Vol. 10(11), pp. 304-318, November 2018
DOI: 10.5897/JPBCS2018.0766
Article Number: FB9DCBE58905
ISSN: 2006-9758

http://www.academicjournals.org/JPBCS

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Journal of Plant Breeding and Crop Science

Full Length Research Paper

Morphological characterization of common bean (*Phaseolus vulgaris* L.) landraces of Central region of Benin Republic

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Received 7 August, 2018; Accepted 6 September, 2018

Common bean (*Phaseolus vulgaris* L.) is an important food consumed in every region in Republic of Benin; however, it remains a neglected and under-utilized crop. In order to assess the value of bean germplasm of the central region in the Republic of Benin for useful breeding programs, 57 accessions were collected from 23 villages. After a classification based on the morphological variables of the seeds, these accessions were evaluated using 30 morphological traits (18 qualitative and 12 quantitative) following the IBPGR descriptors in experimental field at Faculty of Sciences and Technology of Dassa. Based on the seeds morphological variability, the accessions have been grouped in 8 morphotypes. However, 9 morphological types were obtained with cluster analysis based on UPGMA classification method using qualitative variables, whereas in Principal Component Analysis (PCA) they were gathered into 4 clusters using quantitative variables. The accessions in cluster 1 (11 accessions) were identified as possessing the highest values in quantitative traits like days to maturity, and number of pods per plant. While accessions in cluster 2 (3 accessions) have had the lowest number of days to flowering and the highest pods length, the accessions of cluster 3 (23 accessions) presented the highest 100-seed weight. Correlation coefficient of 100-seed weight was positively significant ($p \leq 0.001$) with leaf length, pod width, and seeds length while it was negatively correlated ($p \leq 0.05$) with days to flowering, pod length and the number of seeds per pod. Cluster 3 accessions may serve as useful genetic material in future, for any breeding programmes to improve the productivity of other common bean accessions through hybridization.

Key words: Common bean, cluster analysis, diversity, landraces, qualitative traits, quantitative traits.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the most cultivated and consumed legume throughout the world (Blair et al., 2009; Coelho et al., 2009). This legume is an annual and self-pollinated crop (Ferreira et al., 2000), which intensely grows throughout the whole tropical area and some temperate regions of the planet (Coelho et al., 2009; Hegay et al., 2012). It is widely cultivated in the tropics for its green edible leaves and green pods consumed as vegetables, and dried seeds harvested at maturity (De Luque et al., 2014). Common bean is an important food and source of dietary minerals that potentially provide all the 15 essential minerals (Welch et al., 2000), and daily protein requirements for humans (Broughton et al., 2003; Ulukapi and Onus, 2014). This legume is presumed as one of the basic components of African food, mostly in form of grain (Bode et al., 2013).

In the Republic of Benin, beans are important staple, but its production has declined since 2008 from 143,625 T to 95,794 T in 2014 (Food and Agricultural Organization [FAO], 2014). This decline in production can be explained by several biotic and abiotic stresses that affect the crop during its cultivation and storage (Beebe et al., 2013; Hinkossa et al., 2013; Yaqoob et al., 2013; De Luque et al., 2014; Asfaw and Blair, 2014; Polania et al., 2016). Moreover, these biotic and abiotic stresses lead to the disappearance of common bean landraces and their genetic erosion in Central region of Benin Republic (Missihoun et al., 2017). The preservation and efficient utilisation of existing common bean landraces in this region of Benin Republic requires detailed knowledge of their genetic variability such as agro-morphological characteristics. In addition, to increase farmers' production and productivity of this legume, the development of cultivars with improved resistance to biotic and abiotic stresses is necessary (Miklas et al., 2006; Doumbia et al., 2013). Unfortunately, there are no reported studies on collection and characterisation of these common bean genetic resources in the central region of Benin Republic. Consequently, there is a need to collect, and characterise common bean populations in this region before they disappear for an efficient conservation and to guide breeding programs.

Common bean is known for its adaptability to different environments, creating a wide range of landraces (Bitocchi et al., 2012). An important varietal diversity would be thus managed by farmers. To be useful for plant breeders, genetic resources must be characterised by morphological and agronomic traits (Martins et al., 2006; Stoilova et al., 2013). In fact, morphological characterization allows clarification of some problems of synonymies that exist in local denomination of landraces and permits knowing the correlations between agronomic performances for breeding programmes (Balkaya and Karagac, 2005; Balkaya et al., 2010; Karaagac and Balkaya, 2013). The characterization of accessions also allows quantification and structuring of the genetic variability in the germplasm (Bode et al., 2013). The objective of this study is to assess the morphological diversity and agronomic performances of common bean landraces of the central region in the Republic of Benin which is highly important for breeding programmes, for the conservation and the preservation of this genetic resource.

MATERIALS AND METHODS

Plant material and study location

Fifty-seven common bean accessions were collected from 23 villages in the central region of the country (Figure 1 and Table 1). A trial was conducted under open field conditions at the experimental site of Faculty of Sciences and Technology of Dassa. The region is characterized by 4 seasons including two rainy seasons and two dry seasons with an annual rainfall ranging from 900 to 1100 mm (Akoègninou et al., 2006). The temperature varies from 24 to 29°C with an average of 27°C (Yabi and Afouda, 2012).

Morpho-agronomic characterisation

The 57 common bean accessions were firstly classified using visual technique following Mohammed et al. (2016) based on seed's morphological description characteristics (coat colour, size, coat pattern and hilum colour). The agro-morphological characterization was conducted at the experimental site of the Faculty of Sciences and Techniques of Dassa, during the common bean cropping season of 2016 to 2017. The experimental design was a randomised complete block with five replicates. Each experimental unit consists of 4 rows measuring 4 m in length. The distance between rows of common beans was 1 m with 0.8 m between plants in the row using traditional farmers' production management in the study area. Three seeds were put in each hole, and 15 days after germination, seedlings were removed to leave only one seedling per hole. Weeds were removed manually from experimental plots. All accessions were assigned to creeping plants, staked and trained to climb the stakes (Rana et al., 2015). The descriptors used included eighteen (18) qualitative and twelve (12) quantitative variables (Table 2) among those recommended by IBPGR (1982). All of the observations were made according to the methods of IBPGR (1982).

Statistical analyses

Qualitative data were used to build a dendrogram with UPGMA (unweighted pair group method with arithmetic average) algorithm (Sneath and Sokal, 1973) using the sequential agglomerative hierarchical nested clustering (SAHN) of the NTSYS-pc software (Rohlf, 2000). Quantitative data were analysed by descriptive statistics with Minitab 17.1.0 software to determine the mean, minimum, maximum, standard deviation, and coefficient of variation. To measure the degree of association between pairs of quantitative variables, Pearson correlation coefficient was calculated using Minitab 17.1.0 software. Principal Component Analysis (PCA) was also performed with Minitab 17.1.0 software to project on the axis the analysed accessions. For quantitative morphological traits, an analysis of variance (ANOVA) was performed with the aid of SPSS software Version 17.0. Significant differences between means were separated using Student Newman Keuls test ($p < 0.05$).

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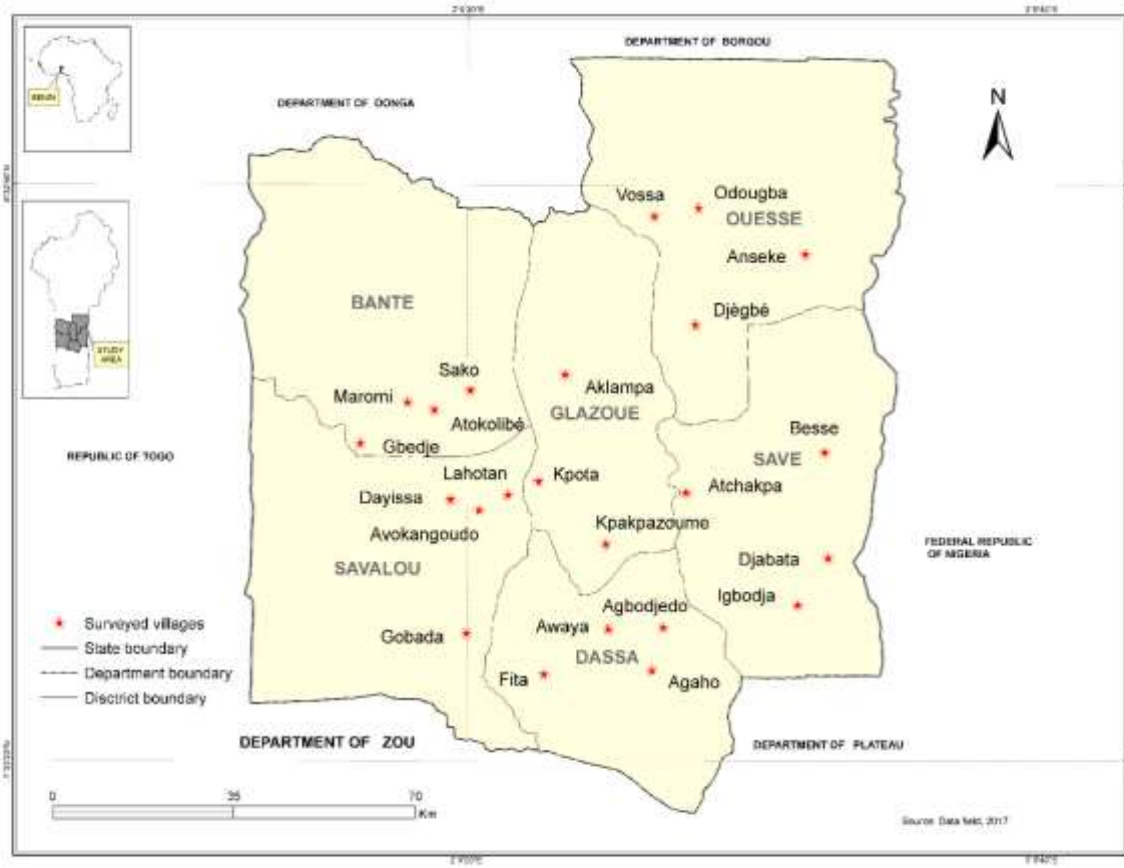

Figure 1. Map of central region of Benin Republic showing the villages of common bean sampling.

Table 1. List of the 57 studied common bean accessions, their code, corresponding prospected village and sociolinguistic group where accession was collected.

S/N	Accession name	Codes	Villages	Sociolinguistic groups
1	Akpakoun doudou	Akp29	Igboja	Tchabè
2	Akpakoun kpikpa	Akp17	Aklampa	Mahi
3	Akpakoun kpikpa	Akp22	Igboja	Tchabè
4	Akpakoun sonhouékan	Akp43	Anssèkè	Tchabè
5	Akpakoun vovo	Akp1	Agao	Idaatcha
6	akpakoun vovo	Akp18	Doyissa	Mahi
7	akpakoun vovo	Akp23	Gobada	Mahi
8	akpakoun vovo	Akp24	Kpota	Mahi
9	Akpakoun wéwé	Akp49	Djègbé	Fon
10	Akpakoun wéwé	Akp8	Djègbé	Fon
11	Akpakoun wéwé	Akp12	Igboja	Tchabè
12	Akpakoun wéwé	Akp13	Odougba	Fon
13	Akpakoun wéwé	Akp14	Vossa	Mahi
14	Akpakoun wéwé kpevi	Akp7	Agbodjedo	Mahi
15	Akpakoun wéwé kpevi	Akp11	Lahotan	Mahi
16	Akpakoun Winiwini	Akp38	Djègbé	Fon
17	Akpakoun Winiwini	Akp40	Odougba	Fon
18	Akpakoun wiwi	Akp30	Agao	Idaatcha
19	Akpalakoun	Akp44	Sako	Nago

Table 1. Contd.

20	Akpalakoun founfou	Akp50	Fita	Idaatcha
21	Akpalakoun founfou	Akp53	Malomi	Ifè
22	Akpalakoun founfou	Akp54	Malomi	Ifè
23	Akpalakoun wéwé	Akp9	Atokolibé	Ifè
24	Alawoaho	Akp2	Bessé	Tchabè
25	Alawoaho	Akp6	Bessé	Tchabè
26	Dawo	Akp31	Igboja	Tchabè
27	Djihikouin	Akp39	Vossa	Mahi
28	Djihikouin	Akp41	Vossa	Mahi
29	Djihikouin	Akp42	Vossa	Mahi
30	Ewaarigui	Akp32	Sako	Nago
31	Ewoudjè	Akp45	Djabata	Tchabè
32	Ibè	Akp55	Atchakpa	Idaatcha
33	Kpalagui	Akp33	Atokolibé	Ifè
34	Kpalakoun founfoun	Akp56	Atokolibé	Ifè
35	Kpalakoun	Akp34	Fita	Idaatcha
36	Kpalakoun	Akp35	Agbodjedo	Mahi
37	kpalakoun	Akp19	Anssèkè	Tchabè
38	kpalakoun	Akp25	Kpakpa-Zoume	Mahi
39	kpalakoun	Akp27	Lahotan	Mahi
40	kpalakoun	Akp28	Agao	Idaatcha
41	kpalakoun kpikpa	Akp20	Anssèkè	Tchabè
42	kpalakoun kpikpa	Akp21	Atchakpa	Idaatcha
43	kpalakoun kpikpa	Akp26	Kpakpa-Zoume	Mahi
44	kpankoui	Akp46	Anssèkè	Tchabè
45	Kpankoui vovo	Akp3	Awaya	Fon
46	Kpankoui vovo	Akp4	Anssèkè	Tchabè
47	Kpankoui vovo	Akp5	Avokangoudo	Fon
48	Kpankoui wéwé	Akp51	Odougba	Fon
49	Kpankoui wéwé	Akp52	Anssèkè	Tchabè
50	Kpankoui wiwi	Akp36	Igboja	Tchabè
51	Kpokpodo	Akp37	Djègbé	Fon
52	Mitoyikou	Akp10	Djègbé	Fon
53	Mitoyikou	Akp15	Djègbé	Fon
54	Mitoyikou	Akp16	Djègbé	Fon
55	Sèkpavikoun	Akp47	Vossa	Mahi
56	Sesse	Akp57	Gbedjé	Nago
57	Sonouhoué	Akp48	Anssèkè	Tchabè

Table 2. Morphological and phenological characters observed and their abbreviation.

No.	Character	Abbreviation
	Qualitative data	
1	Hypocotyl colour	HC
2	Cotyledon Colour	CC
3	Stem pigmentation	SP
4	Stem colour	StC
5	Leaf shape	LS
6	Leaf colour	LC
7	Corolla colour	CoC
8	Calyx colour	CxC

Table 2. Contd.

9	Pod curvature	PC
10	Pod beak position	PBP
11	Pods Colour at maturity stage	PCM
12	Pod colour at harvest stage	PCH
13	Seed coat pattern	US
14	Seed coat colour	SdC
15	Presence of colour around of hilum	HiC
16	Brilliance of seed	BS
17	Seeds shape	SS
18	Plant growth	PG
	Quantitative data	
19	Days to flowering	DF
20	Days to maturity	DM
21	Days to harvest	DH
22	Leaves length	LvL
23	leaves width	LW
24	Number of pods per plant	NPP
25	Pods length	PL
26	Pods width	PW
27	Number of seeds per pod	NSP
28	Seeds length	SL
29	Seeds width	SW
30	Weight of 100 seeds	W100S

RESULTS

Distribution of phenotypic characters

The 57 common bean accessions were classified in eight morphotypes according to the seed morphological description characteristics (Figure 2). The characteristics corresponding to the eight morphotypes were presented in Table 3. The analysis of qualitative data has shown that five traits (hypocotyl colour (purple), cotyledon colour (green), calyx colour (green), pods colour at harvest stage (cream), and plant growth (determinate climbing)) were not polymorphic, while the remaining showed a considerable level of variation (Table 4). Various seed's colours were found with the brown (28.1% of accessions) and red (21.1% of accessions) seed's coat colour as the most dominant (Table 4). A total of 63.2% of the germplasm had no seed coat pattern. Most accessions had cuboid seed shape (47.4%), medium brilliance (84.2%), and presence of colour around hilum (63.2%). A greater proportion of common bean accessions had green stem with purple pigmentation (64.9%), oval leaves shape (94.7%), green leaves colour (49.1%), white corolla colour (66.7%), slightly curved pod curvature (89.5%), non-marginal pod beak position (94.7%), and green pod with yellow pigmentation at physiological maturity stage (61.4%) (Table 4).

Morphological diversity

Cluster analysis based on morphological qualitative traits grouped the 57 accessions into 9 morphological types (Figure 3):

1) The first one (M1: 6 accessions) is characterized by low pigmentation of stem which have green colour with purple pigmentation, oval and green leaves, corolla coloured in white with carmine stripes, slightly curved pods, non-marginal pod beak position, pods having a green with yellow pigmentation at physiological maturity stage, mottled seeds coat pattern, cream seeds coat colour, presence of colour around hilum of seeds, medium brilliance, and oval seeds.

2 The second morphological type (M2: 7 accessions) was different from the first one by stem having pigmentations at the top and bottom of petiole, pods having a yellow pigmentation at physiological maturity stage, absence of mottle in seeds coat, white colour of seeds coat, cuboid shape of seeds, and slightly curved pods.

3) The characteristics of the third morphological type (M3: 3 accessions) are similar to those of the second morphological type (M2) except the curved pods.

4) The fourth morphological type (M4: 12 accessions) is characterized by green with pink pigmentation colour of leaves, white colour of corolla, red colour of seeds coat,

Group 1:
Seed coat pattern: Absent
Seed coat colour: cream
Presence of hilum colour: absent
Size: intermediate

Group 2:
Seed coat pattern: Absent
Seed coat colour: brown
Presence of hilum colour: present
Size: small

Group 3:
Seed coat pattern: Absent
Seed coat colour: cream
Presence of hilum colour: present
Size: small

Group 4:
Seed coat pattern: Absent
Seed coat colour: cream
Presence of hilum colour: absent
Size: too small

Group 5:
Seed coat pattern: mottled
Seed coat colour: brown
Presence of hilum colour: present
Size: intermediate

Group 6:
Seed coat pattern: Mottled
Seed coat colour: cream
Presence of hilum colour: present
Size: high

Group 7:
Seed coat pattern: Absent
Seed coat colour: red
Presence of hilum colour: absent
Size: small

Group 8:
Seed coat pattern: mottled
Seed coat colour: cream
Presence of hilum colour: present
Size: small

Figure 2. Different groups obtained from seeds classification.

Table 3. Accessions corresponding of each group obtained based on morphological description of seeds collected.

Group	Number of accessions	Accessions of each group
G1	6	Akp49; Akp50; Akp51; Akp52; Akp53; Akp54
G2	10	Akp7; Akp8; Akp9; Akp10; Akp11; Akp12; Akp13; Akp14; Akp15; Akp16
G3	5	Akp38; Akp39; Akp40; Akp41; Akp42
G4	3	Akp55; Akp56; Akp57
G5	6	Akp43; Akp44; Akp45; Akp46; Akp47; Akp48
G6	9	Akp29; Akp30; Akp31; Akp32; Akp33; Akp34; Akp35; Akp36; Akp37
G7	12	Akp17; Akp18; Akp19; Akp20; Akp21; Akp22; Akp23; Akp24; Akp25; Akp26; Akp27; Akp28
G8	6	Akp1; Akp2; Akp3; Akp4; Akp5; Akp6

Table 4. Distribution of 57 common bean accessions for 17 qualitative morphological traits.

Variable	Observations	Number of accessions
Stem pigmentation	Absent	17
	Low	18
	At the top and bottom of petiole	10
	Average	9
	Important	3
Stem colour	Green	17
	Green with pink pigmentation	3
	Green with purple pigmentation	37
Leaf shape	Oval	54
	Triangular	3
Leaf colour	Green	28
	Medium green	26
	Dark green	3
Corolla colour	White	38
	White with carmine stripes	19
Pod curvature	Straight	3
	Slightly curved	51
	Curved	3
Pod beak position	Marginal	3
	Non-marginal	54
Pod colour at physiological maturity stage	Green with yellow pigmentation	35
	Yellow	22
Seed coat pattern	Absent	36
	Mottled	21
Seed coat colour	Brown	16
	Cream	6
	Marron	6
	Red	12
	Purple	9
	Black	8
Presence of colour around of hilum	Present	36
	Absent	21
Brilliance of seeds	Medium	48
	Shiny	9
Seed shape	Oval	9
	Cuboid	27
	Kidney shaped	12
	Markedly truncate	9

Table 4. Contd.

Hypocotyl colour	Purple	57
Cotyledon colour	Green	57
Calyx colour	Green	57
Pods colour at harvest stage	Cream	57
Plant growth	Determinate climbing	57

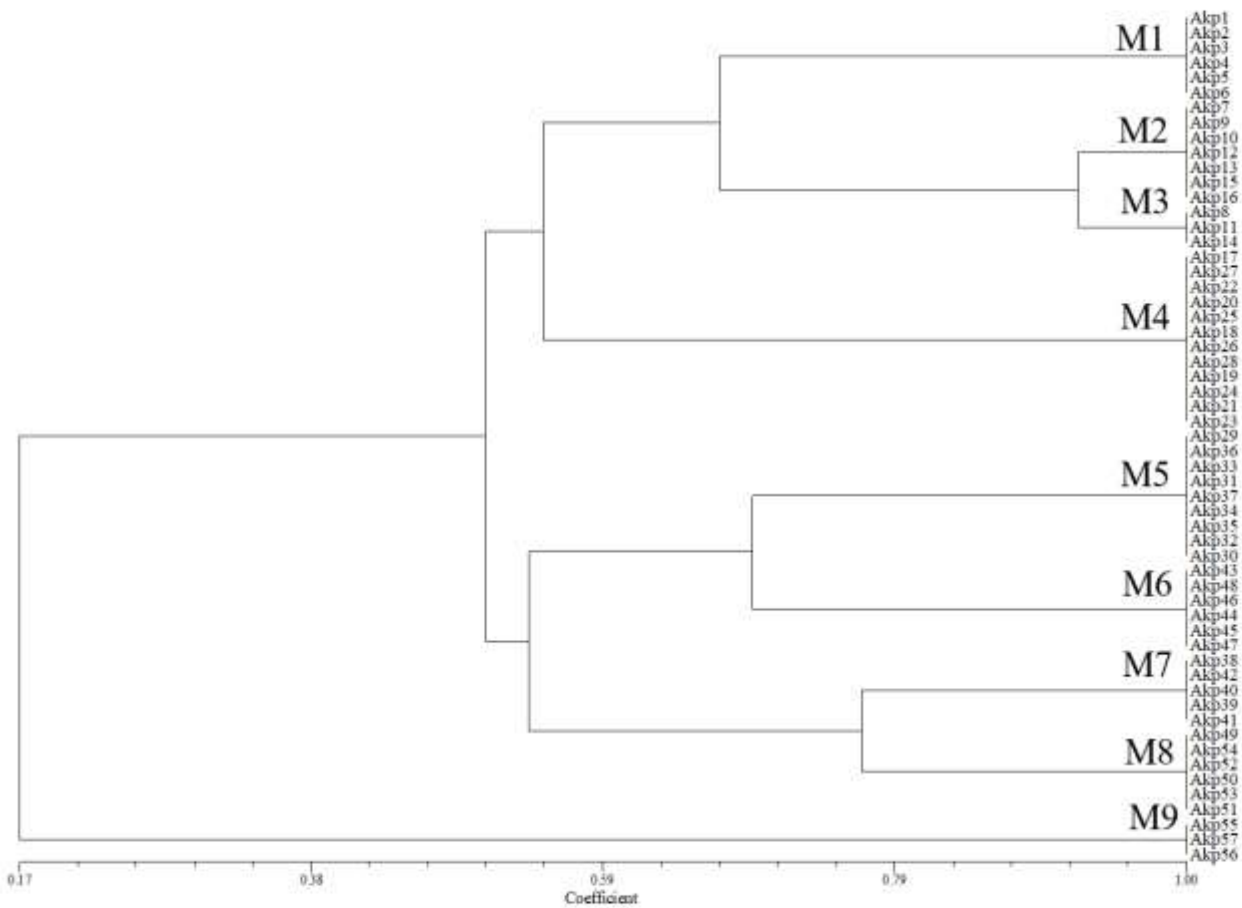

Figure 3. Dendrogram showing different morphological types of common bean in central Benin.

and presence of colour around seeds of hilum.

5) The fifth morphological type (M5: 9 accessions) have an average pigmentation of stem, pods having a green with yellow pigmentation at physiological maturity stage, mottled seeds coat, purple colour of seeds coat, absence of colour around seeds of hilum, and markedly truncated shape of seeds.

6) The sixth morphological type (M6: 5 accessions) is characterized by the absence of stem's pigmentation, green colour of stem, green leaves, absence of mottle on seeds coat, cream colour of seeds coat, and cuboid seeds.

7) The characteristics of the seventh morphological type (M7: 6 accessions) are mottled seeds coat, chestnut colour of seeds' coat, and kidney shape of seeds.

8) The eighth morphological type (M8: 6 accessions) is characterized by a medium green colour of leaves, absence of mottle on seed's coat, absence of colour around hilum seeds, and shiny brilliance of seeds.

9) The ninth morphological type (M9: 3 accessions) is characterized by an important pigmentation of the stem, green with pink pigmentation of stem, triangular shape of the leaves, dark green colour of leaves, corolla having white colour with carmine stripes, straight curvature of

Table 5. Variation in quantitative traits among the 57 common beans accessions.

Variable	Mean	Min	Max	Var	StDev	CoefVar
DF	79.44 ± 1.23	60.33	101.33	86.02	9.27	11.67
DM	108.81 ± 1.27	88.67	128.33	92.53	9.62	8.84
DH	118.27 ± 1.07	102.00	132.00	65.12	8.07	6.82
LvL	9.57 ± 0.1	7.50	11.35	0.63	0.79	8.27
LW	6.57 ± 0.14	3.25	8.63	1.17	1.08	16.47
NPP	35.96 ± 1.85	12.67	66.33	194.82	13.96	38.82
PL	7.65 ± 0.57	5.50	26.67	18.38	4.29	56.01
PW	1.61 ± 0.02	1.13	1.90	0.02	0.15	9.59
NSP	2.69 ± 0.28	1.33	13.00	4.54	2.13	79.23
SL	1.05 ± 0.03	0.60	1.60	0.04	0.20	18.52
SW	0.62 ± 0.01	0.31	0.73	0.01	0.09	14.36
W100S	39.25 ± 1.04	4.00	51.00	61.55	7.85	19.99

Min: Minimal; Max: maximal; Var: variance; DevSt: standard deviation; CoefV: coefficient of variation; DF: days to flowering; DM: days to maturity; DH: days to harvest; LvL: leaves length; LW: leaves width; NPP: number of pods per plant; PL: pods length; PW: pods width; NSP: number of seeds per pod; SL: seeds length; SW: seeds width; W100S: weight of 100 seeds.

pods, marginal beak position of pods, purple colour of the seeds' coat, and oval seeds.

Quantitative variations

The mean, maximum, minimum, standard deviation and coefficient of variation of each of the 12 quantitative measured variables are presented in Table 5. The results indicated that variability among the accessions was significant (p=0.000) for the twelve traits. The results show that the variables such as the number of seeds per pod, the length of pods, and the number of pods per plant have the highest coefficient of variation (Table 5). According to results, days to flowering ranged from 60.3 (Akp38) to 101.3 days (Akp56) with a mean of 79.4 days and a standard deviation of 9.2. Mean days until physiological maturity was 108.81 and days to harvest were 118.27. The length of the leaves ranged from 7.50 (Akp20) to 11.35 cm (Akp55), with an average of 9.57 and a variation coefficient of 8.27%. Regarding the pods width, the range was 1.13 (Akp56) to 1.90 cm (Akp33), with an average of 1.61 cm and a variation coefficient of 9.59%. The length of the pods varied from 5.50 (Akp54) to 26.67 cm (Akp55) with an average of 7.65 cm. The length of the seeds varied from 0.60 (Akp57) to 1.60 cm (Akp8, Akp10 and Akp13) while seeds width ranged from 0.31 (Akp55, Akp56 and Akp57) to 0.73 cm (Akp9 and Akp14) with an average of 0.62 cm. The weight of 100 seeds ranged from 4 (Akp36) to 51 g (Akp14) with a mean number of seeds per pod of 2.69.

Phenotypic trait correlations

Correlation coefficients among traits are shown in Table 6. Indeed, the days to flowering (DF) was positively correlated with days to maturity (DM) (r = 0.894***), days to harvest (DH) (r = 0.890***), the length of pods (PL) (r = 0.503***), and the number of seeds per pod (NSP) (r = 0.518***); whereas, the days to flowering (DF) was negatively correlated with the width of leaves (LW) (r = -0.370**), the number of pods per plant (NPP) (r = -0.683***), the length seeds (SL) (r = -0.505***), the width of seeds (SW) (r = -0.679***), and the weight of 100 seeds (W100S) (r = -0.411***). The pods width was positively correlated with seeds length (SL) (r = 0.569***), seeds width (SW) (r = 0.652***), weight of 100 seeds (W100S) (r = 0.283*), leaves length (LvL) (r = 0.272*), and leaves width (LW) (r = 0.789***). However, the pods width was negatively correlated with the number of seed per pod (NSP) (r = -0.562***), and pods length (PL) (r = -0.534***). The weight of 100 seeds has a positive correlation with leaves width (LW) (r = 0.271*), pods width (PW) (r = 0.283*), seeds length (SL) (r = 0.549***), and seeds width (SW) (r = 0.627***), while it is negatively correlated with the days to flowering (DF) (r = -0.411***), pods length (PL) (r = -0.505***), and number of seeds per pod (NSP) (r = -0.487***).

Principal component analysis (PCA)

PCA showed that only the first three axes had an Eigen value higher than 1 and represent about 80% of total variability or dispersion (Table 7). Thus, most of the data structure can be captured in these dimensions. The remaining principal components account for a very small proportion of the variability and are probably less important. This has been confirmed by the fact that all measured variables are in correlation with these three axes. Indeed, except leaves length variable, the other

Table 6. Correlation coefficients among 12 morphological quantitative traits in 57 common beans accessions of central Benin.

Variable	DF	DM	DH	LvL	LW	NPP	PL	PW	NSP	SL	SW	W100S
DF	1.00											
DM	0.89***	1.00										
DH	0.89***	0.95***	1.00									
LvL	-0.08^{ns}	-0.03^{ns}	-0.06ns	1.00								
LW	-0.37**	-0.24^{ns}	-0.22ns	0.49***	1.00							
NPP	-0.68***	-0.71***	-0.68***	-0.02^{ns}	0.30*	1.00						
PL	0.50***	0.46***	0.38**	0.14^{ns}	-0.54***	-0.35**	1.00					
PW	-0.18^{ns}	-0.09^{ns}	-0.04^{ns}	0.27*	0.79***	0.07^{ns}	-0.53***	1.00				
NSP	0.52***	0.47***	0.41**	0.12^{ns}	-0.59***	-0.37**	0.98***	-0.56***	1.00			
SL	-0.50***	-0.26*	-0.30*	0.17^{ns}	0.56***	0.35**	-0.45***	0.57***	-0.47***	1.00		
SW	-0.68***	-0.47***	-0.45***	0.09^{ns}	0.67***	0.46***	-0.76***	0.65***	-0.76***	0.80***	1.00	
W100S	-0.41***	-0.19^{ns}	-0.18^{ns}	0.04^{ns}	0.27*	0.15^{ns}	-0.50***	0.28*	-0.49***	0.55***	0.63***	1.00

DF: Days to flowering; DM: days to maturity; DH: days to harvest; LvL: leaves length; LW: leaves width; NPP: number of pods per plant; PL: pods length; PW: pods width; NSP: number of seeds per pod; SL: seeds length; SW: seeds width; W100S: weight of 100 seeds. Significant correlations at *p < 0.05, **p < 0.01, ***p < 0.001; ns: not significant.

Table 7. Eigen values, correlations between variables and the first three factorial axes.

Variable	PC1	PC2	PC3
DF	-0.34**	0.30**	0.10
DM	-0.29**	0.42**	0.10
DH	-0.28**	0.43**	0.15
LvL	0.05	0.19	-0.74**
LW	0.29**	0.32**	-0.31**
NPP	0.26**	-0.34**	-0.11
PL	-0.33**	-0.11	-0.36**
PW	0.24**	0.43**	-0.11
NSP	-0.34**	-0.12	-0.32**
SL	0.30**	0.20	-0.07
SW	0.38**	0.15	0.07
W100S	0.23**	0.16	0.24**
Eigen value	5.97	2.28	1.38
Proportion (%)	50	19	11
Cumulative proportion (%)	50	69	80

PC: Principal component; DF: days to flowering; DM: days to maturity; DH: days to harvest; LvL: leaves length; LW: leaves width; NPP: number of pods per plant; PL: pods length; PW: pods width; NSP: number of seeds per pod; SL: seeds length; SW: seeds width; W100S: weight of 100 seeds. **Indicate the correlative values.

eleven variables are in correlation with the first axis (LW, NPP, PW, SL, SW and W100S are positively correlated while DF, DM, DH, PL and NSP are negatively correlated) because the correlation of each of them is not close to zero (higher than 0.2). Leaves length variable has negative correlation with the third axis. Six variables (DF, DM, DH, NPP and PW) are simultaneously in correlation with the first and second axis while three variables (PL, NSP and W100S) are in correlation with the first and third axis. No variable is simultaneously in correlation with the second and the third axis but one variable (LW) is in correlation with the three axes alone. This analysis of the principal component showed that all variables are important for spatial representation of accessions study.

The correlation of the variables about the first and the second axis (loading plot) is as shown in Figure 4. Furthermore, observing the loading plot and the score

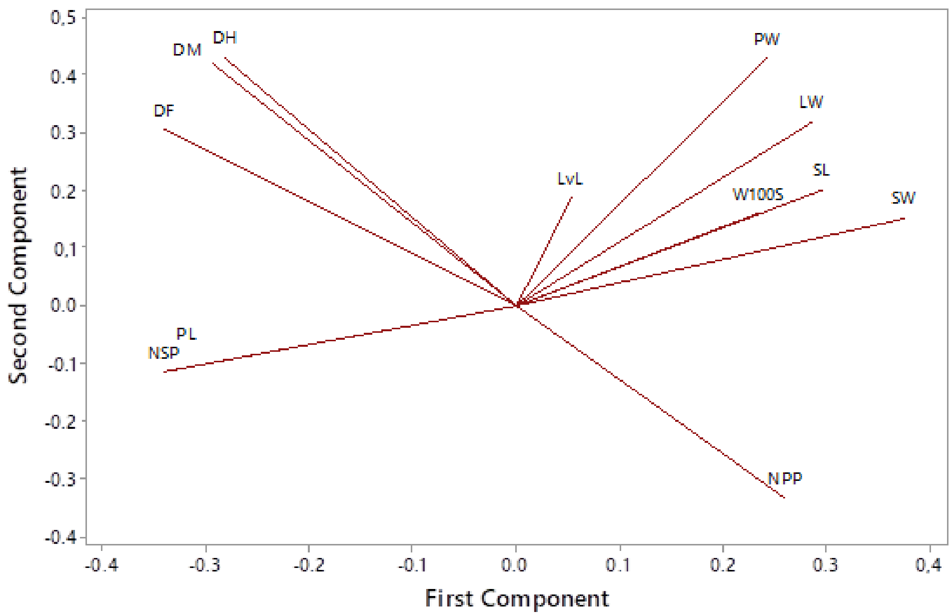

Figure 4. Graphic representation of contribution of each variable to the contribution of the first and second component (axes 1 and 2).

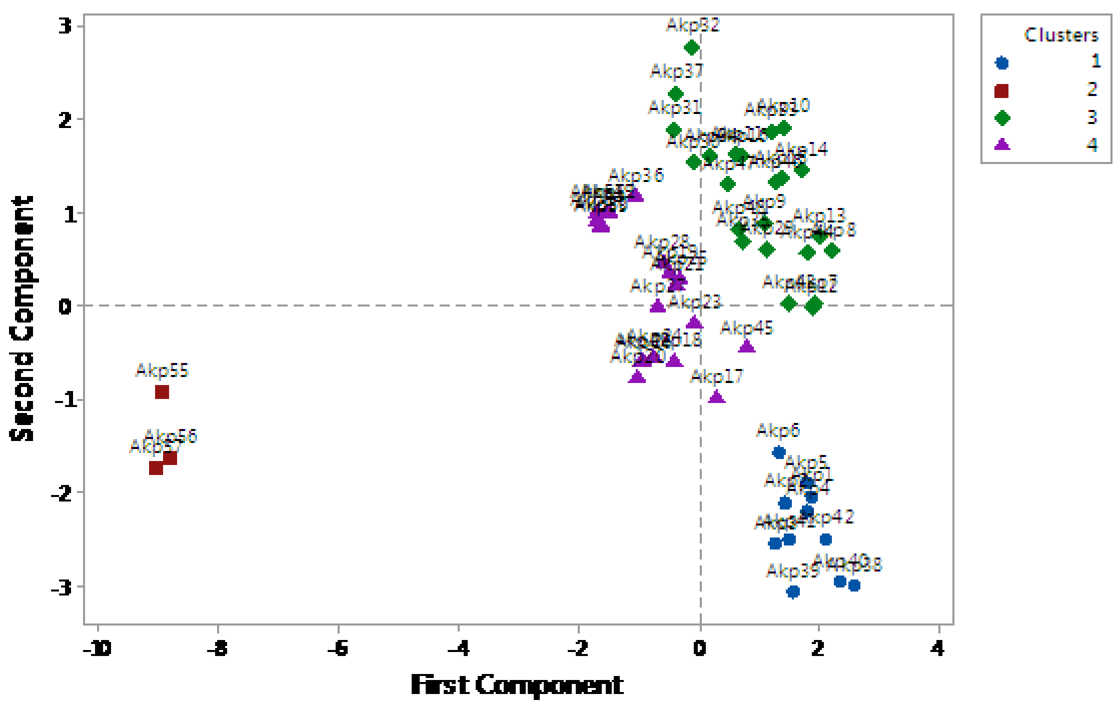

Figure 5. Two-dimension plot of Principal Component Analysis (PCA) clustering based on morphological similarity of 57 common accessions collected in central Benin.

plot obtained from principal component analysis, the studied accessions have been grouped in 4 clusters (Figure 5). The first one (11 accessions) is characterized by a high length of pods, number of seeds per pod, days to flowering, days to maturity and days to harvest while it is represented by low pods width, leaves width, seeds

Table 8. Comparison of the means of each variable between the four clusters using ANOVA and Student Newman Keuls tests.

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4
DF	66.33±1.43^{a}	100.67±0.33^{d}	78.62±1.01^{b}	84.41±0.81^{c}
DM	93.73±1.18^{a}	127.89±0.29^{c}	110.58±1.20^{b}	112.22±1.03^{b}
DH	105.88±1.13^{a}	131.89± 0.11^{c}	119.41±1.17^{b}	121.75±0.88^{b}
LvL	9.32±0.22^{b}	9.75± 0.97^{a}	10.00±0.11^{c}	9.18±0.15^{b}
LW	6.45±0.22^{b}	3.67± 0.41^{a}	7.37±0.11^{c}	6.14±0.15^{b}
NPP	54.06±3.17^{c}	14.11± 1.44^{a}	34.67±1.75^{b}	30.77±2.63^{b}
PL	6.50±0.10^{b}	25.44±0.62^{d}	7.29±0.04^{c}	6.03±0.11^{a}
PW	1.53±0.04^{b}	1.20±0.04^{a}	1.74±0.01^{c}	1.56±0.02^{b}
NSP	2.06±0.10^{a}	11.44±0.87^{b}	2.38±0.08^{a}	2.08±0.06^{a}
SL	1.05±0.02^{b}	0.61±0.00^{a}	1.20±0.04^{c}	0.95±0.02^{b}
SW	0.64±0.00^{c}	0.30±0.00^{a}	0.67±0.01^{c}	0.59±0.00^{b}
W100S	39.00±1.57^{b}	22.00±0.00^{a}	43.43±0.94^{b}	37.15±1.88^{b}

Means within rows followed by the same lower-case letter are not significantly different ($p \geq 0.05$); DF: Days to flowering; DM: days to maturity; DH: days to harvest; LvL: leaves length; LW: leaves width; NPP: number of pods per plant; PL: pods length; PW: pods width; NSP: number of seeds per pod; SL: seeds length; SW: seeds width; W100S: weight of 100 seeds.

length, weight of 100 seeds, seeds width and number of pods per plant. The second cluster (3 accessions) contains accessions that have opposite performances to the first cluster. It is characterised by a high pods width, leaves width, seeds length, weight of 100 seeds, seeds width, and number of pods per plant while the pods length, number of seeds per pod, days to flowering, days to maturity and days to harvest are very low. The third and fourth clusters (23 and 20 accessions respectively) seem to belong to the same cluster because both clusters are located near the origin of the first axis; thus, they present variables that the values are closed to the means. However, the days to flowering, days to maturity and days to harvest of the third cluster are lower than the ones of the fourth cluster. The values of the pods width, leaves width, seeds length, weight of 100 seeds, and seeds width of the third cluster are on the other hand, higher than the ones of the fourth cluster.

The comparison of the means of each variable using ANOVA enabled confirmation that the four clusters are significantly different ($p \leq 0.001$). Therefore, the characteristics and accessions of each cluster are respectively presented in Table 8. This analysis showed that accessions of the Clusters 1, 3 and 4 have a high performance of weight for 100 seeds (W100S). But regarding the precocity of landraces, accessions of Cluster 1 have the best productivity.

Comparing the four clusters coming from the quantitative data analysis with the ones from the qualitative data analysis, we have notified that: Cluster 1 gathers the morphological types M1 and M7, Cluster 2 is the same with morphological type M9, Cluster 3 contains morphological types M2, M3, M5 without Akp36 and M6 without Akp45, and Cluster 4 regroups the morphological types M4, M8, and accessions Akp36 of M5 and Akp45 of M6.

DISCUSSION

The results of this study showed that the common bean landraces collection of the central region of the Republic of Benin have a wide range of morphological and agronomic characteristics. The number of morphological types obtained from the studied accessions using the 17 qualitative variables (9 morphological types) was almost similar to the number of groups obtained only considering seed's morphological description characteristics (8 morphotypes). Showing the importance of seed's morphological characteristics as indicator of common bean diversity (Ulukapi and Onus, 2014), and to understand why folk nomenclature and taxonomy of this legume in central region of Benin Republic were mainly based on seeds' coat colour (Loko et al., 2018). Moreover, some studies showed that descriptors linked to seeds are the most discriminant traits of common beans (Hegay et al., 2013; Stoilova et al., 2013; Ulukapi and Onus, 2014), and considered as highly heritable traits, therefore important for breeding programmes (Kumar et al., 2014).

The accessions bearing brown-red colour and cuboid shape dominated in common bean collection of central region of Benin Republic. Similar observations on the dominance of these colour and shape in common bean collections have been recorded in other parts of the world (Meza et al., 2013; Saba et al., 2016). Knowing that the colour, shape and size of common bean seeds are of special attention for consumers (Stoilova et al., 2013), these dominant seeds characteristics could reflect farmers and consumers preferences. Thus, to orient breeders with the morphological type of common bean to be improved for adoption by farmers and consumers, the findings of Loko et al. (2018) suggested that selection based on common bean seed coat colour would have a definite role in the framework of on-farm conservation of this legume in central Benin.

The growth habit of all common bean accessions was climbing type. The predominance of this growth habit type is probably related to ecological adaptation as well as to the cropping system being followed in the study area (Rana et al., 2015). Indeed, Missihoun et al. (2017) observed that in central Benin, common bean production generally involves intercropping in the fields with other crops such as maize, cassava, pigeon pea or oil palm tree. Aware of the fact that the scarcity of suitable materials for stacking is the main constraint of bean production in Central region of Benin Republic (Missihoun et al., 2017), it is important to create semi-climbers varieties for reduction of this constraint. The hybridisation of climbing bean type found in central Benin by a bush bean type namely Houintakpakun found in southern Benin (Missihoun et al., 2017) is necessary for enlarging the genetic base for increasing levels of resistance to both biotic and abiotic stress factor affecting common bean production in this region.

The cluster analysis based on morphological qualitative traits showed a significant number of similarities between accessions which seem to attest the presence of duplicates. Duplication of common bean landraces in numerous collections throughout the world were often highlighted by several authors (Chiorato et al., 2006; Madakbas and Ergin, 2011; Akhshi et al., 2014; Rana et al., 2015). In fact, in central region of Benin Republic, folk nomenclature of common bean landraces varies from one socio-linguistic group to another, and several folk varieties could be attributed to a single landrace and many landraces could have a similar name (Loko et al., 2018). To detect and identify these duplicates in common bean collections, molecular analysis was recommended by several authors (Singh et al., 1991; Madakbas and Ergin, 2011; Meza et al., 2013; Rana et al., 2015).

Descriptive statistics of quantitative data reflected high level of variation among the 57 common bean accessions. These finding could reflect their genetic differences and provide a good material for breeders. The average days of flowering (79.44) and the days until physiological maturity (108.81) of common bean accessions of central Benin is higher than those obtained in similar studies of common beans (Garcia et al., 1997; Gomez et al., 2004; Stoilova et al., 2005; Meza et al., 2013; Ulukapi and Onus, 2014). These differences could be explained by the fact that these physiological traits are influenced by environmental conditions, mainly temperature and photoperiod length (Meza et al., 2013).

Different correlations existing among quantitative variables showed that it is possible to improve several performances from breeding one of them. In fact, strongly correlated traits are possibly under the influence of the same genes which during selection could be selected simultaneously based on one of the traits (Okii et al., 2014). The significant positive correlation of seed weight with leaves width (LW), pods width (PW), seeds length (SL), and seeds width (SW) indicated that these characters are efficient in yield determination. Similar findings were reported by Rana et al. (2015). However, seeds' weight was negatively correlated with days to flowering, pod length and number of seeds per pod. These findings are in certainty with Okii et al. (2014) and Rana et al. (2015) who found negative and significant correlations between days to flowering and number of seeds per pod, with grains yielded. That means the early maturity landraces have a good productivity. Similar results have been observed in Turkey (Madakbas and Ergin, 2011) and in Albania (Bode et al., 2013) but the correlative variables are not identical.

Quantitative analysis regrouped the studied accessions in 4 clusters which facilitates the selection of diverse parents for common beans breeding programs. The comparison of clusters showed that Cluster 1 and 3 contains the best accessions which must be recommended to the farmers in central region of Benin. However, these accessions have presented the highest number of pods per plant but pods length of these clusters is lower than general mean (7.65 cm). It is therefore very important to set up a breeding programme taking into account the accessions of these clusters and the ones of cluster 2 which have the longest pods (25.44 cm). Agronomic tests in other region of the country are also of great importance to compare the performances of these accessions collected in central Benin. Further studies in north and south Benin are recommended to collect and characterize all landraces cultivated in Benin.

Conclusion

This study points out the diversity and agronomic performances within common bean in the central region of Benin Republic. This characterization allowed us to group the landraces cultivated in this region in 8 morphotypes according to the seed traits. Regarding qualitative variables of IBPGR descriptors, the collected accessions have been classified in 9 morphotypes while the quantitative variables regrouped the accessions in 4 clusters. Common bean accessions of Cluster 1 and 3 have shown some good agronomical characteristics and could be recommended to farmers. However, breeding programs could be initiated to ameliorate some agronomic traits of common bean landraces of these clusters for the happiness of farmers and consumers. The difference between the number of clusters generated by qualitative variables on one hand and quantitative data on the other hand has revealed that environmental conditions influences morphological characterization.

Molecular characterization is thus important for evaluating common bean diversity cultivated in central Benin. The study should also be widened to other regions of the country.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to farmers who gave their common beans seeds for this study along with anonymous reviewers for their comments on previous versions of the manuscript.

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