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Phenotypic Characterization of 183 Turkish Common Bean Accessions for Agronomic, Trading, and Consumer-Preferred Plant Characteristics for Breeding Purposes

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Abstract: Plant landraces represent a repository of a gene pool, local adaptation of their domestic species, and thereby are considered a great source of genetic variations. Such genetic variation can be helpful to mitigate the current and future food challenges. A total of 183 common bean accessions including three commercial varieties collected from 19 Turkish provinces were grown to record their morpho-agronomic variations and to evaluate the best performing accessions under multi-environmental conditions. Plant height, days to maturity, pods weight, seed length, and 100-seed weight were used to evaluate the best performing accessions under different environmental conditions. A wide range of variations for traits like days to maturity (99–161), plant height (21–168.7 cm), seed length (7.41–16.4 mm), seeds per plant (17.8–254.4), and 100-seeds weight (24.97–73.8 g) were observed and can be useful for breeding purposes. The analytic results derived from the first three eigenvectors suggested that plant height, plant weight, 100-seed weight, and days to flowering were biologically significant bean traits. Seed yield per plant was positively and significantly correlated with plant weight and pods weight. Genotype × environment biplot discriminated the studied common bean accessions based on their plant height and growth habit. Plant height, days to maturity, seed width, and first pod height were found highly heritable traits and were least affected by environmental forces. Among 19 provinces, accessions of Bilecik showed maximum pods per plant, seed yield per plant and 100-seed weight, while Erzincan and Sivas provinces reflected the prevalence of bushy and early maturing accessions. Information provided herein comprehensively explored the occurrence of genotypic variations which can be used for the development of candidate varieties responding to breeder, farmer, and consumer preferences.

Keywords: *Phaseolus vulgaris*; germplasm characterization; genotype-by-environment interaction; heritability; Turkey

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1. Introduction

The world is confronted with food insecurity due to climate change and nearly 800 million people from developing countries go to bed hungry [1]. World population is increasing rapidly and estimated to reach 10 billion by 2050. Therefore, it is necessary to increase the world food production by 60%–110% to meet the expected food demand in 2050 [2,3]. In order to meet global food demands, there is need to harness plant genetic diversity. Characterization of genetic resources is a valid strategy in this regard because it helps to explore the genotypic and phenotypic variations that can be effectively utilized by the breeding community [4,5]. Nearly, 41,500 accessions of genus *Phaseolus* are present in the International Center for Tropical Agriculture (CIAT) [6]; additionally, there are hundreds of landraces present in farmer's fields in different bean growing countries. Most of the accessions available at the germplasm centers are made easily available to breeders, hence, their characterization is carried out in respective institutes as well as by the global bean researcher community. However, the collection and characterization of bean diversity available in farmer's field is a daunting task. Common bean (*Phaseolus vulgaris* L.) is considered one of the most diverse crops by reflecting variations in its growth habit, plant height, pods, maturity, seed weight, and size [7]. Therefore, it is necessary to explore the valuable traits of common bean available in farmer's fields.

Common bean is cultivated in nearly all parts of the world and its yield has been increased significantly during recent years. An increase in common bean yield has been observed during last two decades in Turkey mainly due to inclusion of new cultivars having better environmental adaptation [8]. Turkey is not a center of origin of common bean and it is supposed that it was introduced to Turkey from Europe in the 17th century by the Ottoman traders travelling between Europe and Asia [9–11]. Bean landraces present in small farmers' fields are playing a vital role in the country's economy [12,13]. Annual common bean production of Turkey was 235,000 tons versus nearly 26,833,394 tons of common bean produced worldwide [14]. A total of 39 dry beans and 200 fresh bean commercial cultivars have been registered to date in Turkey (Variety registration and seed certification center; www.tarimorman.gov.tr).

The environment has a direct effect on agriculture. Fluctuations in the environment during the growing period can directly affect the yield of any crop. During the selection of stable and better-performing genotypes, it is necessary to fully understand genotype × environment interaction (GEI) [15]. Effects of genotypes, environment, and interaction of both help to understand the phenotypic performance of any crop and provide a broader picture about its adaptation to different environments [16,17].

Characterization of genetic resources has always remained one of the favorite methods of scientific community to investigate the novel variations which can be used for the development of improved cultivars expressing higher yield with better quality, biotic and abiotic stress resistance [4,13,18]. A good number of studies have been conducted to explain the morphological, phenological, and agronomic variability among local populations of common bean in different parts of the world [19–24]. Rana et al. [23] explored the agronomic and morphological variations in common bean germplasm and suggested some well-performing genotypes for the breeding perspective. Madakbaş and Ergin [24] and Bozoğlu and Sozen [9] used Turkish common bean germplasm to explore the phenotypic variations and reported the existence of wide range of phenotypic diversity in their studied germplasm. As is obvious from previous studies, a good level of variation is present in the phenotype of common bean and more attention should be given to explore the possibilities of its utilization for the production of good quality food for the world. Most of the earlier studies were mainly aimed to explore the phenotypic variations in common bean germplasm under a single environment and location. Therefore, there is a scarcity of information about the effect of genotype, genotype by environment and interaction of both on the performance of common bean germplasm under multi-location/environmental conditions. By considering these factors, we aimed an in-depth investigation to understand the level of agro-morphological variations in Turkish common bean germplasm by conducting field experiment at two locations and in five environments. This study was also aimed to investigate the GEI and heritability, and to evaluate the best performing accessions that can be suggested as candidate parents for common bean breeding.

2. Materials and Methods

2.1. Plant Material and Field Experiments

A total of 180 common bean accessions and 3 commercial cultivars collected from 19 Turkish provinces were used as plant material in this work. The commercial cultivars (Akman, Goynuk, Ksracsehir) used in this study were developed through the single plant selection having resistance to various diseases and have been used as standard cultivars in several other studies [25,26]. The accessions (landraces) were previously collected from farmers' field (Table S1, Figure 1). This collection panel was established by Baloch at the Bolu Abant Izzet Baysal University (BAIBU) in 2014. Accessions were grown under field conditions in augmented design for two consecutive years during 2014 and 2015 at BAIBU (coordinates; 40.7325° N, 31.6082° E, altitude; 752 m above mean sea level) followed by selfing and single plant selection. Seeds were sown by hand in elementary plots, each consisting of 2 m-long rows, with a 50 cm inter- and 10 cm intra-row spacing in an augmented design in BAIBU on 24, 27, and 17 April of 2016, 2017, and 2018, respectively. We followed the same sowing strategy for the second location, i.e., Cumhuriyet University (coordinates: 9.7087° N, 37.0203° E, altitude; 1293m above mean sea level) in Sivas province of Turkey on 15 and 12 April of 2017 and 2018, respectively. The soil of the experimental area of BAIBU has loamy texture a slightly alkaline character (pH 7.59), and low organic matter contents (1.80–1.86%). The experimental area of Sivas contained mainly silt (48.3%) and clay (37.1%), low content of organic matter (1.7%) with a pH of 7.28. Climatic conditions of both locations during the whole period of study are presented in the Table S2. The three experimental years in Bolu (2016, 2017 and 2018) and two in Sivas (2017, 2018), were considered as five environments for analytical purposes, as this is a common practice in agricultural experimentations [27]. After thinning, a total of 10 plants in each row for each accession were maintained for phenotypic characterization. Di-ammonium phosphate (DAP) and ammonium sulfate were used as a source of fertilizer. Four irrigations and three hoeings were performed during each growing season at both locations.

2.2. Evaluation of Agronomic Traits

Morphological and agronomical characterization of selected accessions and cultivars was performed according to the cultivar evaluation criteria developed by International Plant Genetic Resources Institute IPGRI [28] and Community Plant Variety Office (EU-CPVO), (2013). We recorded 22 morphological and agronomic traits (Table S3). All traits were measured on 10 representative individual plants, for two locations, and five environments. A total of 10 randomly selected, fully developed, and undamaged seeds were used for the measurement of seed length, width, and height using a digital Vernier caliper. Electronic seed counter was used for the measurement of 100-seed weight by taking randomly selected fully matured and undamaged seeds in triplicate measurements and averaged. Root length (cm) was measured by following the methodology of Aghamir et al. [29]. Various qualitative characters like were measured according to IPGRI descriptors for *Phaseolus* [28] and presented in Table S3.

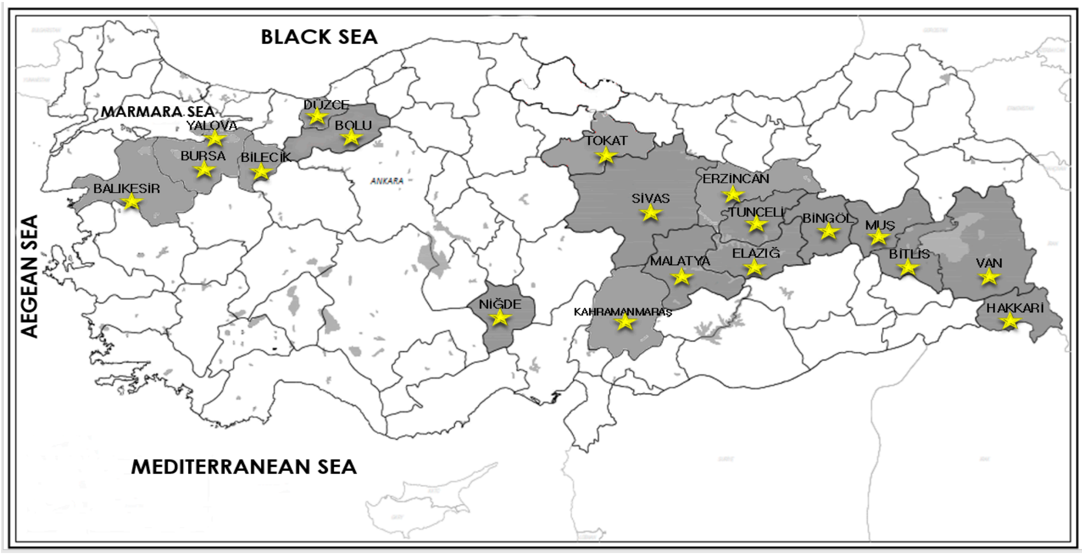

Figure 1. Collection provinces of 183 Turkish common bean accessions.

2.3. Statistical Analysis

Augmented block design [30] with three standard check varieties (Akman, Goynuk, Ksracsehir) was used for this study and the statistical inferences were derived using the online software for augmented block design developed by Rathore et al. [31]. Whole germplasm was sown in eight blocks according to augmented block design where these check varieties were used as control group and repeated eight times. Replication of these check varieties were used to standardize the data and to calculate the adjusted means. The analysis was run in two steps as dictated by the experimental design. In the first step analysis of variance (ANOVA) was computed within the environment and adjusted means were derived. The adjusted means were then used to run ANOVA across environments solving the appropriate mixed model equation to contemporarily account for both genotypic and genotype × environment interaction effects. Before carrying out the combined analysis, the Fligner-Killeen test was used to evaluate the homogeneity of variances. Fligner-Killeen test is a non-parametric test which is very robust against departures from normality. In the mixed model equation, environmental effects were treated as random, while the genotypic effects were considered as fixed as suggested in Gomez and Gomez [27]. Heritability was calculated using the appropriate variance components extracted from the linear mixed model equation fitted attributing genotype and environment random effects as suggested in Habyarimana [32,33]. The model was fitted with a restricted maximum likelihood using the R package [34]. The quantitative traits were analyzed with different statistics like mean, range, variance, and linear correlation coefficients using the statistical software XLSTAT (www.xlstat.com). XLSTAT software was also used to investigate the scatter plot, multivariate biplot, and principal component analysis (PCA) for the Turkish common bean germplasm.

3. Results

Analysis of variance (ANOVA) revealed that genotypic effects were statistically significant ($p < 0.05$) for all traits except days to emergence and root length. On the other hand, GEI was statistically significant for all traits except for days to emergence, days to first flower, plant height, pods per plant, pods weight, primary branches, root length, and 100 seed-weight (Table 1). Ranking of traits under different environments was also observed and did not revealed any significant changes in the ranking of studied traits. All traits reflected high heritability except days to emergence, secondary branches, and root length. Among the studied traits, low heritability (0.052) was observed for days to emergence, and high heritability (0.958) for plant height (Table 2).

Table 1. Summary of analysis of variance (ANOVA) for different traits of Turkish common bean accessions.

Traits	Source of Variation	F Value
Days to Emergence	Genotypes	0.394
	G × E	0.261
Days to 1st Flower	Genotypes	3.07 **
	G × E	1.34
Days to 50% Flowering	Genotypes	1.88 *
	G × E	2.13 *
1st Pod Height	Genotypes	12.99 ****
	G × E	1.89 *
Primary Branches/Plant	Genotypes	3.82 ***
	G × E	1.54
Secondary Branches/Plant	Genotypes	2.51 **
	G × E	2.47 **
Plant Height	Genotypes	10.07 ****
	G × E	0.90
Days to Maturity	Genotypes	189.81 ***
	G × E	17.63 ***
Plant Weight	Genotypes	11.55 ****
	G × E	3.85 **
Root Length	Genotypes	0.82
	G × E	0.53
Pods/Plant	Genotypes	3.79 ***
	G × E	1.31
Pod Weight/Plant	Genotypes	9.06 ****
	G × E	3.38
Pod Length	Genotypes	8.48 ****
	G × E	7.31 ****
Pod Width	Genotypes	5.28 ****
	G × E	5.36 ****
Single Pod Weight	Genotypes	8.69 ****
	G × E	8.07 ****
Seeds/Pod	Genotypes	3.68 ***
	G × E	1.75 *
Seed Length	Genotypes	13.72 ****
	G × E	5.63 ****
Seed Width	Genotypes	6.79 ****
	G × E	3.75 ***
Seed Height	Genotypes	13.61 ****
	G × E	3.41 ***
Seeds/Plant	Genotypes	4.06 ***
	G × E	2.42 *
Yield Per Plant	Genotypes	9.76 ****
	G × E	3.55 **
100 Seeds/Weight	Genotypes	8.42 ****
	G × E	0.93

Statistically significant ($p < 0.05$), ≠ Environment, * ($p < 0.05$), ** ($p < 0.01$); *** ($p < 0.001$), **** ($p < 0.0001$).

Table 2. Estimates of heritability in the Turkish common bean germplasm.

Traits	varE	varU	h2
DE	0.678	0.012	0.052
DF	0.354	0.450	0.792
DFtF	0.230	0.298	0.795
FPdH	0.207	0.751	0.916
PB	0.525	0.426	0.709
SB	0.801	0.154	0.365
PH	0.105	0.808	0.959
DMt	0.102	0.849	0.943
PW	0.354	0.587	0.833
RL	0.821	0.076	0.218
PdPP	0.505	0.454	0.729
PdWt	0.386	0.547	0.809
PdL	0.165	0.451	0.891
PdWd	0.195	0.389	0.857
SPdW	0.314	0.385	0.786
SPSPd	0.436	0.428	0.747
SL	0.199	0.609	0.902
SWd	0.105	0.554	0.940
SH	0.293	0.659	0.871
SPPt	0.640	0.330	0.608
YPP	0.373	0.559	0.818
100 SW	0.278	0.723	0.886

varE: environmental variance, varU: genotypic variance, h2: broad sense heritability; DE (Days to emergence). DF (days to first flowering). DFtF (days to 50% flowering). FPdH (first pod height). PB (primary branches). SB (secondary branches). PH (plant height). DMt (days to maturity). PW (plant weight). RL (root length). PdPP (number of pods per plant). PdWt (pods weight). PdL (pod length; cm). PdWd (pod width; mm). SPdW (single pod weight; g). SPSPd (seeds per single pod). SL (seed length; mm). SWd (seed width; mm). SH (seed height; mm). SPPt (number of seeds per plant). YPP (Yield per plant; g), and 100 SW (100 seeds weight; g).

Mean, maximum, and minimum values for 22 traits revealed the existence of a wide range of phenotypic variations in Turkish common bean germplasm (Table 3). Mean values of 22 traits for the studied germplasm across five environments is provided in Table S4. Days to emergence ranged from 10 to 15 days for Bingol-36 and Van-36 accessions respectively, while 13 days were found to be the average amount of days to emergence. Days to flowering ranged from 51 (Mus-46) to 75 (Hakkari-51) days with an average of 61 days. Some of the accessions matured after 99 days (minimum days to maturity by Maltya-25) while some accessions were found late maturing (161 days to maturity by Tunceli-1). 100-seed weight ranged from 24.97 to 73.88 g for Malatya-13 and Hakkari-1 accessions, respectively, while the average 100-seed weight in this study was 42.21 g (Table 3). Studied germplasm was collected from 19 provinces and accessions originating from Bilecik province bore maximum numbers of pods per plant, higher pods weight, yield per plant, and 100-seed weight followed by Bingol province (Table 4). On the other hand, accessions from Erzincan province reflected low performance for all traits except 100-seed weight. Scatter plot for days to maturity and plant height clearly discriminated the studied germplasm according to their growth habit and days to maturity (Figure 2).

Table 3. Values of mean, maximum, minimum and standard deviation (Std) for the 22 different traits determined in the 183 Turkish common bean accessions.

Traits	Minimum	Maximum	Mean	Std. Deviation
DE	10	15	13	1.09
DF	51	75	61	4.39
DFtF	59	80	67	4.61
FPdH	6.4	68.9	23	13.53
PB	1.6	5.3	3.6	0.84
SB	0.7	5.4	2.9	1.00
PH	21.0	168.76	99.55	43.65
DMt	99	161	133	14.64
PW	22.4	137.5	58.6	21.93
RL	2.6	9.6	5.2	1.27
PdPP	7.01	42.7	19.5	6.71
PdWt	14.30	84.80	37.5	14.62
PdL	8.3	19.7	11.4	1.97
PdWd	5.9	14.01	9.3	1.39
SPdW	0.9	3.7	2.0	0.53
SPSPd	1.8	8.2	3.9	0.98
SL	7.4	16.4	12.5	1.79
SWd	5.3	9.7	7.1	0.91
SH	4.02	10.9	5.7	0.88
SPPt	17.81	254.5	60.1	31.00
YPP	5.9	59.5	22.02	9.86
100 SW	24.97	73.88	42.21	9.04

DE (Days to emergence). DF (days to first flowering). DFtF (days to 50% flowering). FPdH (first pod height). PB (primary branches). SB (secondary branches). PH (plant height). DMt (days to maturity). PW (plant weight). RL (root length). PdPP (number of pods per plant). PdWt (pods weight). PdL (pod length; cm). PdWd (pod width; mm). SPdW (single pod weight; g). SPSPd (seeds per single pod). SL (seed length; mm). SWd (seed width; mm). SH (seed height; mm). SPPt (number of seeds per plant). YPP (Yield per plant; g), and 100 SW (100 seeds weight; g).

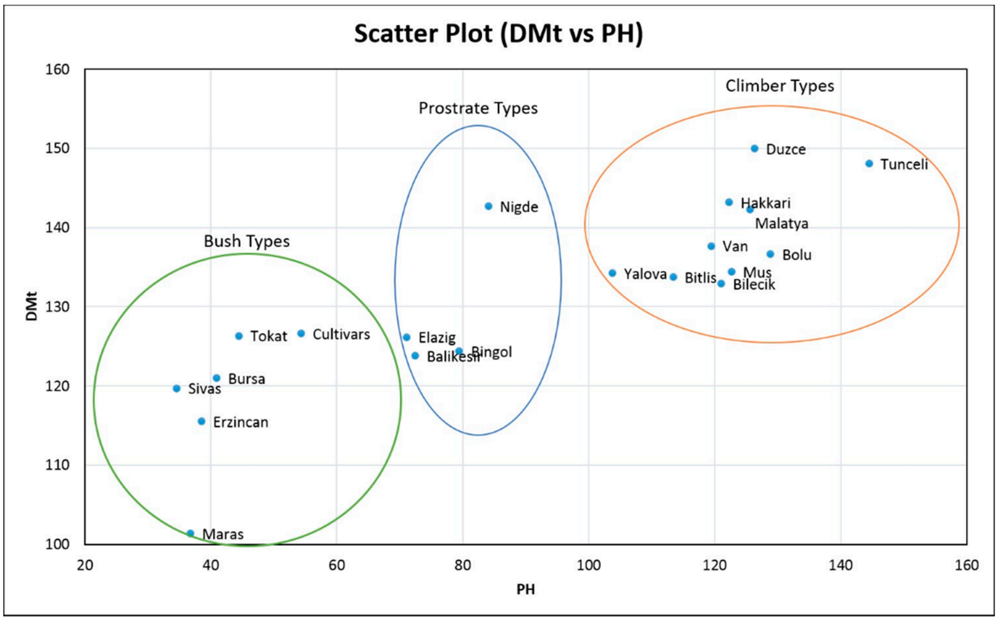

Figure 2. Scatter plot plant height and days to maturity diversity in Turkish common bean germplasm for various Turkish provinces.

Table 4. Averaged values of the 22 traits for 180 accessions and three commercial cultivars of common bean based on the collection provinces in Turkey.

Provinces	Number of Accessions	DE	DF	DFtF	FPdH	PB	SB	PH	DMt	PW	RL	PdPP
Bingol	18	11.92 ± 1.09	58.34 ± 2.56	64.10 ± 3.56	16.04 ± 8.32	3.97 ± 0.75	2.41 ± 1.52	79.44 ± 43.94	124.3 ± 10.18	63.91 ± 20.28	5.75 ± 1.37	20.83 ± 8.11
Hakkari	22	12.73 ± 0.95	63.366 ± 4.15	69.872 ± 5.28	287478 ± 9.65	3.466 ± 0.81	2.26 ± 0.47	122.27 ± 17.90	139.586 ± 10.27	67.35 ± 26.02	5.690 ± 1.30	18.05 ± 7.87
Tokat	1	13.54 ± 3.22	61.85 ± 6.59	66.59 ± 7.15	14.09 ± 6.09	4.32 ± 0.40	3.44 ± 0.89	44.42 ± 6.95	126.3 ± 4.93	35.22 ± 7.01	3.99 ± 1.25	9.18 ± 8.80
Maras	1	13.21 ± 3.10	55.85 ± 6.03	60.26 ± 5.60	10.83 ± 4.55	3.89 ± 0.48	4.81 ± 2.40	36.75 ± 8.08	101.3 ± 15.94	28.76 ± 5.33	6.62 ± 2.03	12.81 ± 11.13
Bitlis	30	12.06 ± 0.72	61.43 ± 3.57	66.81 ± 3.70	22.88 ± 9.72	3.24 ± 0.75	2.62 ± 0.89	113.37 ± 34.44	133.7 ± 8.42	66.07 ± 21.67	4.87 ± 1.18	22.45 ± 7.65
Malatya	14	11.18 ± 0.54	63.01 ± 4.94	68.90 ± 5.008	31.29 ± 16.77	3.33 ± 0.77	3.21 ± 0.91	125.59 ± 40.22	142.3 ± 15.58	63.24 ± 21.98	5.57 ± 0.63	18.84 ± 5.38
Tunceli	3	11.07 ± 0.38	64.25 ± 2.85	68.23 ± 3.46	32.13 ± 16.63	2.77 ± 0.35	2.60 ± 0.80	144.48 ± 15.34	148.1 ± 12.03	64.77 ± 4.53	5.85 ± 0.33	18.03 ± 2.48
Van	17	12.74 ± 1.53	64.60 ± 4.19	69.70 ± 4.26	29.52 ± 14.22	3.43 ± 0.94	3.06 ± 0.98	119.41 ± 35.28	137.4 ± 5.14	66.93 ± 22.19	4.96 ± 1.64	20.13 ± 4.73
Elazig	13	13.18 ± 0.54	59.52 ± 4.59	64.52 ± 4.84	14.34 ± 8.66	4.06 ± 0.45	3.27 ± 0.69	71.10 ± 46.87	126.1 ± 16.59	47.44 ± 18.17	4.50 ± 0.92	19.61 ± 8.21
Mus	22	13.43 ± 0.55	59.25 ± 3.74	65.79 ± 2.83	25.28 ± 13.90	3.25 ± 0.80	2.79 ± 0.82	122.63 ± 25.61	134.4 ± 10.42	53.36 ± 14.84	4.63 ± 0.71	20.59 ± 4.54
Sivas	12	13.24 ± 0.61	57.05 ± 1.98	62.92 ± 2.01	10.53 ± 2.88	4.28 ± 0.68	3.16 ± 1.040	34.60 ± 7.20	119.7 ± 11.31	40.48 ± 11.45	5.58 ± 1.109	14.69 ± 3.35
Alikesir	6	12.97 ± 0.68	57.35 ± 2.36	65.11 ± 5.85	18.42 ± 11.06	3.59 ± 0.98	3.17 ± 1.09	72.43 ± 47.91	123.8 ± 15.65	51.40 ± 17.21	4.75 ± 1.94	17.15 ± 8.46
Bilecik	7	13.37 ± 0.38	61.37 ± 4.19	67.65 ± 4.90	41.11 ± 2.01	3.09 ± 0.54	2,13 ± 0.05	121.03 ± 6.69	134.4 ± 13.9	79.47 ± 34,04	4.10 ± 1.47	24.83 ± 5.27
Duzce	2	12.13 ± 0.23	68.42 ± 6.36	72.58 ± 2.35	39.88 ± 22.22	2.95 ± 1.64	2.94 ± 0.30	126.30 ± 2.52	150.0 ± 8.95	42.39 ± 13.35	4.40 ± 1.32	14.80 ± 3.18
Yalova	3	12.63 ± 0.33	62.36 ± 5.66	69.03 ± 6.18	32.31 ± 17.76	2.76 ± 1.13	3.51 ± 0.64	103.74 ± 52.57	134.2 ± 11.40	57.80 ± 15.06	5.08 ± 0.15	20.67 ± 1.16
Erzincan	4	12.55 ± 0.32	56.92 ± 2.32	63.42 ± 3.55	11.83 ± 2.55	4.33 ± 0.49	4.57 ± 0.68	38.49 ± 5.91	115.5 ± 3.59	38.74 ± 11.83	6.83 ± 0.70	15.14 ± 2.99
Bursa	2	12.47 ± 1.65	56.42 ± 1.17	62.75 ± 0.23	12.12 ± 2.29	4.10 ± 0.20	3.84 ± 0.44	40.90 ± 1.71	121.0 ± 6.60	39.34 ± 4.72	5.87 ± 0.79	15.05 ± 0.37
Nigde	2	11.97 ± 0.94	62.42 ± 0.24	67.08 ± 0.23	15.15 ± 0.12	3.36 ± 0.57	3.26 ± 0.19	84.04 ± 4.55	142.6 ± 2.35	44.09 ± 18.12	5.44 ± 0.29	20.62 ± 6.03
Bolu	1	12.63 ± 2.41	63.58 ± 4.71	67.92 ± 8.50	25.91 ± 2.9	2.86 ± 0.99	3.23 ± 1.07	128.85 ± 22.3	128.4 ± 8.41	47.3 ± 17.4	4.81 ± 2.17	14.98 ± 4.87
Cultivars	3	10.55 ± 0.57	60.82 ± 2.61	66.04 ± 2.59	13.25 ± 0.41	4.33 ± 0.30	3.82 ± 0.44	54.33 ± 13.0	126.6 ± 4.30	40.48 ± 6.26	5.98 ± 0.86	19.86 ± 3.11

Provinces		PdWt	PdL	PdWd	SPdW	SPSPd	SL	SWd	SH	SPPt	TSW	100Swt
Bingol	18	42.72 ± 14.80	10.23 ± 1.01	9.19 ± 0.71	2.18 ± 0.56	3.89 ± 0.92	12.25 ± 2.10	6.72 ± 0.68	5.47 ± 0.59	64.74 ± 53.57	22.47 ± 9.08	46.93 ± 11.61

Table 4. *Cont.*

Provinces	Number of Accessions	DE	DF	DFtF	FPdH	PB	SB	PH	DMt	PW	RL	PdPP
Hakkari	22	42.42 ± 14.3	12.43 ± 2.71	10.39 ± 1.73	2.01 ± 0.62	3.99 ± 1.16	12.54 ± 1.71	7.09 ± 0.85	5.51 ± 0.76	63.40 ± 28.25	23.65 ± 9.98	41.16 ± 11.62
Tokat	1	25.01 ± 9.23	14.79 ± 0.70	12.62 ± 2.18	2.49 ± 0.67	3.07 ± 0.32	15.73 ± 1.25	8.44 ± 0.99	7.90 ± 0.53	25.41 ± 11.04	17.32 ± 4.23	51.78 ± 2.50
Maras	1	16.81 ± 3.97	9.17 ± 1.96	8.75 ± 2.25	1.69 ± 0.12	3.50 ± 0.63	12.71 ± 0.85	7.09 ± 1.16	5.87 ± 0.26	33.78 ± 16.67	9.83 ± 6.43	48.21 ± 12.91
Bitlis	30	44.24 ± 15.60	10.85 ± 1.46	9.07 ± 1.35	2.31 ± 0.60	4.27 ± 1.11	12.17 ± 1.67	6.99 ± 0.90	5.57 ± 0.70	70.44 ± 30.75	25.06 ± 11.64	40.99 ± 6.91
Malatya	14	38.49 ± 14.09	12.45 ± 2.83	9.33 ± 1.75	1.98 ± 0.67	4.42 ± 0.70	12.28 ± 1.30	7.15 ± 1.28	5.96 ± 1.29	66.30 ± 34.92	22.80 ± 9.75	38.42 ± 6.56
Tunceli	3	42.31 ± 2.35	11.16 ± 1.15	11.46 ± 1.08	2.28 ± 0.37	4.07 ± 0.39	12.94 ± 1.35	8.08 ± 0.54	6.80 ± 0.33	55.29 ± 9.53	25.20 ± 2.42	44.28 ± 1.74
Van	17	43.32 ± 13.53	13.15 ± 2.14	9.53 ± 1.34	1.93 ± 0.48	3.84 ± 1.27	13.11 ± 1.70	7.18 ± 0.97	5.26 ± 0.72	63.32 ± 20.86	26.79 ± 9.39	43.564 ± 10.59
Elazig	13	31.17 ± 14.24	11.43 ± 1.24	8.03 ± 0.55	1.76 ± 0.21	3.49 ± 0.58	12.03 ± 1.13	6.24 ± 0.73	5.23 ± 0.69	59.69 ± 24.009	21.240 ± 10.58	37.02 ± 5.56
Mus	22	34.35 ± 7.81	11.18 ± 1.65	9.12 ± 1.005	1.85 ± 0.39	3.95 ± 0.82	12.38 ± 1.73	7.50 ± 0.82	5.89 ± 0.66	64.66 ± 19.38	22.50 ± 6.03	40.12 ± 7.85
Sivas	12	23.69 ± 5.69	10.72 ± 1.378	10.13 ± 1.15	1.79 ± 0.28	2.98 ± 0.56	12.57 ± 2.002	7.14 ± 0.75	6.80 ± 1.28	28.89 ± 5.72	12.17 ± 3.006	42.79 ± 8.14
Balikesir	6	29.75 ± 14.63	10.83 ± 1.28	8.71 ± 0.59	1.78 ± 0.19	3.64 ± 0.72	12.83 ± 2.10	6.99 ± 0.79	5.95 ± 0.37	43.56 ± 30.87	15.58 ± 8.46	43.52 ± 7.14
Bilecik	7	59.74 ± 19.65	10.38 ± 0.84	9.15 ± 1.43	2.03 ± 0.67	4.27 ± 1.21	11.65 ± 2.22	7.38 ± 1.10	6.15 ± 0.61	77.22 ± 38.79	31.06 ± 15.28	39.10 ± 8.33
Duzce	2	25.21 ± 8.64	12.99 ± 2.53	9.10 ± 0.60	2.60 ± 0.21	5.37 ± 0.29	12.31 ± 1.31	7.65 ± 0.55	5.90 ± 0.47	51.74 ± 15.28	18.52 ± 6.61	47.34 ± 1.08
Yalova	3	38.39 ± 11.51	11.97 ± 1.47	8.50 ± 0.91	2.17 ± 0.02	4.49 ± 1.004	12.66 ± 2.82	7.30 ± 0.15	6.42 ± 0.31	63.54 ± 29.35	21.41 ± 9.36	46.68 ± 8.96
Erzincan	4	20.68 ± 5.39	11.21 ± 0.38	8.15 ± 0.46	1.66 ± 0.24	3.47 ± 0.31	13.67 ± 0.91	6.44 ± 0.29	5.41 ± 0.32	35.13 ± 6.63	12.67 ± 2.82	48.25 ± 5.73
Bursa	2	22.38 ± 2.65	11.005 ± 0.27	8.27 ± 0.65	1.65 ± 0.24	3.62 ± 0.40	13.94 ± 0.67	6.58 ± 0.04	5.54 ± 0.01	38.97 ± 3.27	13.86 ± 2.34	47.95 ± 2.02
Nigde	2	33.10 ± 13.29	11.66 ± 0.59	9.97 ± 1.20	1.66 ± 0.25	3.39 ± 0.60	14.13 ± 3.02	7.91 ± 1.08	5.06 ± 0.25	52.83 ± 10.46	22.02 ± 10.84	54.69 ± 17.59
Bolu	1	27.99 ± 9.96	11.06 ± 1.19	8.64 ± 2.85	1.81 ± 0.69	4.04 ± 0.32	10.08 ± 2.15	7.31 ± 1.79	6.99 ± 0.85	53.26 ± 14.59	17.70 ± 4.79	59.89 ± 12.86
Cultivars	3	25.33 ± 6.02	9.93 ± 0.87	8.14 ± 0.04	1.34 ± 0.09	3.78 ± 1.02	10.20 ± 3.15	6.11 ± 0.69	5.17 ± 0.53	58.36 ± 32.90	15.63 ± 3.22	38.71 ± 5.44

DF (days to first flowering), DFtF (days to 50% flowering), FPdH (first pod height), PB (primary branches), SB (secondary branches), PH (plant height), DMt (days to maturity), PW (plant weight), RL (root length), PdPP (number of pods per plant), PdWt (pods weight), PdL (pod length; cm), PdWd (pod width; mm), SPdW (single pod weight; g), SPSPd (seeds per single pod), SL (seed length; mm), SWd (seed width; mm), SH (seed height; mm), SPPt (number of seeds per plant), TSW (total seed weight; g), and 100 SWt (100 seeds weight; g).

A wide range of variations were also observed in Turkish common bean germplasm for various qualitative traits (Table S5; Figure 3). Studied germplasm reflected three growth habits, i.e., climber, intermediate bush and prostrate. Climber growth habit was found in prevalence (62% of the total accessions), followed by intermediate bushy (24% of the total accessions), and prostrate growth habit (14% of the total accessions). White, purple, and pink were flower colors present in the studied germplasm. White-colored flowers were the most prevalent type of flowers (73% of the total accessions), followed by purple-colored (23% of the total accessions), and lilac flowers (4% of the total accessions). Whole germplasm was divided into two subgroups based on bracteole size, i.e., small sized bracteole (57%) and intermediate sized bracteoles. Fifty-six percent of the accessions bore pods with concave curvature, while 32% showed very slight to no degree of curvature. The observed leaf shapes included triangular, circular, and quadrangular types; however, the triangular (39% of the evaluated population) was the most dominant shape of the terminal leaf. A wide range of seed colors was observed including white, yellow, beige, brown, dark red, purple, and black (Figure 4). The most dominant seed color was white (53%). Pod color also varied within the studied germplasm ranging from light to dark green, pink, and red-colored pods (Figure 5).

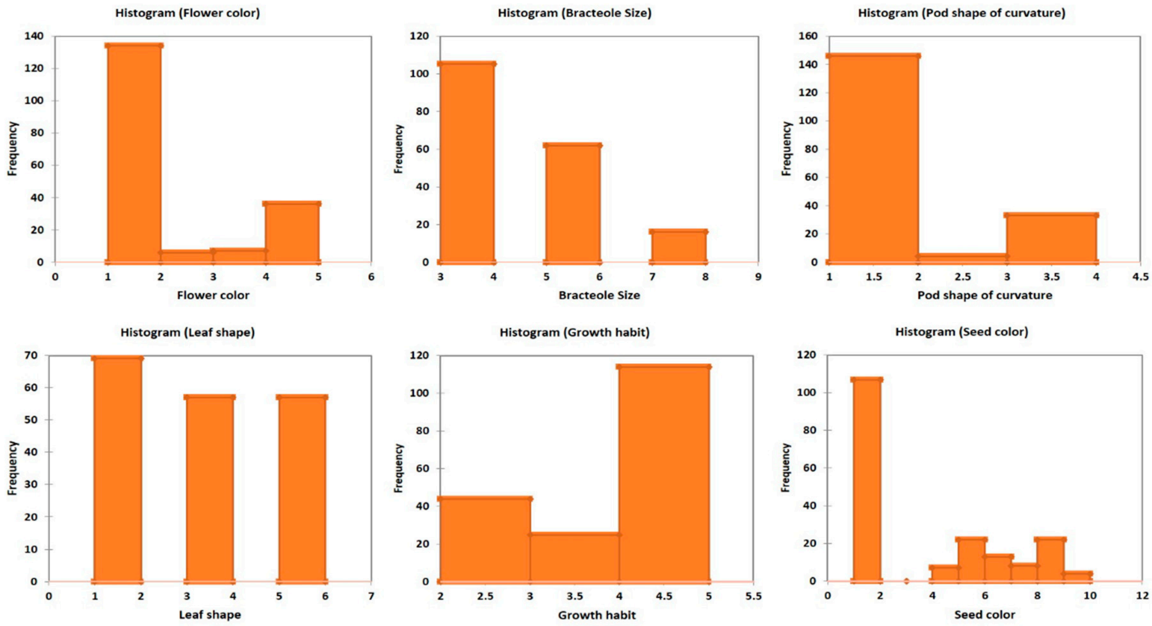

Figure 3. Frequency distribution charts of studied qualitative traits in Turkish common bean germplasm. Flower color: [1]White, [2]Light purple, [3]lilac, [4]Purple; Bracteole Size: [3]Small, [5]Medium, [7]Large; Pod shape of curvature: [1]Concave, [2]S-shaped, [3]Convex; Leaf shape: [1]Triangular, [3]Circular, [5]Quadrangular; Growth habit: [2]Indeterminate bushes, [3]prostrate, [4]Climber; Seed color: [1]White, [4]yellow, [5]beige, [6]brown, [7]dark red, [8]purple, [9]black. All traits were scored according to criteria suggested by the International Board for Plant Genetic Resources (IBPGR) descriptors for *Phaseolus* (IBPGR, 1982), UPOV (International Union for the protection of new varieties of plants) and IPGRI (International Plant Genetic Resources Institute).

Figure 4. Pods size, shape, and color diversity in Turkish common bean germplasm.

Figure 5. Seed color and shape diversity in Turkish common bean germplasm.

Correlation Coefficients Among the Different Quantitative Traits and Multivariate Analysis

The matrix for correlation coefficients reflected significant and positive correlation of pod weight with days to flowering, days to 50% flowering, first pod height, plant height, days to maturity, pod width, single pod weight, seeds per single pod, number of seeds per plant, and yield per plant (Table 5). Highest correlation (r = 0.888) was between plant weight and pods weight. Plant height reflected a strong association with days to maturity (r = 0.744) and plant weight (r = 0.611). However, a weak correlation of plant height was observed with number of pods per plant (r = 0.400), pod length (r = 0.276), pod width (r = 0.259), single pod weight (r = 0.324), and seed width (r = 0.350). First pod height is an important trait and reflected a strong correlation with plant height (r = 0.691), days to maturity (r = 0.640) and plant weight (r = 0.533). There was a strong and negative correlation between first pod height and primary branches (r = -0.619). Though days to flowering reflected strong association with days to 50% flowering (r = 0.883) and first pod height (r = 0.672); however, it also exhibited negative correlation with primary branches (*r* = 0.476) and secondary branches (*r* = 0.265). Number of pods per plant reflected a strong association with pods weight (*r* = 0.883), number of seeds per plant (*r* = 0.633), and yield per plant (*r* = 0.607). Yield per plant reflected very strong correlation with pods weight (*r* = 0.872), plant weight (*r* = 0.790), number of seeds per plant (*r* = 0.750), and number of pods per plant (*r* = 0.607). Yield per plant also reflected weak correlation with days to flowering (*r* = 0.425), days to 50% flowering (*r* = 0.423), first pod height (*r* = 0.452), days to maturity (*r* = 0.481), pod width (*r* = 0.241), single pod weight (*r* = 0.484), and seed width (*r* = 0.340). Some other combinations of traits reflecting a very significant and positive correlation were days to 50% flowering with days to maturity (*r* = 0.682), seed length with 100-seed weight (*r* = 0.579), and seed width with pod width (*r* = 0.559). 100 seed weight is considered an important trait in common bean and it showed a highly significant and positive correlation with pod width, single pod weight, seed length, seed width, and seed height.

First five principal components (PCs) accounted for a total of nearly 71% of the overall variance (Table S6). Principal component (PC) 1 accounted for ~35% of the total variation and was mainly associated with plant height, plant weight, seed yield per plant, and pods weight. Principal component 2 accounted for 14% of the total variability and was mostly characterized by 100-seed weight, seed width, and seed length. Nearly eight percent variability was explained by PC3 and days to flowering and days to 50% flowering were the traits that characterized this factor the most. Principal components 4 and 5 accounted for a total of nearly seven and six percent of the variation, respectively. The genotypes vs. traits biplot (GT Biplot) analysis using the first two PCs explained nearly 49% of the total trait variation (Figure 6). Biplot analysis discriminated the common bean accessions according to their plant height, growth habit, and 100-seed weight.

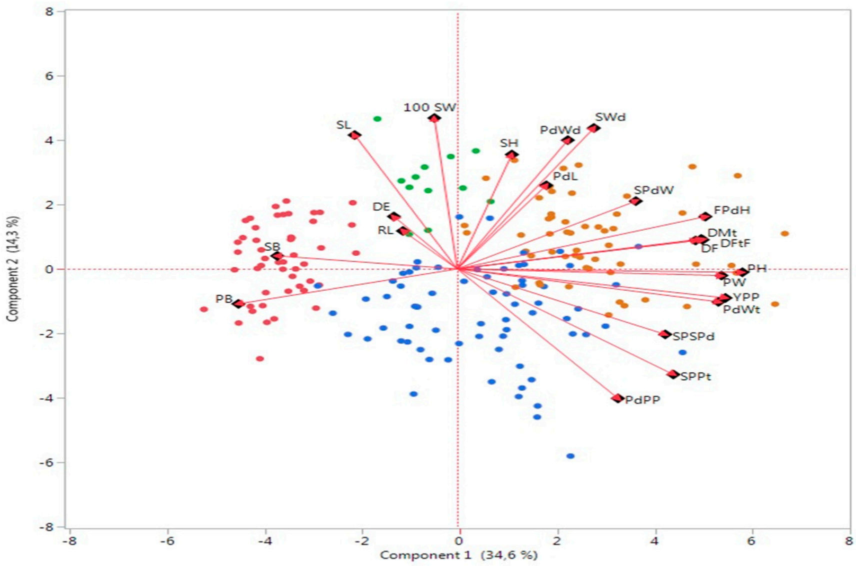

Figure 6. Genotype × trait biplots of Turkish common bean germplasm under five environments.

Table 5. Correlation coefficients among 22 agro-morphological traits of Turkish common bean accessions.

	DE	DF	DFtF	FPdH	PB	SB	PH	DMt	PW	RL	PdPP	PdWt	PdL	PdWd	SPdW	SPSPd	SL	SWd	SH	SPPt	YPP	100 SWt
DE	1	−0.153 *	−0.133	−0.031	0.028	0.062	−0.152*	−0.191 **	−0.206 **	−0.161 *	−0.174 *	−0.199 **	−0.01	0.059	−0.062	−0.217 **	0.114	0.165*	0.106	−0.207 **	−0.109	0.071
DF		1	0.883 **	0.672**	−0.476 **	−0.265**	0.652**	0.646 **	0.456 **	−0.071	0.166 *	0.411 **	0.441 **	0.271 **	0.285**	0.366 **	−0.177 *	0.182*	0.064	0.330 **	0.425**	−0.073
DFtF			1	0.716 **	−0.505**	−0.274 **	0.688 **	0.682**	0.465**	−0.061	0.191 **	0.406 **	0.388 **	0.239 **	0.262**	0.382**	−0.181 *	0.233 **	0.112	0.331 **	0.423 **	−0.067
FPdH				1	−0.619 **	−0.314 **	0.691 **	0.640 **	0.533 **	−0.033	0.114	0.398 **	0.328 **	0.241 **	0.388 **	0.427 **	−0.187 *	0.404 **	0.264 **	0.322**	0.452**	−0.001
PB					1	0.523 **	−0.649 **	−0.531 **	−0.385**	0.180 *	−0.111	−0.311 **	−0.169 *	−0.161 *	−0.423 **	−0.406 **	0.244 **	−0.374 **	−0.234 **	−0.253 **	−0.366 **	0.027
SB						1	−0.570 **	−0.390 **	−0.377 **	0.296 **	−0.254 **	−0.380 **	−0.076	−0.235**	−0.286 **	−0.269 **	0.243 **	−0.174 *	0.003	−0.284 **	−0.367 **	0.099
PH							1	0.744 **	0.611 **	−0.236 **	0.400 **	0.583 **	0.276 **	0.259 **	0.324 **	0.491 **	−0.266 **	0.350 **	0.039	0.500 **	0.603 **	−0.145*
DMt								1	0.494 **	−0.114	0.242**	0.447 **	0.188 *	0.336 **	0.207 **	0.289 **	−0.233 **	0.399 **	0.115	0.354 **	0.481 **	0.012
PW									1	0.057	0.521 **	0.888 **	0.190 *	0.291 **	0.446 **	0.407 **	−0.185*	0.301 **	0.161 *	0.584 **	0.790 **	0.048
RL										1	−0.274 **	−0.074	0.112	0.065	0.043	−0.097	0.084	−0.100	0.011	−0.129	−0.169 *	0.126
PdPP											1	0.668 **	−0.228 **	−0.094	0.019	0.332**	−0.358 **	−0.051	−0.183 *	0.633 **	0.607 **	−0.282**
PdWt												1	0.109	0.287 **	0.464 **	0.473 **	−0.183 *	0.292**	0.043	0.667 **	0.872**	0.005
PdL													1	0.265**	0.218 **	0.139	0.358 **	0.040	−0.077	0.001	0.137	0.128
PdWd														1	0.283 **	−0.051	0.229 **	0.559 **	0.316 **	−0.027	0.241 **	0.291 **
SPdW															1	0.555**	0.017	0.443 **	0.324 **	0.257 **	0.484 **	0.239 **
SPSPd																1	−0.425**	0.084	−0.008	0.575**	0.546 **	−0.304 **
SL																	1	0.203 **	0.020	−0.412**	−0.181 *	0.579 **
SWd																		1	0.540 **	−0.007	0.340 **	0.446 **
SH																			1	−0.125	0.086	0.271 **
SPPt																				1	0.750 **	−0.243 **
YPP																					1	0.001
100 SWt																						1

* Statistically significant at $p \leq 0.05$; ** statistically significant at $p \leq 0.01$. DE (Days to emergence), DFF (days to first flowering), DFtF (days to 50% flowering), FPdH (first pod height), PB (primary branches), SB (secondary branches), PH (plant height), DMt (days to maturity), PW (plant weight), RL (root length), PdPP (number of pods per plant), PdWt (pods weight), PdL (pod length; cm), PdWd (pod width; mm), SPdW (single pod weight; g), SPSPd (seeds per single pod), SL (seed length; mm), SWd (seed width; mm), SH (seed height; mm), SPPt (number of seeds per plant), YPP (yield per plant; g), and 100 SWt (100-seed weight).

4. Discussion

All traits (except days to emergence) reflected significant genotypic effects, indicating the existence of useful genotypic variability for breeding purposes (Table 1). G × E interaction was not significant for days to emergence, days to first flower, plant height, pods per plant, pods weight, primary branches, root length, and 100-seed weight, implying that selections made in one environment can be usefully exploited in the other environments, which can expedite the process of cultivar development and cut the costs associated with this activity. Genotypic variations and G × E effects observed in this work were found in agreement with previous works [32,35–38].

In this study, all traits were found highly heritable except days to emergence, root length, and secondary branches as per scale of Robinson [39] (Table 2). The magnitude of heritability is mainly governed by the level of genetic variability, while higher heritability results in lower environmental effects on a specific trait [40]. Analysis of variance (ANOVA) for most of studied traits reflected that genotypic variances were highly significant within as well as across the environment, revealing their higher level of heritability. The findings of this study are in line with previous studies [38,41,42] stating that days to maturity, pods per plant, number of seeds per plant, and 100 seeds weight are less influenced by environmental forces and are highly heritable traits under multi-year/locations.

The wide-range of phenotypic values obtained for 22 traits (Table 3) reflected the occurrence of important variability for various agro-morphological traits in studied Turkish common bean germplasm, which was found in line with the previous studies [23,43]. Traits related to seed are considered important for common bean and taken as the major determinants of commercial acceptability of commercial varieties [23]. 100-seed weight is an important character, having a positive and significant impact on common bean yield. 100-seed weight ranged between 24.9 g for Malatya13 to 73.8 g for Hakkari1 accession. Mean 100-seed weight (42.2 g) resulted in this study is significantly higher than the previous studies from Turkey [9,44]. Higher averaged seed weight recorded in this study was possibly due to the inclusion of large numbers of accessions having bigger seed size as compared to previous studies. Voysest [45] suggested that 100-seed weight of common bean can vary between < 15 to > 90 g/100 seed. Thus, the mean value of 100-seed weight recorded in this study is found in line with previous studies as well [46,47].

Marked diversity was observed in seed color of Turkish common bean germplasm (Figure 5). These observations suggested that preference of people for different seed colors might have played a vital role in the distribution of these accession within their respective provinces. Variations in 100-seed weight for different colored seeds were also observed. Analysis of variance (ANOVA) for 100 seed weight and seed color (Least Significant Difference (LSD) = 4.79 *) revealed that both white and colored seeds had statistically significant 100 seed weight (data not shown). Results of this study showed that white color accessions have statistically significant higher seeds weight (42.3 g/100), while the remaining all other colored accessions had a little bit lower averaged 100-seed weight 41.5 g/100. Apart from seed color, growth habit also reflected variations from indeterminate bushy to climbing type. The prevalence of one growth habit is related to the geographical adaption as well as the cropping system [23]. Climbing growth habit was prevalent (62%) in Turkish common bean as compared to bushy and prostrate growth habit (Figure 3). Accessions that have a bushy growth habit resulted in higher averaged 100-seed weight (46.3g) as compared to climber and prostrate accessions having relatively lower seeds weight, i.e., 40.4 g/100.

Climatic conditions and people preference can play an important role in the distribution of common bean in a specific area [23,48]. During this study, climatic conditions and people's preferences according to seed size and color were the main factors playing an important role in the distribution of accessions in their respective provinces (Nadeem and Baloch personal presumption). Accessions belonging to Erzincan, Sivas, and Bursa reflected indeterminate bushy growth habit with early maturity. Hakkari, Malatya, Tunceli, and Van provinces reflected the prevalence of climber accessions requiring more days to maturity. People of these provinces mainly utilize common bean for its fresh pods and, not surprisingly, accessions belonging to these provinces displayed a higher number of pods per plant, pod length, and pod width. Similar findings were reported by the Balkaya and Ergün [49] for the utilization of climber genotypes for their fresh pods. Table 4 shows the variation for studied traits in their respective provinces. Scatter plot between days to maturity and plant height (Figure 3) discriminated the provinces-wise accessions based on these traits. Provinces that had bushy accessions and required lesser days to maturity made their separate group. Mostly, climber genotypes in common bean mature late; therefore, herein, the same pattern was found for those provinces having climbing accessions.

During this study correlation among 22 traits was evaluated and a large number of observations increased the power of test as stated by Ozer et al. [50]. Significant and positive correlations for various traits was observed in this study and only values of 0.5 or above are herein discussed. A highly significant and positive correlation between days to maturity and plant height (Table 5) observed in this study indicated that as plant height increases, the maturity is delayed. We also observed these characteristics in the accessions belonging to Hakkari, Malatya, Tunceli, and Van provinces. Plant height also reflected a highly significant and positive correlation with first pod height and yield per plant, suggesting that this trait can be possibly a good proxy for the selection of superior common bean genotypes. The positive correlation was observed between different traits and the existence of correlation can be due to genetic linkage or epistatic effects among various genes [50]. Positive associations of seed weight with different traits were also observed and these results were in agreement with earlier studies in common bean [51,52].

Generally, PCA is used to quantify the degree and pattern of divergence among various populations to understand the evolutionary trends and the relative participation of various components [53]. The first five PCs accounted for a total of 71% variability (Table S6). The analytic results derived from the first 3 eigenvectors (PCs) suggested that plant height, plant weight, 100-seed weight and days to flowering were the main traits that could be utilized most effectively to characterize the common bean populations. These findings are in line with the earlier studies revealing these traits as main contributors in common bean diversity [54–56]. Genotypes vs. traits biplot analysis (GT Biplot) discriminated common bean accessions according to their plant height, growth habit, and 100-seed weight (Figure 6). Accessions having bushy growth habit (red and green color) appeared in separate clusters from the rest of accessions prostrate and climber growth habit (blue and orange). Green color bushy accessions contain much higher 100-seed weight as compared to red ones. Accessions represented in blue and orange colors were prostrate and climber in nature, respectively. However, accessions in blue color reflected lesser 100-seed weight as compared to orange ones.

Selection of Superior Accessions for the Characters of Interest

Selection of best performing and stable accessions under multi-environment/year was also one of the aims of this study. A positive and highly significant correlation of pod weight was observed with various yield contributing traits like single pod weight, seeds per single pod, number of seeds per plant, and yield per plant. Correlation analysis clearly explained that the selection of any accessions for pods weight will automatically select the other associated traits due to their gene linkage or epistatic effects between different genes. Therefore, among 183 common bean accessions, 12 those accession was selected having bushy growth habit with higher pods weight, seed length, 100-seed weight, and minimum days to maturity (Table 6). Bingol53, Sivas18, Sivas69, Erzincan5, and Bursa1 were chosen as the five most promising accessions among the 12 evaluated accessions. These five chosen accessions can be used for further breeding perspectives. We are now conducting multi-year/location yield experiments and evaluating the best performing genotypes such as Bingol53, Sivas18, Sivas69, Erzincan5, and Bursa1. After successful characterization and evaluation, we will send these accessions for the registration to the Seed Registration and Certification Center of Agriculture and Forestry Ministry of Turkey. The accessions used and characterized in this study are available to common bean breeding community from the authors under the jurisdiction of Turkish seed transfer act.

Table 6. Agro-Morphological characteristics of 12 best performing common bean accessions in five environments.

Accessions	Traits																				
	DE	DF	DFtF	FPdH	PB	SB	PH	DMt	PW	RL	PdPP	PdWt	PdL	PdWd	SPdW	SPSPd	SL	SWd	SH	SPPt	YPP	100SWt
Bingol-53	13	57	61	11.6	5	5	25.2	113	84	8.7	18.5	52	10.5	2.5	9.3	3	15.3	6.3	5.9	39.3	17.7	67.1
Bingol-65	12	56	61	11.8	4	4	41.2	111	53.1	7.7	15.2	37.7	10.6	2	8.7	2.6	14.4	6.5	5.5	32.4	17.5	57.5
Bitlis-53	12	57	62	16	4	5	38.8	127	47.3	9.6	14.9	26.2	10	2.3	7.7	2.8	14.4	6.5	5.4	37.1	14.2	54.4
Van-47	14	55	62	12.9	4	4	48.8	109	37.8	8.9	14.6	23.5	10.2	2	7.5	3.3	13.4	6.1	5.4	36.7	13.8	43.6
Elazig-30	13	57	60	10	5	4	36.5	119	43.1	4.9	16.8	31.8	11.3	2	8.1	3.3	13.6	6.2	5.5	72.2	17.1	40.7
Sivas-18	13	59	65	13.7	3	2	52.1	129	70.8	4.2	16	39.8	12.9	2.2	10.3	2.3	15.7	8.1	6.4	34.1	20.1	59
Sivas-62	12	56	63	8	5	3	33.5	107	33.8	6.4	13.7	21.5	11.4	1.5	8.8	1.9	14.1	7.2	6.5	23.7	12.1	52
Sivas-69	13	55	61	10	4	2	29.1	107	39	6.2	9.8	22.5	11.6	1.9	9.1	2.7	13.9	7.2	6.4	23.8	12.5	49.1
Balikesir-18	14	56	62	11	5	2	38.6	109	37	5.4	15.8	21.6	10.4	1.7	8.3	3	14.9	6.6	5.7	27.5	10	48.1
Erzincan-3	12.	59	68	15.5	5	5	45.1	119	55.3	7.3	14.9	26.5	11.3	1.7	8.5	3.6	12.9	6.7	5.3	39.5	16.1	55.6
Erzincan-5	12.	55	61	10.1	4	4	40.3	110	37.3	5.8	16.5	23.5	10.8	1.8	7.6	3.2	12.9	6	5	34.8	12.8	44.3
Bursa-1	14	55	63	13.7	4	4	39.6	116	42.6	6.4	15.3	24.2	11.2	1.8	7.8	3.9	14.4	6.6	5.5	41.2	15.5	49.3

DE (Days to emergence), DFF (days to first flowering), DFtF (days to 50% flowering), FPdH (first pod height), PB (primary branches), SB (secondary branches), PH (plant height), DMt (days to maturity), PW (plant weight), RL (root length), PdPP (number of pods per plant), PdWt (pods weight), PdL (pod length; cm), PdWd (pod width; mm), SPdW (single pod weight; g), SPSPd (seeds per single pod), SL (seed length; mm), SWd (seed width; mm), SH (seed height; mm), SPPt (number of seeds per plant), YPP (yield per plant; g), and 100 SWt (100-seed weight; g).

5. Conclusions

This study comprehensively explored a wider range of qualitative and quantitative traits variations in Turkish common bean germplasm under five environments and two locations. All traits (except days to emergence) reflected significant genotypic effects, indicating the existence of useful genotypic variability for breeding purposes. All traits were found highly heritable except days to emergence, root length, and secondary branches. Plant height reflected a highly significant and positive correlation with first pod height and yield per plant, suggesting that this trait can be possibly a good proxy for the selection of superior common bean genotypes. Pods weight, seed length, 100 seed weight, early maturity, and bushy growth habit was used as selection criteria for the evaluation of best performing accessions. A total of 12 best performing accessions were evaluated in this study, which can be used as candidate parents for common bean improvement.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/2/272/s1. Table S1. Passport data of 183 Turkish common bean accessions. Table S2. Climatic conditions of Bolu and Sivas locations during the whole period of study. Table S3. Various agronomic and qualitative traits measured in Turkish common bean. Table S4. Adjusted means of 22 traits using five environments for Turkish common bean germplasm. Table S5. Diversity of various qualitative traits in Turkish common bean germplasm. Table S6. Eigenvalues of the first five principal component axes (PC) for the Turkish common bean germplasm.

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