resources. *Agronomy*, 12(3): 612. <https://doi.org/10.3390/agronomy12030612>
- Borel, J. C., Ramalho, M. A. P., de Carvalho, V. R. F., Abreu, Â. D. F. B. (2013). Genetic and Phenotypic parameters in common bean segregant populations from intra and inter-gene pool crosses of elite lines. *Euphytica*, 193(1): 39-47. <https://doi.org/10.1007/s10681-013-0907-1>
- Bornowski, N., Hart, J. P., Palacios, A. V., Ogg, B., Brick, M. A., Hamilton, J. P., Beaver, J. S., Buell, C. R., & Porch, T. (2023). Genetic variation in a tepary bean (*Phaseolus acutifolius* A. Gray) diversity panel reveals loci associated with biotic stress resistance. *The Plant Genome*, 16: e20363. <https://doi.org/10.1002/tpg2.20363>
- Buitrago-Bitar, M.A., Cortés, A. J., López-Hernández, F., Londoño-Caicedo, J. M., Muñoz-Florez, J. E., Muñoz, L. C., & Blair, M. W. (2021). Allelic diversity at abiotic stress responsive genes in relationship to ecological drought indices for cultivated tepary bean, *Phaseolus acutifolius* A. Gray, and its wild relatives. *Genes*, 12(4): 556. <https://doi.org/10.3390/genes12040556>
- Burbano-Erazo, E., León-Pacheco, R. I., Cordero-Cordero, C. C., López-Hernández, F., Cortés, A. J., & Tofiño-Rivera, A. P. (2021). Multi-environment yield components in advanced common bean (*Phaseolus vulgaris* L.) × tepary bean (*P. acutifolius* A. Gray) interspecific lines for heat and drought tolerance. *Agronomy*, 11(10): 1978. <https://doi.org/10.3390/agronomy11101978>
- Cagirgan, M. I., & Yildirim, M. B. (1990). An application of factor analysis to data from control and macro mutant populations of 'Quantum' barley. *Journal of Faculty of Agriculture of Akdeniz University*, 4: 125-138.
- Canci, H., & Toker, C. (2009). Evaluation of yield criteria for drought and heat resistance in chickpea (*Cicer arietinum* L.). *Journal of Agronomy and Crop Science*, 195(1): 47-54. <https://doi.org/10.1111/j.1439-037X.2008.00345.x>
- Cattel, R. B. (1965). Factor analysis: An introduction to essentials. I. The propose and underlying models. *Biometrics*, 21: 190-215.
- Checa, O., Ceballos, H., & Blair, M. V. (2006). Generation means analysis of climbing ability in common bean (*Phaseolus vulgaris* L.). *Journal of Heredity*, 97(5): 456-465. <https://doi.org/10.1093/jhered/esl025>
- Cortes, A. J. (2013). On the origin of the common bean (*Phaseolus vulgaris* L.). *American Journal of Plant Sciences*, 4(10): 1998-2000. <https://doi.org/10.4236/ajps.2013.410248>
- De la Fuente, M., Lopez-Pedrouso, M., Alonso, J., Santalla, M., De Ron, A. M., Alvarez, G., & Zapata, C. (2012). In-depth characterization of the phaseolin protein diversity of common bean (*Phaseolus vulgaris* L.) based on two-dimensional electrophoresis and mass spectrometry. *Food Technology and Biotechnology*, 50(3): 315-325.
- Dohle, S., BernyMier y Teran, J.C., Egan, A., Kisha, T., & Khoury, C.K. (2019). Wild Beans (*Phaseolus* L.) of North America. In S. Greene, K. Williams, C. Khoury, M. Kantar, & L. Marek (Eds.), *North American Crop Wild Relatives*. Springer (pp. 99-127). Cham. https://doi.org/10.1007/978-3-319-97121-6_4

- Ellis, T. H. N., Hofer, J. M., Vikeli, E., Ambrose, M. J., Higuera-Poveda, P., Wingen, L. U., & Chayut, N. (2021). Diversity of pod shape in *Pisum*. *Diversity*, 13(5): 203. <https://doi.org/10.3390/d13050203>
- Flores-Sosa, Á. R., Aquino-Bolaños, E. N., Cardador-Martínez, A., Chávez-Servia, J. L., Vera-Guzmán, A. M., Carrillo-Rodríguez, J. C., & Jiménez, J. E. A. (2020). Variation in protein and amino acids content among landraces of common bean (*Phaseolus vulgaris* L.). *Emirates Journal of Food and Agriculture*, 32(10): 750-760. <https://doi.org/10.9755/ejfa.2020.v32.i10.2175>.
- García-Díaz Y. D., Vera-Guzmán A. M., Aquino-Bolaños E. N., Muciño-Serrano S., & Chávez-Servia J. L. (2022). Phenolic compounds, antioxidant activity and mineral contents in grains of *Phaseolus lunatus* L. and *P. coccineus* L. landraces. *Legume Research*, 45(9): 1155-1160. <https://doi.org/10.18805/LRF-690>
- Gepts, P. (1998). Origin and evolution of common bean: Past events and recent trends. *HortScience*, 33(7): 1124-1130. <https://doi.org/10.21273/HORTSCI.33.7.1124>
- Gross, Y., & Kigel, J. (1994). Differential sensitivity to high temperature of stages in the reproductive development of common bean (*Phaseolus vulgaris* L.). *Field Crops Research*, 36(3): 201-212. [https://doi.org/10.1016/0378-4290\(94\)90112-0](https://doi.org/10.1016/0378-4290(94)90112-0)
- Guerra-García, A., Suárez-Atilano, M., Mastretta-Yanes, A., Delgado-Salinas, A., & Piñero, D. (2017). Domestication genomics of the open-pollinated scarlet runner bean (*Phaseolus coccineus* L.). *Frontiers in Plant Science*, 8: 1891. <https://doi.org/10.3389/fpls.2017.01891>
- Hamabwe, S. M., Otieno, N., Soler-Garzón, A., Miklas, P., Parker, T., Kramer, D. M., Chattopadhyay, A., Cheelo, P., Kuwabo, K., & Kamfwa, K. (2023). Identification of quantitative trait loci for drought tolerance in Bukoba/Kijivu Andean mapping population of common bean. *Theoretical and Applied Genetics*, 136: 222. <https://doi.org/10.1007/s00122-023-04463-2>
- Hamburdă, S. B., Munteanu, N., Stoleru, V., Butnariu, G., Teliban, G. C., & Popa, L. D. (2014). Experimental results on runner bean cultivation (*Phaseolus coccineus* L.) in intercropping system. *Lucrări Științifice, Seria Horticultură*, 57 (1): 75-80.
- Jankulovska, M., Ivanovska, S., & Atanasova, N. S. (2021). Morphological variability of seed qualitative and quantitative traits in Macedonian runner bean local varieties. *ISHS Acta Horticulturae 1320: VIII South-Eastern Europe Symposium on Vegetables and Potatoes*. <https://doi.org/10.17660/ActaHortic.2021.1320.5>
- Kwak, M., & Gepts, P. (2009). Structure of genetic diversity in the two major gene pools of common bean (*Phaseolus vulgaris* L. Fabaceae). *Theoretical and Applied Genetics*, 118(5): 979-992. <https://doi.org/10.1007/s00122-008-0955-4>
- Landi, N., Alberico, L., Clemente, A., Peddion, S., Hussain, H. Z., Ragucci, S., ... & Di Maro, A. (2023). Nutritional, metabolic and genetic profiling of 'Cerato' and 'Curniciello' bean landraces from Caserta, Southern Italy. *Food Bioscience*, 55: 102975. <https://doi.org/10.1016/j.fbio.2023.102975>
- Lin, T. Y., & Marhart, A. H. (1990). Temperature effects on mitochondrial respiration in *Phaseolus acutifolius* A. Gray and *Phaseolus vulgaris* L. *Plant Physiology*, 94(1): 54-58. <https://doi.org/10.1104/pp.94.1.54>
- Lioi, L., Zuluaga, D. L., Pavan, S., & Sonnante, G. (2019). Genotyping-by-sequencing reveals molecular genetic diversity in Italian common bean landraces. *Diversity*, 11(9): 154. <https://doi.org/10.3390/d11090154>
- Mackie, W. (1943). Origin, dispersal, and variability of the lima bean, *Phaseolus lunatus*. *Hilgardia*, 15 (1): 1-29.
- Majid, M. A., Khanum, S., Saikh, M. A. Q., Bhuiya, A. D. (1982). Genetic variability and correlation studies in black gram. *Bangladesh Journal of Agriculture*, 7: 98-102.
- Mammo, K., Wegary, D., Lule, D., & Mekbib, F. (2015). Agronomic performance and compatibility of common bean genotypes intercropped with maize. *Ethiopian Journal of Crop Science*, 4(1): 30-44.
- Martínez-Nieto, M. I., González-Orenga, S., Soriano, P., Prieto-Mossi, J., Larrea, E., Doménech-Carbó, A., Tofei, A. M., Vicente, O., & Mayoral, O. (2022). Are traditional lima bean (*Phaseolus lunatus* L.) landraces valuable to cope with climate change? Effects of drought on growth and biochemical stress markers. *Agronomy*, 12(7): 1715. <https://doi.org/10.3390/agronomy12071715>
- Marzooghian, A., Moghaddam, M., Valizadeh, M., & Kooshki, M. H. (2012). Genetic diversity of common bean genotypes as revealed by seed storage proteins and some agronomic traits. *Plant Breeding and Seed Science*, 67: 125-137. <https://doi.org/10.2478/v10129-011-0075-1>
- MINITAB. (2014). *Minitab statistical software, release 17 for windows* [Computer software]. MINITAB Inc., State College.

- Mohamed, F., Mohamed, M., Schmitz-Eiberger, N., Keutgen, N., & Noga, G. (2005). Comparative drought postponing and tolerance potentials of two tepary bean lines in relation to seed yield. *African Crop Science Journal*, 13(1): 49-60.
- Mulanya, M. M., Kimani, P. M., Narla, R. D., & Ojwang, P. O. (2019). Genetic inheritance of photoperiod sensitivity in Runner bean (*Phaseolus coccineus* L.). *Australian Journal of Crop Science*, 13(9): 1511-1519. <https://doi.org/10.21475/ajcs.19.13.09.p1784>
- Nadeem, M. A., & Baloch, F. S. (2023). Genome-wide association studies revealed DArTseq loci associated with seed traits in Turkish common bean germplasm. *Turkish Journal of Agriculture and Forestry*, 47: 479-496. <https://doi.org/10.55730/1300-011X.3103>
- Nemli, S., Ascioğul, T. K., Kaya, H. B., Kahraman, A., Eşiyok, D., & Tanyolac, B. (2014). Association mapping for five agronomic traits in the common bean (*Phaseolus vulgaris* L.). *Journal of the Science of Food and Agriculture*, 94(15): 3141-3151. <https://doi.org/10.1002/jsfa.6664>
- Nurmansyah, N., Alghamdi, S. S., Migdadi, H. M., Khan, M. A., & Afzal, M. (2020). AFLP-based analysis of variation and population structure in mutagenesis induced faba bean. *Diversity*, 12(8): 303. <https://doi.org/10.3390/d12080303>
- Omae, H., Kumar, A., & Shono, M. (2012). Adaptation to high temperature and water deficit in the common bean (*Phaseolus vulgaris* L.) during the reproductive period. *Journal of Botany*, 2012: 803413. <https://doi.org/10.1155/2012/803413>
- Papathanasiou, F., Ninou, E., Mylonas, I., Baxevanos, D., Papadopoulou, F., Avdikos, I., Sistanis, I., Koskosidis, A., Vlachostergios, D. N., Stefanou, S., Tigka, E., & Kargiotidou, A. (2022). The evaluation of common bean (*Phaseolus vulgaris* L.) genotypes under water stress based on physiological and agronomic parameters. *Plants*, 11(18): 2432. <https://doi.org/10.3390/plants11182432>
- Paredes, M., Becerra, V., & Tay, J. (2009). Inorganic nutritional composition of common bean (*Phaseolus vulgaris* L.) genotypes race Chile. *Chilean Journal of Agricultural Research*, 69(4): 486-495. <https://doi.org/10.4067/S0718-58392009000400002>
- Pineda Ivars, M., Galdón Rodríguez, B., Álvarez Paiz, N., Morales Afonso, D., Mesa Ríos, D., Romero Díaz, C., & Rodríguez-Rodríguez, E. M. (2023). Physico-chemical and nutritional characterization of *Phaseolus vulgaris* L. Germplasm. *Legume Research*, 46(3): 273-280. <https://doi.org/10.18805/LRF-715>
- Porch, T. G. (2006). Application of stress indices for heat tolerance screening of common bean. *Journal of Agronomy and Crop Science*, 192: 390-394. <https://doi.org/10.1111/j.1439-037X.2006.00229.x>
- Porch, T., & Jahn, M. (2001). Effects of high-temperature stress on microsporogenesis in heat-sensitive and heat-tolerant genotypes of *Phaseolus vulgaris*. *Plant Cell & Environment*, 24: 723-731. <https://doi.org/10.1046/j.1365-3040.2001.00716.x>
- Porch, T. G., Beaver, J. S., Debouck, D. G., Jackson, S. A., Kelly J. D., & Dempewolf, H. (2013). Use of wild relatives and closely related species to adapt common bean to climate change. *Agronomy*, 3(2): 433-461. <https://doi.org/10.3390/agronomy3020433>
- Purwanti, E., & Fauzi, A. (2019). The morphological characteristics of *Phaseolus lunatus* L. in different areas of East Java, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 276(1), 012017. <https://doi.org/10.1088/1755-1315/276/1/012017>
- Rainey, K. M., & Griffiths, P. D. (2005). Evaluation of *Phaseolus acutifolius* A. Gray plant introductions under high temperatures in a controlled environment. *Genetic Resources and Crop Evolution*, 52(2): 117-120. <https://doi.org/10.1007/s10722-004-1811-2>
- Reddy Rajasekhar, B., Pandey, M., Singh, J., Singh, P. M., & Rai, N. (2024). Principal component analysis and stability of genotypes in french bean (*Phaseolus vulgaris* L.). *Legume Research*, 47(5): 745-750. <https://doi.org/10.18805/LR-4569>
- Rosario-Arellano Del J.L., Iglesias-Rojas N. G., Tencos-Muñoz L. C., Ugalde-Acosta F. J., Andrés-Meza P., Verdejo-Lara R. A., Leyva-Ovalle O. R., Rosario-Arellano Del J., Serna-Lagunes R., & Murguía-González J. (2025). Variability in morphometric and agronomic traits of native bean seeds (*Phaseolus vulgaris* L.) and edaphoclimatic characterization. *Legume Research*, 48(1): 64-74. <https://doi.org/10.18805/LRF-826>

- Sadeghi, A., Cheghamirza, K., & Dorri, H. R. (2011). The study of morphoagronomic traits relationship in common bean (*Phaseolus vulgaris* L.). *Biharean Biologist*, 5(2): 102-108.
- Shankar, T. U., Semwal, D. P., Gupta, V., Archak, S., Nair, R. M., & Tripathi, K. (2023). Spatial distribution, diversity mapping, and gap analysis of wild *Vigna* species conserved in India's National Genebank. *Diversity*, 15(4): 552. <https://doi.org/10.3390/d15040552>
- Smart, J. (1992). *Phaseolus vulgaris* L. In L. J. G. van der Maesen & S. Somaatmadja (Eds.), *Plant Resources of South-East Asia* (pp. 60-63). Pudoc/Prosea, Wageningen, the Netherlands.
- Singh, M., Bisht, I. S., & Dutta, M. (2014). Introduction. In M. Singh, I. Bisht, & M. Dutta. (Eds.), *Broadening the Genetic Base of Grain Legumes*. Springer, New Delhi. https://doi.org/10.1007/978-81-322-2023-7_1
- Sinkovič, L., Pipan, B., Sinkovič, E., & Meglič, V. (2019). Morphological seed characterization of common (*Phaseolus vulgaris* L.) and runner (*Phaseolus coccineus* L.) bean germplasm: A Slovenian gene bank example. *BioMed Research International*, 2019: 6376948. <https://doi.org/10.1155/2019/6376948>
- Small, E. (2014). 45. Tepary Bean—an ideal arid zone crop. *Biodiversity*, 15(2-3): 220-228. <https://doi.org/10.1080/14888386.2014.903203>
- Spataro, G., Tiranti, B., Arcaleni, P., Bellucci, E., Attene, G., Papa, R., Spagnoletti, P., Zeuli, P., & Negri, V. (2011). Genetic diversity and structure of a worldwide collection of *Phaseolus coccineus* L. *Theoretical and Applied Genetics*, 122(7): 1281-1291. <https://doi.org/10.1007/s00122-011-1530-y>
- Suárez, J. C., Contreras, A. T., Anzola, J. A., Vanegas, J. I., & Rao, I. M. (2021a). Physiological characteristics of cultivated tepary bean (*Phaseolus acutifolius* A. Gray) and its wild relatives grown at high temperature and acid soil stress conditions in the Amazon region of Colombia. *Plants*, 11(1): 116. <https://doi.org/10.3390/plants11010116>
- Suárez, J. C., Urban, M. O., Contreras, A. T., Grajales, M. Á., Cajiao, C., Beebe, S. E., & Rao, I. M. (2021b). Adaptation of interspecific mesoamerican common bean lines to acid soils and high temperature in the Amazon region of Colombia. *Plants*, 10(11), 2412. <https://doi.org/10.3390/plants10112412>
- Stefanov, D., Petkova, V., & Denev, I. D. (2011). Screening for heat tolerance in common bean (*Phaseolus vulgaris* L.) lines and cultivars using jip-test. *Scientia Horticulturae*, 128(1): 1-6. <https://doi.org/10.1016/j.scienta.2010.12.003>
- Tene, T. M., Sari, H., Canci, H., Maaruf, A., Eker, T., & Toker, C. (2023). Traits related to heat stress in *Phaseolus* species. *Agriculture*, 13(5): 953. <https://doi.org/10.3390/agriculture13050953>
- Tene, T. M., Eker, T., Canci, H., Babacan, U., Cengiz, M. F., & Toker, C. (2025). Star of biochemical traits of heat-tolerant and heat-sensitive *Phaseolus* genotypes in coping with heat stress. *Plant Growth Regulation*, 105: 1511-1528. <https://doi.org/10.1007/s10725-025-01340-4>
- Tigist, S. G., Sibiya, J., Amelework, A., & Keneni, G. (2023). Agromorphological and physiological performance of Ethiopian common bean (*Phaseolus vulgaris* L.) genotypes under different agroecological conditions. *Plants*, 12(12), 2342. <https://doi.org/10.3390/plants12122342>
- Toker, C. (2004). Evaluation of selection criteria using phenotypic and factor analysis in chickpea. *Acta Agriculturae Scandinavica, Section B- Soil & Plant Science*, 54: 45-48. <https://doi.org/10.1080/09064710310022023>
- Toker, C., & Cagiran, M. I. (2004). The use of phenotypic correlations and factor analysis in determining characters for grain yield selection in chickpea (*Cicer arietinum* L.). *Hereditas*, 140: 226-228. <https://doi.org/10.1111/j.1601-5223.2004.01781.x>
- Toker, C., Canci, H., & Yildirim, T. (2007). Evaluation of perennial wild *Cicer* species for drought resistance. *Genetic Resources and Crop Evolution*, 54: 1781-1786. <https://doi.org/10.1007/s10722-006-9197-y>
- Türkan, I., Bor, M., Özdemir, F., & Koca, H. (2005). Differential responses of lipid peroxidation and antioxidants in the leaves of drought-tolerant *P. acutifolius* Gray and drought-sensitive *P. vulgaris* L. subjected to polyethylene glycol mediated water stress. *Plant Science*, 168(1): 223-231. <https://doi.org/10.1016/j.plantsci.2004.07.032>
- UPOV, International Union for the Protection of New Varieties of Plants. (2005). French bean. International union for the protection of new varieties of plants, Geneva.
- Yeken, M. Z., Kantar, F., Çancı, H., Özer, G., & Çiftçi, V. (2018a). Breeding of dry bean cultivars using *Phaseolus vulgaris* landraces in Turkey. *Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi*, 4(1): 45-54. <https://doi.org/10.24180/ijaws.408794>

- Yeken, M. Z., Akpolat, H., Karaköy, T., & Çiftçi, V. (2018b). Assessment of mineral content variations for biofortification of the bean seed. *Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi*, 4(2): 261-269. <https://doi.org/10.24180/ijaws.455311>
- Yeken, M. Z., Özer, G., Çelik, A., & Çiftçi, V. (2018c). Türkiye'de ticari fasulye (*Phaseolus vulgaris* L.) çeşitlerinde bean common mosaic virus ve bean common mosaic necrosis virus etmenlerine dayanıklılıkla ilişkili genlerin karakterizasyonu. *Türk Tarım ve Doğa Bilimleri Dergisi*, 5(4): 613–619. <https://doi.org/10.30910/turkjans.471371>
- Vázquez, V., Patricia, M. L., MuruagaMartínez, J. S., MayekPérez, N., PérezGuerrero, A., & Ramírez-Sánchez, S. E. (2014). Characterization of the runner bean (*Phaseolus coccineus* L.) of the trans-Mexican Neovolcanic belt and Sierra Madre oriental. *Revista Mexicana de Ciencias Agrícolas*, 5(2): 191-200.
- WOS, Web of Science. (2023, August 16).<https://www.webofscience.com/wos/wosc/summary/fcf5bfed-873e-41dc-8c-7c-03984f932bf9-9e239b96/relevance/1>

SUPPLEMENTARY



P. acutifolius
(PI 312198)



P. acutifolius
(PI 477033)



P. acutifolius var.
acutifolius
(PI 535202)



P. acutifolius var.
tenuifolius
(PI 535236)



P. acutifolius
(PI 319447)



P. coccineus
(PI 325594)



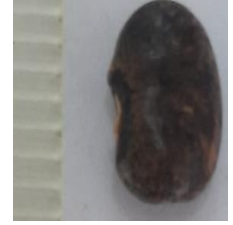
P. coccineus
(PI 317580)



P. coccineus
(PI 257222)



P. coccineus
(PI 311211)



P. coccineus var.
coccineus
(PI 535284)



P. lunatus
(PI 257409)



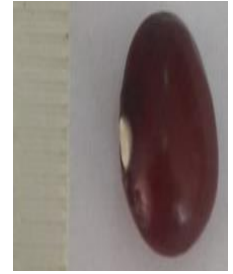
P. lunatus
(PI 256820)



P. lunatus
(PI 256423)



P. lunatus
(PI 195341)



P. lunatus
(PI 299389)



P. dumosus
(PI 201323)



P. dumosus
(PI 311196)



Phaseolus sp.
(PI 413672)



P. coccineus
(APN 3081)



P. coccineus
(APN 3080)

Figure S1. Seeds of genotypes and registered cultivars of *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* and *P. vulgaris* used in the study.

Şekil Ek 1. Çalışmada kullanılan *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* ve *P. vulgaris* tescilli çeşitler ve genotiplere ait taneler.



P. acutifolius



P. coccineus



P. coccineus



P. dumosus



P. dumosus



P. vulgaris

Figure S2. Flowers of genotypes and registered cultivars of *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* and *P. vulgaris* used in the study.

 ekil Ek 2.  alıřmada kullanılan *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* ve *P. vulgaris* tescilli  eřitler ve genotiplere ait  i ekler.



P. acutifolius



P. coccineus



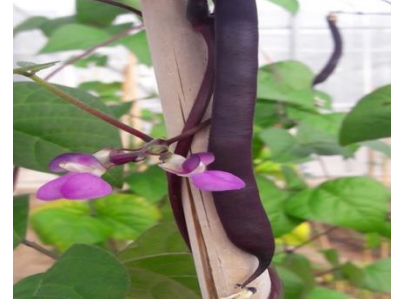
P. dumosus



P. lunatus



P. vulgaris



P. vulgaris

Figure S3. Pods of genotypes and registered cultivars of *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* and *P. vulgaris* used in the study.

Şekil Ek 3. Çalışmada kullanılan *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* ve *P. vulgaris* tescilli çeşitler ve genotiplere ait baklalar.



P. acutifolius (PI 312198)



P. acutifolius var. *tenuifolius*
(PI 535236)



P. coccineus (PI 317580)



P. dumosus (PI 201323)



P. lunatus (PI 257409)



P. vulgaris (APN 3015)

Figure S4. Leaves of genotypes and registered cultivars of *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* and *P. vulgaris* used in the study.

 ekil Ek 4.  alıřmada kullanılan *P. acutifolius*, *P. dumosus*, *P. coccineus*, *P. lunatus* ve *P. vulgaris* tescilli  eřitler ve genotiplere ait yapraklar.