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Morphological and Agronomical Characterisation of Variability among a Collection of *Phaseolus lunatus* (L.) Local Morphotypes from Cote d'Ivoire

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***Abstract* – In Cote d'Ivoire, *Phasolus lunatus*, is a neglected and underutilized legume grown for occasional family needs. In the present study, we evaluated the morphological and agronomical variation within a collection of eight local morphotypes collected. Twenty-one agro morphological parameters of plants, fruits and seeds were measured on ten individuals per morphotype. Results of univariate analyses show significant variations for 18 of these 21 agro morphological parameters when comparing the morphotypes. Multivariate analyses showed morphologically diverse groups: Factorial Discriminant Analysis (FDA) showed the group of long, thicker and heavier dry seeds, the group of large fruits with small seeds of low weight and thickness and the group of fruits small in thickness and length. The Hierarchical Ascending Classification (HAC) distinguishes the group of vigorous individuals with big seed and the group of less vigorous individuals with small seeds. While FDA proposes classes grouping morphotypes, HAC does not allow the grouping of individuals of the same morphotype.**

***Keywords* – Lima Beans, Morphological Characterisation, Morphotypes, NULs.**

I. INTRODUCTION

The quality and availability of food resources is a guarantee of food security [1]. Legumes play a crucial role in a healthy, balanced diet and even in sustainable food production. The high nutritional density, the high protein content (18 to 30%, i.e. two to three times more than the seeds of major cereals), the diversity of food products, the accessible cost, the economic potential, the long shelf life reducing food wastage [2], [3], [4] are the important assets in the fight against food insecurity and the well-being of both rural and urban populations. Moreover, through their capacity for symbiotic atmospheric nitrogen fixation, they contribute to the preservation of soil health and the improvement of nutrient-poor sub-Saharan soils and are easily integrated into marginal environments [5] [6].

Legumes are cultivated throughout sub-Saharan Africa, particularly in Cote d'Ivoire, where they are among the most important crops for staple foods [7]. These include groundnuts, cowpeas, pigeon peas, which are the most widespread legumes and are grown on varying degrees of land [8]. However, some legume species are still marginal, in particular *Phaseolus lunatus*. In spite of its food, economic and agronomic importance, the involvement of this legume in food habits remains problematic, as it remains an orphan in Cote d'Ivoire, absent from agricultural programs. The species is cultivated in family farming to meet specific needs. Cultivation systems are exclusively traditional, the areas devoted to cultivation are insignificant and the non-existence of an organized sector makes production levels low [9]. These factors considerably limit its use in the fields by farmers and especially its use by the population. Moreover, scientific research is still marked by the lack of work because *Phaseolus lunatus* is very little addressed in scientific research programs. Documented evidence of research activities in Cote d'Ivoire is scarce. The lack of improved varieties is to be underlined.

Studies on genetic variability are indeed embryonic [9] and have identified eight poorly known traditional morphotypes still dependent on peasant management. However, traditional varieties remain an important source of genes, the preservation of which contributes to maintaining the genetic richness of the species [10]. One of the difficulties in taking advantage of these resources is the lack of characterization and knowledge of the resource. Due to the lack of characterization on the attributes of the germplasm, the potential for production and adaptation are thus unexplored in *P. lunatus* in Cote d'Ivoire, making it difficult to intensify. The genetic diversity of the species ensures a varied production, a guarantee of a rich and diversified diet. The importance of genetic diversity in the improvement of species is therefore recognized. Evaluation of quantitative agro morphological parameters would contribute significantly to the enhancement and sustainable management of the genetic resources of *P. lunatus in* Cote d'Ivoire.

II. MATERIALS AND METHODS

Study Site and Plant Material

The study took place from May 2019 to December 2019 at the Nangui Abrogoua University experimental farm, located in Abidjan District, Cote d'Ivoire. The District of Abidjan is located between 5°17' and 5°31' north latitude and between 3°45' and 4°22' west longitude. It is characterized by an average rainfall of 2000 mm/year. Rainfall is divided into two rainy seasons and two dry seasons. The dry seasons are mild due to the fact that they are tempered by sea breezes. The plant material used consists of 8 morphotypes of *P. lunatus* from the Nangui Abrogoua University collection of minor crop legumes.

Experimental Device

The experimental device consists of a complete randomized block covering an area of 396 m^2 (22 × 18 m). The block is subdivided into 8 elementary plots, each of which is devoted to one morphotype. For each morphotype, 10 seeds were sown randomly, resulting in a total of 80 plants.

Data Collection

Data were taken from 10 randomly selected plants. Twenty-one quantitative characteristics were selected from the list of descriptors of *P. lunatus* [11]. These were time of emergence, length of hypocotyl, length and width of upper leaflet, leaflet shape index, length of petiole, length and diameter of stem, number of branches, time of appearance of first flower, time of appearance of the first fruit, length of the dry fruit, length, width, thickness and weight of the dry fruit, length, width, thickness and weight of dry seed, the rate of husk, the weight of 100 dry seeds.

Data Analysis

Statistical analyses of the different agromorphological traits of the eight *P. lunatus* morphotypes grown in Côte d'Ivoire were performed using XLSTAT version 18.0. The Univariate Analysis of Variance (MANOVA) was first used to evaluate the agromorphological differences between the morphotypes. When this difference is significant, the Analysis of Variance (ANOVA) is used to compare the morphotypes. Pearson correlation analysis was used in this study to highlight the degree of association of the variables taken in pairs. When this degree is greater than or equal to 0.70 between two variables, one of the two is eliminated and the other is used for multivariate analyses.

Reduced centered data were used for the realization of multifactorial analyses Discriminant Factor Analysis (DFA) and Hierarchical Ascending Classification (HAC) in order to highlight the structuring of the agro morphological variability of *P. lunatus*.

III. RESULTS

Morphological Variability between Morphotypes

Multiple analysis of variance (MANOVA) performed for all agromorphological traits of *P. lunatus* revealed a very highly significant difference ($F = 1.249$; $P < 0.0001$) between the eight morphotypes studied. The ANOVA (Analysis of variance) showed a significant difference between the morphotypes for 18 of the 21 parameters used (Table 1). Only petiole length, time of first flower appearance and time of first fruit appearance did not show significant differences between morphotypes (Table 1). None of the 18 discriminating characteristics allows a clear distinction between the morphotypes. The highest values of the studied characteristics appear variably in each of the 8 morphotypes. However, morphotype M4 falls into the category of the lowest values recorded, for mean values ± standard deviation of 8 of the discriminant parameters: the time taken from sowing to emergence (5.90 ± 1.17 d), the leaflet shape index (1.19 ± 0.09), the smallest seeds with an average length of 19.23 ± 0.96 mm, an average width of 12,38 ± 0.68 mm and an average thickness of 4.90 ± 0.31 mm, the seed weight per fruit (2.37 ± 0.42 g), the weight of 100 seeds (81.38 ± 14.21 g) and the pod rate (2.50 ± 0.2%), (Table 1). On the other hand, morphotype M4 presents for four of the parameters measured the highest value: hypocotyl length (36.80 ± 4.24 mm), length (100.98 ± 5.17mm) and width (21.78 ± 0.79 mm) of fruit and number of branches (12.10 ± 3.35).

Table 1. Means values ± standard deviation recorded for eight local *P. lunatus* morphotypes from Cote d'Ivoire.

	M1	M2	M3	M4	M05	M6	M7	M24	*F*	*P*
TmEg	7.60 ± 1.6^{b}	7.50 ± 1.18^{b}	7.00 ± 1.49^{ab}	5.90 ± 1.17^{a}	6.80 ± 1.14^{ab}	8.00 ± 1.41^{b}	7.90 ± 1.73^{b}	7.90 ± 1.2^{b}	2.73	0.014
LgHp	35.00 ± 5.46^{b}	38.80 ± 11.36^{b}	37.90 ± 5.43^{b}	36.80 ± 4.24^{b}	28.70 ± 4.85^{a}	34.90 ± 4.25^{b}	33.10 ± 5.72^{ab}	35.54 ± 8.3^{b}	2.27	0.038
LgLf	70.87 ± 3.49^{abcd}	68.15 ± 4.47^{a}	72.62 ± 3.55^{bcde}	69.32 ± 4^{ab}	69.35 ± 4.07^{abc}	72.68 ± 3.53^{cde}	73.79 ± 3.01^{de}	74.81 ± 3.58^{e}	4.07	0.001
WdLf	60.38 ± 3.71^{bc}	56.58 ± 1.94^{a}	60.02 ± 3.71^{bc}	58.47 ± 4.09^{abc}	60.56 ± 3.61^{bc}	59.27 ± 2.33^{abc}	61.10 ± 2.48^{c}	58.18 ± 2.37^{ab}	2.32	0.034
iSLf	1.18 ± 0.05^{a}	1.21 ± 0.07^{ab}	1.21 ± 0.08^{abc}	1.19 ± 0.09^{a}	1.15 ± 0.05^{a}	1.23 ± 0.07^{abc}	1.28 ± 0.2^{bc}	1.29 ± 0.07^{c}	2.64	0.017
LgPt	66.23 ± 23.98^{a}	72.53 ± 23.63^{ab}	84.26 ± 25.5^{ab}	70.01 ± 23.67^{ab}	76.79 ± 22.7^{ab}	73.48 ± 12.2^{ab}	88.55 ± 19.19^{b}	74.63 ± 21.34^{ab}	1.13	0.356 *
LgSt	3.09 ± 0.44^{b}	2.56 ± 0.5^{a}	3.64 ± 0.69^{cd}	3.16 ± 0.79^{bc}	3.61 ± 0.32^{cd}	3.37 ± 0.64^{bcd}	3.25 ± 0.66^{bc}	3.85 ± 0.11^{d}	5.12	< 0.0001
DaSt	5.63 ± 0.33^{a}	6.48 ± 1.32^{ab}	8.74 ± 2.14^{cd}	8.16 ± 2.16^{cd}	8.30 ± 1.8^{cd}	9.45 ± 2.55^{d}	9.11 ± 2.1^{d}	7.36 ± 0.94^{bc}	5.35	< 0.0001
NbBr	3.90 ± 1.2^{a}	6.60 ± 4.43^{ab}	13.40 ± 6.33^{d}	12.10 ± 3.35^{d}	10.40 ± 5.4^{cd}	10.10 ± 5.22^{bcd}	12.20 ± 2.2^{d}	7.10 ± 2.28^{abc}	6.26	< 0.0001
TmFl	76.50 ± 4.48^{ab}	72.10 ± 5.43^{ab}	71.30 ± 6.02^{a}	72.80 ± 6.84^{ab}	77.40 ± 6.29^{b}	71.30 ± 8.06^{a}	76.20 ± 5.69^{ab}	76.20 ± 6^{ab}	1.75	0.111 *
TmFr	79.60 ± 4.7^{abc}	75.10 ± 5.3^{ab}	74.20 ± 5.59^{a}	76.50 ± 7.49^{abc}	81.10 ± 6.67^{c}	75.50 ± 8^{ab}	80.10 ± 5.55^{bc}	79.70 ± 5.96^{abc}	1.84	0.093 *
LgFr	93.11 ± 7.85^{a}	90.65 ± 2.83^{a}	100.26 ± 4.52^{b}	100.98 ± 5.17^{b}	90.69 ± 3.19^{a}	93.88 ± 2.82^{a}	90.16 ± 1.94^{a}	91.67 ± 2.73^{a}	10.24	< 0.0001
WdFr	20.41 ± 0.88^{c}	19.57 ± 1.02^{ab}	18.84 ± 1.46^{a}	21.78 ± 0.79^{d}	19.26 ± 0.78^{a}	20.04 ± 0.51^{bc}	19.14 ± 0.36^{a}	21.66 ± 0.45^{d}	17.53	< 0.0001
TkFr	13.02 ± 0.46^{f}	11.06 ± 1.86^{bc}	12.06 ± 0.93^{de}	11.32 ± 0.99^{cd}	12.75 ± 0.61^{ef}	10.31 ± 0.32^{ab}	10.99 ± 0.47^{bc}	9.96 ± 0.53^{a}	14.81	< 0.0001
WgFr	4.17 ± 0.29^{bc}	4.18 ± 0.53^{bc}	4.38 ± 0.57^{ab}	3.94 ± 0.53^{c}	4.18 ± 0.39^{bc}	4.27 ± 0.29^{bc}	4.72 ± 0.32^{a}	4.47 ± 0.37^{ab}	3.28	0.004

	M1	M2	M3	M4	M05	M6	M7	M24	*F*	*P*
LgSd	20.72 ± 0.63^{b}	21.98 ± 0.66^{c}	22.16 ± 0.95^{c}	19.23 ± 0.96^{a}	19.53 ± 0.6^{a}	20.48 ± 0.53^{b}	21.79 ± 0.4^{c}	20.51 ± 0.19^{b}	27.86	< 0.0001
WdSd	13.66 ± 0.34^{cd}	13.76 ± 0.43^{cd}	14.31 ± 0.43^{e}	12.38 ± 0.68^{a}	12.46 ± 0.37^{a}	13.00 ± 0.29^{b}	13.84 ± 0.25^{d}	13.44 ± 0.34^{c}	28.08	< 0.0001
TkSd	5.28 ± 0.32^{b}	5.82 ± 0.53^{de}	5.41 ± 0.32^{bc}	4.90 ± 0.31^{a}	5.29 ± 0.14^{bc}	5.56 ± 0.27^{cd}	5.94 ± 0.28^{e}	5.19 ± 0.18^{b}	11.84	< 0.0001
WgSd	2.63 ± 0.23^{cd}	2.73 ± 0.53^{bc}	2.97 ± 0.32^{ab}	2.37 ± 0.42^{d}	2.82 ± 0.37^{abc}	2.67 ± 0.25^{bcd}	3.09 ± 0.33^{a}	2.69 ± 0.2^{bc}	4.05	0.0009
RtHs	2.72 ± 0.13^{bc}	3.09 ± 0.88^{abc}	3.54 ± 1.79^{a}	2.50 ± 0.2^{c}	3.18 ± 0.57^{ab}	2.73 ± 0.36^{bc}	2.95 ± 0.31^{abc}	2.53 ± 0.16^{bc}	4.47	0.0004
Wg100Sd	87.74 ± 6.38^{ab}	92.71 ± 14.81^{bc}	101.14 ± 9.38^{c}	81.38 ± 14.21^{a}	94.96 ± 12.25^{bc}	89.08 ± 7.81^{ab}	101.77 ± 11.16^{c}	90.48 ± 6.95^{ab}	4.02	0.0009

The variances of variables whose value of the probability *P* is followed by a star are not significant. **TmEg :** time of emergence, **LgHp :** length of hypocotyl, **LgLf :** length of upper leaflet, **WdLf :** width of upper leaflet, **iSLf** : leaflet shape index, **LgPt :** length of petiole, **LgSt :** length of stem, **DaSt :** diameter of stem, **NbBr :** number of branches, **TmFl :** time of appearance of first flower, **TmFr :** the time of appearance of the first fruit, **LgFr :** the length of the dry fruit, **WdFr :** the width of dry fruit, **TkFr :** thickness of the dry fruit, **WgFr :** weight of the dry fruit, **LgSd :** the length of dry seed, **WdSd :** width of dry seed, **TkSd :** thickness of dry seed, **WgSd :** weight of dry seed, **RtHs :** the rate of husk, **Wg100Sd :** the weight of 100 dry seeds.

Correlations among Characters

The correlation matrix (Table 2) shows positive and significant (r > 0.70) values between 4 pairs of variables (TmFl - TmFr: 0.98; LgSd - WdSd: 0.85; WgSd - WgFr: 0.75; Wg100Sd - WgSd: 0.92. By eliminating one of the variables in pairs of correlated variables to avoid redundancies in the multivariate analysis, the variables TmFl, WgFr, WdSd and Wg100Sd were excluded from the multivariate analyses.

Table 2. Pearson correlation matrix among variables recorded for eight local *P. lunatus* morphotypes from Cote d'Ivoire.

Varia--bles	Tm Eg	Lg Hp	Lg Lf	Wd Lf	iS Lf	Lg Pt	Tm Fl	Lg St	Da St	Tm Fr	Nb Br	Lg Fr	Wd Fr	Tk Fr	Wg Fr	Lg Sd	Wd Sd	Tk Sd	Wg Sd	Rt Hs	Wg 100Sd
TmEg	1.00	-0.29	0.24	-0.09	0.23	0.04	-0.09	-0.10	0.00	-0.06	-0.06	-0.12	-0.24	-0.06	0.16	0.17	0.17	0.06	0.12	0.11	0.10
LgHp		1.00	-0.13	-0.04	-0.06	-0.08	-0.12	-0.09	-0.14	-0.13	-0.14	0.12	0.06	0.07	-0.12	0.12	0.18	0.18	0.02	0.11	-0.01
LgLf			1.00	0.39	0.50	0.20	0.11	0.37	0.20	0.14	0.25	0.11	0.13	-0.29	0.25	0.27	0.31	0.11	0.14	-0.09	0.15
WdLf				1.00	-0.33	0.26	0.30	0.19	0.16	0.33	0.17	0.08	-0.07	0.12	-0.02	0.05	0.10	0.03	0.04	0.11	0.03
iSLf					1.00	0.02	-0.05	0.18	0.10	-0.04	0.11	-0.02	0.12	-0.28	0.35	0.26	0.26	0.24	0.25	-0.08	0.26
LgPt						1.00	0.14	0.13	0.09	0.17	0.21	-0.10	-0.22	-0.01	0.09	0.14	0.18	0.13	0.08	0.12	0.10
TmFl							1.00	-0.16	-0.05	**0.98**	0.09	-0.18	0.14	0.06	0.03	-0.07	-0.08	-0.11	-0.11	-0.19	-0.11
LgSt								1.00	0.28	-0.12	0.29	-0.04	0.01	-0.12	0.05	-0.07	0.00	-0.05	0.17	0.16	0.23
DaSt									1.00	0.03	0.61	0.05	-0.18	-0.20	-0.03	0.01	-0.12	0.08	0.09	0.14	0.11
TmFr										1.00	0.13	-0.20	0.14	0.05	0.01	-0.09	-0.10	-0.11	-0.12	-0.19	-0.12
NbBr											1.00	0.23	-0.13	-0.14	0.04	0.08	-0.02	-0.06	0.13	0.13	0.17
LgFr												1.00	0.29	0.14	0.16	-0.12	-0.01	-0.36	0.01	-0.10	-0.04
WdFr													1.00	-0.38	0.05	-0.34	-0.24	-0.44	-0.36	-0.61	-0.36
TkFr														1.00	0.02	-0.10	0.00	0.00	0.32	0.33	0.26

Varia--bles	Tm Eg	Lg Hp	Lg Lf	Wd Lf	iS Lf	Lg Pt	Tm Fl	Lg St	Da St	Tm Fr	Nb Br	Lg Fr	Wd Fr	Tk Fr	Wg Fr	Lg Sd	Wd Sd	Tk Sd	Wg Sd	Rt Hs	Wg 100Sd
WgFr															1.00	0.36	0.45	0.42	**0.75**	-0.14	0.64
LgSd																1.00	**0.85**	0.64	0.40	0.19	0.41
WdSd																	1.00	0.48	0.48	0.24	0.46
TkSd																		1.00	0.56	0.24	0.53
WgSd																			1.00	0.43	**0.92**
RtHs																				1.00	0.47
Wg100 Sd																					1.00

The values in bold of the variables are strongly correlated at the threshold of 0.7 (**TmFl** and **TmFr**), (**LgSd** and **WdSd**), (**WgSd** and **WgFr**), (**Wg100Sd**and **WgSd**) et (**Wg100Sd** and **WgFr**). **TmEg :** time of emergence, **LgHp :** length of hypocotyl, **LgLf :** length of upper leaflet, **WdLf :** width of upper leaflet, **iSLf** : leaflet shape index, **LgPt :** length of petiole, **TmFl :** time of appearance of first flower, **LgSt :** length of stem, **DaSt :** diameter of stem, **TmFr :** the time of appearance of the first fruit, **NbBr :** number of branches, **LgFr :** the length of the dry fruit, **WdFr :** the width of dry fruit, **TkFr :** thickness of the dry fruit, **WgFr :** weight of the dry fruit, **LgSd :** the length of dry seed, **WdSd :** width of dry seed, **TkSd :** thickness of dry seed, **WgSd :** weight of dry seed, **RtHs :** the rate of husk, **Wg100Sd :** the weight of 100 dry seeds.

Structuring Morphological Diversity

Table 3 shows the correlations between Discriminant Factor Analysis and the initial variables. The first two (2) components explain respectively 45.61% and 21.26% of the variability, i.e. 66.87% of the total variability. The variables that contributed significantly to the formation of the F1 axis are the width of the dry fruit (+0.63), the length of the dry seed (-0.86) and the thickness of the dry seed (-0.64). However, the dry fruit thickness variable (+0.71) alone contributes significantly to the formation of the F2 axis.

Table 3. Eigvalues, variance in discriminant function analysis axes 1 and 2 and factorial weights of quantitative variables.

AXES	F1	F2
Eigenvalue	7.84	3.65
Discrimination (%)	45.61	21.26
Cumulative %	45.61	66.87
TmEg : time of emergence (d)	-0.21	-0.34
LgHp : length of hypocotyl (mm)	-0.16	0.04
LgLf : length of upper leaflet (mm)	-0.14	-0.27
WdLf : width of upper leaflet (mm)	-0.01	0.14
iSLf : leaflet shape index	-0.17	-0.36
LgSt : length of stem (m)	0.12	-0.02
DaSt : diameter of stem (mm)	-0.16	-0.09

AXES	F1	F2
NbBr : number of branches	-0.18	0.16
LgFr : the length of the dry fruit (mm)	0.08	0.49
WdFr : the width of dry fruit (mm)	**0.63**	-0.27
TkFr : thickness of the dry fruit (mm)	0.13	**0.71**
LgSd : the length of dry seed (mm)	**-0.86**	0.01
TkSd : thickness of dry seed (mm)	**-0.64**	-0.29
WgSd : weight of dry seed (g)	-0.43	-0.01
RtHs : the rate of husk (%)	-0.30	0.26

The values in bold correspond to those of the variables that significantly contributed to the formation of axes F1 and F2.

The projection of individuals in the factorial plane defined by axes 1 and 2 highlights three main groups (Figure 1). Group I, consisting mainly of morphotypes M2, M3 and M7, is located on the negative side of axis F2 and on either side of axis F1. It is characterized by longer, thicker and heavier dry seeds. Group II consists of the morphotypes M1, M4 and M5 and is located on the positive side of the F2 axis. This group is characterized by large fruits with small seeds of low weight and low thickness (Figure 2). Group III consists of individuals of morphotypes M6 and M24 and is located on the lower part of the F2 axis. This group is characterized by individuals with fruits that are small in thickness and length (Figure 2).

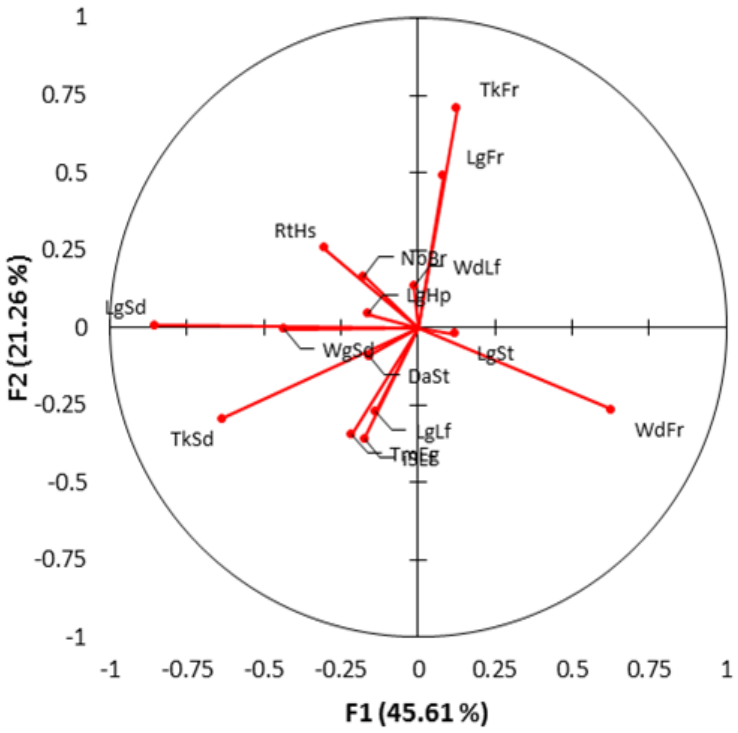

Fig. 1. Correlation circle of variables in DFA's factoriel plan.

iSLf : leaflet shape index, **TmEg :** time of emergence, **LgSd :** the length of dry seed, **TkSd :** thickness of dry seed, **WgSd :** weight of dry seed, **RtHs :** the rate of husk, **LgHp :** length of hypocotyl, **WdLf :** width of upper leaflet, **TkFr :** thickness of the dry fruit, **LgFr :** the length of the dry fruit, **WdFr :** the width of dry fruit.

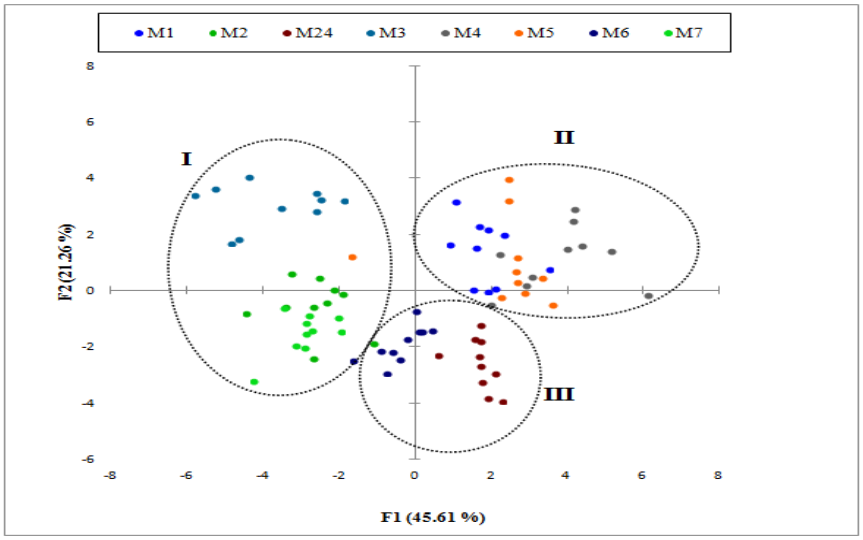

Fig. 2. Representation of the three diversity groups of *Phaseolus lunatus* traditional morphotypes in factorial plan 1-2.

The hierarchical ascending classification (HAC) based on 15 agromorphological characters of *P. lunatus* enabled the morphotypes to be grouped into two groups (Figure 3). Group I is characterized by morphotypes with thick fruits (11.91 ± 1.45 mm), short seed lengths (20.24 ± 1.25 mm) and small thicknesses (5.20 ± 0.37 mm) (Table 4). It is made up of individuals from morphotypes M2, M3, M4, M5, M6, M7 and M24. Group 2 consists of morphotypes M1, M2, M3, M4, M5, M6 and M24. It is characterized by morphotypes having relatively flat fruits (2.58 ± 0.41 mm) with long (21.28 ± 0.96 mm) and thick (5.62 ± 0.40 mm) seeds (Table 4). The Mahalanobis distance calculated presents a very highly significant difference ($P < 0, 0001$) (Table 5).

Table 4. Means, standard deviation and statistical test of the differents groups obtained from the ACH for the discriminant variables.

Variables	Group 1	Group 2	F	*P*
TmEg : time of emergence (d)	7.03 ± 1.34	7.58 ± 1.56	2.85	0.0955*
LgHp : length of hypocotyl (mm)	33.92 ± 5.45	36.10 ± 7.99	1.97	0.1641*
LgLf : length of upper leaflet (mm)	69.12 ± 3.57^{b}	73.45 ± 3.69^{a}	28.11	< 0.0001
WdLf : width of upper leaflet (mm)	58.97 ± 3.49	59.62 ± 3.14	0.76	0.3862*
iSLf : leaflet shape index	1.17 ± 0.06^{b}	1.25 ± 0.12^{a}	12.92	0.0006
LgSt : length of stem (m)	3.02 ± 0.67^{b}	3.58 ± 0.52^{a}	17.75	< 0.0001
DaSt : diameter of stem (mm)	7.22 ± 1.94^{b}	8.49 ± 2.13^{a}	7.78	0.0066
NbBr : number of branches	7.89 ± 5.10^{b}	10.84 ± 4.62^{a}	7.35	0.0083
LgFr : the length of the dry fruit (mm)	94.63 ± 7.10	93.31 ± 4.30	1.04	0.3116*
WdFr : the width of dry fruit (mm)	20.32 ± 1.06	19.89 ± 1.52	2.18	0.1442*
TkFr : thickness of the dry fruit (mm)	11.91 ± 1.45^{a}	11.02 ± 1.10^{b}	9.68	0.0026
LgSd : the length of dry seed (mm)	20.24 ± 1.25^{b}	21.28 ± 0.96^{a}	17.41	< 0.0001
TkSd : thickness of dry seed (mm)	5.20 ± 0.37^{b}	5.62 ± 0.40^{a}	23.32	< 0.0001
WgSd : weight of dry seed (g)	2.58 ± 0.41^{b}	2.89 ± 0.31^{a}	15.33	0.0002
RtHs : the rate of husk (%)	2.71 ± 0.46^{b}	3.08 ± 0.98^{a}	4.38	0.0395

Table 5. Mahalanobis distance matrix.

	Groupe 1	
	D^2	P
Groupe 2	8.8701	< 0.0001

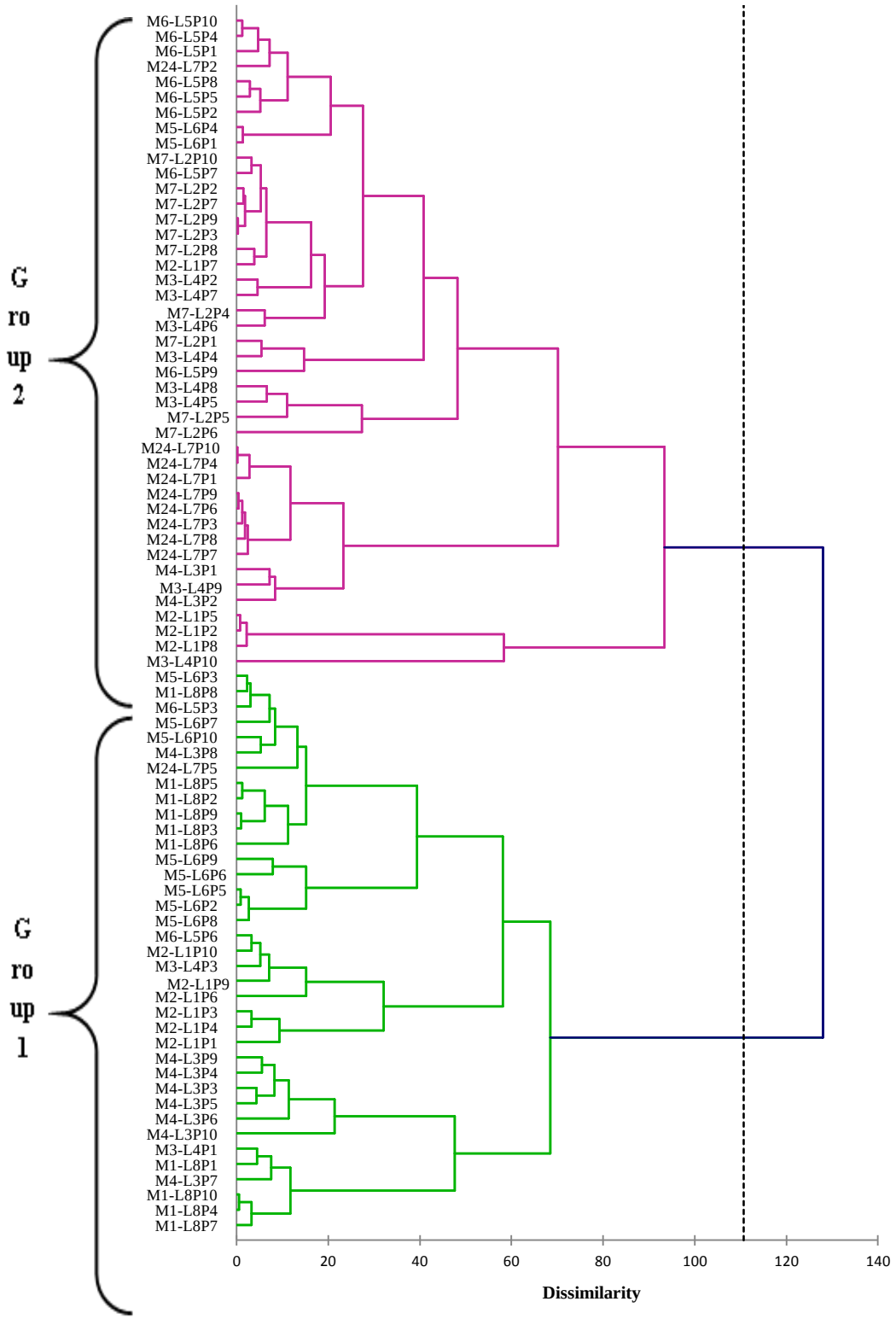

Fig. 3. Dendrogram of height populations of *Phaseolus lunatus* based on Euclidean distances of morphological traits [Group 1 (37 individuals) and Group 2 (43 individuals)].

IV. DISCUSSION

Morphological Descriptors and Assessment of Phenotypic Variability

Twenty-one agro-morphological parameters were used for the characterization of eight local morphotypes of *Phaseolus lunatus* collected in eastern Cote d'Ivoire. They were submitted to univariate analyses. These analyses revealed significant heterogeneity within the height morphotypes. Indeed, 18 agro-morphological parameters showed a difference among the morphotypes. However, 12 parameters (leaflet length, stem length, stem diameter, number of branches, fruit length, fruit width, fruit thickness, fruit length, seed length, seed width, seed thickness, seed weight) showed a highly significant difference ($P < 0.001$) among morphotypes. Two discriminant parameters (number of seeds and fruit weight) showed a highly significant difference ($P < 0.01$) (leaflet shape, fruit weight) and four parameters (emergence time, hypocotyl length, leaflet width, pod percentage) showed a significant difference ($P < 0.5$) among morphotypes. These discriminating parameters can be observed on the stem, leaves, fruit and seeds. They could therefore be used for a routine assessment of the morphological variability of the species at all stages of its development. [12], have highlighted the usefulness of such markers in the differentiation of *P. lunatus* genotypes. The heritability of these markers is therefore defined. They are relevant markers for varietal selection. These may be appropriate bases in Cote d'Ivoire for varietal selection purposes. And for the traditional varieties studied whose characterization is not elaborated these various studied morphological parameters can be used as a basis for further research.

Structure of Morphological Variability

Multivariate analyses are useful and widely used tools for detecting genetic divergence and grouping individuals using multiple morphological data simultaneously [13] [14].

The matrix of data from the eight morphotypes was subjected to Discriminant Factor Analysis (DFA) and Hierarchical Ascending Classification (HAC) to determine the parameters that best express variability and define homogeneous groups. With respect to the DFA, the variation observed in the canonical plane of axes 1 and 2 expresses 66.87% of the total variation. Based on the contributions of the parameters (at the 5% threshold) to the formation of these axes, only four of the 15 observed modalities describe the morphological variation within the collection. These are: dry fruit width, dry seed length, dry seed thickness and dry fruit thickness. These different variables significantly correlated to the F1 and F2 axes are all yield variables. The F1 and F2 axes could therefore be termed yield axes. DFA has therefore made it possible to establish links between certain morphotypes on the one hand and convergences between the variables on the other. Three morphological groups were revealed. The first group consisted of three morphotypes M01, M02 and M03 corresponding to individuals with long, thicker and heavier dry seeds. The second group consists of morphotypes M05, M07 and M15 characterized by large fruits with short, thin and light seeds. The last group is made up of individuals of morphotypes M04 and M6 characterized by individuals with fruits of small thickness and length.

The HAC has allowed the identification of two groups. The first group includes individuals of the morphotypes M2, M3, M4, M5, M6, M7 and M24 (except M1) and the second group includes individuals of the morphotypes M1, M2, M3, M4, M5, M6 and M24 (except M7). The Mahalanobis distance calculated between the two groups shows a very highly significant difference ($P < 0,0001$). This implies that the two groups are phenotypically different. Ten agromorphological parameters discriminate these two groups. These are leaflet

length, leaflet shape index, stem length, stem diameter, number of stem branches, seed length, thickness and weight, and pod rate, which have lower average values for individuals in the first group than those in the second group. However, fruit thickness appears to be greater in the second group than in the first. In other themes, the second group includes vigorous individuals producing large fat while the first group includes less vigorous individuals with small seeds. There is no relationship between the morphotypes and their position in these groups. The groups formed tended to gather individuals on the basis of the agromorphological parameters recorded rather than on the basis of the morphotypes initially identified and borrowed from the producers. The organoleptic criterion based on colour and pattern of the integument is not sufficient for group classification. Each group consists of seven of eight morphotypes based on colouring. The same morphotype may therefore have both large-seeded and small-seeded individuals. These results compared morphotypes without being able to group individuals of the same morphotype in the same group. This diversity of shapes and colours deserves to be preserved by considering it as a reservoir of genetic characteristics that can respond to specificity within consumers. Biological diversity means diversity of colours, shapes, tastes and therefore diversity of use of the resource. Rao and Hodgkin [15], considered that the rational use of a resource depends on knowledge and understanding of that resource diversity. In our case, within the group of large-seeded accessions, for example, the variability of morphotypes can respond to the eating habits of the people who consume them. Vigorous accessions with important ramifications could, in cultural association with other food crops, meet the need for protection against wind and/or water erosion. In addition, these accessions should be able to contribute to soil restoration through the production of a large biomass and the regulation of nitrogen flow in crop associations.

V. CONCLUSION

The first results of an agro-morphological study on *Phaseolus lunatus* in Cote d'Ivoire have revealed a clear variability within our sample. The eight morphotypes analysed show variation for most of the descriptors used, those related to yield as well as vegetative stage. These are interesting descriptors that can be used for varietal selection and estimation of phenotype parameters for a *P. lunatus* extension in Cote d'Ivoire. This study has also provided an understanding of the general structure in the traditional morphotypes of *P. lunatus*, which will help to define strategies for better conservation and use of the collection. However, since morphological traits are not sufficient to capture the maximum diversity for the constitution of a gene bank, as most of the morphological traits are under the influence of the environment, molecular analyses are needed to better understand the diversity and genetic structure within the *P. lunatus* collection of the Nangui Abrogoua University.

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