PRINCIPLE COMPONENT ANALYSIS (PCA) OF BEAN GENOTYPES (*Phaseolus vulgaris* L.) CONCERNING AGRONOMIC, MORPHOLOGICAL AND BIOCHEMICAL CHARACTERISTICS

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Abstract. This study was established in Bayburt University with 3 replications according to the Randomized Complete Block Design (RCBD) pattern in Bayburt University Organic Agriculture Research and Application Treatment Area in order to determine the agro-morphological, biochemical and quality characteristics of 5 local bean (*Phaseolus vulgaris* L.) genotypes (Aydintepe, Mollakoy, Konursu, Yukarikirzi, Suludere) and 2 registered bean varieties (Ala Ciftci, Mispir). During the research, Principle Component Analysis (PCA) was performed on dry bean genotypes. The first principal component had 37.899% of the total variation (PC1). The second principle component (PC2) explained 19.975% of the total variation. The third principle component had 15.906 of the total variation (PC3). The cumulative ratio of the three primary components in total variation was 73.780%. In the first principle component, Carotenoid (0.905), Chlorophyll-B (0.798), Pod Number per Plant (0.745), Pod Length (0.701), Chlorophyll-C (0.684), Chlorophyll-A (0.608), Branch Number (0.563), First Pod Height (0.491) and Thousand Seed Weight (0.314) had the highest coefficients. The genotypes used in the study differ greatly from each other in terms of agronomic, morphological and biochemical characteristics. This is important for breeders trying to create variability, and it may be recommended to include these genotypes as genitors in breeding studies.
Keywords: *local genotypes, variety, Phaseolus vulgaris L., Principle Component Analysis (PCA)*

Introduction

Bean (*Phaseolus vulgaris* L.) is an edible legume plant belonging to The Leguminosae family. It has been reported by researchers that in the family, beans are the commonly produced species in the world (Singh et al., 2007). Leguminosae family is the second commonly important family in agriculture after Gramineae family. Although grains are a very important source of energy, legumes are an important source of protein for humanity (Singh, 2005, 2007). This family meets 33 percent of human protein needs (Graham and Vance, 2003). On the other hand, *Phaseolus* species are important worldwide for human and animal consumption (Graham and Ranalli, 1997; Logozzo et al., 2007; Aquino-Bolanos et al., 2016). Beans are consumed as canned and frozen as well as fresh and dried beans (Paredes et al., 2009).

Lewis et al. (2005), reported that legumes include agroforestry species, oilseed crops, major grain legumes, ornamental crops, forage crops etc.

Legumes are economically important because it is used in world trade as linoleum, chemicals, lubrication, paints, ethanol coatings, pharmaceutical products, soap, resins, cosmetics, plastic coatings etc. (Singh et al., 2007).

Beans are grown on five continents and these continents are Asia, North and South America, East Africa and West-Southeast Europe (Siemonsma and Na Lapang, 1992). According to 2018 data in the world, 33 million hectares of dry beans were harvested and 28.9 million tons were produced. In the same year 225 thousand tons of dry bean

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production was performed in 89 thousand hectares of land in Turkey. Yield for dry bean in the world was 874 kg/ha and in Turkey was 2531 kg/ha (FAO, 2019).

Central America (Mesoamerica) and South America (Andea) regions are the bean gene pools (Gepts, 1998; Checa et al., 2006; Angioi et al., 2010; Bitocchi et al., 2012; Cortes, 2013). The Central America (Mesoamerica) gene pool extends from Mexico to Colombia, and the South America (Andea) gene pool extends from Southern Peru to Northwest Argentina (De la Funte, 2012). Dry beans (*Phaseolus vulgaris* L., 2n = 2x = 22) are a type of self-pollinated product (Yeken et al., 2018).

After the beans were cultured, many genotypes that differ in morpho-agronomic characteristics were developed and this diversity is used in breeding and expansion of the gene pool (Sinkovic et al., 2019).

Principal Component Analysis (PCA) is a multivariate statistical technique that aims to reduce the dimensionality of high dimensional data sets (Wiley, 1981). It does so by computing much smaller variables (Principle Components) that represent the original data set. Each new variable is a linear combination of the original variables. The first principle component is the linear combination of original variables that explains the maximum amount of variance. The second principal component is perpendicular to the first principal component and describes the maximum amount of remaining variance in the data. All essential components are perpendicular to each other, so there is no unnecessary information (Dona et al., 2009).

Difficulty may be encountered in interpreting and summarizing analysis results with too many variables. In such cases, principal component analysis (PCA), one of the multivariate statistical methods, is widely used (Sangun, 2007). In this way, principal component analysis has been used in many studies (Rencher, 2002; Marcus, 2004; Pierce et al., 2006; Shittu et al., 2007; Widodo et al., 2007; Madakbas and Ergin, 2011; Rencher and Christensen, 2012; Canci et al., 2019). On the other hand, Principal Component Analysis (PCA), which is used to eliminate the dependency structure between variables or for dimension reduction, is used as an analysis used alone, as well as a data preparation technique for other analyzes (Sharma, 1996). On the other hand, PCA analysis in dry bean was used to calculate the Euclidean distances between cultivars (Adams, 1977).

This research was carried out in order to obtain information that could be the basis for future cultivar development studies in the bean plant. For this purpose, important Agronomic, morphological and biochemical characteristics of bean genotypes and standard varieties collected from different locations were examined and the PCA analysis results of these characteristics were presented.

Materials and Methods

Site Description

In this study was established in Bayburt University Aydıntepe Vocational School Research Area (40°24’05.7” N, 40°08’31.3” E) in Turkey. In the research, Aydintepe, Ala Ciftci, Mollakoy, Konursu, Mispir, Yukarikirzi, Suludere bean (*Phaseolus vulgaris* L.) genotypes were used. Two of them (Ala Ciftci, Mispir) were registered bean variety and the others are local bean genotypes.

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Experiment

The experiment was laid out in a randomized complete block design (RCBD) with three replications with 3 replications. 4 rows of planting were made in each plot, and the seeds were planted by hand at a depth of 5-6 cm in rows opened with a marker and 50 cm between inter-row spacing and 10 cm intra-row spacing was used (The plot size is 5.0 m x 0.5 m x 4 row = 10 m^2). According to Sehirali (1988), the water requirement of the bean plant depending on the climatic conditions was provided by the sprinkler system. Weeds were destroyed manually according to the situation in the environment. On the other hand, 6.0 kg P_2O_5 and 2.5 kg N_2 per decare fertilizer was used at the time of planting. Growing rules for bean plants were applied equally to all plots (Meral et al., 1998; Bozoglu et al., 2002; Karadavut et al., 2011; Sozen et al., 2012; Sozen and Karadavut, 2016; Girgel and Cokkizgin, 2019).

Measurements

The following features measured according to Hardwick et al. (1978), IBPGR (1982), Berrocal-Ibarra et al. (2002), Karadavut et al. (2011) Asemanrafat and Honar (2017), Boydston et al. (2018), Saleh et al. (2018); the sample was taken on ten plants and its average was determined plant height, stem diameter, branch number, first pod height, pod length, pod width, pod number per plant, seed number per pod. It was decided to reach 50% of the plot for the following features, number of days to emergence, number of days to flowering, number of days to physiological maturity. Thousand seed weight was calculated according to this: 100 seeds were counted 4 times; the average was taken and multiplied by 10 (Girgel and Cokkizgin, 2019). The seed yield value was found by converting into kg/ha with proportion after the plots were harvested (Hardwick et al., 1978; Meral et al., 1998; Karadavut et al., 2011; Sozen and Karadavut, 2016; Girgel and Cokkizgin, 2019).

Chlorophyll-A, Chlorophyll-B, Chlorophyll-C, carotenoid, proline, malondialdehyde, total phenolic compounds parameters determined according to Chandler and Dodds (1983), Lichtenthaler (1987), and Kabbadj et al. (2017).

Statistical Analyses

The effect levels of the characters determining Principle Component Analysis (PCA) and Correlation Coefficient Analysis. PCA and Correlation coefficients were calculated using the xlstat statistical analysis program, which is a program that uses the Microsoft Excel infrastructure (XLSTAT, 2020).

Results and Discussions

Summary Statistics

According to results; number of days to emergence, number of days to flowering, plant height, stem diameter, branch number, first pod height, pod length, pod width, pod number per plant, seed number per pod, thousand seed weight, seed yield, number of days to physiological maturity, chlorophyll-a, chlorophyll-b, chlorophyll-b, carotenoid, proline, malondialdehyde, total phenolic compounds varied between 11.667-20.000 day, 58.000-69.333 day, 39.473-42.967 cm, 3.603-4.837 mm, 2.667-4.000 number, 15.433-18.700 cm, 9.000-11.587 cm, 1.320-1.810 cm, 2.333-4.000 number, 3.333-5.333 number, 341.667-450.333 g, 877.33-1546.67 kg/ha, 115.667-127.000 day, 210.947-282.526 µg/g, 82.023-128.235 µg/g, 126.287-159.569 µg/g, 0.696-1.578 µg/g, 1.120-1.926 µmol/gr, 1.577-2.796

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nmol/g, 19.210-23.434 mmol GA/g, respectively (*Table 1*). These results were found to be lower than what they obtained in the Bilashini Devi et al. (2018) study. This situation is the result of plant genetics, climate and environmental factors. Our findings are in agreement with other studies (Kamaluddin and Ahmed, 2011; Madakbas and Ergin, 2011; Gopinath et al., 2014; Hosseinpour et al., 2014; Aydogan, 2017; Kadioglu et al., 2020).

Table 1. *Summary Statistics for Bean Genotypes*

Variable	Minimum	Maximum	Mean	Std. deviation
NDE	11.667	20.000	16.095	2.904
NDUF	58.000	69.333	63.095	4.086
PH	39.473	42.967	41.209	1.265
SD	3.603	4.837	4.103	0.500
BN	2.667	4.000	3.114	0.418
FPH	15.433	18.700	16.650	1.161
PL	9.000	11.587	10.190	0.858
PW	1.320	1.810	1.507	0.168
PNPP	2.333	4.000	3.305	0.589
SNPP	3.333	5.333	4.219	0.710
TSW	341.667	450.333	401.667	46.187
SY	877.33	1546.67	123.976	25.813
NDPM	115.667	127.000	123.810	4.264
CHL-A	210.947	282.526	255.054	22.870
CHL-B	82.023	128.235	102.275	16.229
CHL-C	126.287	159.569	144.333	12.493
CARO	0.696	1.578	1.094	0.269
PROL	1.120	1.926	1.531	0.254
MDA	1.577	2.796	2.036	0.437
TPC	19.210	23.434	21.855	1.437

NDE:Number of days to emergence (day), NDUF:Number of days to flowering (day), PH: Plant height (cm), SD:Stem diameter (mm), BN:Branch number (number), FPH:First pod height (cm), PL:Pod lenght (cm), PW:Pod width (cm), PNPP:Pod number per plant (number), SNPP:Seed number per pod (number), TSW:Thousand seed weight (g), SY:Seed yield (kg/ha), NDPM:Number of days to physiological maturity (day), CHL-A:Chlorophyll-A (µg/g), CHL-B:Chlorophyll-B (µg/g), CHL-C:Chlorophyll-B (µg/g), CARO:Carotenoid (µg/g), PROL:Proline (µmol/gr), MDA: Malondialdehyde (nmol/g), TPC:Total phenolic compounds (mmol GA/g)

Correlation Coefficient Analysis

According to the correlation coefficient analysis (Pearson, 1900), positive-significant relationships were found between number of days to flowering and Malondialdehyde (r=0.854), stem diameter and branch number (r=0.757), first pod height and carotenoid (r=0.772), pod length and pod number per plant (r=0.870), seed number per pod and thousand seed weight (r=0.765), Chlorophyll-A and Chlorophyll-B (r=0.866), Chlorophyll-A and Chlorophyll-C (r=0.909), Chlorophyll-A and Carotenoid (r=0.861), Chlorophyll-B and Chlorophyll-C (r=0.843), Chlorophyll-B and Carotenoid (r=0.884), Chlorophyll-C and Carotenoid (r=0.814) (*Table 2*). Especially chlorophyll A, chlorophyll B, and chlorophyll C were found to be positively correlated as they are properties associated with photosynthesis. In terms of agronomical characters' correlation coefficients were similar to Tofiq et al. (2016) results. On the other hand, similar views were reported regarding the correlation coefficients between yield components (Aydogan, 2017). This situation reveals that there is a close relationship between biochemical characters especially between Chlorophyll elements with Carotenoid.

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Table 2. *Correlation matrix (Pearson (n))*

Variables	NDE	NDUF	PH	SD	BN	FPH	PL	PW	PNPP	SNPP	TSW	SY	NDPM	CHL-A	CHL-B	CHL-C	CARO	PROL	MDA
NDUF	-0.135																		
PH	0.329	-0.604																	
SD	-0.342	0.006	-0.110																
BN	-0.291	0.118	0.162	**0.757**															
FPH	0.067	0.303	0.430	0.201	0.734														
PL	0.237	0.265	-0.138	-0.405	-0.497	-0.298													
PW	0.229	0.208	-0.294	0.305	0.267	0.013	0.456												
PNPP	0.279	-0.145	-0.057	-0.379	-0.699	-0.650	**0.870**	0.303											
SNPP	0.374	-0.655	0.566	0.327	0.461	0.300	-0.556	0.126	-0.378										
TSW	0.737	-0.233	0.403	-0.057	0.211	0.423	-0.412	0.074	-0.391	**0.765**									
SY	0.433	-0.248	0.365	0.562	0.256	0.118	-0.141	0.108	0.023	0.460	0.347								
NDPM	0.575	-0.389	0.736	-0.250	0.083	0.352	0.332	0.336	0.273	0.489	0.448	0.179							
CHL-A	-0.146	0.302	0.168	0.294	0.469	0.633	-0.654	-0.554	**-0.788**	0.078	0.238	0.260	-0.338						
CHL-B	0.119	-0.007	0.370	0.521	0.563	0.583	-0.679	-0.340	-0.678	0.453	0.472	0.667	-0.095	**0.866**					
CHL-C	-0.091	0.160	0.020	0.351	0.455	0.469	**-0.857**	-0.484	**-0.881**	0.283	0.418	0.243	-0.441	**0.909**	**0.843**				
CARO	0.015	-0.081	0.548	0.297	0.623	**0.772**	-0.748	-0.452	**-0.823**	0.514	0.518	0.334	0.083	**0.861**	**0.884**	**0.814**			
PROL	-0.495	-0.717	0.065	0.078	-0.212	-0.619	-0.219	-0.310	0.169	0.117	-0.404	-0.149	-0.202	-0.346	-0.282	-0.215	-0.231		
MDA	0.010	**0.854**	-0.572	-0.105	-0.239	-0.059	0.639	0.264	0.356	**-0.813**	-0.436	-0.085	-0.300	-0.014	-0.224	-0.210	-0.429	-0.574	
TPC	0.484	0.217	-0.194	-0.730	**-0.881**	-0.437	0.466	-0.260	0.518	-0.510	-0.012	-0.112	-0.112	-0.153	-0.286	-0.194	-0.403	-0.234	0.487

Values in bold are different from 0 with a significance level alpha=0.05.
NDE:Number of days to emergence (day), NDUF:Number of days to flowering (day), PH: Plant height (cm), SD:Stem diameter (mm), BN:Branch number (number), FPH:First pod height (cm), PL:Pod lenght (cm), PW:Pod width (cm), PNPP:Pod number per plant (number), SNPP:Seed number per pod (number), TSW:Thousand seed weight (g), SY:Seed yield (kg/ha), NDPM:Number of days to physiological maturity (day), CHL-A:Chlorophyll-A (µg/g), CHL-B:Chlorophyll-B (µg/g), CHL-C:Chlorophyll-B (µg/g), CARO:Carotenoid (µg/g), PROL:Proline (µmol/gr), MDA: Malondialdehyde (nmol/g), TPC:Total phenolic compounds (mmol GA/g)

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Principal Component Analysis

Principal component analysis (PCA), which is a size reduction method using the data set of the studied agricultural characteristics, applied. All of the total variation has been derived from 6 principal component axis and Eigenvalues, Variability values (%) and Cumulative values (%) showed that *Table 3*. The first principal component had 37.899% of the total variation (PC1). The second principle component (PC2) explained 19.975% of the total variation. The third principle component had 15.906 of the total variation (PC3). The cumulative ratio of the three primary components in total variation was 73.780%. The rest of principle components (PC4=12.710%, PC5=7.689% and PC6=5.821%) had 26.22% of the total variation. As a result of the PCA analysis, 6 principle component axes were obtained and these axes represented all of the total variation. The 6 principle components explained 100% of the total variation. Madakbas and Ergin (2011) also reported that all variations were explained with the first 6 principle components in their work.

Table 3. *Eigenvalues, Variability and Cumulative Values*

	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	7.580	3.995	3.181	2.542	1.538	1.164
Variability %	37.899	19.975	15.906	12.710	7.689	5.821
Cumulative %	37.899	57.874	73.780	86.489	94.179	100.000

Scree Plot (Graphical representation of Eigenvalues) was given in *Fig. 1*. Eigenvalues were 7.580 for PC1 and 3.995 (PC2), 3.181 (PC3), 2.542 (PC4), 1.538 (PC5) and 1.164 (PC6), respectively. If the eigenvalues are above 1, it indicates that the evaluated principal component weight values are reliable (Mohammadi and Prasanna, 2003). On the other, Iezzoni and Pritts (1991) reported that if the eingenvalue value is greater than 1 (PCs with eigenvalue >1.0), it is more informative than the original variable.

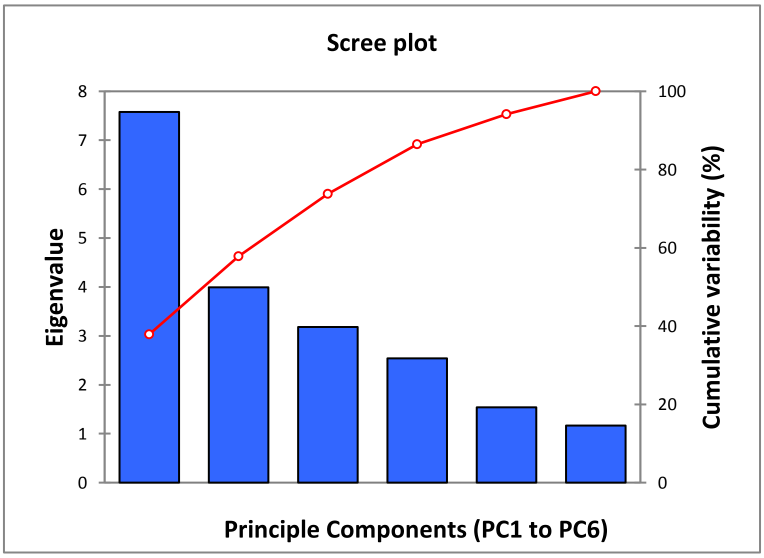

Figure 1. *Graphical representation of Eigenvalues*

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When this biplot is examined (*Fig. 2*), there is a positive relationship between the narrow angle features, for example NDPM with NDE or CARO with CHL-B etc. Right-angle features are not related to each other, for example CARO with NDPM. Wide-angle features have negative relationships with each other for example CARO with PNPP etc. The biplot technique enables the determination of the relationships between the variables as well as the detailed description of a multivariate data set (Yan and Rajcan, 2002).

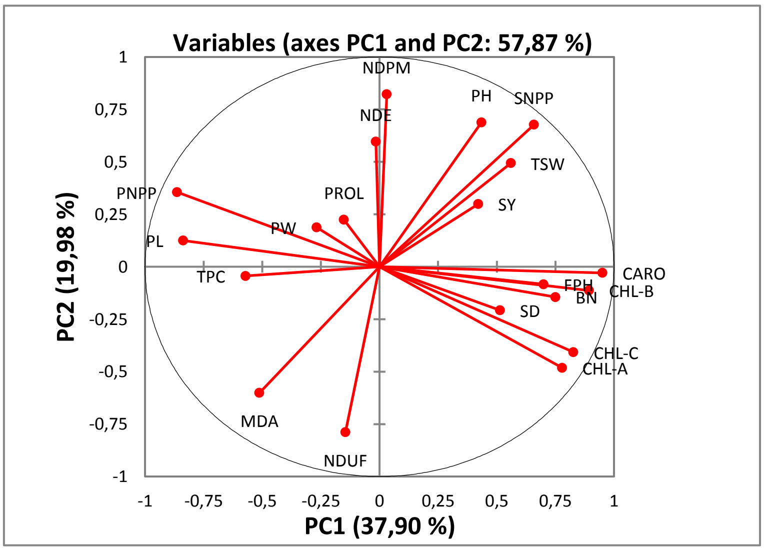

Figure 2. *Principal Component Analysis (PCA) biplot showing the distribution of agronomic, morphological and biochemical characteristics in the first principle component and the second principle component. NDE:Number of days to emergence (day), NDUF:Number of days to flowering (day), PH: Plant height (cm), SD:Stem diameter (mm), BN:Branch number (number), FPH:First pod height (cm), PL:Pod lenght (cm), PW:Pod width (cm), PNPP:Pod number per plant (number), SNPP:Seed number per pod (number), TSW:Thousand seed weight (g), SY:Seed yield (kg/ha), NDPM:Number of days to physiological maturity (day), CHL-A:Chlorophyll-A (µg/g), CHL-B:Chlorophyll-B (µg/g), CHL-C:Chlorophyll-B (µg/g), CARO:Carotenoid (µg/g), PROL:Proline (µmol/gr), MDA: Malondialdehyde (nmol/g), TPC:Total phenolic compounds (mmol GA/g)*

In the first principle component, CARO (0.905), CHL-B (0.798), PNPP (0.745), PL (0.701), CHL-C (0.684), CHL-A (0.608), BN (0.563), FPH (0.491) and TSW (0.314) had the highest coefficients, respectively (*Table 4*). In the second principle component, NDPM (0.677), NDUF (0.623), PH (0.474), SNPP (0.458), MDA (0.362) had the highest coefficients, respectively. For the third principle component PROL (0.903), NDE (0.484) had the highest coefficients, respectively. On the other hand, in the fourth principle component PW (0.701), TPC (0.456), SD (0.418) had the highest coefficients. In the fifth essential component SY (0.539) had the highest coefficients. Yeken et al. (2019) reported that the principle component values obtained from botanical features at these levels.

When the biplot graph of the genotypes used in the study is examined (*Fig. 3*), it is seen that the genotypes are quite different from each other and they are distributed in the graph. It is possible to say that only Ala Ciftci and Aydintepe genotypes can be similar. This situation can be fully explained by the reflection of genetic factors on the studied parameters (agronomic, morphological and biochemical characteristics). Similar results gained by Madakbas et al. (2006).

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Table 4. *Principle component analysis results of the studied agronomic, morphological and biochemical characteristics*

	PC1	PC2	PC3	PC4	PC5	PC6
NDE	0.000	0.356	**0.484**	0.050	0.071	0.039
NDUF	0.021	**0.623**	0.312	0.027	0.013	0.004
PH	0.189	**0.474**	0.004	0.036	0.060	0.238
SD	0.265	0.043	0.054	**0.418**	0.205	0.014
BN	**0.563**	0.021	0.000	0.391	0.024	0.001
FPH	**0.491**	0.007	0.221	0.039	0.220	0.023
PL	**0.701**	0.016	0.152	0.046	0.004	0.082
PW	0.072	0.035	0.095	**0.701**	0.011	0.086
PNPP	**0.745**	0.126	0.007	0.002	0.049	0.071
SNPP	0.434	**0.458**	0.009	0.020	0.010	0.069
TSW	**0.314**	0.244	0.191	0.030	0.003	0.218
SY	0.177	0.089	0.057	0.019	**0.539**	0.118
NDPM	0.001	**0.677**	0.133	0.038	0.120	0.030
CHL-A	**0.608**	0.232	0.031	0.091	0.000	0.038
CHL-B	**0.798**	0.013	0.034	0.017	0.096	0.042
CHL-C	**0.684**	0.166	0.001	0.097	0.023	0.029
CARO	**0.905**	0.001	0.011	0.038	0.022	0.024
PROL	0.023	0.050	**0.903**	0.010	0.007	0.006
MDA	0.262	**0.362**	0.311	0.016	0.019	0.031
TPC	0.327	0.002	0.172	**0.456**	0.042	0.002

Values in bold correspond for each variable to the factor for which the squared cosine is the largest

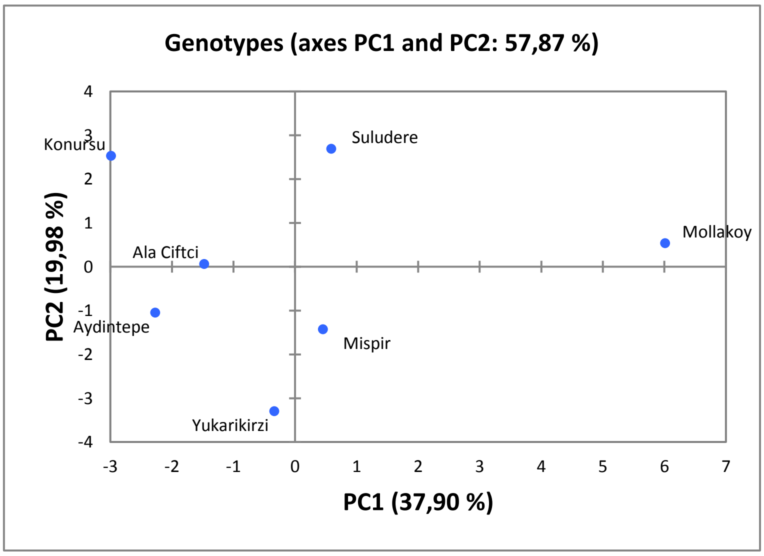

Figure 3. *Principal Component Analysis (PCA) biplot showing the distribution of bean genotypes in the first principle component and the second principle component*

The graphic in which the biplots of bean genotypes were combined with the examined agronomic, morphological, biochemical characteristics was given in *Fig. 4*. In this graph, as stated above, while narrow angle features have a positive relationship, wide angles have a negative relationship, while there is no correlation between right angles. On the

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other hand, similarly the Euclidean distances between cultivars were used to calculate in dry bean (Adams, 1977).

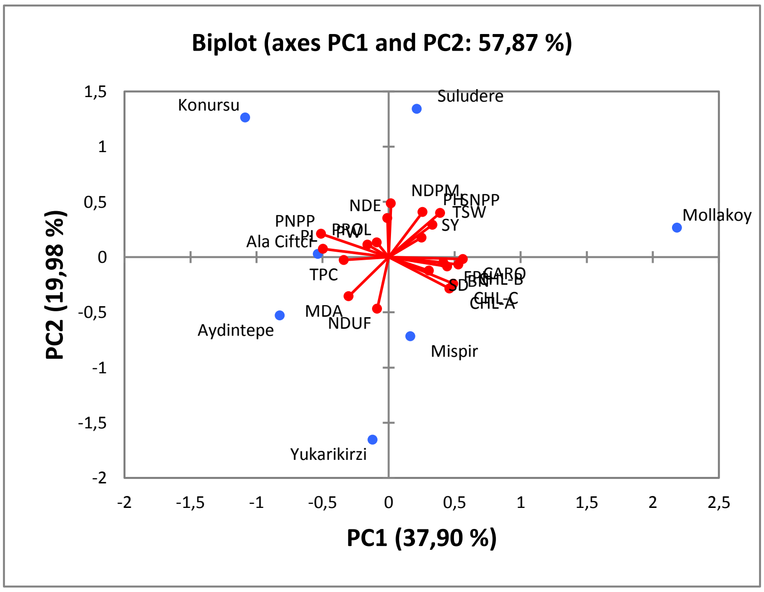

Figure 4. *Principal Component Analysis (PCA) biplot of the agronomic, morphological and biochemical characteristics of local bean genotypes for the first two principle components*

In terms of the genotypes PCA analysis results was given in *Table 5*. According to it; Mollakoy (0.921) and Konursu (0.411) have the highest coefficient value in the first Principle Component (PC1). In the second Principle Component (PC2), Yukarikirzi and Suludere had the highest coefficient values (0.651 and 0.438 respectively). Ala Ciftci (0.599) and Aydintepe (0.543) genotypes are the genotypes with the highest coefficient in the third Principle Component (PC3). And finally, the Mispir registered bean variety in the sixth Principle Component (PC6) had a high coefficient value (0.393). It stated that the populations differ more from each other. It is stated that Turkey is considered rich in beans biodiversity (Canci et al., 2019). Ashgari and Vojdani (1997), as a result of their studies, it has been determined that climate diversity and genetic difference were closely related.

Table 5. *Principle component analysis results of the bean genotypes*

	PC1	PC2	PC3	PC4	PC5	PC6
Aydintepe	0.267	0.058	**0.543**	0.027	0.046	0.059
Ala Ciftci	0.138	0.000	**0.599**	0.011	0.217	0.036
Mollakoy	**0.921**	0.007	0.000	0.067	0.004	0.000
Konursu	**0.411**	0.295	0.005	0.205	0.025	0.059
Mispir	0.019	0.189	0.048	0.305	0.045	**0.393**
Yukarikirzi	0.007	**0.651**	0.087	0.007	0.238	0.010
Suludere	0.021	**0.438**	0.017	0.400	0.079	0.044

Values in bold correspond for each variable to the factor for which the squared cosine is the largest

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Conclusions

It can be said that the genotypes used in the study differ greatly from each other. This is important for breeders trying to create variability, and it may be recommended to include these genotypes as genitors in breeding studies.

The important features in the first principle component, Pod number per plant, Pod length, Branch number, First pod height and Thousand seed weight, should be taken into account in the agronomic, morphological breeding studies. In the future, Carotenoid, Chlorophyll-B, Chlorophyll-C, Chlorophyll-A, properties could be taken into consideration in biochemical breeding studies.

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