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Phenotypic diversity of rice bean collection [*Vigna umbellata* (Thunb.) Ohwi et Ohashi] in Burkina Faso based on quantitative traits

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ABSTRACT

Ricebean (*Vigna umbellata*) is a multipurpose legume known for its richness in protein, minerals and vitamins. It is a plant used in soil protection and as green manure with nutritious fodder. Although very important, rice bean is a neglected and underutilized grain legume. In Burkina Faso, few studies have been carried out on this crop of interest. It is in this sense that this present study aimed at analysing the phenotypic diversity of the ricebean collection. The experiment was conducted at Farako-Bâ a research station in a randomized complete block design with three (3) replications. The accessions were evaluated on fifteen (15) quantitative variables. Analysis of variance revealed a highly significant difference ($P < 0.001$). The diversity analysis carried out with the quantitative traits revealed strong correlations between these traits. Principal component analysis (PCA) revealed 70.80% of total variability. Agglomerative Hierarchical Clustering (AHC) structured the accessions into four distinct groups, corroborated by discriminant factor analysis (DFA). Accessions R80, R85 distinguished themselves with both a short cycle and a better quantitative production of seeds and fodder. These early accessions, productive in seeds and fodder, could be exploited within the framework of future ricebean improvement programs.
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Keywords: Accessions, Phenotypic diversity, Ricebean, Burkina Faso.

INTRODUCTION

In sub-Saharan Africa, agriculture is the main source of income for almost all rural populations. It is a major sector of the economy requiring intensification and diversification (Eromosel et al., 2008). In Burkina Faso, the sector accounts for 35% of gross domestic product (GDP) and employs 82% of the working population (Barry, 2016).

Burkina Faso is increasingly experiencing the negative effects of climate change, which is having a major impact on food and nutritional security (Neya, 2019). The production landscape is currently witnessing low crop yields that have led to pronounced imbalances in food demand and supply. In a quest for sustainable solutions to food and nutrition insecurity, global agricultural research programmes are now shifting focus from staple or major crops towards orphan or under-utilized plant species in a quest of

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sustainable solutions to food and nutrition insecurities (Ndlovu, 2019).

Exploiting underutilized legumes to broaden the genetic resource base in agriculture is an urgent need given the current agricultural scenario. Crop diversification offers opportunities to introduce temporal and spatial heterogeneity in uniform cropping systems and will help build resilience to biotic and abiotic stresses (Dhillon and Tanwar, 2018). Underutilized legumes play an important role in such a scenario by providing better alternatives with high degrees of stress tolerance. Underutilized crops are a diverse set of minor crops that tend to be regionally important but not commercially exploited around the world and as such they have received little attention from research networks (Cullis and Kunert, 2017).

Ricebean is one of the underutilized legumes that has recently attracted attention due to its multipurpose utility and potential for maintaining sustainability, profitability and diversification of agriculture (Katoch, 2020). Rice beans, often grown on poor soils in East Asia, are used mainly as dried legumes or fodder (Tomooka, 2009). Rice bean have a good amino acid composition and are rich in several nutrients compared to other pulses.

An increase in rice bean consumption has been shown to result in less severe nutritional deficiencies in calcium, potassium, iron, lysine and certain B vitamins (Andersen and Chandyo, 2009). In addition to its value as a human food, rice bean is an important forage legume grown in a diverse climate for a variety of uses. Rice bean, as fodder in the vegetative stage, contain a large amount of protein (1419 percent) which is on a par with cowpea and black gram (Dash, 2013). It is a warm-season annual; a legume with a moderately short lifespan. It is grouped in the large genus Vigna, which also includes other legumes such as cowpea, Bambara groundnut and mung bean. In addition to producing high-quality, nutritious seeds (Yao et al., 2012), it is highly tolerant of drought and soil acidity (Fan et al., 2014), and is resistant to bruchids (Kashiwaba et al., 2003) and several diseases.

These characteristics make this species an important genetic resource for plant breeding in the face of frequent climatic extremes and the increased risk of pests and diseases. Although it has many uses compared to most crops, it is considered underutilised and its full potential has not yet been realised (Joshi et al., 2008). There is therefore a need to review the scope of research into the special traits of rice bean. In view of this interest, the government of Burkina Faso must take political measures to include the rice bean in strategic sectors for food and nutritional security. At present, the genetic diversity of the rice bean collection in INERA's germplasm has not been fully established. Thus objective of the present study was to explore and exploited the agromorphological diversity of the rice bean.

MATERIALS AND METHODS

Plant material

The experiment was established with twenty-four (24) rice bean accessions introduced into Burkina Faso. These accessions were taken from the germplasm of the CREAF/Kamboinsé plant genetics and biotechnology laboratory. The laboratory received the seeds from the partnership with Nelson Mandela African Institut of sciences and Technology (NM-AIST) Tanzanie with origin from the National Bureau of Plant Genetic Resources (NBPGR-India).

Study site

The study was conducted at National Institute for the Environment and agricultural research (INERA) station in Farako- Bâ. This station, is located on the national road (NR1) Bobo-Dioulasso–Banfora, and 15 km from Bobo-Dioulasso (11°07′00.0″N 4°25′00.0” W).

The annual rainfall of the study site ranged from 900 to 1200 mm/year, with a 5- to 6-month dry season (from November to April). For the 2021-2022 crop year, the average rainfall recorded from January to September was 1262.4 mm in 59 rainy days. Temperatures range from 17 to 37°C during the dry season and 10 to 32°C during the rainy season.

Soils are mostly tropical ferruginous with low nitrogen, phosphorus, and organic matter content, and require fertilizer application for better crop production (Nouhoun et al., 2021).

The vegetation in this region consists of trees and shrubs, savanna, wooded savanna, and gallery forests (Nouhoun et al., 2021).

Experimental design

The layout of the field was in Randomized Complete Block Design (RCBD) with 24 treatments as rice bean accessions and under three replication blocks. The spacing between the row and plant were 0.90 m and 0.40 m respectively. Individual plots are separated from each other by 1 meter and the repetitions by two (2) meters. Thus, the total area of the research plots was 161,5 m^2 (8,5 m x 19 m).

Crop management

The trial was conducted during the 2022 rainy season. The soil was ploughed with a tractor and harrowed with a daba for land preparation to set up the experiment. 3 to 4 seeds were planted per hole and two seedlings were left after thinning 14 days after planting.

Two weeks after planting, weeding was carried out and NPK fertiliser (15-15-15) was applied at a rate of 100 kg/ha. To reduce weed competition and aerate the soil better, another weeding operation (01) was carried out four weeks after planting and the rest on request. To protect the plants from insects and pests, a systemic insecticide K-Optimal (Lambda Cyhalothrin 15 g/L + Acetamiprid 20 g/L) at a rate of 1 L per hectare was applied. Two insecticide treatments were carried out, one at flower bud formation and the other at pod formation. The other treatments were applied as required. The systemic fungicide Azox (Azoxystrobin 250 g/l), a concentrated suspension at a dose of 40 ml/ha, was also used to protect the plants from prevalent fungal diseases

Data collection

Fifteen quantitative variables were observed. Table 1 shows the variables studied and their abbreviations. Data were collected from 6 randomly selected plant samples for each trait.

Statistical analysis

The data was subjected to analysis of variance (ANOVA) and Newman-Keuls tests at the 5% to identify the variables that discriminate between accessions. The coefficient of variation (CV) was used to assess the level of variation in the means observed between accessions for each trait. The correlations were used to check the two-by-two relationships between variables.

Principal component analysis (PCA) was used to determine the association between the traits studied. Well-represented and poorly correlated variables were used to group varieties by Agglomerative hierarchical clustering (AHC) dendrogram analysis using Euclidean distance into different clusters by the Ward method. The groups resulting from this classification were characterised using factorial discriminating analysis (FDA). XLSTAT 2016 and GenStat v410.3n were used to analyse the data.

Table 1: Variables studied

N°	Variables	N°	Variables
1	Emergence	**9**	Pod length (– in cm)
2	Days to 50% flowering	**10**	100 seed weight (– in grams)
3	Days to 95% maturity	**11**	Weight pods (g)
4	Measurement of chlorophyll content	**12**	Weight grain (kg)
5	Plant height (cm)	**13**	Dry Weight fodder (kga)
6	Terminal leaf Width (cm)	**14**	Fodder yield (kg/ha)
7	Pod number per plant	**15**	Grain yield (kg/ha)
8	Number of branches/plants		

RESULTS

Variability of ricebean traits within the collection

The results of the analysis of variance (ANOVA) in Table 2 show that all the quantitative characteristics studied discriminate significantly between the accessions studied at the 5% and 1% thresholds. In fact, the coefficients of determination for the various traits were very high ($R2 \geq 30\%$). It was 49.72% for seed yield and 90.37% for seed weight.

The coefficients of variation were 6.19% for date 50% flowering and 62.56% for dry haulm weight. They were high (CV> 30%) for plant height (CV = 31.23%), number of pods per plant (CV = 33. 90%), pod weight (CV = 38.33%), seed yield (CV = 43.07%), seed weight (CV = 43.07%), Dry Weight fodder (CV = 62.56%), fodder yield (CV = 62.56%). Analysis of the germination rate showed that the seedlings all emerged between the 3rd and 4th day after sowing (DAS).

The average 50% flowering date was 43 days after sowing. Early accessions flowered at 40 days after sowing (R10, R42) and late accessions at 47 days after sowing (R101). Seed maturity ranged from 68 days for accessions R42 and R10 to 82 days for accession R111, with an average of 73.69 days. In terms of the number of pods per plant, accessions R85 (106.50 pods) and R80 (120.52 pods) had the highest number of pods. Accession R58 with 40.82 pods had the lowest number of pods per plant.

Pod length varied between 7.38 cm (R127) and 10.67 cm (R14), with an average of 8.56 cm. Plant height (cm) varied from 34.81 (R5) to 134.19 cm (R28). For dry weight fodder and fodder yield, accession R80 with values of 1.16 kg and 6429.63 kg/ha respectively had both the highest dry weight fodder and the highest fodder yield. Accession R148, with 0.12 kg and 688.89 kg/ha of dry weight fodder and fodder yield respectively, had the lowest fodder weight and was the least productive accession in terms of dry biomass. Pod weights varied from 0.19 kg to 0.72 kg, with an average of 0.39 kg. The accession R28 had the highest pod weight (0.72 kg) and the accession R148 the lowest (0.19 kg). Seed weight varied from 0.08 kg to 0.38 kg with an average of 0.22 kg. R148 recorded the lowest seed weight, while accession R85 had a high seed weight. In terms of dry seed yield, accessions R80 (1606.29 kg/ha), R27 (1641.81 kg/ha) and R85 (2134.36 kg/ha) were the most productive at over 1.5 t/ha. The least productive accession was R148 with 450.93 kg/ha.

For the 100-seed weight variable, accession R5 (7.79 g) had the highest weight, above 6 g. Accession R80 (4.38 g) had the lowest weight.

With regard terminal leaf width, the average width was 5.81 cm. The maximum width was over 7 cm observed in accessions R80 (7.27 cm), while accession R58 (4.45 cm) showed the smallest width. The average number of primary branches was 3.95. The maximum of 5.67 branches was observed in accessions R28 and a minimum of 2 branches in accession R167.

The chlorophyll content of the varieties tested, with an average value of 40.92%, ranged from 32.17 to 57.07 respectively for accession R5 and accession R101.

Relationships between the rice bean traits studied

An examination of the correlation matrix presented in Table 3. the matrix of Pearson correlation coefficients (r) establishing the linear relationships between the various characteristics, taken in pairs. It showed positive, negative and significant values between pairs of variables. Germination was negatively correlated with plant height (r = - 0.443), dry fodder weight (r = -0.473) and fodder yield (r = - 0.473). Flowering was also negatively correlated with 100-seeds weight (r = - 0.463).

A positive correlation was noted between flowering date and seed maturation (r = 0.652). Plant height was positively correlated with dry fodder weight (r = 0.685), fodder yield (r = 0.685), grain weight (r = 0.513), grain yield (r = 0.513), terminal leaflet width (r = 0.608) and pod length (r = 0.439).

The number of pods per plant was positively and significantly correlated with dry fodder weight (r = 0.627), fodder yield (r = 0.627), seed weight (r = 0.613) and seed yield. There was also a positive correlation between pod length and 100-seed weight (r = 0.554). Pod weight was positively and significantly correlated with seed weight (r = 0.662), seed yield (r = 0.662), fodder weight (r = 0.662) and fodder yield (r = 0.662). In addition, seed weight was positively correlated with fodder weight (r = 0.848), seed yield (r = 0.848) and fodder yield (r = 1.000).

Finally, dry fodder weight was positively and significantly correlated with fodder yield (r = 1.000) and seed yield (r = 0.848). There was also a positive correlation between fodder yield and seed yield (r = 0.848).

Structure of the agro-morphological variability

The nature and degree of divergence of rice bean accessions were assessed using principal component analysis (PCA) based on fifteen quantitative agromorphological traits.

Table 4 shows the results of the PCA analysis. The principal component axes were described by their eigenvalue and their variability rate. As a result of this analysis, the first three axes expressed 41.86%, 18.03% and 10.92% of the total variability respectively, giving a cumulative variance of 70.80%. Axis 1, which expresses 41.86% of total variability, is the most important in the agronomic characterisation of rice bean accessions. The variables that contributed to the formation of this axis were germination, number of pods per plant, plant height, terminal leaflet width, dry fodder weight, fodder yield, pod weight, grain weight and grain yield. This axis can be described as a vegetative development and yield axis.

The main contributions to axis 2 (18.03%) were defined by four variables: flowering, maturity, pod length and 100-seed weight. Analysis of the traits involved in the formation of axis 2 reveals that it is characteristic of the plant's phenology and vegetative growth. Axis 3 (10.92%) is defined positively by the number of branches. This axis reflects a yield component.

A synthetic view of the differentiation between accessions is provided by Agglomerative Hierarchical Clustering (AHC). Figure 1 shows the dendrogram resulting from the HAC. It classifies the accessions into four groups of phenotypic diversity. These four groups are made up of 6, 7, 2 and 9 accessions respectively. The structuring of the groups is strongly influenced by the yield and yield components.

Characteristics of the groups

Factorial discriminant analysis (FDA) was used to identify the most discriminating agro-morphological characteristics, which enabled the accessions to be grouped into these four distinct groups. Figure 2 shows the results and the graphical representation of FDA in the canonical plane 1-2 with the greatest total variance, i.e. 97.07%. The first component accounted for 79.65% compared with 17.43% for the second component. The relationship of the groups with the axes showed that groups II and III correlated with axis 2 are opposite. Groups I and II, on the other hand, correlated negatively and positively respectively with the two axes.

The squares of the Mahalanobis distances (D2) in Table 5 separating the four phenotypic diversity groups in pairs show that these groups differ significantly from each other at the 5% threshold. They show that groups I and II are the furthest apart (D2 = 428.915) and that groups III and IV are the closest (D2 =17.395).

The test of Lambda of Wilks in discriminant factorial analysis gives a value of F and critical F respectively of 3.183 and 2.146 and a p-value = 0.007 at the 5% threshold between the four (4) groups obtained, which confirms that they are indeed distinct entities. These characteristics according to their decreasing discriminatory power revealed by the Wilk test are summarized in Table 6.

Average performance of the groups

The complete examination of differentiation between the four phenotypic diversity groups was completed by analysis of variance and the Newman-Keuls test. The results in Table 7 show very highly significant differences (P < 0.001) between the groups for the fifteen variables. Analysis of the Fisher F statistic and the coefficient of determination R^2 indicates that the traits emergence, plant height, terminal leaflet width, number of pods per plant, pod length, dry haulm weight, haulm yield, seed weight and seed yield are the most discriminating, with relatively high F and R^2 values.

Analysis of the mean values for the group variables shows that group I contains 6 accessions. The accessions in this group showed moderate performance for most of the variables studied, i.e. average plant height, dry haulm weight and average haulm yield. Group II comprises 7 accessions with the best performance for most characteristics. The variables pod length, plant height, dry haulm weight and haulm yield were above the average for the group. Group III, comprising 2 accessions, groups together individuals with high yield components. These accessions presented a high number of pods per plant, a high haulm weight and yield and a high seed weight and yield. Finally, group IV include most of the accessions in the study (9 in total). It was thus characterised by early and medium flowering accessions. On the other hand, the variables plant height, haulm weight, dry yield, pod weight, seed weight, seed yield, terminal leaflet width and number of branches showed low values below the average. Most of the early maturing accessions were in this class.

Table 2: Results of Analysis of variance from all accessions for 15 quantitative traits.

Traits	Minimum	Maximum	mean	CV	R² (%)	Pr > F
Emg	3	4	3.53	14.25	59.13	0.001**
D50F	40	47.33	43.26	6.19	53.2	0.006**
D50M	68	82.33	73.69	6.81	72.99	< 0.0001**
CCt	32.17	57.07	40.92	21.32	53.13	0.006**
PHT	34.81	134.19	94.8	31.23	62.7	0.000**
TLW	4.45	7.27	5.81	16.12	58.67	0.001**
PNP	40.82	120.52	69.38	33.9	65.04	< 0.0001**
NBPP	2	5.67	3.94	24.03	72.82	< 0.0001**
PLT	7.38	10.67	8.56	10.81	72.03	< 0.0001**
100SW	4.38	7.79	6	19.14	75.93	< 0.0001**
WgtP	0.19	0.72	0.39	38.33	90.37	< 0.0001**
WG	0.08	0.38	0.22	43.07	49.72	0.017**
DWF	0.12	1.16	0.57	62.56	54.38	0.004**
DYld	688.89	6429.63	3168.21	62.56	54.38	0.004**
GYld	450.93	2134.36	1210.98	43.07	49.72	0.017**

*Analysis of variance significant at the 5% level; **Analysis of variance highly significant at the 1% level; CV - Coefficient of Variation; R^2(%) - coefficient of determination; Emg – Emergence; D50F - days to 50% flowering; D50M - days to 95% maturity; CCt - chlorophyll content; PHT - plant height (cm); TLW - terminal leaf Width (cm); PNP - pod number per plant; NBPP - number of branches/plants; PLT - pod length (cm); 100SW - 100 seed weight (g); WgtP - weight pods (kg); WG - weight grain (kg); DWF - weight fodder (kg); DYld - fodder yield; Gyld (kg/ha) - grain yield (kg/ha).

Table 3: Correlation matrix for quantitative characteristics of the rice bean collection.

Traits	Emg	D50F	D50M	MCC	PHT	TLW	PNP	NBPP	PLT	100SW	WgtP	WG	DWF	DFY	GYld
Emg	**1**														
D50F	-0.224	**1**													
D50M	-0.298	**0.652**	**1**												
MCC	-0.299	0.196	0.206	**1**											
PHT	**-0.443**	-0.16	0.126	0.379	**1**										
TLW	-0.348	-0.078	0.277	0.305	**0.608**	**1**									
PNP	-0.1	0.098	0.338	0.239	0.348	**0.544**	**1**								
NBPP	-0.22	0.096	0.369	-0.087	0.15	0.346	-0.065	**1**							
PLT	-0.184	-0.322	-0.152	-0.318	**0.439**	0.357	-0.091	0.351	**1**						
100SW	0.019	**-0.463**	-0.397	-0.236	0.039	0.032	-0.134	0.18	**0.554**	**1**					
WgtP	-0.101	-0.362	-0.135	-0.104	0.344	**0.503**	0.319	0.3	0.287	0.18	**1**				
WG	-0.291	-0.158	0.22	0.205	**0.513**	**0.737**	**0.613**	0.115	0.182	-0.036	**0.662**	**1**			
DWF	**-0.473**	0.02	0.344	0.262	**0.685**	**0.835**	**0.627**	0.317	0.291	-0.138	**0.567**	**0.848**	**1**		
DFY	**-0.473**	0.02	0.344	0.262	**0.685**	**0.835**	**0.627**	0.317	0.291	-0.138	**0.567**	**0.848**	**1**	**1**	
GYld	-0.291	-0.158	0.22	0.205	**0.513**	**0.737**	**0.613**	0.115	0.182	-0.036	**0.662**	**1**	**0.848**	**0.848**	**1**

*significant, **highly significant, Emg – Emergence; D50F - days to 50% flowering; D50M - days to 95% maturity; CCt - chlorophyll content; PHT - plant height (cm); TLW - terminal leaf Width (cm); PNP - pod number per plant; NBPP - number of branches/plants; PLT - pod length (cm); 100SW - 100 seed weight (g); WgtP - weight pods (kg); WG - weight grain (kg); DWF - weight fodder (kg); DYld - fodder yield; Gyld - grain yield (kg/ha).

Table 4: Eigenvalues and percentage of variation expressed for the first three axes based on quantitative characteristics in principal component analysis.

Principal components	PC1	PC2	PC3
Eigenvalue	6.28	2.7	1.64
Proportion (%)	41.86	18.03	10.92
Cumulative (%)	41.86	59.89	70.8
Emg	-0.19	-0.12	-0.34
D50F	-0.02	0.49	0.27
D50M	0.14	0.42	0.31
MCC	0.12	0.29	-0.12
PHT	0.29	-0.06	0.08
TLW	0.35	-0.03	0.05
PNP	0.26	0.15	-0.28
NBPP	0.13	-0.07	0.57
PLT	0.13	-0.4	0.38
100SW	-0.02	-0.46	0.18
WgtP	0.25	-0.27	-0.13
WG	0.36	-0.04	-0.21
DWF	0.39	0.04	0.02
DFY	0.39	0.04	0.02
GYld	0.36	-0.04	-0.21

Emg – Emergence; D50F - days to 50% flowering; D50M - days to 95% maturity; CCt - chlorophyll content; PHT - plant height (cm); TLW - terminal leaf Width (cm); PNP - pod number per plant; NBPP - number of branches/plants; PLT - pod length (cm); 100SW - 100 seed weight (g); WgtP - weight pods (kg); WG - weight grain (kg); DWF - weight fodder (kg); DYld - fodder yield; Gyld (kg/ha) - grain yield (kg/ha).

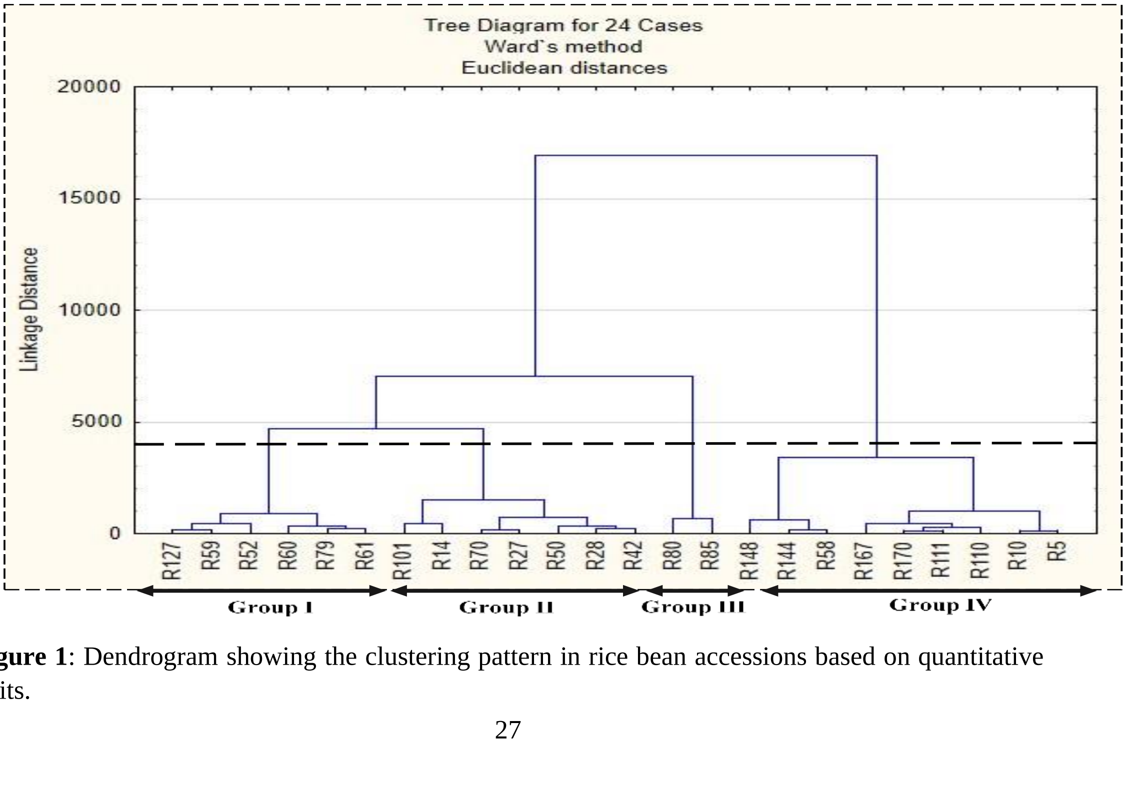

Figure 1: Dendrogram showing the clustering pattern in rice bean accessions based on quantitative traits.

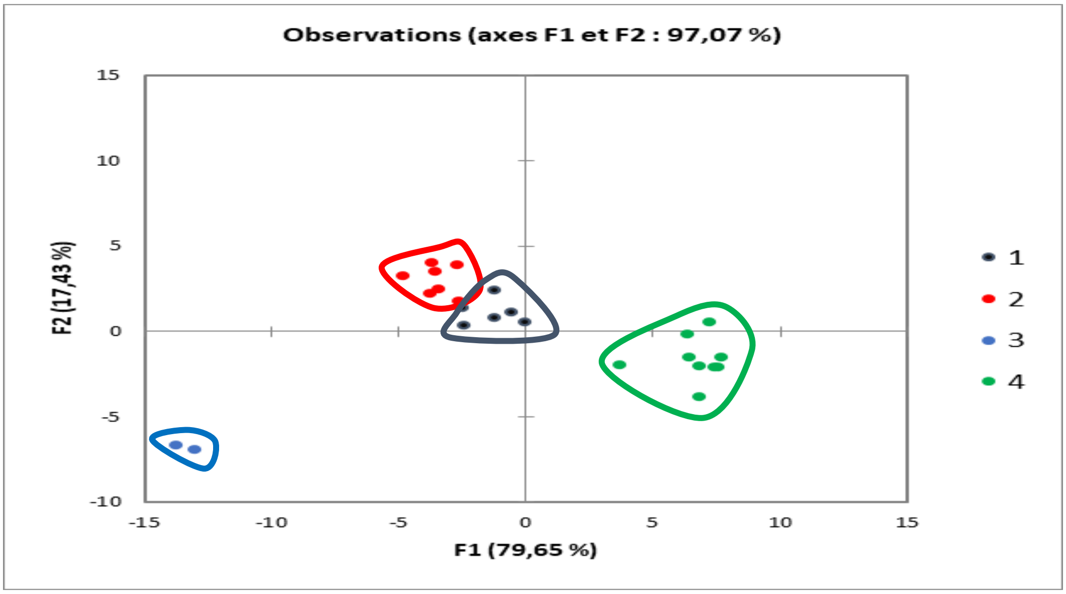

Figure 2: Discriminant analysis performed on two axes (F1&F2) on the 4 classes obtained through hierarchical clustering.

Table 5: Squares of Mahalanobis distances between groups.

Groups	Group I	Group II	Group III	Group IV
Group I	0			
Group II	17.395	0		
Group III	212.592	194.102	0	
Group IV	76.798	126.103	428.915	0

Table 6: Classification in descending order of agromorphological characters discriminating phenotypic diversity groups of rice bean accessions according to Wilk's lambda test resulting from discriminant factor analysis (DFA).

Traits	Order	Lambda de Wilks	F	P-value
DFY	1	0.081	75.796	< 0.0001
WG	2	0.327	13.698	< 0.0001
DWF	3	0.081	75.796	< 0.0001
GYld	4	0.327	13.698	< 0.0001
TLW	5	0.416	9.377	0.0004
PNP	6	0.465	7.657	0.001
PHT	7	0.431	8.795	0.001
PLT	8	0.665	3.361	0.039
Emg	9	0.683	3.092	0.05

Emg – Emergence; D50F - days to 50% flowering; D50M - days to 95% maturity; CCt - chlorophyll content; PHT - plant height (cm); TLW - terminal leaf Width (cm); PNP - pod number per plant; NBPP - number of branches/plants; PLT - pod length (cm); 100SW - 100 seed weight (g); WgtP - weight pods (kg); WG - weight grain (kg); DWF - weight fodder (kg); DYld - fodder yield; Gyld (kg/ha) - grain yield (kg/ha).

Table 7: average performance of four rice bean groups for the discriminating characters.

Groups	1	2	3	4	R^2	F	Pr > F
Frequency(%)	**25**	**29.167**	**8.333**	**37.5**			
Emg	3.611a	3.286 a	3.167 a	3.741 a	0.317	3.092	0.050*
D50F	43.278 a	42.810 a	44.333 a	43.370 a	0.042	0.295	0.828 ns
D50M	73.167 a	73.524 a	79.167 a	72.963 a	0.153	1.204	0.334 ns
MCC	42.228 a	43.657 a	40.267 a	38.059 a	0.143	1.116	0.366 ns
PHT	89.099 ab	116.634 a	116.543 a	76.788 b	0.569	8.795	0.001**
TLW	5.782 bc	6.229 b	7.005 a	5.230 c	0.584	9.377	0.000**
PNP	63.994 b	70.663 b	113.512 a	62.157 b	0.535	7.657	0.001**
NBPP	3.944 a	4.429 a	3.833 a	3.593 a	0.18	1.459	0.256 ns
PLT	8.147 a	9.250 a	8.233 a	8.370 a	0.335	3.361	0.039*
100SW	5.760 a	6.485 a	4.845 a	6.033 a	0.197	1.638	0.212 ns
WgtP	0.382 a	0.454 a	0.542 a	0.307 a	0.29	2.722	0.072 ns
WG	0.229 b	0.252 b	0.337 a	0.158 c	0.673	13.698	< 0.0001**
DWF	0.562 c	0.763 b	1.121 a	0.304 d	0.919	75.796	< 0.0001**
DFY	3120.988 c	4237.037 b	6229.630 a	1688.066 d	0.919	75.796	< 0.0001**
GYld	1269.980 b	1402.208 b	1870.325 a	876.404 c	0.673	13.698	< 0.0001**

*Significant; **highly significant; Emg – Emergence; D50F - days to 50% flowering; D50M - days to 95% maturity; CCt - chlorophyll content; PHT - plant height (cm); TLW - terminal leaf Width (cm); PNP - pod number per plant; NBPP - number of branches/plants; PLT - pod length (cm); 100SW - 100 seed weight (g); WgtP - weight pods (kg); WG - weight grain (kg); DWF - weight fodder (kg); DYld - fodder yield; Gyld (kg/ha) - grain yield (kg/ha).

DISCUSSION

The high coefficient of variation obtained for a significant number of quantitative variables indicates the presence of strong heterogeneity within the rice bean collection in Burkina Faso. According to Savitha et al. (2008), the wide diversity of characteristics provides sufficient opportunity to select genotypes according to demand or the type of breeding programme. Several ricebean accessions from the present study can be selected for certain desired characteristics. All accessions flowered before 47 DAS. The cycle ranged from 68 DAS to 82 DAS. This sowing-flowering-maturity cycle of the accessions is quite similar to that of accessions of crops neglected in Burkina Faso, such as *Macrotyloma geocarpum* (Nana et al., 2020) and bambara groundnut (Ouoba et al., 2016).

This differentiation in ricebean crop cycles was also highlighted by Dhillon and Tanwar (2018), who observed a maturity cycle varying from 120 to 150 days after sowing. At first sight, this variation is an intrinsic characteristic of the accessions. However, the divergence can be attributed to environmental influences such as temperature and then photoperiod exerting a differential pressure on the plant material tested.

Indeed, rice bean is a highly photosensitive crop that requires a short period of daylight for flowering, and flowering can be significantly delayed or prevented if these requirements are not met (Katoch, 2020). Temperatures were relatively high, as was day length, during the course of the trial (July to October). In a study carried out on the distribution of rice beans in India and Nepal, Gautam et al. (2007), in the course of a survey of rice bean growers, categorised as early varieties those whose number of days (from sowing to maturity) was less than 95 days, as medium varieties from 95 to 120 days and as late varieties those whose number of days was greater than 120 days. On the basis of their classification, all the rice bean accessions tested in the present study early cycle.

The strong, positive correlations between flowering and maturity mean that maturity could be predicted from the date of flowering. These parameters would therefore provide information on the length of the cycle of the varieties. Similar results on flowering and pod maturity were also reported by Omokanye et al. (2003) for cowpea and Barro et al. (2023) for vegetable cowpea varieties. Varieties that produced flowers and pods early reached physiological maturity very early. On the other hand, varieties that produce flowers and pods late are the last to reach physiological maturity. The set of accessions with early flowering and early maturity can be classified as early maturing genotypes and can be used for drought tolerance in breeding programmes. This is a good trait to explore in breeding for drought tolerance, as early maturity has been noted as a drought escape mechanism for many crops (Shavrukov et al., 2017; Gbaguidi et al., 2015).

Results on plant height show that the height of rice bean plants varied between accessions, ranging from the lowest R5 (34.81 cm) to the highest R28 (134.19 cm). For Katoch (2020), plant height generally ranged from less than 1 m to more than 2.5 m, and many variations in height have also been reported (Singh et al., 2006; Katoch, 2011; Pattanayak et al., 2018). The height of the plant is very important, as it comes into play during cultivation operations, giving an idea of the operation to be carried out. According to Katoch (2020), when the plants are 10 to 15 cm high, weeding has a number of positive effects on plant growth. What's more, the most appropriate time for staking is when the rice bean plants are around 50 cm tall. Accession R85 had the highest yield, at 2134.36 kg/ha. The lowest yield was observed with accession R148 (450.93 kg/ha). This variation in yield is higher than the world average, which is around 200-300 kg/ha (Rajerison, 2006).

The forage yield of the accessions was used to identify those that were productive and those that were less productive in terms of forage. Accession R80 performed well in terms of biomass output (6429.63 kg/ha). Its foliage was abundant and remained green. Accession R80 had a yield close to that of the IC341991 variety (6.27 t/ha), developed in India, which showed exceptional forage yields of over 6,000 kg/ha on station (Bhoomika, 2018). The results of the correlation between seed yield and dry fodder yield showed that there is a direct link between grain yield and dry fodder yield. Accessions R85 (2134.36 kg/ha) and R80 (1606.29 kg/ha), which had the highest grain yields, had the highest dry fodder yields at 6429.63 kg/ha and 6029.63 kg/ha respectively. All these accessions are a real source of protein for human consumption and fodder reserves for livestock. These data are sufficient to classify some of the accessions with high grain and dry fodder yields as multiple-use accessions. This is necessary because it gives the farmer the opportunity to use the same variety for seed and dry fodder production in the same environment, instead of using two specific varieties in different environments (Coulibaly et al., 2020).

The application of multivariate statistical analysis, such as PCA, can help to understand the relationship between variables. These could be useful for inferring the nature of attributes and reducing the complexity of data collection (Hussein et al., 2012). The first three principal components accounted for 70.80% of the total variability between accessions. The nature of this variability is revealed through the parameters of phenology, vegetative characteristics and yield.

While PCA was used to elucidate the status and nature of variability within accessions, AHC was used to quantify the genetic component of this variability. On the basis of a cluster analysis, 24 rice bean accessions were classified into four groups. Each member of the group contains accessions with specific traits. Accessions R10 and R5 in group IV proved to be early maturing types. Accessions R80 and R85 in group III showed a higher number of pods/plant and a higher yield of seeds and haulms per plant.

These accessions could be used as parental sources for the rice bean crossing programme for diversified uses. In this way, hybridisation between these genotypes could be effective in the future breeding programme in developing rice bean varieties with early maturation, high yield and a greater number of pods per plant.

Conclusion

Morphological and agronomic analysis through quantitative variables of the 24 rice bean accessions reveals great variability within the Burkina Faso collection. This significant variability could be due to the expression of strong heterogeneity. The accessions identified showed good quantitative characteristics. These results show that certain accessions performed well, such as R42 (average cycle length: 68 JAS), R14 (high pod length: 10.67 cm), R28 (plant height 134.19 cm). Accessions R80 and R85 had the desired characteristics of short cycle, quantitative seed production and fodder. Significant correlations were also observed between the different quantitative variables. Such correlations will help to identify important variables that can be used for varietal improvement.

Multivariate analyses based on the 15 quantitative characteristics revealed significant agromorphological diversity, structured into four phenotypic diversity groups. Vegetative and yield parameters proved to be the most relevant in explaining the agromorphological divergence between these groups. In the context of climate change and in order to increase farmers' resilience, food diversification through the introduction of rice bean is a good alternative for crop production, consumption and human nutrition. These results could guide rice bean improvement programmes with a view to obtaining varieties with interesting agronomic characteristics.

COMPETING INTERESTS

The authors declare that they have no competing interest.

AUTHORS' CONTRIBUTIONS

ZC: collected the data, followed the field trial and participated in the analysis and writing of the manuscript. AB: followed the tests, supervised the work and participated in the analysis and correction of the manuscript. WFSZ: participated in the correction of the manuscript. TJN: followed the trial, participated in data collection and manuscript correction.

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