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## MORPHOLOGICAL EVALUATION OF COMMON BEAN DIVERSITY IN BOSNIA AND HERZEGOVINA USING THE DISCRIMINANT ANALYSIS OF PRINCIPAL COMPONENTS (DAPC) MULTIVARIATE METHOD

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In order to analyze morphological characteristics of locally cultivated common bean landraces from Bosnia and Herzegovina (B&H), thirteen quantitative and qualitative traits of 40 *P. vulgaris* accessions, collected from four geographical regions (Northwest B&H, Northeast B&H, Central B&H and Sarajevo) and maintained at the Gene bank of the Faculty of Agriculture and Food Sciences in Sarajevo, were examined. Principal component analysis (PCA) showed that the proportion of variance retained in the first two principal components was 54.35%. The first principal component had high contributing factor loadings from seed width, seed height and seed weight, whilst the second principal component had high contributing factor loadings from the analyzed traits seed per pod and pod length. PCA plot, based on the first two principal components, displayed a high level of variability among the analyzed material. The discriminant analysis of principal components (DAPC) created 3 discriminant functions (DF), whereby the first two discriminant functions accounted for 90.4% of the variance retained. Based on the retained DFs, DAPC provided group membership probabilities which showed that 70% of the accessions examined were correctly classified between the geographically defined groups. Based on the taxonomic distance, 40 common bean accessions analyzed in this study formed two major clusters, whereas two accessions Acc304 and Acc307 didn't group in any of those. Acc360 and Acc362, as well as Acc324 and Acc371 displayed a high level of similarity and are probably the

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same landrace. The present diversity of Bosnia and Herzegovina's common bean landraces could be useful in future breeding programs.

*Key words:* common bean landraces, morphological traits, principal component analysis, discriminant analysis of principal components, hierarchical clustering

## INTRODUCTION

The genus *Phaseolus* comprises of over 30 species, but only five of them are domesticated (DEBOUCK, 1991 and 1999). Among these domesticated species, the common bean is the most widely distributed and has the broadest range of genetic resources (SINGH, 1999). Common bean (*Phaseolus vulgaris* L.) is also the most important annual leguminous food crop (SINGH, 1999). There are about 65.000 accessions of the *Phaseolus* species in major genebanks in the world, of which more than 90% belong to *Phaseolus vulgaris* (GOMEZ, 2004).

The genus *Phaseolus* is of American origin. Two major gene pools of this genus which were first to be recognized are the Mesoamerican and the Andean South American. Results of the studies analyzing allozymes and morphological traits (SINGH *et al.*, 1991) support the existence of these two gene pools. Cultivars from Mesoamerica are usually small or medium-seeded (25 to 40 g/100 seeds weight) and contain S phaseolin, while the South American beans have larger seeds (more than 40 g/100 seeds weight) and contain T, C, H and A phaseolin (SINGH *et al.*, 1991). However, a third gene pool, located in the northern Andes, was described by GEPTS (1998) and is now considered to be the nucleus of bean diversity.

The common bean was introduced into other regions of the world during the 16<sup>th</sup> century. GRAHAM and RANALLI (1997) advocate the theory that most European cultivars are of Andean origin and were probably introduced to Europe through the Iberian Peninsula. Several millennia of domestication in South America and centuries of cultivation in Europe have resulted in numerous landraces which can now be found throughout the world.

Cultivated forms of common beans (landraces) are often highly variable in appearance. The genetic diversity of landraces is thought to be commercially the most valuable part of global biodiversity and is considered of paramount importance for future world food production (WOOD and LENNE, 1997).

A wide range of variation of some morphological and agronomic traits have been observed in bean cultivars (SANTOS DE LIMA and CARNEIRO, 2011), which implies the importance of germplasm evaluation for the selection of plants with traits suitable for local conditions (ARAYA, 2003). Knowledge of patterns of genetic diversity, gained through the evaluation, enhances the efficiency of germplasm conservation and utilization. In recent years, several evaluation studies in the Southeast Europe have been conducted on *Cucurbitaceae* germplasm (MLADENović *et al.*, 2012) and maize inbred lines (BABIĆ *et al.*, 2008).

Common bean is a traditional grain legume cultivated in Bosnia and Herzegovina (B&H). The trend of replacing landraces with improved cultivars is still not significantly present and therefore many landraces can still be found in the B&H bean production. In the last ten years an effort has been underway to preserve bean germplasm in B&H. Numerous inventory and collecting missions have resulted in the establishment of a bean collection within the Gene bank of the Faculty of Agriculture and Food Sciences in Sarajevo. The accessions have so far not been properly evaluated, only regularly regenerated.

Therefore, the objectives of this study were: 1) to analyze the morphological characteristics of locally cultivated common bean landraces using IPGRI (International Plant Genetic Resources Institute) descriptors; 2) to group the common bean landraces in relation to the main sources of phenotypic variability using multivariate statistical approaches.

#### MATERIALS AND METHODS

The variability of 40 common bean accessions (*Phaseolus vulgaris* L.) maintained at the Gene bank of the Faculty of Agriculture and Food Sciences in Sarajevo, was evaluated based on 13 morphological traits (Table 1). All the examined accessions, collected from four different geographical regions are locally used cultivars. Each accession, analyzed in our study, was grown in a two row plot, 2 m long and 1 m wide, with three replications in a randomized complete block design. The field trial was conducted during 2010 and 2011 at the regeneration field of the Gene bank in Butmir, Sarajevo.

Thirteen quantitative and qualitative traits were analyzed using descriptors established for *Phaseolus* (IPGRI, 1982): pod length (cm), pod width (mm), pod beak length (mm), seeds per pod, seed length (mm), seed width (mm), seed height (mm), seed weight (g), pod color, color of wings, seed coat patterns, seed coat lighter color and seed shape. For the analyses, three typical pods, collected from 5 randomly chosen plants in each row were used. The values for morphological traits examined during the two-year trial on 40 common bean accessions were then analyzed using multivariate statistical approaches.

Principal components analysis (PCA) was used as it summarizes patterns of correlations among observed variables and reduces a large number of observed characters to a smaller number of derived variables or components (HOTELLING, 1936). Computations were performed on the correlation matrix for the 13 original variables, 8 quantitative and 5 qualitative traits of 40 analyzed bean accessions.

In order to investigate not only the diversity amongst individuals, but also the diversity between groups of individuals, discriminant function analysis of principal components (DAPC) was used

(JOMBART *et al.*, 2010). The number of retained PCs for DAPC was chosen so as to optimize the  $\alpha$ -score (measure for trade-off between power of discrimination and over-fitting).

Group assignment of the *P. vulgaris* accessions was made according to the geographical region of the collection site (Northwest B&H, Northeast B&H, Central B&H and Sarajevo).

Hierarchical clustering based on taxonomic distances between the 13 original variables was performed using the unweighted pair group method with arithmetic means (UPGMA).

All statistical analyses were carried out using the R software version 2.15.2 (R DEVELOPMENT CORE TEAM, 2012).

Table 1. List of locally grown common bean accessions, along with their national accession number, coordinates and geographical region of the collection site evaluated based on 13 morphological traits.

Accession number	Location	Latitude	Longitude	Elevation	Geographical region
304	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
306	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
307	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
308	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
309	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
310	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
311	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
312	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
315	Travnik	44.23442 °N	17.61613 °E	569 m	Central B&H
316	Lukavac	44.38087 °N	18.24339 °E	267 m	Northeast B&H
318	Cazin	44.56620 °N	15.56150 °E	386 m	Northwest B&H
319	Lukavac	44.38087 °N	18.24339 °E	267 m	Northeast B&H
320	Gornji Vakuf	43.55143 °N	17.32048 °E	704 m	Central B&H
322	Gornji Vakuf	43.55143 °N	17.32048 °E	704 m	Central B&H
323	Busovača	44.04540 °N	17.57550 °E	523 m	Central B&H
324	Bihać	44.49400 °N	15.50890 °E	224 m	Northwest B&H
326	Gornji Vakuf	43.55143 °N	17.32048 °E	704 m	Central B&H
335	Gradačac	44.53096 °N	18.26139 °E	152 m	Northeast B&H
339	Lukavac	44.38087 °N	18.24339 °E	267 m	Northeast B&H
345	Kalesija	44.27334 °N	18.45298 °E	296 m	Northeast B&H
346	Gradačac	44.52123 °N	18.25659 °E	155 m	Northeast B&H
347	Živinice	44.40615 °N	18.52451 °E	268 m	Northeast B&H
348	Živinice	44.42215 °N	18.72911 °E	241 m	Northeast B&H
349	Cazin	44.56620 °N	15.56150 °E	386 m	Northwest B&H
352	Živinice	44.40615 °N	18.52451 °E	268 m	Northeast B&H
353	Lukavac	44.38087 °N	18.24339 °E	267 m	Northeast B&H
354	Bihać	44.46160 °N	15.56670 °E	233 m	Northwest B&H
355	Živinice	44.42215 °N	18.72911 °E	241m	Northeast B&H
358	Živinice	44.40615 °N	18.52451 °E	268 m	Northeast B&H
359	Cazin	44.56620 °N	15.56150 °E	386 m	Northwest B&H
360	Bihać	44.03560 °N	15.53340 °E	407 m	Northwest B&H
362	Cazin	44.56620 °N	15.56150 °E	386 m	Northwest B&H

Table 1. List of locally grown common bean accessions, along with their national accession number, coordinates and geographical region of the collection site evaluated based on 13 morphological traits. continued

Accession number	Location	Latitude	Longitude	Elevation	Geographical region
363	Sarajevo	43.88297 °N	18.38944 °E	639 m	Sarajevo
364	Sarajevo	43.49925 °N	18.19022 °E	506 m	Sarajevo
365	Sarajevo	43.49925 °N	18.19022 °E	506 m	Sarajevo
366	Sarajevo	43.49925 °N	18.19022 °E	506 m	Sarajevo
367	Sarajevo	43.49925 °N	18.19022 °E	506 m	Sarajevo
368	Sarajevo	43.49925 °N	18.19022 °E	506 m	Sarajevo
369	Sarajevo	43.79788 °N	18.35372 °E	520 m	Sarajevo
370	Novi Travnik	44.09459 °N	17.40105 °E	534 m	Central B&H
371	Novi Travnik	44.09459 °N	17.40105 °E	534 m	Central B&H
372	Novi Travnik	44.09459 °N	17.40105 °E	534 m	Central B&H

## RESULTS AND DISCUSSION

### Principal Component Analysis (PCA)

A summary of the 13 measured quantitative and qualitative morphological traits which were observed and analyzed are presented in Table 2 and Table 3. The first two principal components accounted for 54.35% of the total variance observed (Table 4), which is slightly higher than the values published by VASIĆ *et al.* (2008) who analyzed the divergence in dry bean collection (52.80%) and MADAKBAS and ERGIN (2011) who analyzed morphological and phenological characteristics of common bean (53.90%). The first principal component (PC1) accounted for 38.08% of the total variance, and had high contributing factor loadings from seed width, seed height and seed weight. The second principal component (PC2) had high contributing factor loadings from the analyzed traits seed per pod and pod length, and contributed 16.27% to the total variation.

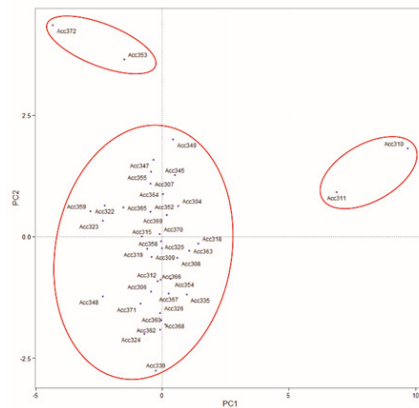


Figure 1. Distribution of the 40 analyzed accessions of *Phaseolus vulgaris* in the first two principal components based on the main sources of variance.

Distribution of the accessions in relations to the first two principal components shows the separation of the 40 accessions of *P. vulgaris* studied based on the main sources of variance (Fig. 1). The first two principal components separated the accessions into three distinct groupings. Fig 1 The first group (Acc372 and Acc353) was separated due to their high values for the traits pod width, seed width, seed length, seed weight and seed height (Fig 2). Accessions contained in the second group (Acc310 and Acc311) were separated due to their specific seed shape, as well as higher values for pod length and number of seed per pod. All of the remaining accessions, assigned to the third group, showed a high degree of dispersion, which indicates that these accessions represent a very diverse material in regards to the most variable traits analyzed in our study.

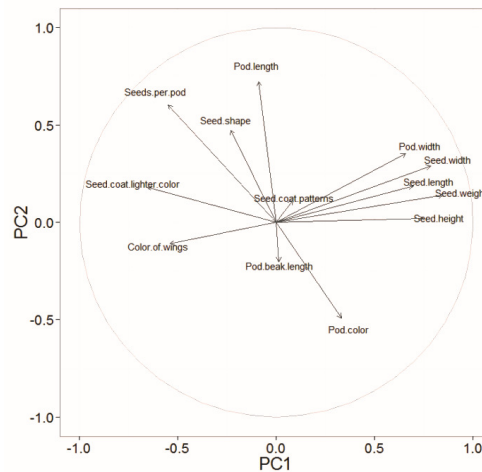


Figure 2. Variables factor map of the Principal Component Analysis (for the first two principal components) based on 13 morphological traits of 40 analyzed common bean accessions. Each morphological trait examined is represented by a vector.

### Discriminant Function Analysis of Principal Components (DAPC)

The optimal  $\alpha$ -score was achieved by retaining 8 principal components. The discriminant analysis of principal components provided 3 discriminant functions. Compared to the PCA analysis (54.35%), the proportion of conserved variance within two discriminant functions was 90.40%. The first discriminant function (DF1) accounted for 83.81% and the second discriminant function (DF2) for 6.59% of the variance conserved (Table 5). Original variables with the highest contribution to the first discriminant function (DF1) were seed shape and pod width (Table 6). For the second discriminant function (DF2), original variables with the highest contribution were pod color and seed coat lighter color.

Table 2. Average values with the standard error for the 8 quantitative traits measured on 40 common bean accessions.

Accession number	Pod length	Pod width	Pod beak length	Seeds per pod	Seed length	Seed width	Seed height	Seed weight
Acc304	11.36 ± 0.251	1.15 ± 0.049	0.78 ± 0.051	5.25 ± 0.163	0.99 ± 0.017	0.80 ± 0.160	0.44 ± 0.015	0.38 ± 0.015
Acc306	10.74 ± 1.857	1.00 ± 0.020	1.20 ± 0.045	3.55 ± 0.101	1.09 ± 0.014	0.63 ± 0.013	0.43 ± 0.009	0.42 ± 0.013
Acc307	8.89 ± 0.154	0.97 ± 0.027	0.72 ± 0.027	5.03 ± 0.135	0.97 ± 0.019	0.71 ± 0.016	0.47 ± 0.009	0.45 ± 0.016
Acc308	10.22 ± 0.329	1.30 ± 0.035	0.64 ± 0.032	5.10 ± 0.194	0.96 ± 0.020	0.53 ± 0.013	0.36 ± 0.012	0.29 ± 0.020
Acc309	10.24 ± 0.199	0.86 ± 0.026	0.88 ± 0.034	5.03 ± 0.188	1.08 ± 0.022	0.60 ± 0.013	0.49 ± 0.013	0.46 ± 0.018
Acc310	11.39 ± 0.272	1.51 ± 0.030	1.06 ± 0.043	3.40 ± 0.167	1.80 ± 0.039	1.10 ± 0.023	0.72 ± 0.030	1.22 ± 0.064
Acc311	11.13 ± 0.229	1.54 ± 0.031	1.04 ± 0.037	3.08 ± 0.115	1.68 ± 0.034	1.02 ± 0.020	0.66 ± 0.016	1.11 ± 0.053
Acc312	8.09 ± 0.190	0.88 ± 0.021	0.93 ± 0.037	4.50 ± 0.139	0.96 ± 0.019	0.68 ± 0.012	0.50 ± 0.013	0.44 ± 0.021
Acc315	10.72 ± 0.226	0.96 ± 0.031	0.61 ± 0.023	5.80 ± 0.183	0.87 ± 0.017	0.57 ± 0.016	0.46 ± 0.016	0.35 ± 0.016
Acc318	10.26 ± 0.227	1.03 ± 0.029	1.14 ± 0.047	4.58 ± 0.199	1.25 ± 0.031	0.69 ± 0.013	0.52 ± 0.011	0.59 ± 0.023
Acc319	10.51 ± 0.220	1.07 ± 0.038	0.68 ± 0.039	4.90 ± 0.216	0.96 ± 0.031	0.56 ± 0.010	0.39 ± 0.020	0.31 ± 0.019
Acc320	10.44 ± 0.196	1.08 ± 0.025	1.21 ± 0.045	4.53 ± 0.172	1.02 ± 0.018	0.67 ± 0.014	0.48 ± 0.014	0.46 ± 0.018
Acc322	11.99 ± 0.253	0.86 ± 0.022	1.20 ± 0.044	5.58 ± 0.196	1.15 ± 0.027	0.56 ± 0.009	0.28 ± 0.011	0.34 ± 0.014
Acc323	11.57 ± 0.218	0.90 ± 0.018	1.12 ± 0.047	5.28 ± 0.160	1.12 ± 0.023	0.53 ± 0.013	0.27 ± 0.009	0.32 ± 0.012
Acc324	9.53 ± 0.152	0.84 ± 0.024	1.15 ± 0.051	3.83 ± 0.151	1.04 ± 0.022	0.49 ± 0.011	0.39 ± 0.011	0.37 ± 0.017
Acc326	9.88 ± 0.232	0.99 ± 0.027	1.18 ± 0.062	3.80 ± 0.169	1.09 ± 0.025	0.51 ± 0.014	0.41 ± 0.013	0.42 ± 0.020
Acc335	9.53 ± 0.313	1.02 ± 0.039	1.39 ± 0.055	4.21 ± 0.260	1.18 ± 0.031	0.62 ± 0.015	0.49 ± 0.012	0.51 ± 0.024
Acc339	8.29 ± 0.266	0.75 ± 0.021	1.13 ± 0.075	3.30 ± 0.180	1.10 ± 0.021	0.51 ± 0.010	0.40 ± 0.012	0.43 ± 0.024
Acc345	12.00 ± 0.324	1.02 ± 0.019	1.11 ± 0.042	5.17 ± 0.204	1.19 ± 0.025	0.69 ± 0.012	0.54 ± 0.013	0.56 ± 0.021
Acc347	12.70 ± 0.235	0.97 ± 0.019	1.04 ± 0.036	5.65 ± 0.132	1.16 ± 0.020	0.62 ± 0.017	0.50 ± 0.013	0.49 ± 0.022

\*all metric units converted to centimeters

DAPC discriminant functions are linear functions of principal components that optimize the separation of individuals into predefined groups. Based on the retained DFs, DAPC provided group membership probabilities of the analyzed accessions which showed the quality of discrimination of retained PCs. Overall, 70% of the accessions were correctly classified by the DAPC (Table 7). There was no clear differentiation between the *P. vulgaris* accession groups originating from three of the four different geographical regions: Northwest B&H, Northeast B&H and Central B&H, while only the Sarajevo group displayed somewhat small degree of separation from the other groups (Figure 3). This indicates a high level of seed material exchange between these regions.

Overall 93% accessions from Sarajevo were correctly classified, while the remaining 7% grouped with the accessions collected from Northeast B&H. By contrast, only 38% accessions from Central B&H were correctly classified, the remaining material was classified as belonging to the other geographical regions (Northeast B&H 12%, Northwest B&H 25%, Sarajevo 25%).

Table 2. (continued) Values of the mean and the standard error for the 8 quantitative traits measured on 40 common bean accessions.

Accession number	Pod length	Pod width	Pod beak length	Seeds per pod	Seed length	Seed width	Seed height	Seed weight
Acc348	10.22 ± 0.226	0.76 ± 0.017	1.13 ± 0.058	5.13 ± 0.197	0.93 ± 0.022	0.50 ± 0.008	0.34 ± 0.008	0.29 ± 0.010
Acc349	13.35 ± 0.280	1.19 ± 0.031	1.26 ± 0.065	5.37 ± 0.189	1.16 ± 0.016	0.68 ± 0.038	0.51 ± 0.013	0.53 ± 0.018
Acc352	11.64 ± 0.221	1.08 ± 0.021	0.92 ± 0.045	5.30 ± 0.161	1.07 ± 0.027	0.60 ± 0.011	0.45 ± 0.013	0.42 ± 0.020
Acc353	15.47 ± 0.457	1.18 ± 0.034	1.05 ± 0.071	5.97 ± 0.242	1.15 ± 0.030	0.58 ± 0.022	0.39 ± 0.012	0.37 ± 0.021
Acc354	10.12 ± 0.197	0.97 ± 0.030	1.34 ± 0.062	4.35 ± 0.174	1.11 ± 0.033	0.61 ± 0.020	0.47 ± 0.018	0.45 ± 0.025
Acc355	12.62 ± 0.326	1.02 ± 0.016	0.96 ± 0.059	5.20 ± 0.222	1.13 ± 0.026	0.60 ± 0.016	0.48 ± 0.019	0.44 ± 0.022
Acc358	11.96 ± 0.233	1.11 ± 0.021	1.77 ± 0.057	4.30 ± 0.144	1.31 ± 0.020	0.63 ± 0.011	0.33 ± 0.012	0.44 ± 0.016
Acc359	11.71 ± 0.221	0.87 ± 0.027	1.13 ± 0.042	5.80 ± 0.176	1.04 ± 0.025	0.52 ± 0.012	0.27 ± 0.010	0.28 ± 0.012
Acc360	9.89 ± 0.332	0.88 ± 0.032	1.41 ± 0.071	3.71 ± 0.244	1.15 ± 0.019	0.53 ± 0.013	0.44 ± 0.011	0.43 ± 0.015
Acc362	9.34 ± 0.192	0.83 ± 0.025	1.26 ± 0.059	3.98 ± 0.184	1.07 ± 0.023	0.53 ± 0.034	0.47 ± 0.034	0.42 ± 0.016
Acc363	9.6 ± 0.207	1.18 ± 0.021	0.71 ± 0.033	4.23 ± 0.181	1.08 ± 0.018	0.67 ± 0.013	0.55 ± 0.009	0.54 ± 0.019
Acc364	11.62 ± 0.264	1.42 ± 0.040	0.57 ± 0.056	5.43 ± 0.168	0.94 ± 0.017	0.61 ± 0.011	0.43 ± 0.011	0.37 ± 0.014
Acc365	11.08 ± 0.171	1.00 ± 0.024	1.42 ± 0.042	5.00 ± 0.156	1.06 ± 0.027	0.57 ± 0.014	0.35 ± 0.009	0.36 ± 0.015
Acc366	9.92 ± 0.200	0.99 ± 0.032	0.96 ± 0.050	4.55 ± 0.138	1.12 ± 0.024	0.61 ± 0.016	0.44 ± 0.011	0.45 ± 0.021
Acc367	9.07 ± 0.196	0.98 ± 0.032	1.11 ± 0.047	4.33 ± 0.210	1.12 ± 0.036	0.59 ± 0.012	0.45 ± 0.012	0.44 ± 0.021
Acc368	8.48 ± 0.223	0.90 ± 0.075	1.12 ± 0.061	4.23 ± 0.213	1.01 ± 0.037	0.57 ± 0.043	0.50 ± 0.055	0.38 ± 0.021
Acc369	10.67 ± 0.205	1.04 ± 0.029	1.54 ± 0.091	4.13 ± 0.096	1.40 ± 0.028	0.57 ± 0.013	0.40 ± 0.026	0.51 ± 0.025
Acc370	12.14 ± 0.316	1.04 ± 0.026	1.73 ± 0.053	4.78 ± 0.121	1.32 ± 0.027	0.64 ± 0.012	0.35 ± 0.012	0.46 ± 0.016
Acc371	10.11 ± 0.221	0.90 ± 0.028	1.09 ± 0.043	4.40 ± 0.195	0.99 ± 0.021	0.49 ± 0.009	0.41 ± 0.012	0.36 ± 0.014
Acc372	12.53 ± 0.252	0.82 ± 0.020	0.78 ± 0.034	7.10 ± 0.202	0.98 ± 0.022	0.51 ± 0.012	0.29 ± 0.013	0.24 ± 0.009

In Northeast B&H, the proportion of correct classification was 70%, while the remaining 30% were classified as belonging to Northwest B&H and Sarajevo accessions. With regards to Northwest B&H, 57% accessions were correctly classified, whilst 43% of *P. vulgaris* landraces were classified as accessions from Central B&H, Northeast B&H and Sarajevo (each with 14%).



Based on the DAPC analyses, the highest level of seed material exchange between the mentioned four regions of B&H has been noted among accessions from Central region of the country. Considering that this region is located between the three others from which the bean accessions were collected, this is only logical. However, in spite of the well-developed infrastructure connecting the capital of B&H to the rest of the country, the bean germplasm collected from Sarajevo remains as the most distinct one based on the analyzed morphological traits.

Table 3. Summary for the 5 qualitative traits measured on 40 common bean accessions.

Accession number	Pod color	Color of wings	Seed coat patterns	Seed coat lighter color	Seed shape
Acc304	Pale yellow to white	Purple	Absent	Black	Oval
Acc306	Pale red stripe on green	White	Spotted bicolor	Pure white	Oval
Acc307	Pale red stripe on green	Purple	Absent	Brown, pale to dark	Cuboid
Acc308	Normal green	Purple	Absent	Purple	Oval
Acc309	Normal green	Lilac	Absent	Brown, pale to dark	Truncate fastigiata
Acc310	Normal green	Strongly veined in red to dark lilac	Striped	Purple	Truncate fastigiata
Acc311	Normal green	White	Absent	Whitish	Truncate fastigiata
Acc312	Pale red stripe on green	Purple	Striped	Brown, pale to dark	Oval
Acc315	Pale yellow to white	Purple	Absent	Black	Oval
Acc318	Carmine stripe on green	Lilac	Striped	Pink	Oval
Acc319	Normal green	Purple	Absent	Black	Oval
Acc320	Purple stripe on green	White	Absent	Pure white	Oval
Acc322	Purple stripe on green	White	Absent	Pale-cream to buff	Kidney shaped
Acc323	Purple stripe on green	White	Absent	Pale-cream to buff	Kidney shaped
Acc324	Normal green	Lilac	Absent	Green to olive	Oval
Acc326	Normal green	Lilac	Absent	Green to olive	Oval
Acc335	Normal green	Lilac	Striped	Pink	Oval
Acc339	Normal green	Lilac	Absent	Green to olive	Oval
Acc345	Pale red stripe on green	Lilac	Striped	Brown, pale to dark	Oval
Acc347	Pale red stripe on green	Lilac	Striped	Brown, pale to dark	Oval

*Table 3. (continued) Summary for the 5 qualitative traits measured on 40 common bean accessions.*

Accession name	Pod color	Color of wings	Seed coat patterns	Seed coat lighter color	Seed shape
Acc348	Normal green	White	Absent	Pure white	Truncate fastigiate
Acc349	Pale red stripe on green	Lilac	Striped	Brown, pale to dark	Oval
Acc352	Normal green	Lilac	Absent	Brown, pale to dark	Oval
Acc353	Carmine stripe on green	White	Striped	Brown, pale to dark	Cuboid
Acc354	Carmine stripe on green	Lilac	Striped	Pink	Oval
Acc355	Pale red stripe on green	Lilac	Striped	Brown, pale to dark	Oval
Acc358	Normal green	White	Absent	Pure white	Kidney shaped
Acc359	Purple stripe on green	White	Absent	Pale-cream to buff	Kidney shaped
Acc360	Normal green	Lilac	Absent	Green to olive	Oval
Acc362	Normal green	Lilac	Absent	Green to olive	Oval
Acc363	Normal green	White	Bicolor	Pure white	Oval
Acc364	Pale yellow to white	Lilac	Absent	Black	Oval
Acc365	Normal green	White	Absent	Pure white	Cuboid
Acc366	Pale yellow to white	White	Absent	Yellow to greenish yellow	Oval
Acc367	Carmine stripe on green	Lilac	Striped	Pink	Oval
Acc368	Carmine stripe on green	Lilac	Striped	Pink	Oval
Acc369	Normal green	Lilac	Absent	Brown, pale to dark	Cuboid
Acc370	Normal green	White	Absent	Pure white	Kidney shaped
Acc371	Normal green	Lilac	Absent	Green to olive	Oval
Acc372	Dark purple	Lilac	Absent	Brown, pale to dark	Cuboid

### Hierarchical clustering

The 40 common bean accessions, analyzed in this study, formed two major clusters (Fig. 4) based on the taxonomic distances utilizing the UPGMA method. The largest number of accessions grouped into the first cluster (25 analyzed accessions). Among the 25 accessions in this cluster, Acc360 and Acc362, as well as Acc324 and Acc371 showed a high similarity which indicates that these accession most likely represent the same landraces. Acc304 and Acc307 did not group in any of the two major clusters, although in the PCA these accessions did not display any degree of separation from the other analyzed accessions. This is probably due to differences in statistical methodology employed by PCA and hierarchical clustering approaches. Cluster analysis shows that the pattern of differentiation based on 13 morphological traits doesn't reflect the geographical distribution of the accessions collection sites, which is in accordance with the results obtained by DAPC.

Table 4. Factor loadings of the 13 morphological traits for the first five principal components, standard deviation and the percentage variance accounted for.

Trait	PC1	PC2	PC3	PC4	PC5
Pod length	-0.0448	0.5520	-0.2268	0.2446	-0.3635
Pod width	0.3279	0.2695	0.0616	0.2108	-0.3498
Pod beak length	0.0069	-0.1541	-0.6839	0.0992	0.1890
Seeds per pod	-0.2749	0.4606	0.2181	0.1260	-0.0830
Seed length	0.3482	0.1429	-0.3983	0.0444	0.1205
Seed width	0.3918	0.2212	-0.0136	-0.0797	-0.0138
Seed height	0.3725	0.0158	0.1465	-0.0609	0.1294
Seed weight	0.4233	0.1060	-0.1318	-0.0405	0.1180
Pod color	0.1653	-0.3767	0.0391	0.5041	-0.244
Color of wings	-0.2692	-0.0837	-0.3543	0.2833	-0.1519
Seed coat patterns	0.0417	0.0865	0.2552	0.6858	0.6010
Seed coat lighter color	-0.3274	0.1381	-0.1659	0.0872	0.1036
Seed shape	-0.1159	0.3612	-0.1101	-0.2099	0.4505
Standard deviation	2.2532	1.4729	1.3220	1.0381	0.9810
Proportion of variance	0.3808	0.1627	0.1311	0.0808	0.0722
Cumulative proportion	0.3808	0.5435	0.6745	0.7554	0.8276

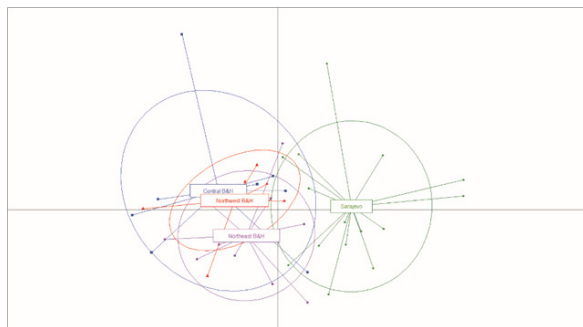


Figure 3. Discriminant function of principal components analysis plot (first two discriminant functions) based on 8 principal components created from 13 morphological traits of 40 common bean accessions collected from four different geographical regions (7 accession from Northwest B&H, 10 from Northeast B&H, 8 from Central B&H and 15 accession from Sarajevo).

*Table 5. Factor loadings of the 8 principal components for the first three discriminant functions and the percentage of conserved variance accounted for.*

Retained PCs	DF1	DF2	DF3
PCA-pc.1	-0.34005	0.05030	0.19766
PCA-pc.2	0.03331	0.16530	-0.50164
PCA-pc.3	-0.32669	-0.07063	-0.18722
PCA-pc.4	-0.35529	-0.52724	-0.10743
PCA-pc.5	-0.01199	0.20117	-0.30814
PCA-pc.6	0.51194	0.21383	0.26363
PCA-pc.7	-1.23725	0.39088	-0.15634
PCA-pc.8	-0.08374	-1.04608	-0.22022
Cumulative proportion	0.8381	0.9040	0.9612

*Table 6. Contribution of the original variables to the first three discriminant functions.*

Trait	DF1	DF2	DF3
Pod length	0.08710	0.09880	0.12195
Pod width	0.09106	0.00002	0.17398
Pod beak length	0.15374	0.00331	0.19653
Seeds per pod	0.05521	0.02226	0.12560
Seed length	0.02825	0.00030	0.03195
Seed width	0.02961	0.02423	0.00002
Seed height	0.06938	0.04573	0.03626
Seed weight	0.00513	0.00041	0.02211
Pod color	0.06153	0.38545	0.04940
Color of wings	0.02338	0.02977	0.02293
Seed coat patterns	0.06367	0.00024	0.05766
Seed coat lighter color	0.00004	0.38850	0.01834
Seed shape	0.33191	0.00097	0.14327

Table 7. Group membership probabilities of the analyzed accessions provided by the DAPC.

	Central B&H	Northeast B&H	Northwest B&H	Sarajevo	Correct classifications
Central B&H (n = 8)	3 acc.	1 acc.	2 acc.	2 acc.	38%
Northeast B&H (n = 10)	0 acc.	7 acc.	2 acc.	1 acc.	70%
Northwest B&H (n = 7)	1 acc.	1 acc.	4 acc.	1 acc.	57%
Sarajevo (n = 15)	0 acc.	1 acc.	0 acc.	14 acc.	93%
Overall (n = 40)	3 (8)	7 (10)	4 (7)	14 (15)	70%

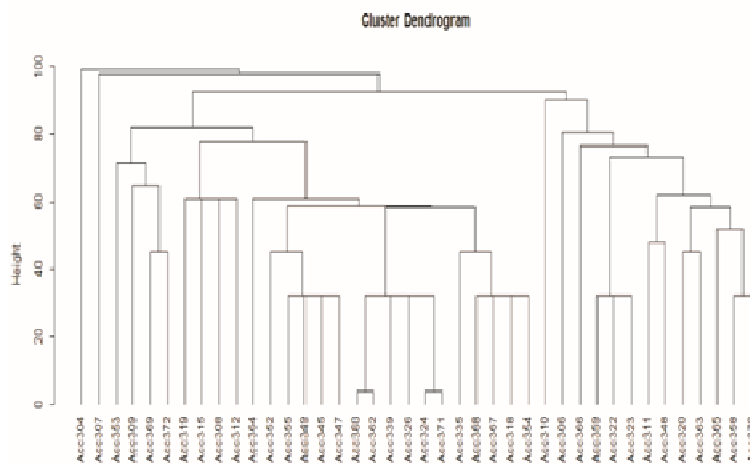


Figure 4. Hierarchical clustering based on the taxonomic distances between 40 analyzed common bean accessions utilizing the UPGMA method.

## CONCLUSION

The results of the PCA of 13 morphological characteristics performed on 40 *P. vulgaris* accessions indicate that a high level of diversity is present in the locally cultivated common bean landraces

DAPC approach proved a useful tool for differentiating of the geographically defined groups of *P. vulgaris* landraces, as well as for quality testing of PC discrimination achieved based on the overall variance retained.

The diversity of Bosnia and Herzegovina's common bean landraces may represent a diverse germplasm which should be further investigated in order to utilize this germplasm in future breeding programs.

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**MORFOLOŠKA EVALUACIJA DIVERZITETA PASULJA U BOSNI I HERCEGOVINI  
PRIMJENOM MULTIVARIJATNE METODE DISKRIMINANTNE ANALIZE  
GLAVNIH KOMPONENTI (DAPC)**

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Izvod

Kako bi se analizirale morfološke karakteristike lokalno uzgajanih kultivara pasulja iz Bosne i Hercegovine (BiH), ispitano je 13 kvantitativnih i kvalitativnih osobina na 40 *P. vulgaris* aksešna, koji su prethodno sakupljeni iz četiri geografske regije (Severozapadna BiH, Severoistočna BiH, Centralna BiH i Sarajevo), te se čuvaju u Gen banci Poljoprivredno-prehrambenog fakulteta u Sarajevu. Analiza glavnih komponenti je pokazala da su prve dve glavne komponente sadržavale 54.35% od ukupne varijance pokusa. Osobine koje su imale značajan udeo u ukupnoj varijabilnosti prve glavne komponente bile su širina semena, visina semena i masa semena, dok su u varijabilnosti druge glavne komponente najviše doprinosile osobine broj semenki u mahuni i dužina mahune. PCA grafikon, formiran na osnovu prve dve glavne komponente, ukazuje na visok stepen varijabilnosti ispitivanog materijala. Diskriminantna analiza glavnih komponenti (DAPC) je dala tri diskriminantne funkcije, pri čemu su prve dve sadržavale 90.40% sačuvane varijance. Na osnovu zadržanih DF, DAPC je omogućila i analizu verovatnoće članstva pojedinačnih uzoraka koja je pokazala da je 70% ispitivanih aksešna ispravno klasifikovano između geografski definisanih grupa. Zasnovano na taksonomskoj distanci, 40 ispitivanih aksešna pasulja su kreirale dva glavna klastera, s tim da aksešni Acc304 i Acc307 nisu grupisane niti u jedan od njih. Uzorci Acc360 i Acc362, kao i Acc324 i Acc371 su pokazali visok stepen sličnosti, što ukazuje na činjenicu da se verovatno radi o istim kultivarima. Diverzitet prisutan kod bosanskohercegovačkih kultivara pasulja može biti od koristi u budućim oplemenjivačkim programima.

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